2004 ASME BOILER & PRESSURE VESSEL CODE

AN INTERNATIONAL CODE

VIII

Division 2 –

Alternative Rules

RULES FOR CONSTRUCTION OF PRESSURE VESSELS

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ADDENDA

Colored-sheet Addenda, which include additions and revisions to individual Sections of the Code, are published annually and will be sent automatically to purchasers of the applicable Sections up to the publication of the 2007 Code. The 2004 Code is available only in the loose-leaf format; accordingly, the Addenda will be issued in the loose-leaf, replacement-page format.

INTERPRETATIONS

ASME issues written replies to inquiries concerning interpretation of technical aspects of the Code. The Interpretations for each individual Section will be published separately and will be included as part of the update service to that Section. They will be issued semiannually (July and December) up to the publication of the 2004 Code. Interpretations of Section III, Divisions 1 and 2, will be included with the update service to Subsection NCA.

Beginning with the 2004 Edition, Interpretations of the Code will be distributed annually in July with the issuance of the edition and subsequent addenda. Interpretations previously distributed in January will be posted in January at www.cstools.asme.org/interpretations and included in the July distribution.

CODE CASES

The Boiler and Pressure Vessel Committee meets regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases which have been adopted will appear in the appropriate 2004 Code Cases book: (1) Boilers and Pressure Vessels and (2) Nuclear Components. Supplements will be sent automatically to the purchasers of the Code Cases books up to the publication of the 2007 Code.

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FOREWORD

04

The American Society of Mechanical Engineers set up a committee in 1911 for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels. This committee is now called the Boiler and Pressure Vessel Committee.

The Committee's function is to establish rules of safety, relating only to pressure integrity, governing the construction[1] of boilers, pressure vessels, transport tanks and nuclear components, and inservice inspection for pressure integrity of nuclear components and transport tanks, and to interpret these rules when questions arise regarding their intent. This code does not address other safety issues relating to the construction of boilers, pressure vessels, transport tanks and nuclear components, and the inservice inspection of nuclear components and transport tanks. The user of the Code should refer to other pertinent codes, standards, laws, regulations, or other relevant documents. With few exceptions, the rules do not, of practical necessity, reflect the likelihood and consequences of deterioration in service related to specific service fluids or external operating environments. Recognizing this, the Committee has approved a wide variety of construction rules in this Section to allow the user or his designee to select those which will provide a pressure vessel having a margin for deterioration in service so as to give a reasonably long, safe period of usefulness. Accordingly, it is not intended that this Section be used as a design handbook; rather, engineering judgment must be employed in the selection of those sets of Code rules suitable to any specific service or need.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction activities. The Code does not address all aspects of these activities and those aspects which are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable designers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

[1] *Construction*, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and they are responsible for the application of these programs to their design.

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practices as determined by the designer.

The Boiler and Pressure Vessel Committee deals with the care and inspection of boilers and pressure vessels in service only to the extent of providing suggested rules of good practice as an aid to owners and their inspectors.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Boiler and Pressure Vessel Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Boiler and Pressure Vessel Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Mandatory Appendix covering preparation of technical inquiries). Proposed revisions to the Code resulting from inquiries will be presented to the Main Committee for appropriate action. The action of the Main Committee becomes effective only after confirmation by letter ballot of the Committee and approval by ASME.

Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute and published at *http://cstools.asme.org/wbpms/public/index.cfm?PublicReview=Revisions* to invite comments from all interested persons. After the allotted time for public review and final approval by ASME, revisions are published annually in Addenda to the Code.

Code Cases may be used in the construction of components to be stamped with the ASME Code symbol beginning with the date of their approval by ASME.

After Code revisions are approved by ASME, they may be used beginning with the date of issuance shown on the Addenda. Revisions, except for revisions to material specifications in Section II, Parts A and B, become mandatory six months after such date of issuance, except for boilers or pressure vessels contracted for prior to the end of the six-month period. Revisions to material specifications are originated by the American Society for Testing and Materials (ASTM) and other recognized national or international organizations, and are usually adopted by ASME. However, those revisions may or may not have any effect on the suitability of material, produced to earlier editions of specifications, for use in ASME construction. ASME material specifications approved for use in each construction Code are listed in the Guidelines for Acceptable ASTM Editions in Section II, Parts A and B. These Guidelines list, for each specification, the latest edition adopted by ASME, and earlier and later editions considered by ASME to be identical for ASME construction.

The Boiler and Pressure Vessel Committee in the formulation of its rules and in the establishment of maximum design and operating pressures considers materials, construction, methods of fabrication, inspection, and safety devices.

The Code Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The Scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the ASME Boiler and Pressure Vessel Committee. ASME is to be notified should questions arise concerning improper use of an ASME Code symbol.

The specifications for materials given in Section II are identical with or similar to those of specifications published by ASTM, AWS, and other recognized national or international organizations. When reference is made in an ASME material specification to a non-ASME specification for which a companion ASME specification exists, the reference shall be interpreted as applying to the ASME material specification. Not all materials included in the material specifications in Section II have been adopted for Code use. Usage is limited to those materials and grades adopted by at least one of the other Sections of the Code for application under rules of that Section. All materials allowed by these various Sections and used for construction within the scope of their rules shall be furnished in accordance with material specifications contained in Section II or referenced in the Guidelines for Acceptable ASTM Editions in Section II, Parts A and B, except where otherwise provided in Code Cases or in the applicable Section of the Code. Materials covered by these specifications are acceptable for use in items covered by the Code Sections only to the degree indicated in the applicable Section. Materials for Code use should preferably be ordered, produced, and documented on this basis; Guideline for Acceptable ASTM Editions in Section II, Part A and Guideline for Acceptable ASTM Editions in Section II, Part B list editions of ASME and year dates of specifications that meet ASME requirements and which may be used in Code construction. Material produced to an acceptable specification with requirements different from the requirements of the corresponding specifications listed in the Guideline for Acceptable ASTM Editions in Part A or Part B may also be used in accordance with the above, provided the material manufacturer or vessel manufacturer certifies with evidence acceptable to the Authorized Inspector that the corresponding requirements of specifications listed in the Guideline for Acceptable ASTM Editions in Part A or Part B have been met. Material produced to an acceptable material specification is not limited as to country of origin.

When required by context in this Section, the singular shall be interpreted as the plural, and vice-versa; and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

Either U.S. Customary units or SI units may be used for compliance with all requirements of this edition, but one system shall be used consistently throughout for all phases of construction.

Either the U.S. Customary units or SI units that are listed in Mandatory Appendix 27 are identified in the text, or are identified in the nomenclature for equations, shall be used consistently for all phases of construction (e.g. materials, design, fabrication, and reports). Since values in the two systems are not exact equivalents, each system shall be used independently of the other without mixing U.S. Customary units and SI units.

When SI units are selected, U.S. Customary values in referenced specifications that do not contain SI units shall be converted to SI values to at least three significant figures for use in calculations and other aspects of construction.

With the publication of the 2004 Edition, Section II, Part D is published as two separate publications. One publication contains values only in U.S. Customary units and the other contains values only in SI units. The selection of the version to use is dependent on the set of units selected for construction.

STATEMENT OF POLICY ON THE USE OF CODE SYMBOLS AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use Code Symbols for marking items or constructions that have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the Code Symbols for the benefit of the users, the enforcement jurisdictions, and the holders of the symbols who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the symbols, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications that might so indicate. An organization holding a Code Symbol and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code."

The ASME Symbol shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of a Code Symbol who may also use the facsimile in advertising to show that clearly specified items will carry the symbol. General usage is permitted only when all of a manufacturer's items are constructed under the rules.

The ASME logo, which is the cloverleaf with the letters ASME within, shall not be used by any organization other than ASME.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the official Code Symbol Stamp described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the various Code Symbols shall not be used on any item that is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME that tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

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SUMMARY OF CHANGES

The 2004 Edition of this Code contains revisions in addition to the 2001 Edition with 2002 and 2003 Addenda. The revisions are identified with the designation **04** in the margin and, as described in the Foreword, become mandatory six months after the publication date of the 2004 Edition. To invoke these revisions before their mandatory date, use the designation "2004 Edition" in documentation required by this Code. If you choose not to invoke these revisions before their mandatory date, use the designation "2001 Edition through the 2003 Addenda" in documentation required by this Code.

Changes given below are identified on the pages by a margin note, **04**, placed next to the affected area.

Page	*Location*	*Change*
iii	List of Sections	Updated to reflect 04
xxi–xxiii	Foreword	Editorially revised
4, 5	AG-151	Revised
7	Table AG-150.1	(1) ASME B16.9 and B16.11 updated (2) ASME/ANSI B16.28 deleted
9	AG-300	Revised
	AG-301.1	Subparagraph (d) redesignated as (e) and revised, and new subparagraph (d) added
38	AM-218.3(c)	In fourth line, cross-reference corrected by errata to read (a) above
51	Table ACS-1	SA-182 F91, SA-213 T91, SA-335 P91, and SA-387 91 added
54	Table ANF-1.3	N06022 and N06059 added for SB-366, SB-564, SB-574, SB-575, SB-619, SB-622, and SB-626
62	AD-130	Revised
74	AD-213	Subparagraph (c) deleted by errata
78	AD-300.1	Nomenclature for *B* revised
81, 82	AD-310.1	Steps 4 and 7 revised
	AD-320	Steps 2 and 5 revised
	AD-331	Step 2 revised in its entirety
84	AD-340(b)	Steps (2) and (4) revised
92	AD-420.1	In third line, cross-reference corrected by errata to read AG-120(a)(1)
108	AD-623	Deleted
129	Fig. AD-1117.4	(1) Illustrations (h) and (h-1) deleted (2) General Note (c) deleted
131	Fig. AD-1117.6	Illustration (h) deleted
142	AF-210.1(b)	First paragraph revised

Page	*Location*	*Change*
173	AF-612	Subparagraphs (d)(8) and (9) redesignated by errata to read (e) and (f), respectively
180	AF-730.3	First paragraph revised
188	AF-810.20(b)	Subparagraph (5) deleted and subparagraph (6) redesignated as (5)
190	Table AF-810.1	For Category A, third entry in first column revised
207	AR-523(b)	First Note revised
355	18-100	First paragraph revised
365	Mandatory Appendix 24	Deleted
371	Mandatory Appendix 27	Added
381	Nonmandatory Appendix E	Cross-reference revised
409	K-100	Cross-reference revised
413–416	Nonmandatory Appendix N	Added

NOTE:
Volume 54 of the Interpretations to Section VIII, Division 2, of the ASME Boiler and Pressure Vessel Code follows the last page of this Edition.

Part AG
GENERAL REQUIREMENTS

ARTICLE G-1
SCOPE AND JURISDICTION

AG-100 SCOPE[1]

(a) For the scope of this Division, pressure vessels are containers for the containment of pressure, either internal or external. This pressure may be obtained from an external source or by the application of heat from a direct or indirect source, or any combination thereof. The rules of this Division, taken as a whole, provide an alternative to the minimum construction requirements for the design, fabrication, inspection, and certification of pressure vessels falling within the scope of Division 1.

(b)(1) Except as provided in (2) below, these rules cover only vessels to be installed at a fixed (stationary)[2] location for a specific service where operation and maintenance control is retained during the useful life of the vessel by the user who prepares or causes to be prepared the Design Specifications required by AG-301.1.

(2) These rules may also apply to pressure vessels installed in oceangoing ships, barges, and other floating craft provided prior written agreement with the local jurisdictional authority[3] can be established covering operation and maintenance control for a specific service and where this operation and maintenance control is retained during the useful life of the pressure vessel by the user who prepares, or causes to be prepared, the Design Specifications required by AG-301.1. Then such a pressure vessel as described above may be constructed and stamped within the scope of this Division provided it meets all other requirements as specified with the following additional provisions.

(a) Loading conditions imposed by movement of the pressure vessel during operation and by relocation of the pressure vessel between work sites or due to loading and discharge, as applicable, shall be considered as part of AD-100 (see Table AD-150.1).

(b) The User's Design Specification shall include the agreements which resolve the problems of operation and maintenance control unique to the particular pressure vessel.

(c) Pressure vessels subject to direct firing but which are not within the scope of Section I, III, or IV may be constructed in accordance with the general rules of Division 2.

(d) Except for vessels specifically prohibited in this Division, types of vessels which may be constructed in accordance with the rules of Division 1 may also be constructed in accordance with the rules of this Division.

(e) In relation to the rules of Division 1 of Section VIII, these rules of Division 2 are more restrictive in the choice of materials which may be used but permit higher design stress intensity values to be employed in the range of temperatures over which the design stress intensity value is controlled by the ultimate strength or the yield strength; more precise design procedures are required and some common design details are prohibited; permissible fabrication procedures are specifically delineated and

[1] In those applications where there are laws or regulations issued by municipal, state, provincial, or federal authorities covering pressure vessels, these laws or regulations should be reviewed to determine size or service limitations of the coverage which may be different or more restrictive than those given in this paragraph.

[2] These rules shall not be used for fabrication of cargo tanks mounted on transport vehicles.

[3] The local jurisdictional authority consists of the municipal, state, provincial, federal, or other governmental agency enforcing laws or regulations applicable to these pressure vessels.

more complete examination testing and inspection are required.

AG-110 ADDITIONAL REQUIREMENTS FOR VERY HIGH PRESSURES

The rules of Division 2 do not specify a limitation on pressure but are not all inclusive for all types of construction. For very high pressures, some additions to or deviations from these rules may be necessary to meet the design principles and construction practices essential to vessels for such pressures. However, only in the event that, after application of additional design principles and construction practices, the vessel still complies with all of the requirements of the Code may it be stamped with the Code symbol.

AG-120 GEOMETRIC SCOPE OF THIS DIVISION

The scope of this Division is intended to include only the vessel and integral communicating chambers[4] and shall include the following:

(a) where external piping is to be connected to the vessel:

(1) the welding end connection for the first circumferential joint for welded connections (see AD-420.1 and AD-602);

(2) the first threaded joint for screwed connections;

(3) the face of the first flange for bolted, flanged connections;

(4) the first sealing surface for proprietary connections or fittings.

(b) where nonpressure parts are welded directly to either the internal or external surface of a pressure vessel, the weld attaching the part of the vessel. For parts beyond this weld and for stud bolted attachments, see Article D-9.

(c) pressure retaining covers for vessel openings, such as manhole and handhole covers;

(d) the first sealing surface for proprietary fittings or components for which rules are not provided by this Division, such as gages, instruments, and nonmetallic components;

(e) the scope of this Division includes provisions for pressure relief devices necessary to satisfy the requirements of Part AR and Appendix 10.

[4] *Communicating chambers* are defined as appurtenances to the vessel which intersect the shell or heads of a vessel and form an integral part of the pressure containing enclosure, e.g., sumps.

AG-121 CLASSIFICATIONS OUTSIDE THE SCOPE OF THIS DIVISION

Based on the Committee's consideration, the following classes of vessels are exempted from the scope of this Division; however, any pressure vessel within these classes not excluded from the scope of this Division by AG-100(b) but which meets all applicable requirements of this Division may be stamped with the U2 Code symbol:

(a) those within the scope of other Sections of this Code;

(b) fired process tubular heaters;

(c) pressure containers which are integral parts or components of rotating or reciprocating mechanical devices, such as pumps, compressors, turbines, generators, engines, and hydraulic or pneumatic cylinders where the primary design considerations and/or stresses are derived from the functional requirements of the device;

(d) except as covered in AG-120(e), structures whose primary function is the transport of fluids from one location to another within a system of which it is an integral part (piping systems);

(e) piping components, such as pipe, flanges, bolting, gaskets, valves, expansion joints, fittings, and the pressure containing parts of other components, such as strainers and devices which serve such purposes as mixing, separating, snubbing, distributing, and metering or controlling flow, provided that pressure containing parts of these components are generally recognized as piping components or accessories;

(f) vessels with a nominal water containing capacity of 120 gal (450 l) or less for containing water under pressure, including those containing air, the compression of which serves only as a cushion;

(g) a hot water supply storage tank heated by steam or any other indirect means when none of the following limitations is exceeded:

(1) a heat input of 200,000 Btu/hr (58.6 kW);

(2) a water temperature of 210°F (99°C);

(3) a nominal water containing capacity of 120 gal (450 l);

(h) vessels having an internal or external operating pressure (see AD-121.3) not exceeding 15 psi (103 kPa) with no limitation on size (see AD-300);

(i) vessels having an inside diameter, width, height, or cross section diagonal not exceeding 6 in. (152 mm), with no limitation on length of vessel or pressure;

(j) pressure vessels for human occupancy.[5]

[5] Requirements for pressure vessels for human occupancy are covered by ASME PVHO-1.

The degree of nondestructive examination(s) and the acceptance standards beyond the requirements of this Division shall be a matter of prior agreement between the Manufacturer and user.

AG-121.1 Unfired Steam Boilers. Unfired steam boilers as defined in Section I shall be constructed in accordance with the rules of Section I or of Section VIII, Division 1. The following pressure vessels in which steam is generated shall be constructed in accordance with the rules of Section VIII, Division 1 or 2:

(a) vessels known as evaporators or heat exchangers;

(b) vessels which are part of a processing system, such as used in the manufacture of chemical and petroleum products.

AG-121.2 Stamping Vessels Outside the Scope of This Division. Vessels not excluded from the scope of this Division by AG-100(b) but which meet all the requirements of this Division, including the requirements for inspection and certification, may be stamped with the Code symbol.

AG-121.3 Combination Units. When a pressure vessel unit consists of more than one independent pressure chamber, only the parts of chambers which come within the scope of this Division need be constructed in compliance with its provisions (see AD-102).

AG-130 FIELD ASSEMBLY OF VESSELS

Field assembly of vessels constructed to this Division may be performed as follows.

(a) The Manufacturer of the vessel completes the vessel in the field.

(b) The manufacturer of parts of a vessel to be completed in the field by some other party stamps these parts in accordance with Code rules and supplies the A-2 Manufacturer's Partial Data Report Forms to the other party. The other party, who must hold a valid U2 Certificate of Authorization, makes the final assembly, required NDE, final pressure test; completes the A-1 Manufacturer's Data Report Form; and stamps the vessel.

(c) The field portion of the work is completed by a holder of a valid U2 Certificate of Authorization other than the vessel Manufacturer. The stamp holder performing the field work is required to supply an A-2 Manufacturer's Partial Data Report Form covering the portion of the work completed by his organization (including data on the pressure test if conducted by the stamp holder performing the field work) to the Manufacturer responsible for the Code vessel. The vessel Manufacturer applies his U2 stamp in the presence of a representative from his Inspection Agency and completes the A-1 Manufacturer's Data Report Form with his Inspector.

In all three alternatives, the party completing and signing the A-1 Manufacturer's Data Report Form assumes full Code responsibility for the vessel. In all three cases, each Manufacturer's Quality Control System shall describe the controls to assure compliance for each Code stamp holder.

AG-140 REQUIREMENTS FOR PRESSURE VESSELS FABRICATED BY LAYERED CONSTRUCTION

The rules in Section VIII, Division 1 and Division 2, to cover the construction of layered vessels have been developed to parallel each other as far as can be done within the parameters of each Division. The design criteria may influence the selection of the Division.

There are several manufacturing techniques used to fabricate layered vessels, and these rules have been developed to cover most techniques used today for which there is extensive documented construction and operational data. Some acceptable layered shell types are shown in Fig. AG-140.1. Some acceptable layered head types are shown in Fig. AG-140.2.

Additions to or deviations from the rules of this Division applicable to vessels of layered construction are given in Part AD Article D-11, Part AF Article F-8, Part AI Article I-1, and Part AS Article S-4. The Manufacturer's Quality Control System as required by Appendix 18 and Article I-1 shall include the construction procedure that will outline the sequence and method of application of layers and measurement of layer gaps. The following terms are used relative to layered vessels.

(a) Layered Vessel. A vessel having a shell and/or heads made up of two or more separate layers.

(b) Inner Shell. The inner cylinder which forms the pressure tight membrane.

(c) Inner Head. The inner head which forms the pressure tight membrane.

(d) Shell Layer. Layers may be cylinders formed from plate, sheet, forgings, or the equivalent formed by coiling or by helically wound interlocking strips. (This does not include wire winding.)

(e) Head Layer. Any one of the head layers of a layered vessel except the inner head.

(f) Overwraps. Layers added to the basic shell or head thickness for the purpose of building up the thickness of a layered vessel for reinforcing shell or head openings, or making a transition to thicker sections of the layered vessel.

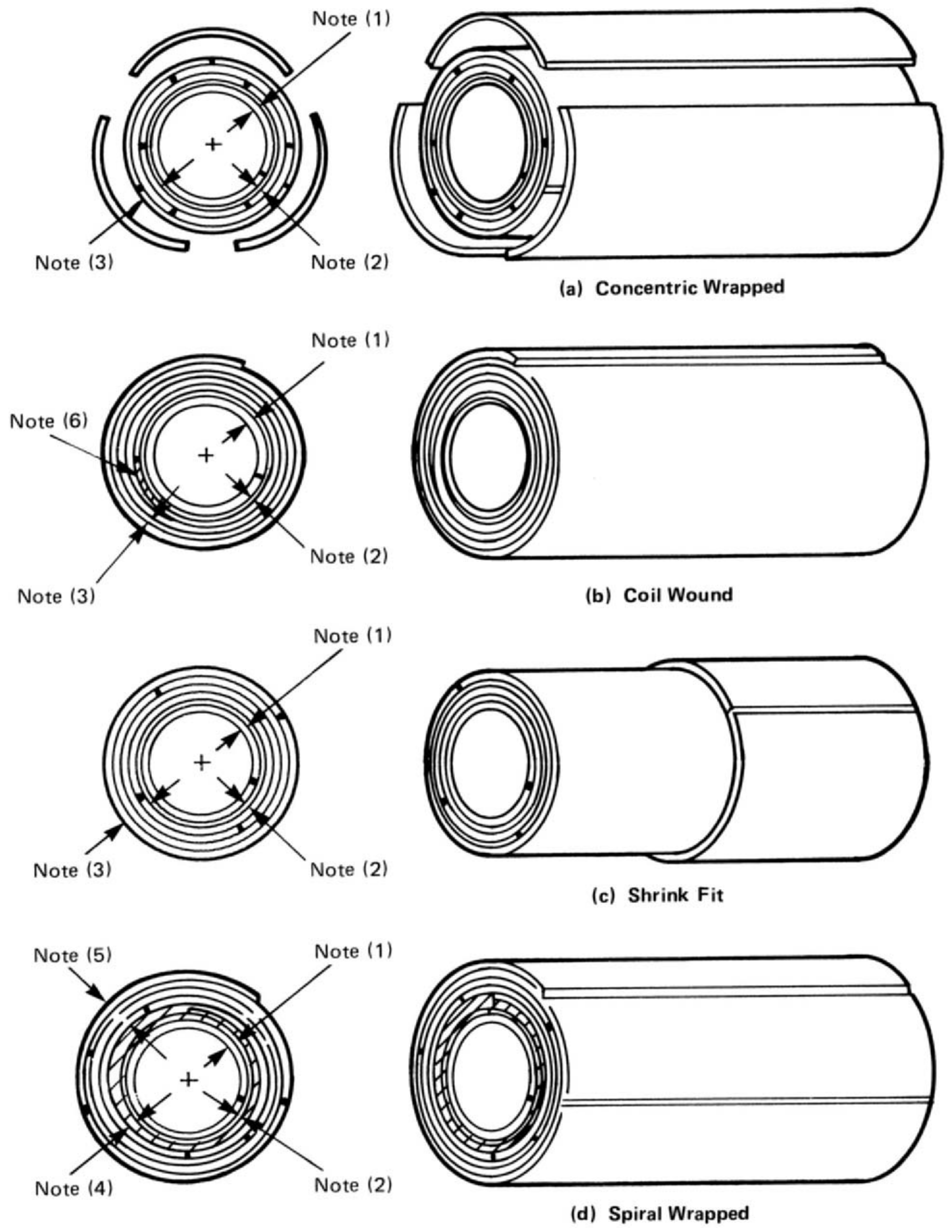


FIG. AG-140.1 SOME ACCEPTABLE LAYERED SHELL TYPES

(g) Dummy Layer. A layer used as a filler between the inner shell (or inner head) and other layers, and not considered as part of the required total thickness.

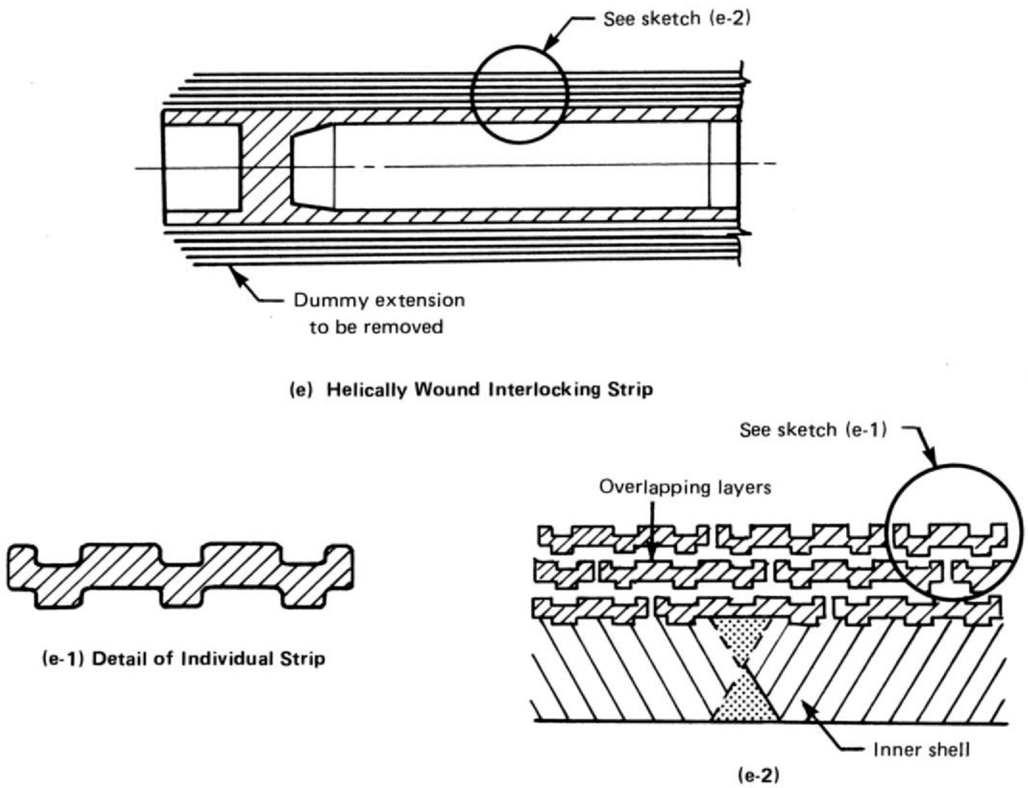
AG-150 STANDARDS REFERENCED BY THIS DIVISION

(a) Throughout this Division references are made to various standards, such as ANSI standards, which describe parts or fittings or which establish dimensional limits for pressure vessel parts. These standards, with the year of the acceptable edition, are listed in Table AG-150.1.

(b) Rules for the use of these standards are stated elsewhere in this Division.

AG-151 Units of Measurement 04

Either U.S. Customary units or SI units may be used for compliance with all requirements of this edition, but



NOTES:
(1) Inner shell
(2) Dummy layer (if used)
(3) Layers
(4) Shell layer (tapered)
(5) Balance of layers
(6) Gap

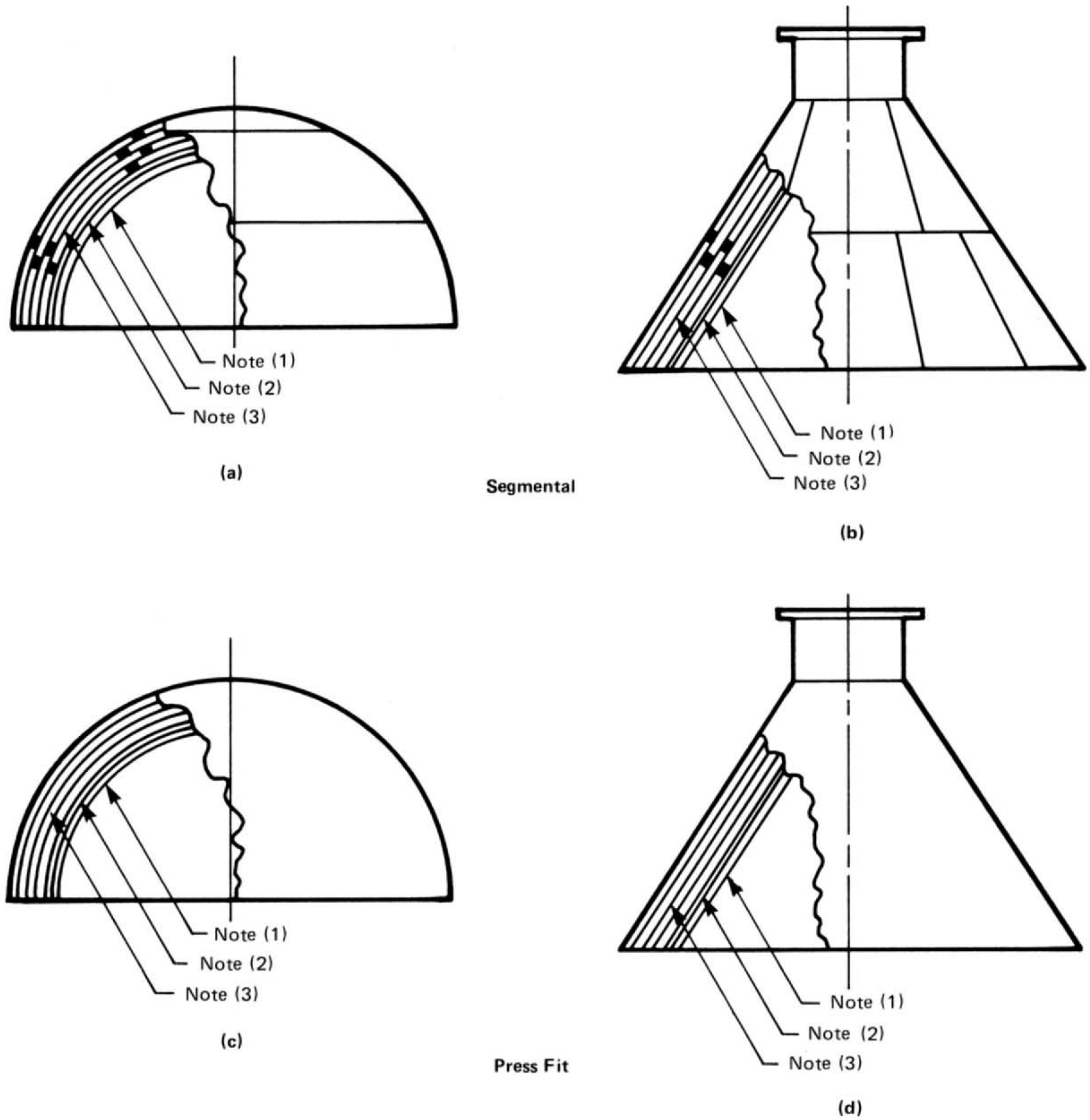
FIG. AG-140.1 SOME ACCEPTABLE LAYERED SHELL TYPES (CONT'D)

one system shall be used consistently throughout all phases of construction.

Either the U.S. Customary units or the SI units that are listed in Mandatory Appendix 27, are identified in the text, or are identified in the nomenclature for equations shall be used consistently for all phases of construction (e.g., materials, design, fabrication, and reports). Since the values in the two systems are not exact equivalents, each system shall be used independently of the other without mixing U.S. Customary units and SI units.

When SI units are selected, U.S. Customary values in referenced specifications that do not contain SI units shall be converted to SI values to at least three significant figures for use in calculations and other aspects of construction.[6]

[6] Guidance for conversion of units from U.S. Customary to SI is found in Nonmandatory Appendix N.



NOTES:
(1) Inner head
(2) Dummy layer (if used)
(3) Head layers

FIG. AG-140.2 SOME ACCEPTABLE LAYERED HEAD TYPES

TABLE AG-150.1 YEAR OF ACCEPTABLE EDITION OF REFERENCED STANDARDS IN THIS DIVISION

04

Title	Number	Year
Unified Inch Screw Threads (UN and UNR Thread Form)	ASME B1.1	1989(R2001) (1)
Pipe Threads, General Purpose, Inch	ASME B1.20.1	1983(R1992) (1)
Pipe Flanges and Flanged Fittings	ASME B16.5	1996
Factory Made Wrought Buttwelding Fittings	ASME B16.9	2001
Forged Fittings, Socket-Welding and Threaded	ASME B16.11	2001
Metallic Gaskets for Pipe Flanges — Ring-Joint, Spiral-Wound, and Jacketed	ASME B16.20	1993
Large Diameter Steel Flanges (NPS 26 Through NPS 60)	ASME B16.47	1996
Square and Hex Nuts (Inch Series)	ASME/ANSI B18.2.2	1987(R1999) (1)
Welded and Seamless Wrought Steel Pipe	ASME B36.10M	2000
Pressure Relief Devices	ASME PTC 25	2001
Qualifications for Authorized Inspection	ASME QAI-1	(2)
Seat Tightness of Pressure Relief Valves	API Standard 527	1991
ASNT Central Certification Program	ACCP	Rev. 3, 1997
ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel	ANSI/ASNT CP-189	1995
Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing	SNT-TC-1A	1996, A98
Methods of Verification and Classification of Extensometers	ASTM E 83	1990
Reference Photographs for Magnetic Particle Indications on Ferrous Castings	ASTM E 125	1963(R1985) (1)
Practice for Fabricating and Checking Aluminum Alloy Ultrasonic Standard Reference Blocks	ASTM E 127	1982a(R1989) (1)
Hardness Conversion Tables for Metals	ASTM E 140	1988
Standard Reference Radiographs for Heavy-Walled (2 to 4½-in. (51 to 114-mm)) Steel Castings	ASTM E 186	1998
Method of Conducting Drop Weight Test to Determine Nil Ductility Transition Temperature of Ferritic Steel	ASTM E 208	1987a
Reference Radiographs for High-Strength Copper-Base and Nickel-Copper Alloy Castings	ASTM E 272	1975(R1989) (1)
Standard Reference Radiographs for Heavy-Walled (4½ to 12-in. (114 to 305-mm)) Steel Castings	ASTM E 280	1998
Standard Reference Radiographs for Steel Castings Up to 2 in. (51 mm) in Thickness	ASTM E 446	1998

NOTES:
(1) R indicates reaffirmed.
(2) See AI-110.

ARTICLE G-2
ORGANIZATION OF THIS DIVISION

AG-200 ORGANIZATION

Division 2 of Section VIII is divided into eight Parts and two types of Appendices, Mandatory and Nonmandatory.

AG-200.1 Parts

(a) Part AG gives the Scope of the Division, establishes its jurisdiction in terms of the extent of its coverage, and sets forth the responsibilities of the user and Manufacturer and the duties of the Inspector of vessels constructed under these rules.

(b) Part AM lists:

(1) the individual materials which may be utilized;

(2) the applicable specifications and special requirements;

(3) the maximum design stress intensity values and other necessary information concerning their properties.

(c) Part AD contains requirements for the design of vessels and vessel parts.

(d) Part AF contains requirements governing the fabrication of vessels and vessel parts.

(e) Part AR contains rules for pressure relieving devices.

(f) Part AI contains requirements controlling inspection and radiographic examination of vessels and vessel parts.

(g) Part AT contains testing requirements and procedures.

(h) Part AS contains requirements for stamping and certifying vessels and vessel parts.

AG-200.2 Appendices. The Mandatory Appendices address specific subjects not covered elsewhere in this Division and their requirements are mandatory when the subject covered is included in construction under this Division. The Nonmandatory Appendices provide information and suggested good practices.

AG-201 ARTICLES AND PARAGRAPHS

AG-201.1 Articles. The main divisions of the Parts of this Division are designated Articles. These are given a number and a title such as Article G-1, Scope and Jurisdiction.

AG-201.2 Paragraphs. The Articles are divided into paragraphs which are given a three-digit number, the first of which corresponds to the article number. Each such paragraph number is prefixed with one or two letters, indicating the Part of the Division in which it is found, and a title such as AD-140, Design Criteria.

(a) Major subdivisions of paragraphs are indicated by the basic paragraph number followed by a decimal point and one or two digits.

(b) Minor subdivisions of paragraphs are designated by lowercase letters in parentheses. Where further subdivisions are needed, they are designated by numerals in parentheses.

AG-201.3 References. When a Part, Article, or paragraph is referred to hereinafter, the reference includes all subdivisions under the Part, Article, or paragraph.

ARTICLE G-3
RESPONSIBILITIES AND DUTIES

04 AG-300 GENERAL

The various parties, i.e., user, Manufacturer, and Inspector, involved in the work of producing vessels under this Division, have definite responsibilities or duties in meeting Code requirements. The responsibilities set forth hereinafter relate only to Code compliance and are not to be construed as involving contractual relations or legal liabilities.

The Code Edition year and Addenda date on the User's Design Specification and the Manufacturer's Design Report shall be the same as the Code Edition year and Addenda date on the Manufacturer's Data Report.

AG-301 USER'S RESPONSIBILITY

04 **AG-301.1 User's Design Specification.** It is the responsibility of the user or an agent[1] acting on his/her behalf, who intends that a pressure vessel be designed, constructed, tested, and certified to be in compliance with these rules, to provide or cause to be provided for such vessel or vessels a User's Design Specification. This shall set forth requirements as to the intended operating conditions in such detail as to constitute an adequate basis for selecting materials and designing, fabricating, and inspecting the vessel or vessels as required to comply with these rules. The User's Design Specification shall include all of the loadings listed in AD-110, as applicable, and the method of supporting the vessel.

(a) It is the user's responsibility to specify, or cause to be specified, whether or not a fatigue analysis of the vessel shall be made for cyclic service,[2] and, when a fatigue analysis is specified, to provide, or cause to be provided, information in sufficient detail so that an analysis for cyclic operation (see also 5-102) can be carried out in accordance with Appendix 5. If the User's Design Specification lists expected operating conditions for which the service evaluation rules in AD-160 indicate need for a fatigue analysis, then such fatigue analysis shall be mandatory and shall be incorporated in the Manufacturer's Design Report. If the User's Design Specification states that no fatigue analysis is required, the Design Specification shall include a statement that the intended vessel operation satisfied the requirements of AD-160.

(b) It is the user's responsibility to specify, or cause to be specified, whether or not a corrosion and/or erosion allowance shall be provided, and, if so, the amount.

(c) When a vessel is to contain fluids of such a nature that a very small amount mixed or unmixed with air is dangerous to life when inhaled, it shall be the responsibility of the user and/or his designated agent to determine if it is lethal.[3] If determined as lethal, the user and/or his designated agent shall so state in the User's Design Specification. It shall be the responsibility of the Manufacturer to comply with the applicable Code provisions [see AM-204, AF-402, and AF-820(d)].

(d) It is the user's responsibility to specify, or cause to be specified, the effective Code Edition and Addenda to be used for construction.

(e) The User's Design Specification need not provide information other than that required in AG-301.1, AG-301.1(a), AG-301.1(b), AG-301.1(c), and AG-301.1(d).

AG-301.2 Certification of User's Design Specification. A Professional Engineer, registered in one or more of the states of the United States of America or the provinces of Canada and experienced in pressure vessel design, shall certify to the compliance of the User's Design Specifications with the above requirements.

AG-302 MANUFACTURER'S RESPONSIBILITY

AG-302.1 Compliance With Requirements of This Division

[1] Wherever *user* appears in this document, it may be considered to apply also to an agent acting in his behalf.

[2] AD-160 covers the evaluation of service conditions to establish the need of a vessel fatigue analysis as provided by Appendix 5.

[3] By *lethal substances* are meant poisonous gases or liquids of such a nature that a very small amount of the gas or of the vapor of the liquid mixed or unmixed with air is dangerous to life when inhaled. For purposes of this Division, this class includes substances of this nature which are stored under pressure or may generate a pressure if stored in a closed vessel.

(a) The structural integrity of a vessel or part thereof as established by conformance with all such rules of this Division as are required to meet the conditions in the User's Design Specification and shown in the Manufacturer's Design Report is the responsibility of the vessel manufacturer.

(b) The manufacturer completing any vessel or part to be marked with the Code symbol has the responsibility of complying with all of the requirements of this Division and, through proper certification, of assuring that any work done by others also complies with all requirements of this Division.

(c) Some types of work, such as forming, nondestructive examination, and heat treating, may be performed by others (for welding, see AF-140.1 and AF-210). It is the vessel or part manufacturer's responsibility to ensure that all work so performed complies with all the applicable requirements of this Division. After ensuring Code compliance, the vessel or part may be Code stamped by the appropriate Code stamp holder after acceptance by the Inspector.

(d) The Manufacturer shall certify to compliance with these requirements by the execution of the appropriate Manufacturer's Data Report, as described in AS-300.

AG-302.2 Manufacturer's Design Report. As a part of his responsibility, the Manufacturer or design agent responsible to him shall make design calculations establishing that the design as shown on the drawings complies with the requirements of this Division for the design conditions that have been specified in the User's Design Specification. A Manufacturer's Design Report shall be prepared which shall include calculations and the drawings necessary to show compliance with this Division. When required by the rules of AD-160, the Design Report shall include an analysis for cyclic operation in accordance with Appendix 5.

AG-302.3 Certification and Filing of Manufacturer's Design Report. A Professional Engineer, registered in one or more of the states of the United States of America or the provinces of Canada and experienced in pressure vessel design, shall certify to compliance of the Manufacturer's Design Report with the requirements of this Division. The Manufacturer's Design Report and the User's Design Specification shall be kept on file at the Manufacturer's plant for at least 5 years. A copy of this Design Report shall be furnished to the user or his agent.

AG-303 INSPECTOR'S DUTIES

It is the duty of the Inspector to make all the inspections specified by the rules of this Division; in addition, he shall make such other inspections as in his judgment are necessary to verify that the materials are in accordance with the requirements of the materials specifications, that the fabrication is in accordance with the Manufacturer's Design Report, and that the requirements of this Division, including all specific design details necessary for compliance with the requirements of this Division, have been met, and he shall so certify on the Manufacturer's Data Report. The Inspector of the completed vessel does not have the duty of determining the completeness or correctness of the design calculation; however, he does have the duty of establishing that the Manufacturer of the completed vessel has the User's Design Specification and the Manufacturer's Design Report on file and that these documents are certified.

Part AM
MATERIAL REQUIREMENTS

ARTICLE M-1
GENERAL REQUIREMENTS

AM-100 MATERIALS PERMITTED

(a) Materials which are to be used under the rules of this Division shall conform to a specification given in Section II and shall be limited to those materials listed in Tables ACS-1, AHA-1, AQT-1, ANF-1.1, ANF-1.2, ANF-1.3, ANF-1.4, ABM-1, ABM-1.1, ABM-1.2, ABM-1.3, and ABM-2. The user shall satisfy himself that the coupling of dissimilar metals will have no harmful effect on the corrosion rate or service life of the vessel for the service intended. See also informative and nonmandatory guidance regarding metallurgical phenomena in Appendix A of Section II, Part D.

The requirements for the base metals, HAZs, and weld metal(s) of a dissimilar metal weldment shall each be applied in accordance with the rules of this Division.

(b) Materials, outside the limits of size and/or thickness stipulated in the title or scope clause of the specifications given in Section II and permitted by the applicable Article of Part AM, may be used if the material is in compliance with the other requirements of the specification and no size or thickness limitation is given in these rules for construction. In those specifications in which chemical composition or mechanical properties vary with size or thickness, materials outside the range shall be required to conform to the composition and mechanical properties shown for the nearest specified range.

(c) The determination of design criteria of this Division includes consideration of the fatigue characteristics of the materials. Unless the conditions of AD-160.1 or AD-160.2, Condition A, are satisfied, only those materials or classes of material for which fatigue curves are given in Appendix 5 may be used for construction of vessels or vessel parts. Where specific materials are listed in the stress intensity tables but corresponding fatigue curves are not given, this is to be interpreted as indicating that fatigue curves will be provided when the data necessary to establish these curves have been made available.

(d) Materials other than those allowed by this Division may not be used, unless data thereon are submitted to and approved by the Boiler and Pressure Vessel Committee in accordance with Appendix 5 of Section II, Part D.

AM-100.1 Repetition of Specified Examinations, Tests, or Heat Treatments. The special requirements provided in Part AM shall apply. Special requirements may specify an examination, test, or treatment which is also required by the materials specification. No heat treatment need be repeated except in the case of quenched and tempered steel as required by AF-605.

AM-101 Certification by Materials Manufacturer

The materials manufacturer shall certify that all requirements of the materials specification and all special requirements of Part AM which are to be fulfilled by the materials manufacturer have been complied with. The certification shall include certified reports of numerical results of all required tests or certificates of compliance, and shall certify that all required inspections and repairs have been performed on the materials. All conflicts between the materials specification and the special requirements herein shall be noted and compliance with the special requirements stated (see AF-101).

AM-105 Prefabricated or Preformed Pressure Parts

Prefabricated or preformed parts which are subject to the working pressure in the vessel and which are furnished by other than the location of the manufacturer responsible for the completed vessel shall conform to all applicable requirements of the Code as related to a completed vessel, including inspection in the shop of the parts manufacturer and the furnishing of Partial Data Reports as provided for in AS-310 except for miscellaneous parts as permitted in AM-105.1 and AM-105.2. Manufacturers with multiple locations, each with its own Certificate of Authorization, may transfer pressure vessel parts from one of their locations to another without Partial Data Reports, provided the Quality Control System describes the method of identification, transfer, and receipt of the parts.

When the prefabricated or preformed parts are furnished with a nameplate and the nameplate interferes with further fabrication or service, and where stamping on the material is prohibited, the Manufacturer of the completed vessel, with the concurrence of the Authorized Inspector, may remove the nameplate. The removal of the nameplate shall be noted in the Remarks section of the vessel Manufacturer's Data Report. The nameplate shall be destroyed. The rules of AM-105.1 and AM-105.2 shall not be applied to quick-actuating closures (Article D-8). Cast parts permitted by AM-105.1 and AM-105.2, when for use in vessels for lethal service [AG-301.1(c)], shall be subject to the requirements of AM-250 or AM-420.

AM-105.1 Cast, Forged, Rolled, or Die Formed Standard Pressure Parts

(a) Standard pressure parts such as pipe fittings, flanges, nozzles, welding necks, welding caps, manhole frames, and covers that are wholly formed by casting, forging, rolling, or die forming shall not require inspection, material certification in accordance with AM-101, or Partial Data Reports. Standard pressure parts that comply with a referenced ANSI standard[1] shall be made of materials permitted under this Division or of materials specifically listed in an ANSI product standard listed elsewhere in this Division. Standard pressure parts that comply with a Manufacturer's standard[2,3] shall be made of materials permitted by this Division. Parts made to either an ANSI standard or Manufacturer's standard shall be marked with the name or trademark of the parts manufacturer and such other markings as are required by the standard. Such markings shall be considered as the parts manufacturer's certification that the product complies with the material specifications and standards indicated, and is suitable for service at the pressure–temperature rating indicated except as limited by the rules in AD-150 and AD-160. The intent of the paragraph will have been met if, in lieu of the detailed marking on the part itself, the parts described herein have been marked in any permanent or temporary manner that will serve to identify the part with the parts manufacturer's written listing of the particular items and such listings are available for examination by the Inspector.

(b) Flanges and flanged fittings may be used at the pressure–temperature rating specified in the appropriate standard listed in this Division. Other pressure–temperature ratings may be used if the flange satisfies the requirements of (a) above and, using the specified gaskets and bolting, satisfies the design requirements of Article D-7 or Appendix 3 of this Division.

(c) ASME B16.9 buttwelding fittings are acceptable for use under this Division except that the pressure–temperature ratings for such fittings shall be calculated as for straight seamless pipe in accordance with the rules of this Division including maximum allowable stress for the material. The thickness tolerances of ASME B16.9 shall apply.

AM-105.2 Cast, Forged, Rolled, or Die Formed Nonstandard Pressure Parts. Nonstandard pressure parts such as shells, heads, removable doors, and pipe coils that are wholly formed by casting, forging, rolling, or die forming may be supplied basically as materials. All such parts shall be made of materials permitted under this Division and the manufacturer of that part shall furnish material certification in accordance with AM-101. Such parts shall be marked with the name or trademark of the manufacturer and with such other markings as will serve to identify the particular parts with accompanying material certification. The Manufacturer of the completed vessel shall satisfy himself that the part complies with the requirements of this Division for the design conditions specified for the completed vessel.

[1] These are pressure parts that comply with an ANSI product standard accepted by reference elsewhere in this Division and listed in Table AG-150.1. The ANSI product standard establishes the basis for the pressure–temperature rating and marking unless modified in this Division.

[2] These are pressure parts that comply with a parts Manufacturer's standard that defines the pressure–temperature rating marked on the part and described in the parts Manufacturer's literature. The Manufacturer of the completed vessel shall satisfy himself that the part is suitable for the design conditions of the completed vessel in accordance with the rules of this Division.

[3] Pressure parts may be in accordance with an ANSI product standard not covered by footnote 1, but such parts shall satisfy the requirements applicable to a parts Manufacturer's standard and footnote 2.

ARTICLE M-2
SPECIAL REQUIREMENTS FOR FERROUS MATERIALS

AM-200 FOR ALL PRODUCT FORMS OF FERROUS MATERIALS

AM-200.1 General Requirements. All forms of ferrous products as permitted by AM-100 may be used subject to all test coupons and test specimens being taken at the frequency stated in the applicable materials specification, and heat treated in accordance with the requirements of AM-201 and AM-202 and to the examination and impact testing requirements of this Part.

AM-200.2 Definition of Thickness. The requirements in this Article make reference to thickness. For the purpose intended, the following definitions of nominal thickness apply.

(a) Plate. The thickness is the dimension of the short transverse direction.

(b) Forgings. The thickness is the dimension defined as follows.

(1) Hollow Forgings. The nominal thickness is measured between the inside and outside surfaces (radial thickness).

(2) Disk Forgings. The nominal thickness is the axial length (axial length ≤ outside diameter).

(3) Flat Ring Forgings. For axial length ≤ 2 in. (50 mm), the axial length is the nominal thickness; for axial length > 2 in. (50 mm), the radial thickness is the nominal thickness (axial length less than the radial thickness).

(4) Rectangular Solid Forgings. The least rectangular dimension is the nominal thickness.

(c) Castings. For castings of the general shapes described for forgings, the same definitions apply. For other castings, the maximum thickness between two cast coincidental surfaces is the nominal thickness.

AM-200.3 Welding Restrictions. Carbon or low alloy steel having a carbon content of more than 0.35% by heat analysis shall not be used in welded construction or be shaped by oxygen cutting (except as provided elsewhere in this Division).

AM-201 Procedure for Obtaining Test Specimens and Coupons

AM-201.1 Plates

(a) Test specimens shall be taken in accordance with the requirements of the applicable material specification, except for the provisions in (b), (c), (d), and (e) below.

Unless otherwise specified, the specimens from plate may be oriented with the length of the specimen parallel to the final direction of plate rolling.

(b) When the plate is heat treated with a cooling rate faster than still-air cooling from the austenitizing temperature, the specimens shall be taken in accordance with requirements of the applicable material specifications and $1t$ from any heat treated edge, where t is the nominal thickness of the material.

(c) Where a separate test coupon is used to represent the vessel material, it shall be of sufficient size to ensure that the cooling rate of the region from which the test specimens are removed represents the cooling rate of the material at least $\frac{1}{4}t$ deep and $1t$ from any edge of the product. Unless cooling rates applicable to the bulk pieces or product are simulated in accordance with AM-202.1, the dimensions of the coupon shall be not less than $3t \times 3t \times t$, where t is the nominal material thickness.

(d) When flat heads, tubesheets, and flanges with integral hubs for butt welding are to be machined from plate, additional specimens shall be taken in the locations shown in Fig. AD-701.1. (See Appendix 20.)

(e) When plate specification heat treatments are not performed by the material manufacturer, they shall be performed by, or be under the control of, the fabricator who shall then place the letter "T" following the letter "G" in the mill plate marking (see SA-20) to indicate that the heat treatments required by the material specifcation have been performed. The fabricator shall also document in accordance with AF-101 that the specified heat treatment has been performed.

AM-201.2 Tubular Products. Specimens shall be taken in accordance with the requirements of the applicable material specification.

AM-201.3 Bars and Bolting Material

(a) Test specimens shall be taken in accordance with the requirements of the applicable material specification, except for the provisions in AM-201.3(b).

(b) Test specimens shall be at least $\frac{1}{4}t$ from the outside or rolled surface and with the end of the specimen no closer than one diameter or thickness from a heat treated end.

(c) For bolting, the specimens shall be taken in conformance with the applicable material specification and with the end of the specimen no closer than one diameter or thickness from a heat treated end.

AM-201.4 Forgings

(a) Test specimens shall be taken in accordance with the requirements of the applicable material specification, except for the provisions in AM-201.4(b), (c), and (d).

(b) When the forging is heat treated with a cooling rate faster than still-air cooling from the austenitizing temperature, the specimens shall be taken at least $\frac{1}{4}t$ of the maximum heat treated thickness from one surface and $1t$ from a second surface. This is normally referred to as $\frac{1}{4}t \times t$, where t is the maximum heat treated thickness. A thermal buffer may be used to achieve these conditions unless cooling rates applicable to the bulk forgings are simulated in accordance with AM-202.1.

(c) For very thick and complex forgings, such as contour nozzles, thick tubesheets, flanges, and other complex forgings that are contour shaped or machined to essentially the finished product configuration prior to heat treatment, the registered engineer who prepares the Design Report shall designate the surfaces of the finished product subjected to high tensile stresses in service. Test specimens for these products shall be removed from prolongations or other stock provided on the product. The coupons shall be removed so that the specimens shall have their longitudinal axes at a distance below the nearest heat treated surface equivalent at least to the greatest distance that the indicated high tensile stress surface will be from the nearest surface during heat treatment and with the midlength of the specimen at a minimum of twice this distance from a second heat treated surface. In any case, the longitudinal axes of the specimens shall not be nearer than $\frac{3}{4}$ in. (19 mm) to any heat treated surface, and the midlength of the specimens shall be at least $1\frac{1}{2}$ in. (38 mm) from any second heat treated surface.

(d) With prior approval of the vessel Manufacturer, test specimens for flat ring and simple ring forgings may be taken from a separately forged piece under the following conditions.

(1) The separate test forging shall be of the same heat of material and shall be subjected to substantially the same reduction and working as the production forgings it represents.

(2) The separate test forging shall be heat treated in the same furnace charge and under the same conditions as the production forgings.

(3) The separate test forging shall be of the same nominal thickness as the production forgings. Test specimen material shall be removed as required in AM-201.4(a) and (b).

AM-201.5 Castings

(a) The conventional ASTM separately cast test coupon meets the intent of AM-202 where normalizing or accelerated cooling heat treatments are employed on castings having a maximum thickness of less than 2 in. (50 mm).

(b) For castings having a thickness of 2 in. (50 mm) and over, the specimens shall be taken from the casting (or an extension of it) at least $\frac{1}{4}t$ of the maximum heat treated thickness from one surface and $1t$ from a second surface. A thermal buffer may be used.

(c) For massive castings that are cast or machined to essentially the finished product configuration prior to heat treatment, the registered engineer who prepares the Design Report shall designate the surfaces of the finished product subjected to high tensile stresses in service. Test specimens for these products shall be removed from prolongations or other stock provided on the product. The specimen shall be removed at a distance below the nearest heat treated surface equivalent at least to the greatest distance that the indicated high tensile stress surface will be from the nearest surface during heat treatment; the location shall also be a minimum of twice this distance from a second heat treated surface. In any case, specimen removal shall not be nearer than $\frac{3}{4}$ in. (19 mm) to a heat treated surface and $1\frac{1}{2}$ in. (38 mm) to a second heat treated surface.

(d) With prior approval of the vessel Manufacturer, test specimens may be taken from a separately cast test coupon under the following conditions.

(1) The separate test coupon shall be of the same heat of material and shall be subjected to substantially the same casting practices as the production casting it represents.

(2) The separate test coupon shall be heat treated in the same furnace charge and under the same conditions as the production casting, unless cooling rates applicable to the bulk castings are simulated in accordance with AM-202.1.

(3) The separate test coupon shall be of the same nominal thickness as the production casting. Test specimen material shall be removed from the region midway

between midthickness and the surface and shall not be nearer than one thickness to a second surface.

AM-202 Procedure for Heat Treating Test Specimens

For general requirements, see AT-113.

AM-202.1 Special Test Specimen Requirement Where Normalizing or Accelerated Cooling Heat Treatments Are Employed. Where ferritic steel products are subjected to normalizing or accelerated cooling from the austenitizing temperature, the test specimens representing those products shall be cooled at a rate similar to and no faster than the main body of the product except in the case of certain forgings and castings [see AM-201.4(c) and AM-201.5(c)]. This rule shall apply for specimens taken directly from the product as well as those taken from separate test coupons representing the product. The following general techniques may be applied to all product forms or test coupons representing the product.

(a) Any procedure may be applied which can be demonstrated to produce a cooling rate in the test specimen that matches the cooling rate of the main body of the product at the region midway between midthickness and the surface ($^1/_4t$) and no nearer any heat treated edge than a distance equal to the nominal thickness being cooled (t) within 25°F (14°C) and 20 sec at all temperatures after cooling begins from the austenitizing temperature.

(b) Faster cooling rates at product edges may be compensated for by:

(1) taking the test specimens at least $1t$ from a quenched edge where t equals the product thickness;

(2) attaching a steel pad at least $1t$ wide by a partial penetration weld to the product edge where specimens are to be removed;

(3) using thermal barriers or insulation at the product edge where specimens are to be removed.

(c) If cooling rate data for the product and cooling rate control devices for the test specimens are available, the test specimens may be heat treated in the device to represent the product provided that the provisions of AM-202.1(a) are met.

(d) When the material is clad or weld deposit overlayed by the producer prior to normalizing or accelerated cooling from the austenitizing temperature, the full thickness samples shall be clad or weld deposit overlayed before such heat treatments.

AM-203 Ultrasonic Examination

AM-203.1 Plate Material

(a) Except as permitted in (b), all plate 4 in. (100 mm) and over in nominal thickness shall be ultrasonically examined in accordance with the requirements of SA-435.

(b) When design rules permit credit for the thickness of cladding on plate conforming to SA-263, SA-264, and SA-265, ultrasonic examination shall be made of the base plate and the bond between the cladding and the base plate in accordance with SA-578 with acceptance criteria of S6 of Supplementary Requirements regardless of the thickness of the plate.

(c) When flat heads, tubesheets, and flanges with integral hubs for butt welding are to be machined from plate, ultrasonic examinations in accordance with the requirements of Appendix 20 shall be made.

AM-203.2 Forgings. All forgings 4 in. (100 mm) and over in nominal thickness shall be examined ultrasonically in accordance with SA-388, and the acceptance standards shall be in accordance with AM-203.2(c). Rings, flanges, and other hollow forgings shall be examined using the angle beam technique. For other forgings, the straight beam technique shall be used.

(a) Reference specimens shall have the same nominal thickness, composition, and P-Number grouping as the forging to be examined in order to have substantially the same structure.

(b) The method used in testing forgings shall conform to the following requirements.

(1) For straight beam examination, the transducers shall be 1 in. to $1^1/_8$ in. (25 mm to 29 mm) diameter or 1 in. (25 mm) square. The nominal frequency used during examination shall be 2.25 Mc/sec unless the grain size or microstructure of the material prevents adequate ultrasonic penetration, in which case the frequency shall be 1 Mc/sec. The instrument shall be set so that the first back reflection is 75 ±5% of screen height when the transducer is placed on an indication-free area of the forging.

(2) For angle beam examination, a 1 × 1 in. (25 mm × 25 mm) or 1 × $^1/_2$ in. (25 mm × 13 mm), 45 deg transducer shall be used at a frequency of 1 mc. Angle beam examination shall be calibrated with a notch of a depth equal to the lesser of $^3/_8$ in. (10 mm) or 3% of the nominal section thickness [$^3/_8$ in. (10 mm) maximum], a length of approximately 1 in. (25 mm), and a width not greater than twice its depth.

(3) All conditions, such as surface finish, ultrasonic frequency, instrument settings, type of transducer and couplant used during calibration, shall be duplicated during the actual examination.

(4) Insofar as practicable, all forgings shall be examined by the straight beam wave method from two directions approximately at right angles. Hollow forgings shall be examined from one circumferential surface and from one face or surface, normal to their axes. Disk

forgings shall be examined from one flat side and from the circumferential surface. Forgings requiring angle beam examination shall be examined in the circumferential direction, unless wall thickness or geometric configuration of the forging makes angle beam examination impracticable. The entire volume of material shall be examined ultrasonically at some state of manufacture, preferably after final heat treatment. If contours of the forging preclude complete ultrasonic examination after final heat treatment, the maximum possible volume shall be examined at this stage.

(c) A forging shall be unacceptable:

(1) if straight beam examination results show one or more discontinuities which produce indications accompanied by a complete loss of back reflection not associated with or attributable to the geometric configuration;

(2) if angle beam examination results show one or more discontinuities which produce indications exceeding in amplitude the indication from the calibration notch.

(d) In the case of straight beam examination, the following conditions shall be reported to the purchaser for his consideration and approval prior to shipment of a forging:

(1) forgings containing one or more indications with amplitudes exceeding adjacent back reflections;

(2) forgings containing one or more discontinuities which produce traveling indications accompanied by reduced back reflection. (A *traveling indication* is defined as an indication which displays sweep movement of the oscilloscope screen at relatively constant amplitude as the transducer is moved.)

(e) In the case of angle beam examination, the following conditions shall be reported to the purchaser for his consideration and approval prior to shipment of the forging:

(1) indications having an amplitude exceeding 50% of the calibration notch amplitude;

(2) clusters of indications located in a small area of the forging with amplitudes less than 50% of the calibration notch amplitude. [A *cluster of indications* is defined as three or more indications exceeding 10% of the standard calibration notch amplitude and located in any volume approximating a 2 in. (50 mm) or smaller cube.]

(f) Additional nondestructive examination procedures or trepanning may be employed to resolve questions of interpretation of ultrasonic indications.

AM-204 General Toughness Requirements for All Steel Products

Unless exempted by AM-213, AM-214, or AM-218, Charpy V-notch impact tests in accordance with AM-204.1 shall be made for steel materials used for shells, heads, nozzles, and other pressure containing parts, as well as for the structural members essential to structural integrity.

TABLE AM-204.1
IMPACT TEST TEMPERATURE DIFFERENTIAL

Minimum Specified Yield Strength, ksi (MPa)	Temperature Difference, °F (°C) [Note (1)]
≤ 40 (275)	10 (6)
≤ 55 (380)	5 (3)
> 55 (380)	0 (0)

NOTE:
(1) Impact test temperature may be warmer than the minimum design temperature by the amount shown.

Toughness requirements for materials listed in Table ACS-1 are given in AM-211.1 and AM-211.2. Toughness requirements for materials listed in Table AHA-1 are given in AM-213. Toughness requirements for materials listed in Table AQT-1 are given in AM-310. For weld and heat affected zone toughness requirements, see Article T-2. For toughness requirements applicable to bolting, see AM-214.

AM-204.1 Test Procedures

(a) Impact test procedures and apparatus shall conform to the applicable paragraphs of SA-370.

(b) Unless permitted by Table AM-204.1, the impact test temperature shall not be warmer than the minimum design metal temperature [see AD-121.2(f)].

AM-204.2 Test Specimens

(a) Each set of impact tests shall consist of three specimens.

(b) The impact test specimens shall be of the Charpy V-notch type and shall conform in all respects to the specimen requirements of SA-370 (for Type A specimens). The standard full-size (10 mm × 10 mm) specimen, when obtainable, shall be used, except that for materials that normally have absorbed energy in excess of 180 ft-lbf (240 J) when tested using full-size specimens at the specified testing temperature, subsize (10 mm × 6.7 mm) specimens may be used in lieu of full-size specimens. However, when this option is used, the acceptance value shall be 75 ft-lbf (100 J) minimum for each specimen.

(c) For material from which full-size specimens cannot be obtained, either due to the material shape or thickness, the specimens shall be either the largest possible subsize specimen obtainable or specimens of full material thickness which may be machined to remove surface irregularities [the test temperature criteria of AM-211.3(b) shall

apply for Table ACS-1 materials having a specified minimum tensile strength less than 95 ksi (655 MPa) when the width along the notch is less than 80% of the material thickness]. Alternatively, such material may be reduced in thickness to produce the largest possible Charpy subsize specimen. Toughness tests are not required where the maximum obtainable Charpy specimen has a width along the notch less than 0.099 in. (2.5 mm), but carbon steels too thin to impact test shall not be used for design temperatures colder than −55°F (−48°C), subject to the exemptions provided by AM-218.2.

AM-204.3 Product Forms

(a) Impact test specimens of each product form shall be located and oriented in accordance with the requirements of AM-201.

(b) The manufacturer of small parts, either cast or forged, may certify a lot of not more than 20 duplicate parts by reporting the results of one set of impact specimens taken from one such part selected at random, provided the same specification and heat of material and the same process of production, including heat treatment, were used for all of the lot. When the part is too small to provide the three specimens of at least minimum size indicated in AM-204.2(b), no impact test need be made [see AM-204.2(c)].

AM-204.4 Certification of Compliance With Impact Test Requirements

(a) Certified reports of impact tests by the materials manufacturer will be acceptable evidence that the material meets the requirements of this paragraph, provided:

(1) the specimens taken are representative of the material delivered [see AM-204.3(a)] and the material is not subjected to heat treatment during or following fabrication that will materially reduce its impact properties; or

(2) the materials from which the specimens are removed are heat treated separately such that they are representative of the material in the finished vessel (see AT-112).

(b) The Manufacturer of the vessel may have impact tests made to prove the suitability of a material which the materials manufacturer has not impact tested provided the number of tests and the method of taking the test specimens shall be as specified for the materials manufacturer.

AM-205 Liquid Penetrant Examination

All austenitic chromium–nickel alloy steel and austenitic–ferritic duplex steel welds, both groove and fillet, which exceed $^3/_4$ in. (19 mm) shall be examined for the detection of cracks by the liquid penetrant method. This examination shall be made following heat treatment if heat treatment is performed. All cracks shall be eliminated.

AM-210 SPECIAL TOUGHNESS REQUIREMENTS

AM-211 Acceptance Criteria for Impact Tests of Ferrous Materials Other Than Bolting (for Bolting Materials, see AM-214)

AM-211.1 Minimum Energy Requirements for Table ACS-1 Materials With Specified Minimum Tensile Strength Less Than 95 ksi (655 MPa). The applicable minimum energy requirement for all specimen sizes shall be that shown in Fig. AM-211, multiplied by the ratio of the actual specimen width along the notch to the width of a full-size specimen, except as otherwise provided in AM-204.2(b).

AM-211.2 Lateral Expansion Requirements for All Other Steels. Except for materials produced and impact tested in accordance with the requirements in the specifications listed in General Note (c) of Fig. AM-211, the applicable minimum lateral expansion opposite the notch for all specimen sizes for Table ACS-1 and Table ABM-1 materials having a specified minimum tensile strength of 95 ksi (655 MPa) or greater and for Table AQT-1 materials shall not be less than the requirements shown in Fig. AM-211.2.

For Table AHA-1 materials, the minimum lateral expansion opposite the notch shall be 0.015 in. (0.38 mm) for MDMTs of −320°F (−196°C) and warmer. For MDMTs colder than −320°F (−196°C), production welding processes shall be limited to shielded metal arc welding (SMAW), gas metal arc welding (GMAW), and gas tungsten arc welding (GTAW). Notch toughness testing shall be performed as specified in (a) or (b) below, as appropriate.

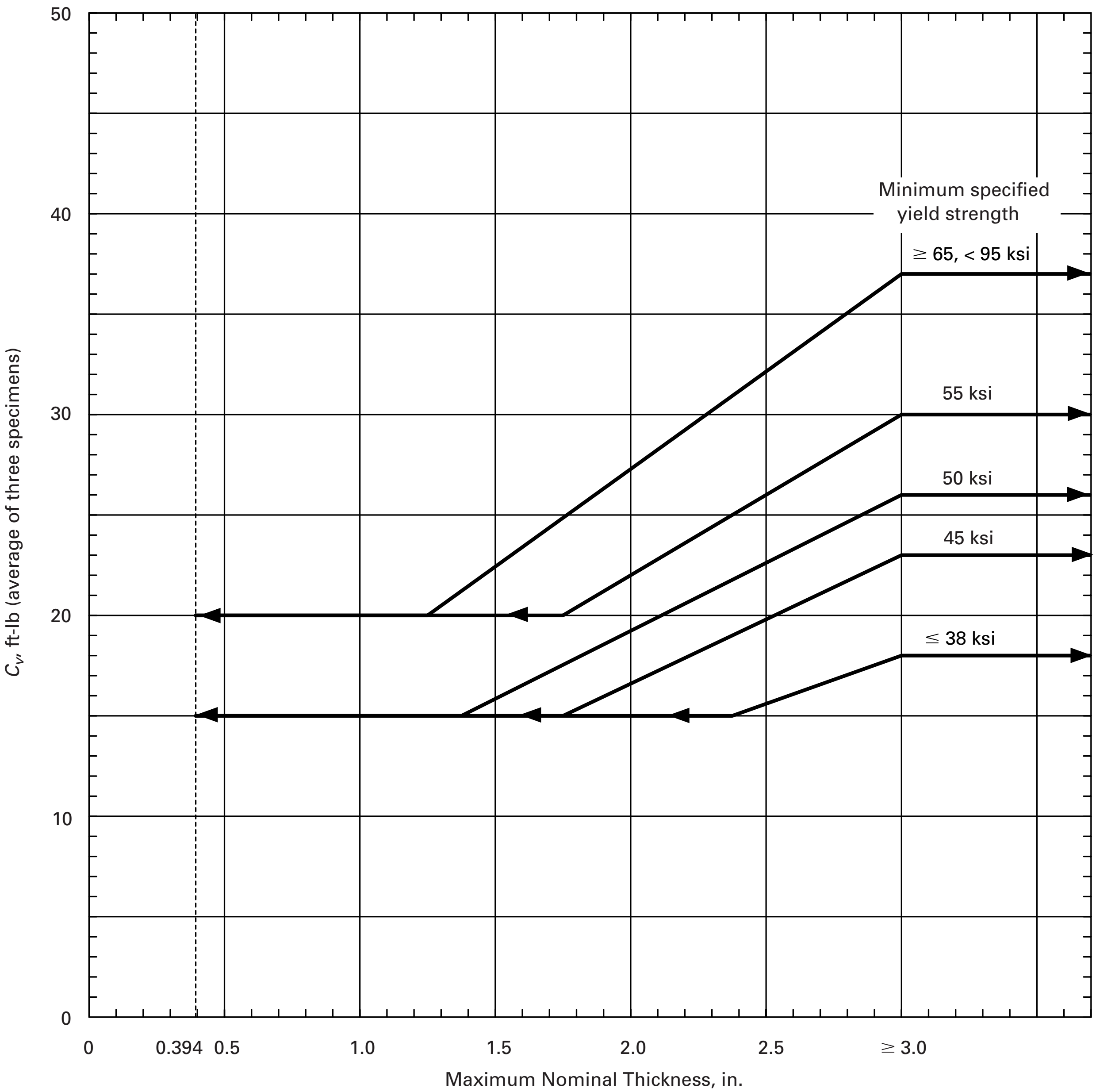
(a) If using Type 316L weld filler metal:

(1) each heat of filler metal used in production shall have a ferrite number (FN) not greater than 5, as determined by applying the chemical composition from the test weld to Fig. AM-211.3; and

(2) notch toughness testing of the base metal, weld metal, and heat affected zone (HAZ) shall be conducted using a test temperature of −320°F (−196°C); and

(3) each of the three specimens from each test set shall have a lateral expansion opposite the notch not less than 0.021 in. (0.53 mm).

(b) If using filler metals other than Type 316L, or when the base metal, weld metal, or filler metal are unable to meet the requirements of (a) above:



GENERAL NOTES:

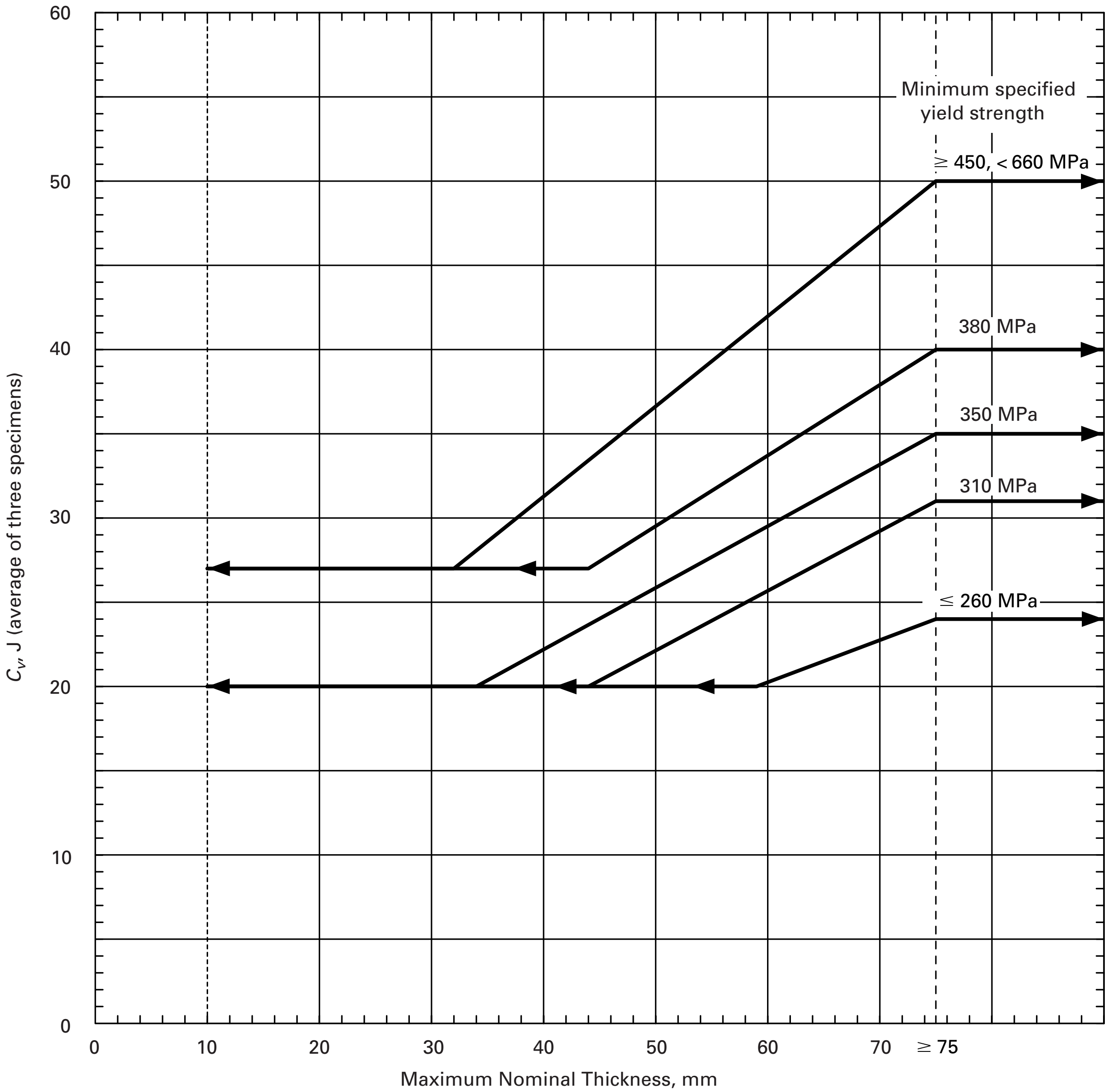
(a) Interpolation between yield strengths shown is permitted.

(b) The minimum impact energy for one specimen shall not be less than two-thirds of the average energy required for three specimens.

(c) Materials produced and impact tested in accordance with SA-320, SA-333, SA-334, SA-350, SA-352, SA-420, SA-437, SA-508 Grade 5 Class 2, SA-540 (except for materials produced under Table 2, Note 4 in the specification), and SA-765 do not have to satisfy these energy values. They are acceptable for use at minimum design metal temperature not colder than the test temperature when the energy values required by the applicable specification are satisfied.

(d) For materials having a specified minimum tensile strength of 95 ksi or more, see AM-211.2.

FIG. AM-211 CHARPY V-NOTCH IMPACT TEST REQUIREMENTS FOR FULL-SIZE SPECIMENS FOR CARBON AND LOW ALLOY STEELS, HAVING A SPECIFIED MINIMUM TENSILE STRENGTH OF LESS THAN 95 ksi, LISTED IN TABLE ACS-1



GENERAL NOTES:

(a) Interpolation between yield strengths shown is permitted.

(b) The minimum impact energy for one specimen shall not be less than two-thirds of the average energy required for three specimens.

(c) Materials produced and impact tested in accordance with SA-320, SA-333, SA-334, SA-350, SA-352, SA-420, SA-437, SA-508 Grade 5 Class 2, SA-540 (except for materials produced under Table 2, Note 4 in the specification), and SA-765 do not have to satisfy these energy values. They are acceptable for use at minimum design metal temperature not colder than the test temperature when the energy values required by the applicable specification are satisfied.

(d) For materials having a specified minimum tensile strength of 655 MPa or more, see AM-211.2.

FIG. AM-211M CHARPY V-NOTCH IMPACT TEST REQUIREMENTS FOR FULL-SIZE SPECIMENS FOR CARBON AND LOW ALLOY STEELS, HAVING A SPECIFIED MINIMUM TENSILE STRENGTH OF LESS THAN 655 MPa, LISTED IN TABLE ACS-1

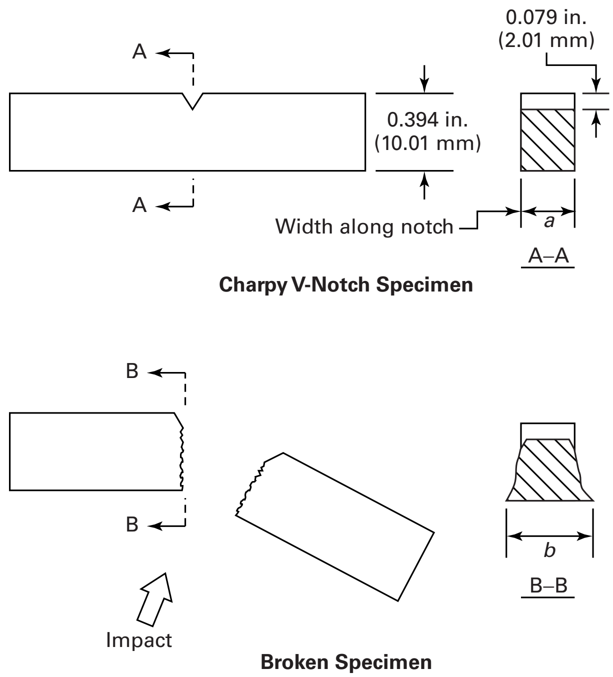


FIG. AM-211.1 ILLUSTRATION OF LATERAL EXPANSION IN A BROKEN CHARPY V-NOTCH SPECIMEN

(1) notch toughness testing shall be conducted at a test temperature not warmer than MDMT, using the ASTM E 1820 J_{IC} method;

(2) a set of two specimens shall be tested in the TL orientation with a resulting K_{IC} *(J)* of not less than 120 ksi$\sqrt{\text{in.}}$ (132 MPa$\sqrt{\text{m}}$); and

(3) each heat or lot of filler metal used in production shall have an FN not greater than the FN determined for the test weld.

AM-211.3 Impact Test Temperature Criteria. For all Charpy impact tests, the following test temperature criteria shall be observed.

(a) For Materials of Thickness Equal to or Greater Than 0.394 in. (10 mm). Where the largest obtainable Charpy V-notch specimen has a width along the notch of at least 0.315 in. (8 mm; see Fig. AM-211.1), the Charpy test of such a specimen shall be conducted at a temperature not warmer than the minimum design metal temperature.[1] Where the largest possible test specimen has a width along the notch less than 0.315 in. (8 mm), the test shall be conducted at a temperature colder than the minimum design metal temperature[1] by the amount shown in Table AM-211.1 for the specimen width. [This requirement does not apply when the option of AM-204.2(b) is used.]

(b) For Materials With Thickness Less Than 0.394 in. (10 mm). Where the largest obtainable Charpy V-notch specimen has a width along the notch of at least 80% of the material thickness, the Charpy test of such a specimen shall be conducted at a temperature not warmer than the minimum design metal temperature.[1]

Where the largest possible test specimen has a width along the notch of less than 80% of the material thickness, the test for Table ACS-1 materials having a specified minimum tensile strength of less than 95 ksi (655 MPa) shall be conducted at a temperature colder than the minimum design metal temperature[1] by an amount equal to the difference (referring to Table AM-211.1) between the temperature reduction corresponding to the actual material thickness and the temperature reduction corresponding to the Charpy specimen width actually tested. [This requirement does not apply when the option of AM-204.2(b) is used.] For Table ACS-1 materials having a specified minimum tensile strength greater than or equal to 95 ksi (655 MPa), for Table AHA-1 materials, and for Table AQT-1 materials, the test shall be conducted at a temperature not warmer than the minimum design metal temperature.

[1] Where applicable for materials listed in Table ACS-1 or Table AHA-1, the impact test temperature may be adjusted in accordance with AM-204.1(b).

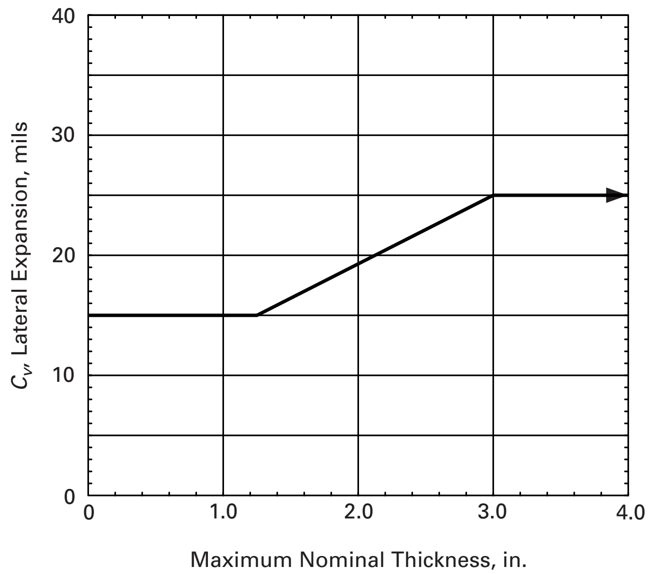


FIG. AM-211.2 CHARPY V-NOTCH IMPACT TEST REQUIREMENTS FOR TABLE ACS-1 MATERIALS HAVING A SPECIFIED MINIMUM TENSILE STRENGTH OF 95 ksi OR GREATER AND FOR TABLE AQT-1 MATERIALS

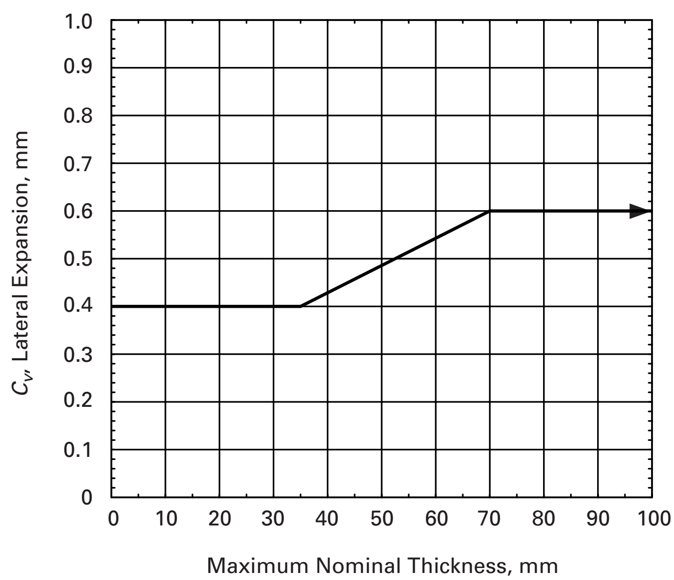
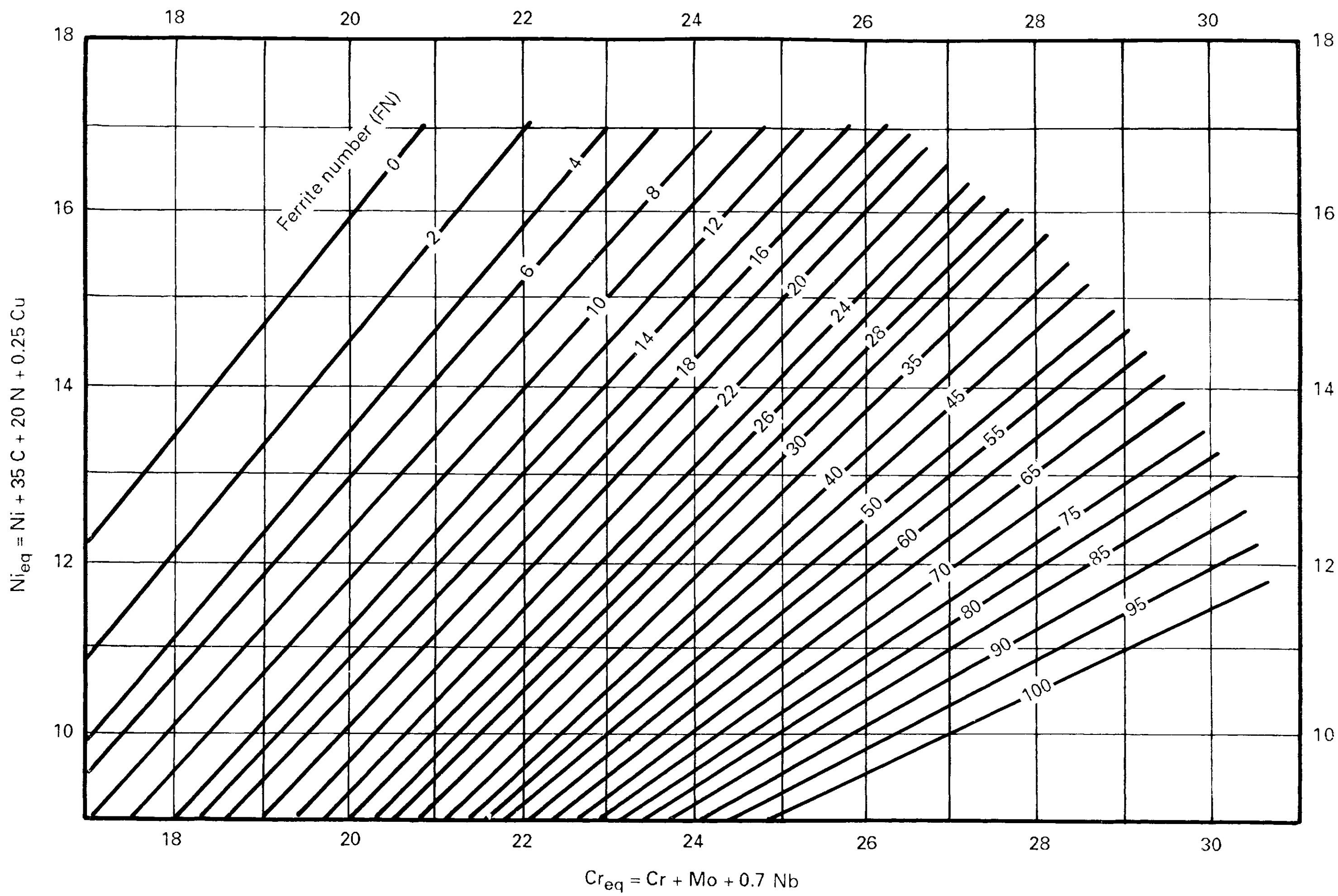


FIG. AM-211.2M CHARPY V-NOTCH IMPACT TEST REQUIREMENTS FOR TABLE ACS-1 MATERIALS HAVING A SPECIFIED MINIMUM TENSILE STRENGTH OF 655 MPa OR GREATER AND FOR TABLE AQT-1 MATERIALS



GENERAL NOTES:

(a) The actual nitrogen content is preferred. If this is not available, the following applicable nitrogen value shall be used:

(1) GMAW welds - 0.08%, except that when self shielding flux cored electrodes are used - 0.12%.

(2) Welds made using other processes - 0.06%.

(b) This diagram is identical to the WRC-1992 Diagram, except that the solidification mode lines have been removed for ease of use.

FIG. AM-211.3 WELD METAL DELTA FERRITE CONTENT

TABLE AM-211.1
CHARPY IMPACT TEST TEMPERATURE REDUCTION BELOW MINIMUM DESIGN METAL TEMPERATURE
For Table ACS-1 Materials Having a Specified Minimum Tensile Strength of Less Than 95 ksi (655 MPa), When the Subsize Charpy Impact Width Is Less Than 80% of the Material Thickness

Actual Material Thickness [See AM-211.3(b)] or Charpy Impact Specimen Width Along the Notch, in. (mm) [Note (1)]	Temperature Reduction, °F (°C)
0.394 (10) (full-size standard bar)	0 (0)
0.354 (9)	0 (0)
0.315 (8)	0 (0)
0.295 (7.5) (3/4 size bar)	5 (3)
0.276 (7)	8 (4)
0.262 (6.7) (2/3 size bar)	10 (6)
0.236 (6)	15 (8)
0.197 (5) (1/2 size bar)	20 (11)
0.158 (4)	30 (17)
0.131 (3.3) (1/3 size bar)	35 (19)
0.118 (3)	40 (22)
0.099 (2.5) (1/4 size bar)	50 (28)

NOTE:
(1) Straight line interpolation for intermediate values is permitted.

AM-211.4 Retests

(a) For Absorbed Energy Criteria. If the absorbed energy criteria are not met, retesting in accordance with the applicable procedures of SA-370 shall be permitted.

(b) For Lateral Expansion Criteria

(1) Retesting is permitted if the average value for three specimens equals or exceeds the value required; and

(a) for Table ACS-1 materials having specified minimum tensile strengths of 95 ksi (655 MPa) or greater and for Table AQT-1 materials, if the measured value of lateral expansion for one specimen in a group of three is less than that required in Fig. AM-211.2; and

(b) for materials of Table AHA-1 for MDMTs no colder than −320°F (−196°C), if the measured value of lateral expansion for one specimen in a group of three is less than 0.015 in. (0.38 mm), but not less than 2/3 of the value required; and

(c) for materials of Table AHA-1 for MDMTs colder than −320°F (−196°C), if the value of lateral expansion for one specimen of a set is less than 0.018 in. (0.46 mm), but not less than 0.015 in. (0.38 mm); and

(d) for materials of Table AQT-1, if the measured value of lateral expansion for one specimen in a group of three is less than that required in Fig. AM-211.2 but not less than 2/3 of the required value.

(2) The retest shall consist of three additional specimens. For materials listed in Table AQT-1 and for Table ACS-1 materials having specified minimum tensile strengths of 95 ksi (655 MPa) or greater, the retest value for each specimen must equal or exceed the value required in Fig. AM-211.2. For Table AHA-1 materials, the retest value for each specimen must equal or exceed 0.015 in. (0.38 mm) for MDMTs no colder than −320°F (−196°C). For MDMTs colder than −320°F (−196°C), see AM-211.2.

(3) In the case of materials with properties enhanced by heat treatment, the material may be reheat treated and retested if the required values are not obtained in the retest or if the values in the initial test are less than the values required for retest. After reheat treatment, a set of three specimens shall be made; for acceptance, the lateral expansion of each of the specimens must equal or exceed the value required in Fig. AM-211.2.

(c) When an erratic result is caused by a defective specimen or there is uncertainty in the test procedure, a retest will be allowed. When the option of AM-204.2(b) is used for the initial test and the acceptance of 75 ft-lbf (100 J) minimum is not attained, retest using full-size (10 mm × 10 mm) specimens will be allowed.

AM-213 Impact Test Temperature Criteria for High Alloy Steels

Impact tests employing the lateral expansion criterion of AM-211.2 shall be performed on materials listed in Table AHA-1 for all combinations of materials and minimum design metal temperatures except as exempted by (b), (c), or (d) below, or AM-213.1. Impact tests are not required where the maximum obtainable Charpy specimen has a width along the notch less than 0.099 in. (2.5 mm).

(a) Required Impact Tests When Thermal Treatments Are Performed. Impact tests are required at the colder of 70°F (21°C) or the minimum design metal temperature, whenever thermal treatments[2] within the temperature ranges listed for the following materials are applied:

(1) austenitic stainless steels thermally treated between 900°F and 1,650°F (482°C and 900°C), except Types 304, 304L, 316, and 316L which are thermally treated at temperatures between 900°F and 1,300°F (482°C and 704°C), are exempt from impact testing provided the MDMT is −20°F (−29°C) and warmer and vessel (production) impact tests of the thermally treated weld metal are performed for Category A and B joints;

(2) austenitic–ferritic duplex stainless steels thermally treated at temperatures between 600°F and 1,750°F (316°C and 954°C);

[2] Thermal treatments of materials do not include thermal cutting or welding.

(3) ferritic and martensitic chromium stainless steels thermally treated at temperatures between 800°F and 1,350°F (427°C and 732°C).

(b) Exemptions from Impact Testing for Base Metals and Heat Affected Zones. Impact testing is not required for the following combinations of base metals and heat affected zones (if welded) and minimum design metal temperatures (MDMTs), except as modified in (a) above.

(1) For austenitic chromium–nickel stainless steels as follows:

(a) Types 304, 304L, 316, 316L, 321, and 347 at MDMTs of −320°F (−196°C) and warmer;

(b) those types not listed in (a) above and having a carbon content[3] not exceeding 0.10% at MDMTs of −320°F (−196°C) and warmer;

(c) having a carbon content[3] exceeding 0.10% at MDMTs of −55°F (−48°C) and warmer;

(d) for castings at MDMTs of −20°F (−29°C) and warmer.

(2) For austenitic chromium–manganese–nickel stainless steels (200 series) as follows:

(a) having a carbon content[3] not exceeding 0.10% at MDMTs of −320°F (−196°C) and warmer;

(b) having a carbon content[3] exceeding 0.10% at MDMTs of −55°F (−48°C) and warmer;

(c) for castings at MDMTs of −20°F (−29°C) and warmer.

(3) For the following steels in all product forms at MDMTs of −20°F (−29°C) and warmer:

(a) austenitic–ferritic duplex steels with a nominal material thickness of $^3/_8$ in. (10 mm) and thinner;

(b) ferritic chromium stainless steels with a nominal material thickness of $^1/_8$ in. (3 mm) and thinner;

(c) martensitic chromium stainless steels with a nominal material thickness of $^1/_4$ in. (6 mm) and thinner.

(c) Exemptions From Impact Testing for Welding Procedure Qualifications. For welding procedure qualifications, impact testing is not required for the following combinations of weld metals and minimum design metal temperatures (MDMTs) except as modified in (a) above.

(1) For austenitic chromium–nickel stainless steel base materials having a carbon content not exceeding 0.10%, welded without the addition of filler metal, at MDMTs of −155°F (−104°C) and warmer.

(2) For austenitic weld metal:

(a) having a carbon content not exceeding 0.10% and produced with filler metals conforming to SFA-5.4, SFA-5.9, SFA-5.11, SFA-5.14, and SFA-5.22 at MDMTs of −155°F (−104°C) and warmer;

(b) having a carbon content exceeding 0.10% and produced with filler metals conforming to SFA-5.4, SFA-5.9, SFA-5.11, SFA-5.14, and SFA-5.22 at MDMTs of −55°F (−48°C) and warmer.

(3) For the following weld metal, when the base metal of similar chemistry is exempt as stated in (b)(3) above, then the weld metal shall also be exempt at MDMTs of −20°F (−29°C) and warmer:

(a) austenitic–ferritic duplex steels;

(b) ferritic chromium stainless steels;

(c) martensitic chromium stainless steels.

(d) Required Impact Testing for Vessel (Production) Plates. For welded construction, vessel (production) impact tests in accordance with AT-203 are required when the MDMT is −320°F (−196°C) and warmer, if the welding procedure qualification requires impact testing, unless otherwise exempted by the rules of this Division. When the MDMT is colder than −320°F (−196°C), vessel (production) impact tests or ASTM E 1820 J_{IC} tests shall be conducted in accordance with AM-211.2.

Vessel (production) impact tests are not required for welds joining austenitic chromium–nickel or austenitic chromium–manganese–nickel stainless steels at MDMTs not colder than −320°F (−196°C) where all of the following conditions are satisfied:

(1) the welding processes are limited to shielded metal arc, submerged arc, gas metal arc (GMAW and FCAW), gas tungsten arc, and plasma arc;

(2) the applicable Welding Procedure Specifications (WPSs) are supported by Procedure Qualification Records (PQRs) with impact testing in accordance with the requirements of AM-204 (using the acceptance criteria of AM-211) at the minimum design metal temperature or colder, or when the applicable PQR is exempted from impact testing by other provisions of this Division;

(3) the weld metal (produced with or without the addition of filler metal) has a carbon content not exceeding 0.10%;

(4) the weld metal is produced by filler metal conforming to SFA-5.4, SFA-5.9, SFA-5.11, SFA-5.14, and SFA-5.22 as modified below.

(a) Each heat and/or lot of welding consumables to be used in production welding with the shielded metal arc (SMAW) and gas metal arc (GMAW) processes shall be qualified by conducting impact tests at or below the MDMT except as exempted by (c)(2) above in accordance with Section II, Part C, SFA-5.4, A9.12. Acceptance criteria shall conform with AM-211.2.

(b) Each heat of welding consumables to be used in production welding with the submerged arc (SAW) process shall be qualified by conducting impact tests with each lot and/or batch of flux at or below the MDMT

[3] The value of the carbon content may be as specified by the purchaser, but must be within the limits of the material specification.

except as exempted by (c)(2) above in accordance with Section II, Part C, SFA-5.4, A9.12. Acceptance criteria shall conform with AM-211.2.

(c) Combining more than one welding process or more than one heat, lot, and/or batch of welding material into a single test coupon is unacceptable. Testing at or below the MDMT except as exempted by (c)(2) above may be conducted by the welding consumable manufacturer provided certified mill test reports are furnished with the consumables.

(d) The following filler metals may be used without impact testing of each heat and/or lot provided that procedure qualification impact testing in accordance with Article T-2 at the minimum design metal temperature or colder is performed using the same manufacturer brand and type filler metal: ENiCrFe-2; ENiCrFe-3; ENiCrMo-3; ENiCrMo-4; ENiCrMo-6; ERNiCr-3; ERNiCrMo-3; ERNiCrMo-4; SFA-5.4, E310-15 or 16.

(e) The following filler metals may be used without impact testing of each heat and/or lot provided that procedure qualification impact testing in accordance with Article T-2 at the minimum design metal temperature or colder is performed: ER308L, ER316L, and ER310 used with GMAW, GTAW, or PAW processes.

AM-213.1 Exemption From Impact Testing. Impact testing of materials listed in Table AHA-1 is not required, except as modified by AM-213(a), when the coincident ratio of design stress[4] in tension to allowable tensile stress is less than 0.3.

AM-214 Toughness Requirements for Bolting Materials

AM-214.1 For Bolting Materials Listed in Table ABM-1

(a) Impact tests are not required for bolting materials listed in Tables ABM-1, ABM-1.2, and ABM-1.3 when used at minimum design metal temperatures equal to or warmer than those shown in these Tables.

(b) Bolting materials to be used for colder temperatures than those shown in Table ABM-1 shall conform to SA-320, except that the toughness criterion shall be Charpy V-notch with acceptance criteria in accordance with AM-211.

AM-214.2 For Bolting Materials Listed in Table ABM-2. Impact testing is required for ferrous bolting materials for use with flanges designed in accordance with Appendices 4, 5, and 6 (see Table ABM-2). The average for three Charpy V-notch impact specimens shall be at least 30 ft–lb (41 J), and the minimum value for any individual specimen shall be 25 ft–lb (34 J).

AM-218 Materials Exempt From Impact Tests

AM-218.1 For Carbon and Low Alloy Steels, Dependent on Design Temperature. Figure AM-218.1 shall be used to establish impact testing exemptions for steels listed in Table ACS-1. Unless otherwise exempted by the rules of this Division, impact testing is required for a combination of minimum design metal temperature [see AD-121.2(f)] and thickness (as defined below) which is below the curve assigned to the subject material. If a minimum design metal temperature and thickness combination is on or above the curve, impact testing is not required by the rules of this Division, except as required by Article T-2 for weld metal and heat affected zones.

Components such as shells, heads, nozzles, manways, reinforcing pads, stiffening rings, flanges, tubesheets, flat cover plates, backing strips, and attachments which are essential to the structural integrity of the vessel when welded to pressure retaining components shall be treated as separate components. Each component shall be evaluated for impact test requirements based on its individual material classification, thickness as defined in (a), (b), or (c) below, and the minimum design metal temperature. The following thickness limitations apply when using Fig. AM-218.1.

(a) Excluding castings, the governing thickness t_g of a welded part is as follows:

(1) for butt joints except those in flat heads and tubesheets, the nominal thickness of the thickest welded joint [see Fig. AM-218.2, sketch (a)];

(2) for corner, fillet, or lap welded joints, including attachments as defined above, the thinner of the two parts joined;

(3) for flat heads or tubesheets, the larger of (2) above or the flat component thickness divided by 4;

(4) for welded assemblies comprised of more than two components (e.g., nozzle-to-shell joint with reinforcing pad), the governing thickness and permissible minimum design metal temperature of each of the individual welded joints of the assembly shall be determined, and the warmest of the minimum design metal temperatures shall be used as the permissible minimum design metal temperature of the welded assembly [see Fig. AM-218.2, sketch (b)].

If the governing thickness at any welded joint exceeds 4 in. (102 mm) and the minimum design metal temperature is colder than 90°F (32°C), impact tested material shall be used.

(b) The governing thickness of a casting shall be its largest nominal thickness.

[4] Applied stress from pressure and nonpressure loadings, including those listed in AD-110, which result in general primary membrane tensile stress.

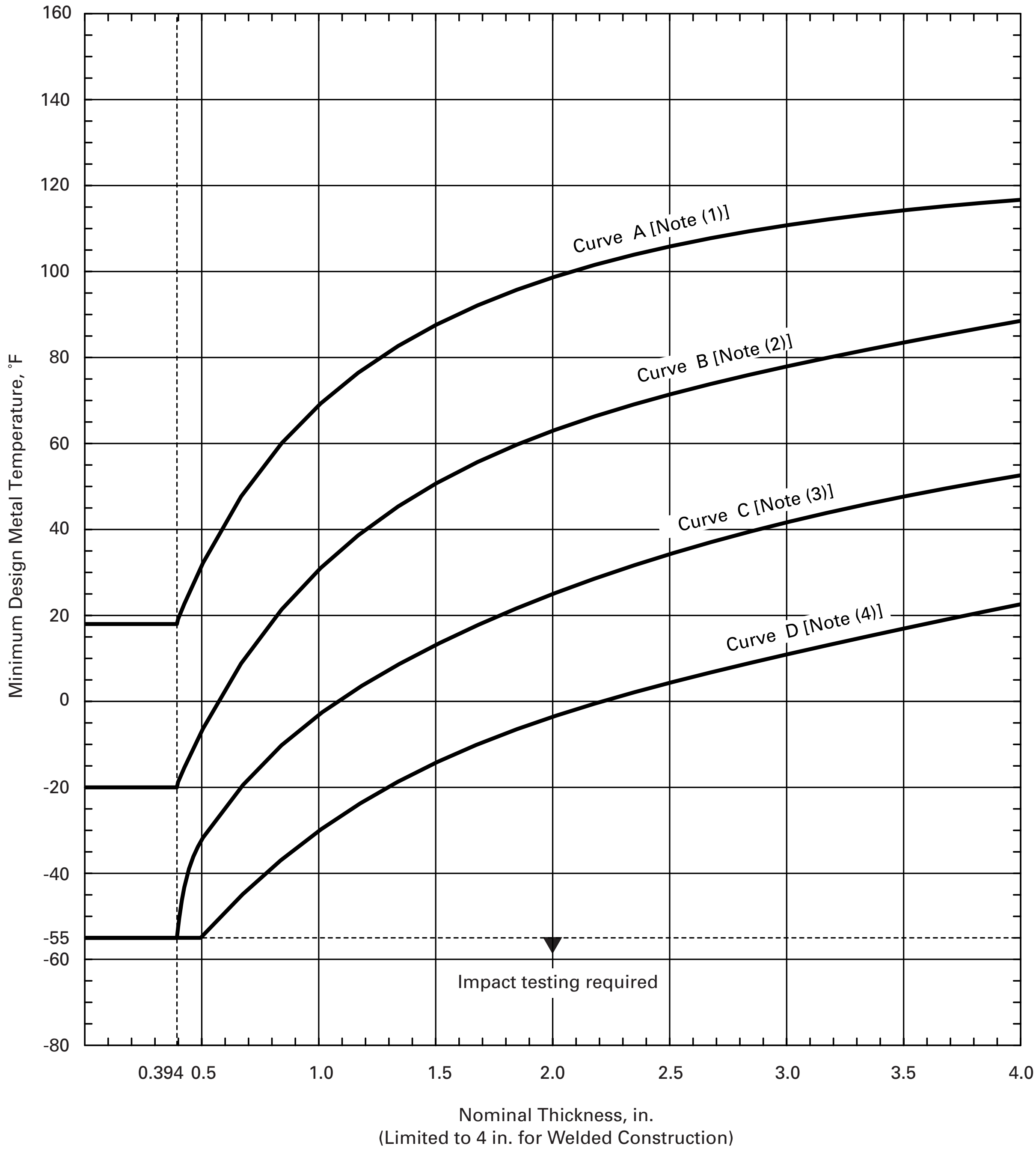


FIG. AM-218.1 IMPACT TEST EXEMPTION CURVES

(Notes to figure follow on next page)

GENERAL NOTES:

(a) Tabular values for this Figure are provided in Table AM-218.1.

(b) Castings not listed in Notes (1) and (2) below shall be impact tested.

(c) For bolting, see AM-214.

(d) When no class or grade is shown in Notes (1) through (4) below, all classes or grades are indicated.

(e) The following shall apply to Notes (1) through (4):

(1) Cooling rates faster than those obtained by cooling in air, followed by tempering, as permitted by the material specification, are considered to be equivalent to normalizing, or normalizing and tempering, heat treatments.

(2) Fine grain practice is defined as the procedures necessary to obtain a fine austenitic grain size as described in SA-20.

NOTES:

(1) The following materials are assigned to Curve A:

(a) all carbon and low alloy steel plates, structural shapes, and bars not listed in Notes (2) through (4) below;

(b) SA-216 Grades WCB and WCC, and SA-217 Grade WC6, if normalized and tempered or water quenched and tempered.

(2) The following materials are assigned to Curve B:

(a) SA-216 Grade WCA if normalized and tempered or water quenched and tempered; Grades WCB and WCC for thicknesses not exceeding 2 in. (51 mm) if produced to fine grain practice and water quenched and tempered;

(b) SA-217 Grade WC9 if normalized and tempered;

(c) SA-285 Grades A and B;

(d) SA-414 Grade A;

(e) SA-515 Grade 60;

(f) SA-516 Grades 65 and 70 if not normalized;

(g) SA-662 Grade B if not normalized;

(h) except for cast steels, all materials of Curve A if produced to fine grain practice and normalized that are not listed in Notes (3) and (4) below;

(i) pipe, fittings, forgings, and tubing not listed in Notes (3) and (4) below;

(j) parts permitted under AM-105 even when fabricated from plate that otherwise would be assigned to a different curve.

(3) The following materials are assigned to Curve C:

(a) SA-182 Grades 21 and 22 if normalized and tempered;

(b) SA-302 Grades C and D;

(c) SA-336 Grades F21 and F22 if normalized and tempered;

(d) SA-387 Grades 21 and 22 if normalized and tempered;

(e) SA-516 Grades 55 and 60 if not normalized;

(f) SA-533 Grades B and C;

(g) SA-662 Grade A;

(h) all materials listed in Note (2) above if produced to fine grain practice and normalized, and if not listed in Note (4) below.

(4) The following materials are assigned to Curve D:

(a) SA-203;

(b) SA-508 Grade 1;

(c) SA-516 if normalized;

(d) SA-524 Classes 1 and 2;

(e) SA-537 Classes 1, 2, and 3;

(f) SA-612 normalized, except that the increased Cb limit in the footnote to Table 1 of SA-20 is not permitted;

(g) SA-662 if normalized;

(h) SA-738 Grade A;

(i) SA-738 Grade A with Cb and V deliberately added in accordance with the provisions of the material specification, not colder than −20°F (−29°C);

(j) SA-738 Grade B not colder than −20°F (−29°C).

FIG. AM-218.1 IMPACT TEST EXEMPTION CURVES (CONT'D)

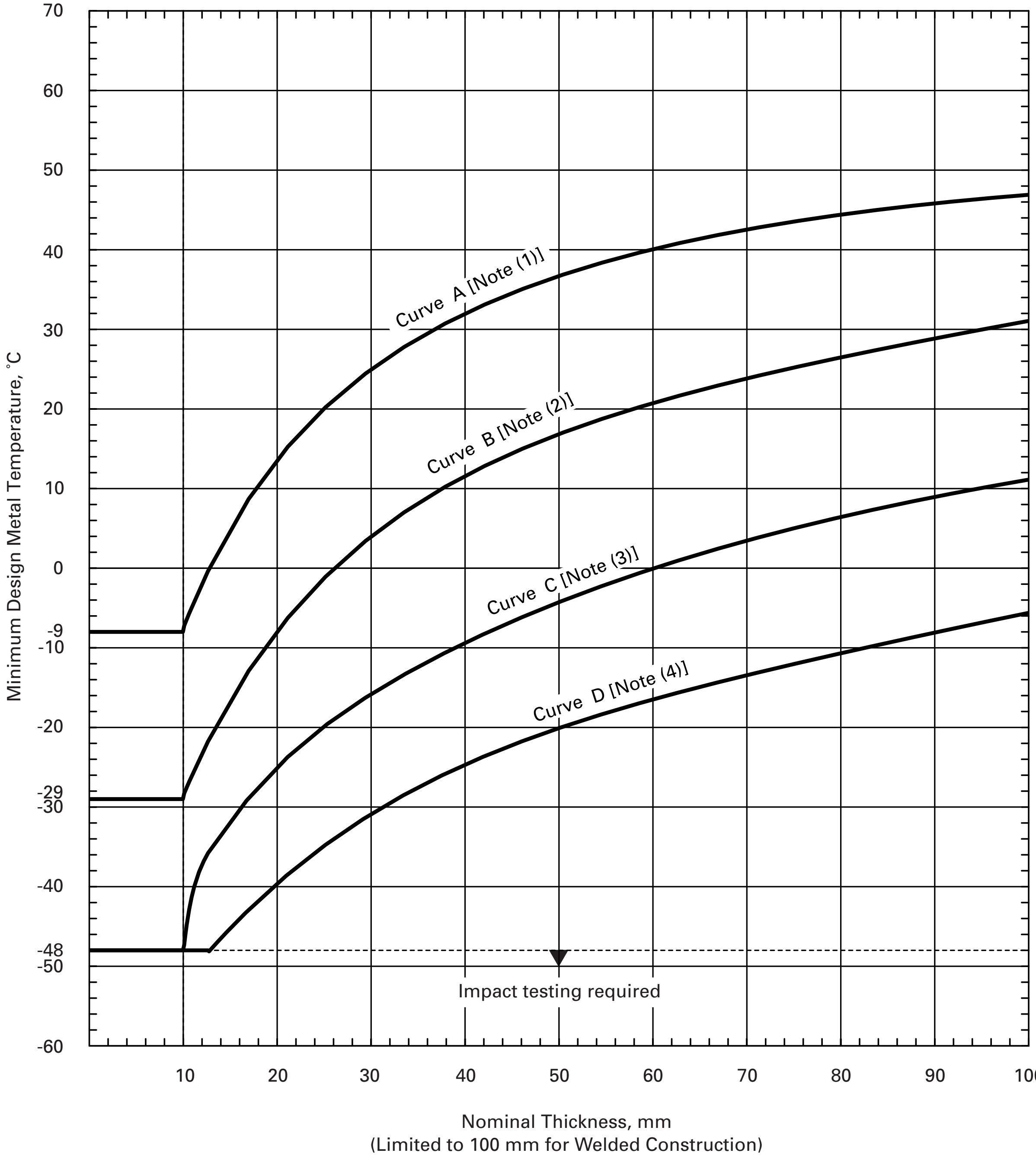


FIG. AM-218.1M IMPACT TEST EXEMPTION CURVES

(Notes to figure follow on next page)

GENERAL NOTES:

(a) Tabular values for this Figure are provided in Table AM-218.1.

(b) Castings not listed in Notes (1) and (2) below shall be impact tested.

(c) For bolting, see AM-214.

(d) When no class or grade is shown in Notes (1) through (4) below, all classes or grades are indicated.

(e) The following shall apply to Notes (1) through (4):

(1) Cooling rates faster than those obtained by cooling in air, followed by tempering, as permitted by the material specification, are considered to be equivalent to normalizing, or normalizing and tempering, heat treatments.

(2) Fine grain practice is defined as the procedures necessary to obtain a fine austenitic grain size as described in SA-20.

NOTES:

(1) The following materials are assigned to Curve A:

(a) all carbon and low alloy steel plates, structural shapes, and bars not listed in Notes (2) through (4) below;

(b) SA-216 Grades WCB and WCC, and SA-217 Grade WC6, if normalized and tempered or water quenched and tempered.

(2) The following materials are assigned to Curve B:

(a) SA-216 Grade WCA if normalized and tempered or water quenched and tempered; Grades WCB and WCC for thicknesses not exceeding 2 in. (51 mm) if produced to fine grain practice and water quenched and tempered;

(b) SA-217 Grade WC9 if normalized and tempered;

(c) SA-285 Grades A and B;

(d) SA-414 Grade A;

(e) SA-515 Grade 60;

(f) SA-516 Grades 65 and 70 if not normalized;

(g) SA-662 Grade B if not normalized;

(h) except for cast steels, all materials of Curve A if produced to fine grain practice and normalized that are not listed in Notes (3) and (4) below;

(i) pipe, fittings, forgings, and tubing not listed in Notes (3) and (4) below;

(j) parts permitted under AM-105 even when fabricated from plate that otherwise would be assigned to a different curve.

(3) The following materials are assigned to Curve C:

(a) SA-182 Grades 21 and 22 if normalized and tempered;

(b) SA-302 Grades C and D;

(c) SA-336 Grades F21 and F22 if normalized and tempered;

(d) SA-387 Grades 21 and 22 if normalized and tempered;

(e) SA-516 Grades 55 and 60 if not normalized;

(f) SA-533 Grades B and C;

(g) SA-662 Grade A;

(h) all materials listed in Note (2) above if produced to fine grain practice and normalized, and if not listed in Note (4) below.

(4) The following materials are assigned to Curve D:

(a) SA-203;

(b) SA-508 Grade 1;

(c) SA-516 if normalized;

(d) SA-524 Classes 1 and 2;

(e) SA-537 Classes 1, 2, and 3;

(f) SA-612 normalized, except that the increased Cb limit in the footnote to Table 1 of SA-20 is not permitted;

(g) SA-662 if normalized;

(h) SA-738 Grade A;

(i) SA-738 Grade A with Cb and V deliberately added in accordance with the provisions of the material specification, not colder than −20°F (−29°C);

(j) SA-738 Grade B not colder than −20°F (−29°C).

FIG. AM-218.1M IMPACT TEST EXEMPTION CURVES (CONT'D)

TABLE AM-218.1
TABULAR VALUES FOR FIG. AM-218.1

Customary Units					SI Units				
Thickness, in.	Curve A, °F	Curve B, °F	Curve C, °F	Curve D, °F	Thickness, mm	Curve A, °C	Curve B, °C	Curve C, °C	Curve D, °C
0.25	18	−20	−55	−55	6.4	−8	−29	−48	−48
0.3125	18	−20	−55	−55	7.9	−8	−29	−48	−48
0.375	18	−20	−55	−55	9.5	−8	−29	−48	−48
0.4375	25	−13	−40	−55	11.1	−4	−25	−40	−48
0.5	32	−7	−34	−55	12.7	0	−22	−37	−48
0.5625	37	−1	−26	−50	14.3	3	−18	−32	−46
0.625	43	5	−22	−48	15.9	6	−15	−30	−44
0.6875	48	10	−18	−45	17.5	9	−12	−28	−43
0.75	53	15	−15	−42	19.1	12	−9	−26	−41
0.8125	57	19	−12	−39	20.6	14	−7	−24	−39
0.875	61	23	−9	−36	22.2	16	−5	−23	−38
0.9375	65	27	−6	−33	23.8	18	−3	−21	−36
1.0	68	31	−3	−31	25.4	20	−1	−19	−35
1.0625	72	34	−1	−28	27.0	22	1	−18	−33
1.125	75	37	2	−26	28.6	24	3	−17	−32
1.1875	77	40	2	−24	30.2	25	4	−17	−31
1.25	80	43	6	−22	31.8	27	6	−14	−30
1.3125	82	45	8	−19	33.3	28	7	−13	−28
1.375	84	47	10	−18	34.9	29	8	−12	−28
1.4375	86	49	12	−16	36.5	30	9	−11	−27
1.5	88	51	14	−14	38.1	31	11	−10	−26
1.5625	90	53	16	−13	39.7	32	12	−9	−25
1.625	92	55	17	−11	41.3	33	13	−8	−24
1.6875	93	57	19	−10	42.9	34	14	−7	−23
1.75	94	58	20	−8	44.5	34	14	−7	−22
1.8125	96	59	22	−7	46.0	36	15	−6	−22
1.875	97	61	23	−6	47.6	36	16	−5	−21
1.9375	98	62	24	−5	49.2	37	17	−4	−21
2.0	99	63	26	−4	50.8	37	17	−3	−20
2.0625	100	64	27	−3	52.4	38	18	−3	−19
2.125	101	65	28	−2	54.0	38	18	−2	−19
2.1875	102	66	29	−1	55.6	39	19	−2	−18
2.25	102	67	30	0	57.2	39	19	−1	−18
2.3125	103	68	31	1	58.7	39	20	−1	−17
2.375	104	69	32	2	60.3	40	21	0	−17
2.4375	105	70	33	3	61.9	41	21	1	−16
2.5	105	71	34	4	63.5	41	22	1	−16
2.5625	106	72	35	5	65.1	41	22	2	−15
2.625	107	73	36	6	66.7	42	23	2	−14
2.6875	107	74	37	7	68.3	42	23	3	−14
2.75	108	74	38	8	69.9	42	23	3	−13
2.8125	108	75	39	9	71.4	42	24	4	−13
2.875	109	76	40	9	73.0	43	24	4	−13
2.9375	109	77	41	10	74.6	43	25	5	−12
3.0	110	78	41	11	76.2	43	26	5	−12

(continued)

TABLE AM-218.1
TABULAR VALUES FOR FIG. AM-218.1 (CONT'D)

Customary Units					SI Units				
Thickness, in.	Curve A, °F	Curve B, °F	Curve C, °F	Curve D, °F	Thickness, mm	Curve A, °C	Curve B, °C	Curve C, °C	Curve D, °C
3.0625	111	78	42	12	77.8	44	26	6	−11
3.125	111	79	43	13	79.4	44	26	6	−11
3.1875	112	80	44	13	81.0	44	27	7	−11
3.25	112	81	44	14	82.6	44	27	7	−10
3.3125	113	81	45	15	84.1	45	27	7	−9
3.375	113	82	46	15	85.7	45	28	8	−9
3.4375	114	83	46	16	87.3	46	28	8	−9
3.5	114	83	47	17	88.9	46	28	8	−8
3.5625	114	84	48	18	90.5	46	29	9	−8
3.625	115	85	49	19	92.1	46	29	9	−7
3.6875	115	85	49	19	93.7	46	29	9	−7
3.75	116	86	50	20	95.3	47	30	10	−7
3.8125	116	87	51	21	96.8	47	31	11	−6
3.875	116	88	51	22	98.4	47	31	11	−6
3.9375	117	89	52	22	100.0	47	32	11	−6
4.0	117	89	52	23	101.6	47	32	11	−5

(c) The governing thickness of flat nonwelded parts, such as bolted flanges, tubesheets, and flat heads, is the flat component thickness divided by 4.

(d) The governing thickness of a nonwelded dished head is the greater of the flat flange thickness divided by 4 or the minimum thickness of the dished portion.

(e) If the governing thickness of the nonwelded part exceeds 4 in. (100 mm) and the minimum design metal temperature is colder than 90°F (32°C), impact tested material shall be used. Examples of the governing thickness for some typical vessel details are shown in Fig. AM-218.2.

NOTE: The use of provisions in AM-204 which waive the requirements for impact testing does not provide assurance that all test results for these materials would satisfy the impact test acceptance criteria of AM-211 if tested.

AM-218.2 Impact Tests of Welding Procedures. For welded construction, the Welding Procedure Qualification shall include impact tests of welds and heat affected zones made in accordance with AM-211 when required by the following provisions.

(a) Welds made with filler metal shall be impact tested in accordance with AM-211 when any of the following apply:

(1) when either base metal is required to be impact tested by the rules of this Division; or

(2) when joining base metals from Fig. AM-218.1 Curves C or D, or metals exempted from impact testing by AM-218.4(e), and the minimum design metal temperature is colder than −20°F (−29°C) but not colder than −55°F (−48°C), unless welding consumables which have been classified by impact tests at a temperature not warmer than the MDMT by the applicable SFA specification are used; or

(3) when joining base metals exempt from impact testing by AM-218.4 when the minimum design metal temperature is colder than −55°F (−48°C).

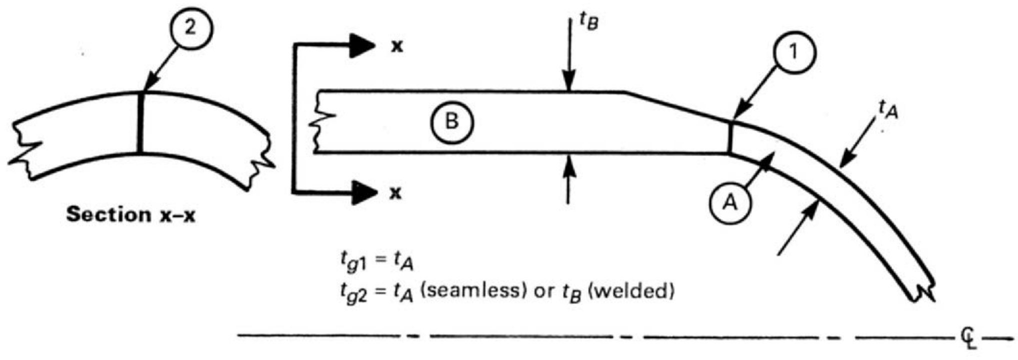
(b) Welds in materials listed in Table ACS-1 made without the use of filler metal shall be impact tested when the thickness of the weld exceeds $\frac{1}{2}$ in. (13 mm) for all minimum design metal temperatures or when the thickness at the weld exceeds $\frac{5}{16}$ in. (8 mm) and the minimum design metal temperature is colder than 50°F (10°C). This requirement does not apply to welds made as part of the material specification.

(c) Weld heat affected zones produced with or without the addition of filler metal shall be impact tested whenever any of the following apply:

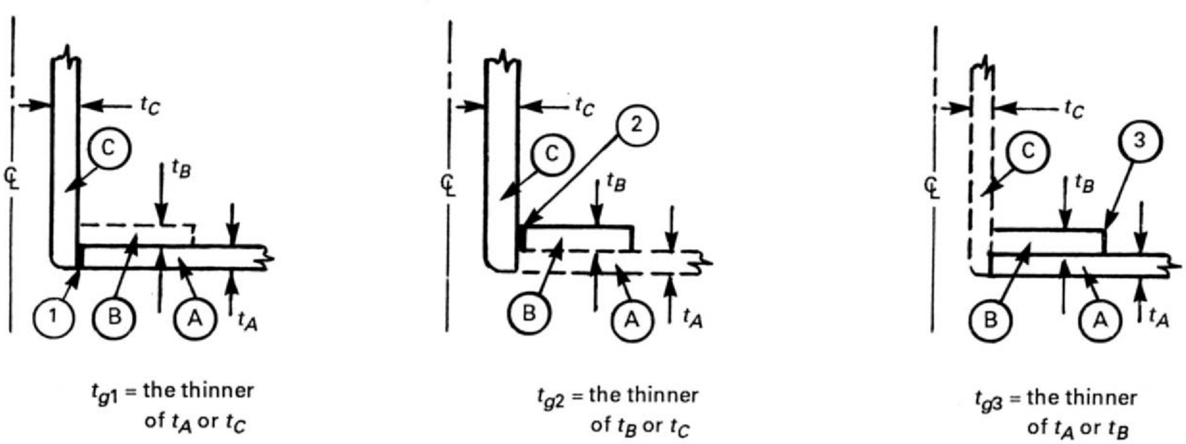
(1) when the base metal is required to be impact tested by the rules of this Division; or

(2) when the welds have any individual weld pass exceeding $\frac{1}{2}$ in. (13 mm) in thickness, and the minimum design metal temperature is colder than 70°F (21°C); or

(3) when joining base metals exempt from testing by AM-218.4(e) when the minimum design metal temperature is colder than −55°F (−48°C).



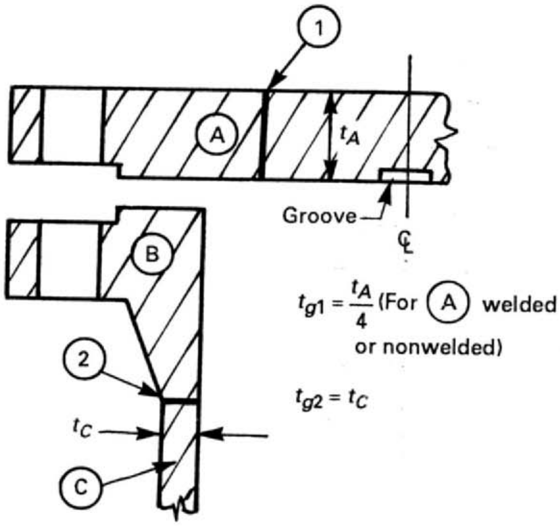
(a) Butt Welded Components



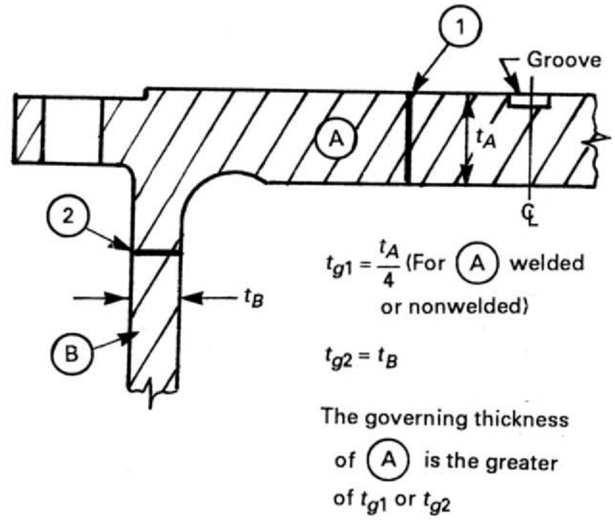
NOTE: Using t_{g1}, t_{g2}, and t_{g3}, determine the warmest MDMT and use that as the permissible MDMT for the welded assembly.

(b) Welded Connection with Reinforcement Plate Added

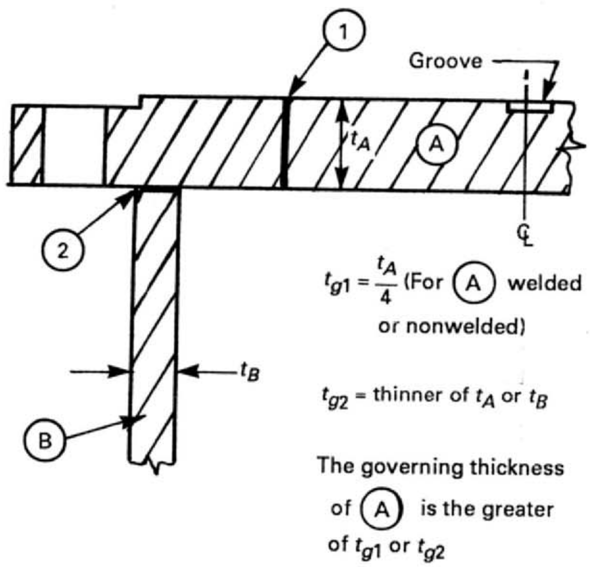
FIG. AM-218.2 SOME TYPICAL VESSEL DETAILS SHOWING THE GOVERNING THICKNESSES AS DEFINED IN AM-218



(c) Bolted Flat Head or Tubesheet and Flange

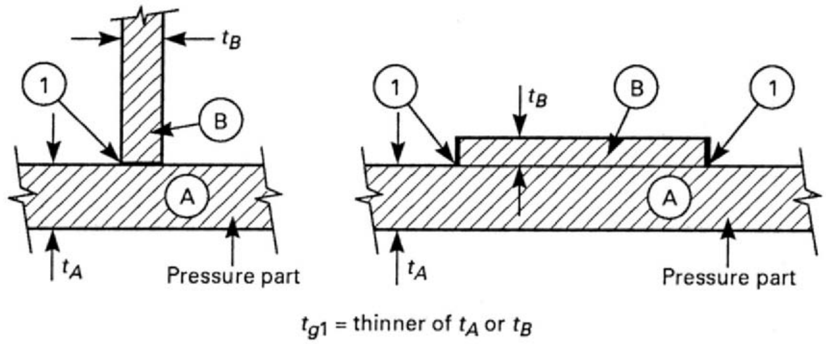


(d) Integral Flat Head or Tubesheet

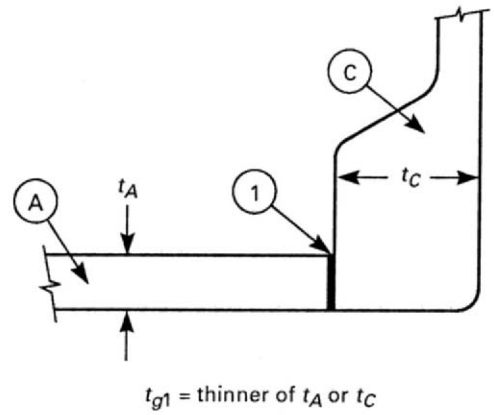


(e) Flat Head or Tubesheet With a Corner Joint

FIG. AM-218.2 SOME TYPICAL VESSEL DETAILS SHOWING THE GOVERNING THICKNESSES AS DEFINED IN AM-218 (CONT'D)



(f) Welded Attachments as Defined in AM-218(a)



(g) Integrally Reinforced Welded Connection

GENERAL NOTE: t_g = governing thickness of the welded joint as defined in AM-218(a)(1).

FIG. AM-218.2 SOME TYPICAL VESSEL DETAILS SHOWING THE GOVERNING THICKNESSES AS DEFINED IN AM-218 (CONT'D)

(d) Vessel (production) impact tests in accordance with AT-203 may be waived for any of the following:

(1) weld metals joining steels exempted from impact testing by AM-218.1 or AM-218.4 for minimum design metal temperatures of −20°F (−29°C) or warmer; or

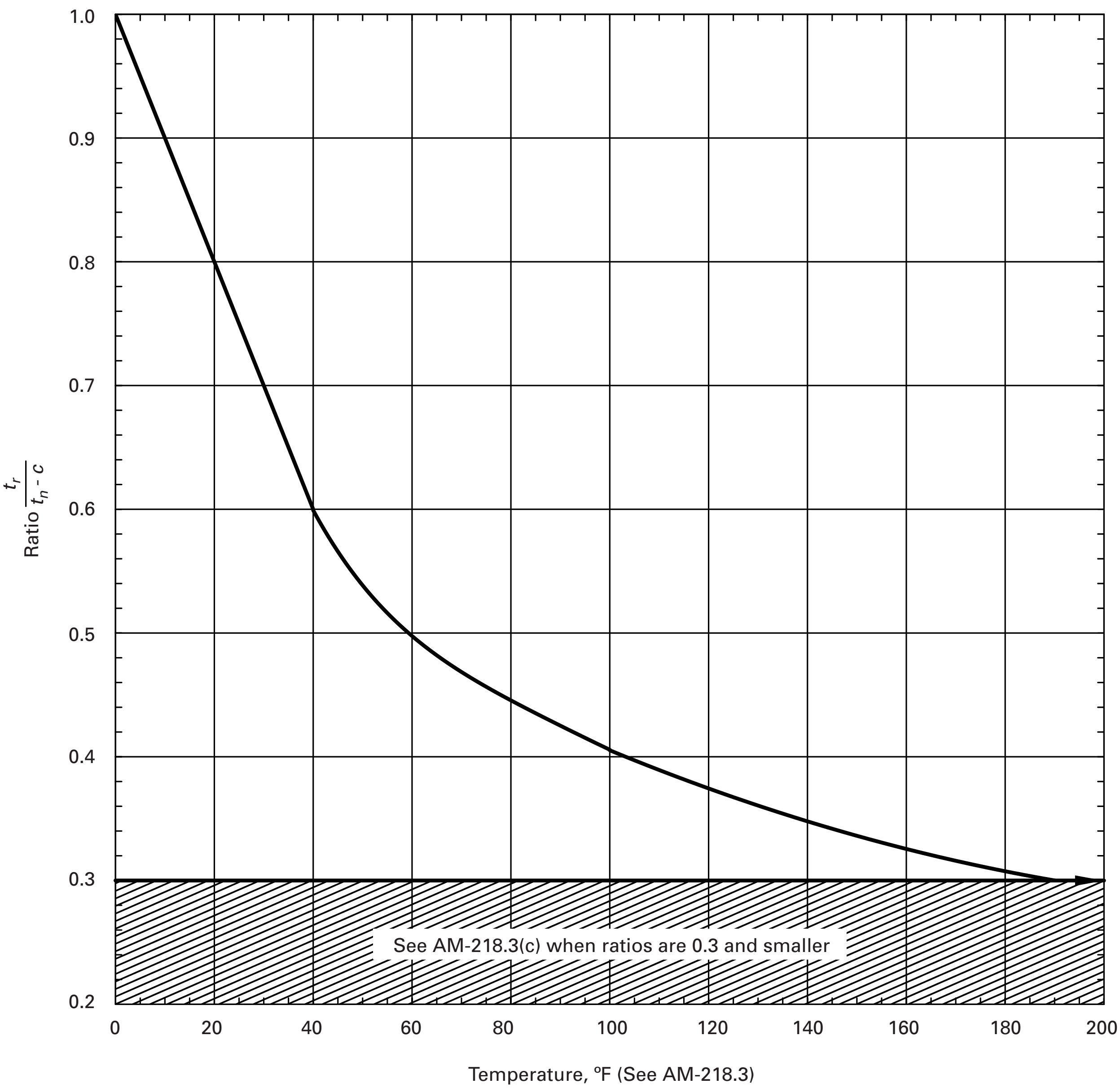
(2) weld metals defined in (a)(2) and (a)(3) above; or

(3) heat affected zones in steels exempted from impact testing by AM-218.1 or AM-218.4, except when (c)(3) above applies.

AM-218.3 For Carbon and Low Alloy Steels, Dependent on Design Stress Intensity Values. When the coincident ratio defined in Fig. AM-218.3 is less than one, Fig. AM-218.3 provides a basis for the use of components made of Table ACS-1 materials to have a colder MDMT than that derived from AM-218.1 without impact testing.

(a) For such components, and for MDMT of −55°F (−48°C) and warmer, the MDMT without impact testing as determined in AM-218.1 for the given material and thickness may be reduced as determined from Fig. AM-218.4. If the resulting temperature is colder than the required MDMT, impact testing of the material is not required.

(b) Figure AM-218.3 may also be used for components not stressed in general primary membrane tensile stress, such as flat heads, covers, tubesheets, and flanges (including bolts and nuts). The MDMT of these components

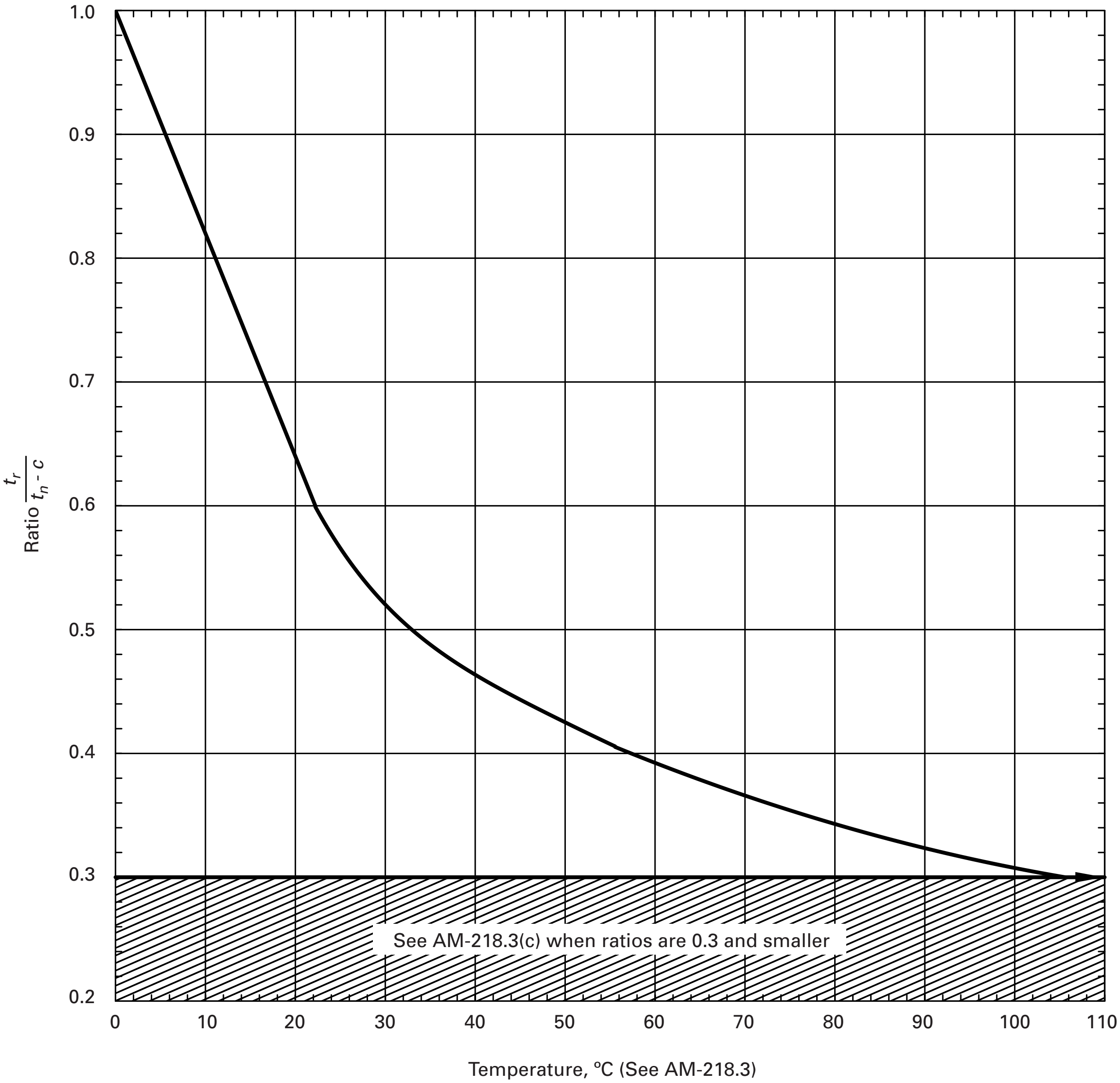


c = corrosion allowance, in.

t_n = nominal thickness of the component under consideration before corrosion allowance is deducted, in.

t_r = required governing thickness in corroded condition of the component under consideration for all applicable loadings [see Note (2) of Fig. AM-218.4]

FIG. AM-218.3 REDUCTION IN MINIMUM DESIGN TEMPERATURE WITHOUT IMPACT TESTING



c = corrosion allowance, mm
t_n = nominal thickness of the component under consideration before corrosion allowance is deducted, mm
t_r = required governing thickness in corroded condition of the component under consideration for all applicable loadings [see Note (2) of Fig. AM-218.4]

FIG. AM-218.3M REDUCTION IN MINIMUM DESIGN TEMPERATURE WITHOUT IMPACT TESTING

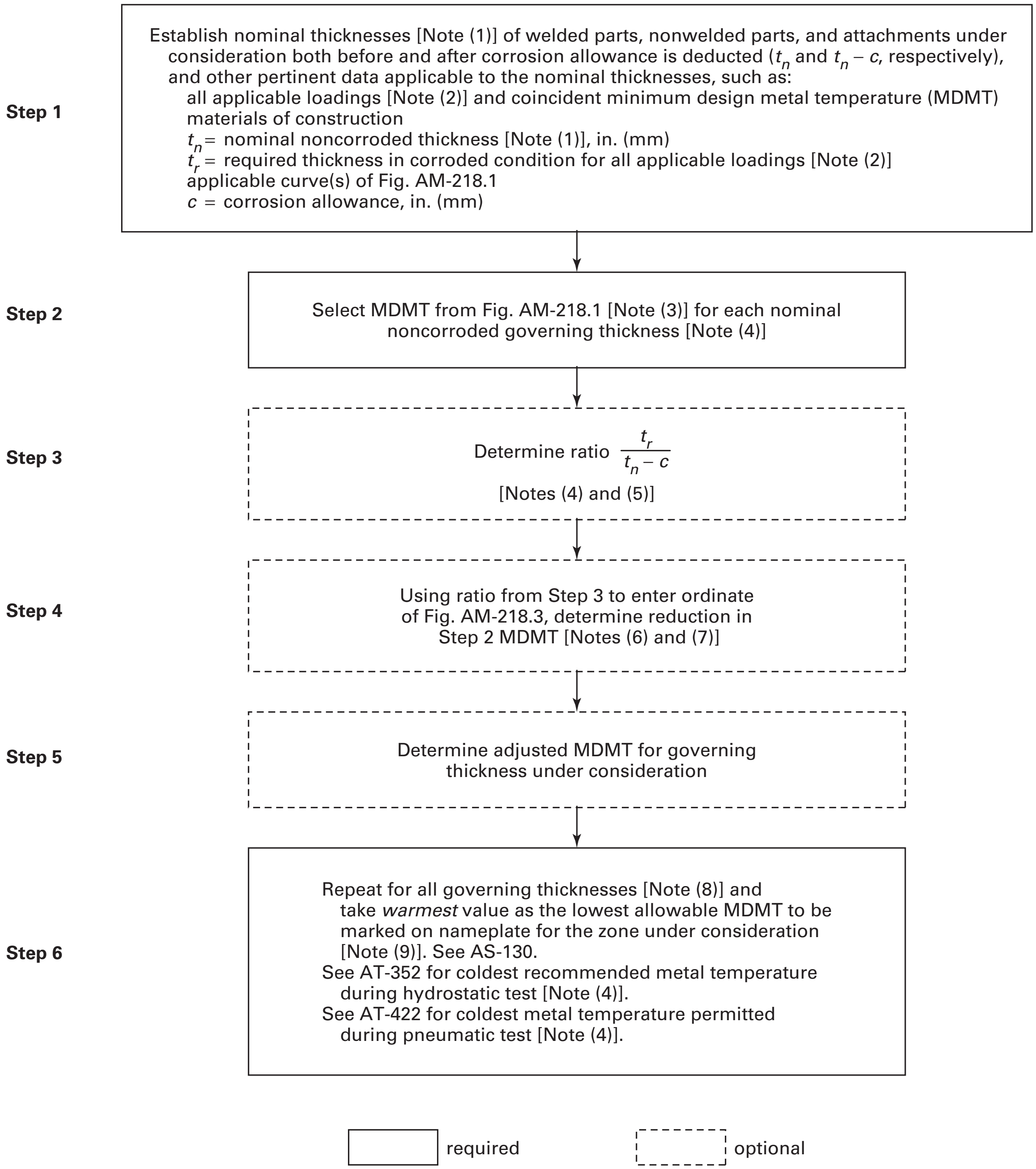


FIG. AM-218.4 DIAGRAM OF AM-218 RULES FOR DETERMINING LOWEST MINIMUM DESIGN METAL TEMPERATURE (MDMT) WITHOUT IMPACT TESTING

[Notes to figure follow on next page]

NOTES:
(1) For pipe where a mill undertolerance is allowed by the material specification, the thickness after mill undertolerance has been deducted shall be taken as the noncorroded nominal thickness t_n for the determination of the MDMT to be stamped on the nameplate. Likewise, for formed heads, the minimum specified thickness after forming shall be used as t_n.
(2) Loadings, including those listed in AD-110, which result in general primary membrane tensile stress at the coincident MDMT.
(3) The construction of Fig. AM-218.1 is such that the MDMT so selected is considered to occur coincidentally with an applied general primary membrane tensile stress at the maximum allowable stress intensity value from Table 2A of Section II, Part D. Tabular values for Fig. AM-218.1 are shown in Table AM-218.1.
(4) If the basis for calculated test pressure is greater than the design pressure (AT-301), a ratio based on the t_r determined from the basis for calculated test pressure and associated appropriate value of $t_n - c$ shall be used to determine the recommended coldest metal temperature during hydrostatic test and the coldest metal temperature permitted during the pneumatic test. See AT-352 and AT-422.
(5) Alternatively, a ratio of the calculated general primary membrane tensile stress, divided by the maximum allowable stress intensity value from Table 2A of Section II, Part D, may be used.
(6) For reductions in MDMT up to and including 40°F (22.2°C), the reduction can be determined by: reduction in MDMT = (1 − ratio)100, °F (°C).
(7) For AM-218.3(b) and AM-218.4(g)(2), a ratio of the maximum design pressure at the MDMT to the maximum allowable pressure (MAP) shall be used. The MAP is defined as the highest permissible pressure as determined by the design formulas for a component using the nominal thickness less corrosion allowance and the maximum allowable stress value from Table 2A of Section II, Part D at the MDMT. For ferritic steel flanges defined in AM-218.4(a), the flange rating, at the warmer of the MDMT or 100°F (38°C), may be used as the MAP.
(8) See AM-218.1 for definitions of governing thickness.
(9) A colder MDMT may be obtained by selective use of impact tested materials as appropriate to the need (see AM-204.4). See also AM-218.4(f).

FIG. AM-218.4 DIAGRAM OF AM-218 RULES FOR DETERMINING LOWEST MINIMUM DESIGN METAL TEMPERATURE (MDMT) WITHOUT IMPACT TESTING (CONT'D)

without impact testing as determined in AM-218.1 or AM-218.4(a) may be reduced as determined from Fig. AM-218.4. The ratio used in Step 3 of Fig. AM-218.4 shall be the ratio of maximum design pressure at the MDMT to the maximum allowable pressure (MAP) of the component at the MDMT. If the resulting temperature is colder than the required MDMT, impact testing of the material is not required, provided the MDMT is not colder than −55°F (−48°C).

04 *(c)* In lieu of using (b) above, the MDMT determined in AM-218.1 or AM-218.4(a) may be reduced for a flange attached by welding, by the same reduction as determined in (a) above for the neck or shell to which the flange is attached. The bolt-up condition need not be considered when determining the temperature reduction for flanges.

(d) For minimum design metal temperatures colder than −55°F (−48°C), impact testing is required for all materials, except as allowed in (e) below.

(e) When the minimum design metal temperature is colder than −55°F (−48°C) and no colder than −155°F (−104°C), and the coincident ratio defined in Fig. AM-218.3 is less than or equal to 0.3, impact testing is not required.

NOTE: One common usage of the exemptions in AM-218.3 will be for those vessels in which the pressure is dependent on the vapor pressure of the contents (e.g., vessels in refrigeration plants, and those subject to low seasonal atmospheric temperatures). For such services, the primary thickness calculations normally will be made for the maximum design pressure coincident with the maximum temperature expected above the line in Fig. AM-218.1 for the applicable group of materials, using the appropriate design stress intensity values of Table 2A of Section II, Part D. Thickness calculations then will be made for the maximum coincident pressure expected below the line in Fig. AM-218.1 for the applicable group of materials using the reduced design stress intensity value(s). The greater of the thicknesses so calculated shall be used. Comparison of pressure ratios to stress ratios may suffice when loadings not caused by pressure are insignificant.

AM-218.4 For Carbon and Low Alloy Steels, Other Requirements and Exemptions

(a) No impact testing is required for ferritic steel flanges used at design temperatures no colder than −20°F (−29°C):

(1) ASME B16.5 flanges;

(2) ASME B16.47 flanges;

(3) long weld neck flanges, defined as forged nozzles that meet the dimensional requirements of a flanged fitting given in ASME B16.5 but have a straight hub/neck. The neck inside diameter shall not be less than the nominal size of the flange, and the outside diameter of the neck and any nozzle reinforcement shall not exceed the diameter of the hub as specified in ASME B16.5.

(b) No impact testing is required for Table ACS-1 materials 0.10 in. (2.5 mm) thickness and thinner, but such exempted Table ACS-1 materials shall not be used at design metal temperatures colder than −55°F (−48°C). For vessels or components made from NPS 4 or smaller tubes or pipe of P-No. 1 materials, the following exemptions from impact testing are also permitted as a function of the material's specified minimum yield strength

(SMYS) for metal temperatures of −155°F (−104°C) and warmer:

SMYS, ksi (MPa)	Thickness, in. (mm)
20 to 35 (138 to 241)	0.237 (6)
36 to 45 (248 to 310)	0.125 (3.2)
46 (317) and higher	0.10 (2.5)

(c) The material manufacturer's identification marking die required by the material specification shall not be stamped on plate material less than 1/4 in. (6 mm) in thickness unless the following requirements are met.

(1) The materials shall be limited to P-No. 1 Group Nos. 1 and 2.

(2) The minimum nominal plate thickness shall be 3/16 in. (5 mm) or the minimum nominal pipe wall thickness shall be 0.154 in. (3.91 mm).

(3) The minimum design metal temperature shall be no colder than −20°F (−29°C).

(d) Unless specifically exempted in Fig. AM-218.1, materials having a specified minimum yield strength greater than 65 ksi (448 MPa) must be impact tested.

(e) Materials produced and impact tested in accordance with the requirements of the specifications listed in General Note (c) of Fig. AM-211 are exempt from impact testing by the rules of this Division at minimum design metal temperatures not more than 5°F (3°C) colder than the test temperature required by the specification.

(f) If postweld heat treating is performed when it is not otherwise a requirement of this Division, a 30°F (17°C) reduction in the temperature at which impact testing is required by Fig. AM-218.1 is permitted for P-No. 1 materials. The resulting exemption temperature may be colder than −55°F (−48°C).

(g) For components made of Table ACS-1 materials that are impact tested, Fig. AM-218.3 provides a basis for the use of these components at a MDMT colder than the impact test temperature, provided the coincident ratio defined in Fig. AM-218.3 is less than one and the MDMT is not colder than −155°F (−104°C).

(1) For such components, the MDMT shall not be colder than the impact test temperature less the allowable temperature reduction as determined from Fig. AM-218.4.

(2) Figure AM-218.3 may also be used for components not stressed in primary membrane tensile stress, such as flat heads, covers, tubesheets, and flanges (including bolts and nuts). The MDMT shall not be colder than the impact test temperature less the allowable temperature reduction as determined from Fig. AM-218.4. The ratio used in Step 3 of Fig. AM-218.4 shall be the ratio of maximum design pressure at the MDMT to the maximum allowable pressure (MAP) of the component at the MDMT.

(3) In lieu of using (2) above, the MDMT for a flange attached by welding shall not be colder than the impact test temperature less the allowable temperature reduction as determined in (1) above for the neck or shell to which the flange is attached.

(h) Vessels or components may be operated at temperatures colder than the MDMT stamped on the nameplate if:

(1) the provisions of AM-218 are met when using the reduced (colder) operating temperature as the MDMT, but in no case shall the operating temperature be colder than −155°F (−104°C); or

(2) as an alternative to (1) above, for vessels or components whose thicknesses are based on pressure loading only, the coincident operating temperature may be as cold as the MDMT stamped on the nameplate less the allowable temperature reduction as determined from Fig. AM-218.4. The ratio used in Step 3 of Fig. AM-218.4 shall be the ratio of maximum pressure at the coincident operating temperature to the design pressure of the vessel at the stamped MDMT, but in no case shall the operating temperature be colder than −155°F (−104°C).

(i) Welded joints shall be postweld heat treated in accordance with the requirements of AF-410 and AF-415 when the MDMT is colder than −55°F (−48°C) and the coincident ratio defined in Fig. AM-218.3 is 0.30 or greater. This requirement does not apply to the following welded joints, in vessels or vessel parts fabricated of P-No. 1 materials that are impact tested at the MDMT or colder in accordance with AM-204. The minimum average energy requirement for base metals and weldments shall be 25 ft–lb (34 J) instead of the values shown in Fig. AM-211.

(1) Type 1 Category A and B joints, not including cone-to-cylinder junctions, that have been 100% radiographed. Category A and B joints attaching sections of unequal thickness shall have a transition with a slope not exceeding 3:1.

(2) Fillet welds having leg dimensions not exceeding 3/8 in. (10 mm) attaching lightly loaded attachments, provided the attachment material and the attachment weld meet the requirements of AM-218 and Article T-2. *Lightly loaded attachment,* for this application, is defined as an attachment for which the stress in the attachment weld does not exceed 25% of the allowable stress. All such welds shall be examined by liquid penetrant or magnetic particle examination in accordance with Appendix 9.

AM-220 FOR INTEGRAL AND WELD METAL OVERLAY CLAD STEEL BASE MATERIAL

Integral and weld metal overlay clad base material and products having applied corrosion resistant linings shall comply with the requirements in the following subparagraphs.

AM-220.1 When Design Calculations Are Based on Total Thickness. Base material with corrosion resistant integral and weld metal overlay cladding used in construction in which the design calculations are based on the total thickness including cladding (see AD-116) shall consist of base plate listed in one of the tables in this Part and shall conform to one of the following specifications:

SA-263 Specification for Corrosion-Resisting Chromium-Steel Clad Plate, Sheet and Strip;

SA-264 Specification for Corrosion-Resisting Chromium-Nickel Steel Clad Plate, Sheet and Strip;

SA-265 Specification for Nickel and Nickel-Base Alloy Clad Steel Plate.

In addition to the above, weld metal overlay cladding may be used as defined in this Article.

AM-220.2 When Design Calculations Are Based on Base-Plate Thickness. Clad plate used in constructions in which the design calculations are based on the base-plate thickness, exclusive of the thickness of the cladding material, may consist of any base-plate material satisfying the requirements of Part AM and any metallic integral or weld metal overlay cladding material of weldable quality that meets the requirements of Part AF.

AM-220.3 Shear Strength of Bond of Integrally Clad Plates. Integrally clad steel plates in which any part of the cladding is included in the design calculations, as permitted in AD-116, shall show a minimum shear strength of 20,000 psi (138 MPa) when tested in the manner described in the plate specification. One shear test shall be made on each such clad plate and the results shall be reported by the mill. A shear or bond strength test is not required for weld metal overlay cladding.

AM-220.4 Removal of Cladding for Mill Tension Tests. When any part of the cladding thickness is specified as an allowance for corrosion, such added thickness shall be removed before mill tension tests are made. When corrosion of the cladding is not expected, no part of the cladding need be removed before testing, even though excess thickness seems to have been provided or is available as corrosion allowance.

AM-230 FOR APPLIED LININGS

Material used for applied corrosion resistant lining may be any metallic material of weldable quality, provided all applicable requirements of Part AF are met.

AM-250 FOR STEEL CASTINGS

AM-251 For Centrifugal Castings

In addition to the minimum requirements of the material specification, all surfaces of centrifugal castings shall be machined after heat treatment to a finish not coarser than 250 μin. (6.35 μm) arithmetical average deviation.

AM-252 Nondestructive Examination of Castings

Castings shall be examined by radiographic, ultrasonic, magnetic particle, and liquid penetrant methods of examination as provided herein and shall meet the requirements of AM-252.1 to AM-252.4, inclusive. Radiographic examination, and when required ultrasonic examination, of castings shall be made after at least one austenizing heat treatment, except austenitic castings not requiring heat treatment may have radiographic and ultrasonic examination performed at any stage of manufacture. Magnetic particle or liquid penetrant examinations shall be made after final heat treatment and after final machining of machined areas.

AM-252.1 Radiographic Examination. All parts of castings regardless of thickness shall be fully radiographed in accordance with the procedures of Article 2 of Section V. The radiographs shall be compared to the appropriate Radiographic Standard listed below, and the maximum acceptable severity levels for imperfections shall be as follows:

(a) for castings having radiographed thickness up to 2 in. (50 mm), ASTM E 446, Standard Reference Radiographs for Steel Castings Up to 2 in. (50 mm) in Thickness, and with maximum severity levels as follows:

Imperfection Category	Thicknesses < 1 in. (< 25 mm)	Thicknesses 1 to < 2 in. (25 to < 50 mm)
A — Gas porosity	1	2
B — Sand and slag	2	3
C — Shrinkage (four types)	1	3
D — Cracks	0	0
E — Hot tears	0	0
F — Inserts	0	0
G — Mottling	0	0

(b) for castings having radiographed thickness from 2 in. to 12 in. (50 mm to 300 mm), ASTM E 186, Standard Reference Radiographs for Heavy-Walled (2 to $4^1/_2$-in. (51 to 114-mm)) Steel Castings or ASTM E 280, Standard Reference Radiographs for Heavy-Walled ($4^1/_2$ to 12-in. (114 to 305-mm)) Steel Castings as appropriate, and with maximum severity levels as below:

Imperfection Category	Thicknesses 2 to $4\frac{1}{2}$ in. (50 to 113 mm)	Thicknesses Over $4\frac{1}{2}$ to 12 in. (Over 113 to 300 mm)
A — Gas porosity	2	2
B — Sand and slag inclusions	2	2
C — Shrinkage		
Type 1	1	2
Type 2	2	2
Type 3	3	2
D — Cracks	0	0
E — Hot Tears	0	0
F — Inserts	0	0

AM-252.2 Ultrasonic Examination. All parts of ferrous castings over 12 in. (300 mm) thick shall be examined by ultrasonic methods in accordance with the procedures of Article 5 of Section V. Castings with imperfections shown by discontinuities whose reflections exceed a height equal to 20% of the normal back reflection, or which reduce the height of the back reflections by more than 30% during movement of the transducer 2 in. (50 mm) in any direction are unacceptable unless other methods of nondestructive testing such as radiographic examination demonstrate to the satisfaction of the vessel Manufacturer and the Inspector that the indications are acceptable or unless such imperfections are removed and the casting is repaired.

AM-252.3 Magnetic Particle Examination. Castings of magnetic material shall be examined on all surfaces by a magnetic particle method in accordance with the methods of Article 9-1. Castings with imperfections shown by Type I indications or by indications exceeding Degree I of Types II, III, IV, and V of ASTM E 125, Reference Photographs for Magnetic Particle Indications on Ferrous Castings, are unacceptable unless the imperfections are removed and casting is repaired.

AM-252.4 Liquid Penetrant Examination. Castings of nonmagnetic material shall be examined on all surfaces by a liquid penetrant method in accordance with the methods of Article 9-2. Castings with cracks and linear imperfections exceeding the following limits are unacceptable:

(a) linear imperfections resulting in more than six indications in any $1\frac{1}{2}$ in. × 6 in. (38 mm × 150 mm) rectangle or $3\frac{1}{2}$ in. (88 mm) diameter circle with these taken in the most unfavorable location relative to the indications being evaluated;

(b) linear imperfections resulting in indications more than $\frac{1}{4}$ in. (6 mm) in length for thicknesses up to $\frac{3}{4}$ in. (19 mm), one-third of the thickness in length for thicknesses from $\frac{3}{4}$ in. (19 mm) to $2\frac{1}{4}$ in. (56 mm), and $\frac{3}{4}$ in. (19 mm) in length for thicknesses over $2\frac{1}{4}$ in. (56 mm) (aligned acceptable imperfections separated from one another by a distance equal to the length of the longer imperfection are acceptable);

(c) all nonlinear imperfections which are indicated to have any dimension which exceeds $\frac{3}{32}$ in. (2.5 mm).

AM-252.5 Repairing of Castings. Where permitted by the rules of this Part, castings with unacceptable imperfections may be repaired in accordance with AM-255. Whenever an imperfection is removed and subsequent repair by welding is not required, the affected area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners.

AM-255 Repairs of Castings by Welding

Castings having imperfections in excess of the maxima permitted in AM-252.1, AM-252.2, AM-252.3, and AM-252.4 may be repaired by welding if the imperfections are removed and provided prior approval is obtained from the vessel Manufacturer. To ensure complete removal of such imperfections prior to making repairs, the base metal shall be reexamined by either magnetic particle or liquid penetrant examination, if it is magnetic, or by liquid penetrant examination, if it is nonmagnetic.

AM-255.1 Requirements for Examining Repairs. All weld repairs of depth exceeding 1 in. (25 mm) or 20% of the section thickness, whichever is the lesser, shall be inspected by radiography in accordance with AM-252.1 and by magnetic particle examination or liquid penetrant examination, if the material is magnetic, or by liquid penetrant examination, if it is nonmagnetic. Where the depth of repairs is less than 20% of the section thickness or 1 in. (25 mm), whichever is the lesser, and where the repaired section cannot be radiographed effectively, the first layer of each $\frac{1}{4}$ in. (6 mm) thickness of deposited weld metal and the finished weld surface shall be examined, as indicated previously, by magnetic particle or liquid penetrant examination. The finished surface examination shall be made after any heat treating operations that are applied to the casting. Weld repairs resulting from ultrasonic examination shall be examined by ultrasonic methods.

AM-255.2 Postweld Heat Treatment of Repaired Castings. When repair welding is done after heat treatment of the casting, the casting shall be postweld heat treated also.

AM-255.3 Required Welding Procedure and Welder Qualifications. All welding shall be performed with a welding procedure qualified in accordance with Section IX. The procedure qualification tests shall be performed on specimens of cast material of the same specification and subject to the same heat treatment before and after welding as will be applied to the work. All welders and operators performing this welding shall also be qualified in accordance with Section IX.

AM-255.4 Certification of Weld Repairs. The location and extent of the weld repairs together with the repair procedure and examination results shall be recorded and transmitted as part of the certification.

AM-258 Identification and Marking of Castings

Each casting shall be marked with the name, trademark, or other traceable identification of the manufacturer and the casting identification, including material designation. The manufacturer shall furnish certification that each casting conforms to all the applicable requirements.

ARTICLE M-3
SPECIAL REQUIREMENTS FOR FERRITIC STEELS WITH TENSILE PROPERTIES ENHANCED BY QUENCHING AND TEMPERING

AM-300 REQUIREMENTS FOR ALL PRODUCT FORMS OF QUENCHED AND TEMPERED FERRITIC STEELS

Steels covered by this Article shall conform to one of the specifications listed in Table AQT-1 and shall be used in conjunction with the requirements of Parts AD and AF of this Division.

The following paragraphs are not intended to apply to steels listed in Table ACS-1 that are furnished in such thicknesses that heat treatment, involving the use of accelerated cooling, including liquid quenching, is used to attain structures comparable to those attained by normalizing thinner sections.

AM-301 Parts for Which Quenched and Tempered Ferritic Steels May Be Used

Quenched and tempered steels listed in Table AQT-1 may be used for the entire vessel or for individual components that are joined to other grades of quenched and tempered steels or to other steels conforming to specifications listed in Tables ACS-1, AHA-1, or ANF-1.3 of this Part, subject to the requirements and limitations of Parts AD and AF.

AM-310 TOUGHNESS REQUIREMENTS FOR QUENCHED AND TEMPERED FERRITIC STEELS

(a) All quenched and tempered steels listed in Table AQT-1 shall be Charpy V-notch tested as required by AM-311. Impact tests shall be conducted at a temperature not warmer than the minimum design metal temperature as determined by AD-121.2(f) but not warmer than +32°F (0°C). Materials may be used at temperatures colder than the minimum design metal temperature as permitted in (b) and (c) below.

(b) When the coincident ratio defined in Fig. AM-218.3 is 0.3 or less, the corresponding minimum design metal temperature shall not be colder than −155°F (−104°C).

(c) When the coincident ratio defined in Fig. AM-218.3 is greater than 0.3, the corresponding minimum design metal temperature shall not be colder than the impact test temperature less the allowable temperature reduction permitted in Fig. AM-218.3 and shall in no case be colder than −155°F (−104°C).

(d) All materials covered by this Part shall have lateral expansion criteria applied to all impact test specimens.

AM-311 Impact Test Specimens

All test specimens shall be prepared from the material in its final heat treated condition according to the requirements of AM-201, AM-202, and Article T-1.

AM-311.1 Number of Impact Tests and Test Specimens. A Charpy V-notch test (three specimens) shall be made for each plate, as it is heat treated, and from each heat of bars, pipe, tubing, rolled sections, forged parts or castings included in any one heat treatment lot.

AM-311.2 Locations and Orientation of Test Specimens. The location and orientation of the specimens shall be the same as required for Charpy type impact tests by AM-204.2 and AM-204.3 except that specimens from plates shall be transverse to the final direction of rolling and for forgings and pipe, tranverse to the direction of major work (see Fig. AM-311.2).

AM-311.3 Size of Test Specimens. Where the geometry permits, the Charpy tests shall be made on standard size specimens (10 mm × 10 mm) in accordance with

Fig. 11a of SA-370. Where the geometry does not permit standard size specimens to be taken, subsize specimens shall be used in accordance with the requirements of AM-204.2.

AM-311.4 Required Lateral Expansion. See AM-211.2.

AM-311.6 Retesting. See AM-211.4(b).

AM-312 Drop-Weight Tests

When the minimum design metal temperature is colder than −20°F (−29°C), drop-weight tests as defined by ASTM E 208, Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels, shall be made on all materials listed in Table AQT-1, with the following exceptions:

(a) SA-522 for any minimum design metal temperature;

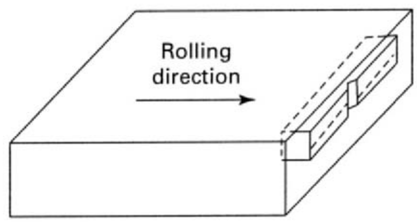
(b) SA-353 and SA-553 when the temperature is not colder than −320°F (−196°C);

(c) SA-645 when the temperature is not colder than −275°F (−170°C).

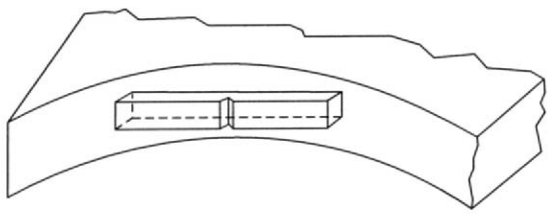
AM-312.1 Number of Tests for Plates. For plates $^5/_8$ in. (16 mm) thick and greater, one drop-weight test (two specimens) shall be made for each plate in the as-heat-treated condition (see AM-311).

AM-312.2 Number of Tests for Forgings and Castings. For forgings and castings of all thicknesses, one drop-weight test (two specimens) shall be made for each heat in any one heat treatment lot. The sampling procedure shall comply with the requirements of ASTM E 208.

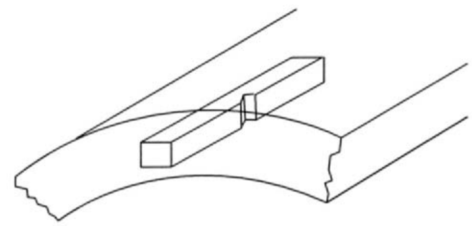
AM-312.3 Required Test Results. Each of the two test specimens shall meet the "no-break" criterion, as defined by ASTM E 208, at the test temperature.



(a) Charpy V-Notch Specimens From Plate

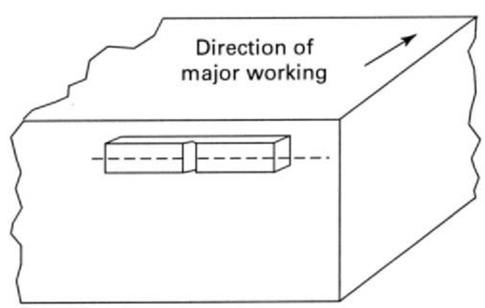


(b-1)



(b-2)

(b) Charpy V-Notch Specimens From Pipe [Note (1)]



(c) Charpy V-Notch Specimens From Forgings

NOTE:

(1) The transverse Charpy V-notch specimen orientation in the pipe shall be as shown in sketch (b-1). If this transverse specimen orientation cannot be accommodated by the pipe geometry, then the alternate orientation shall be as shown in sketch (b-2).

FIG. AM-311.2 ORIENTATION AND LOCATION OF TRANSVERSE CHARPY V-NOTCH SPECIMENS
(for Materials Listed in Table AQT-1)

ARTICLE M-4
SPECIAL REQUIREMENTS FOR NONFERROUS MATERIALS

AM-400 FOR ALL PRODUCT FORMS OF NONFERROUS MATERIALS

All product forms of nonferrous materials permitted by AM-100 may be used subject to the provisions of this Article.

AM-401 Test Coupon Heat Treatment

(a) Fabrication heat treatments of nonferrous material are normally not necessary. If heat treatment is performed, it shall be by agreement between the user and the vessel Manufacturer.

(b) Materials for which the mechanical properties are affected by fabrication heat treatments shall be represented by test specimens that have been subjected to the simulated fabrication heat treatments. The vessel Manufacturer shall specify the pertinent fabrication heat treatment parameters to the material manufacturer.

(c) The requirements of (b) above exclude annealing and stress relieving.

AM-402 Ultrasonic Examination

(a) All plates and forgings 4 in. (100 mm) and over in nominal thickness shall be ultrasonically examined in accordance with the applicable requirements of the ASTM standards and ASME specifications listed in (d) below. Insofar as practicable, all solid rectangular forgings shall be examined by the straight beam technique from two directions at approximately right angles.

(b) Hollow forgings including flanges and rings 4 in. (100 mm) and over in nominal thickness, in addition to (a) above, shall be examined using the angle beam technique by either the contact method or the immersion method. Reference specimens and acceptance criteria shall be in accordance with AM-203.2. Hollow forgings shall be examined from one face or surface normal to the axis and in the circumferential direction unless the wall thickness or geometric configuration makes angle beam examination impracticable. Disk forgings shall be examined from one flat side and from the circumferential surface.

(c) The entire volume of metal shall be ultrasonically examined at some state of manufacture. For heat treated material, examination after final heat treatment is preferred, but if the contour of the forging precludes complete examination at this stage, the maximum possible volume of the forging shall be reexamined after final heat treatment.

(d) Applicable ASTM standards and ASME specifications are:

SE-114 Ultrasonic Testing by the Reflection Method Using Pulsed Longitudinal Waves Induced by Direct Contact;

SE-214 Immersed Ultrasonic Testing by the Reflection Method Using Pulsed Longitudinal Waves;

E 127 Fabricating and Checking Aluminum Alloy Ultrasonic Standard Reference Blocks;

SB-548 Ultrasonic Testing of Aluminum Plate.

(e) In straight beam examination, the transducers shall be $^3\!/_4$ in. to $1^1\!/_8$ in. (19 mm to 29 mm) in diameter or 1 in. (25 mm) square. The nominal frequency shall be appropriate for the material being examined. The instrument shall be set so that the first back reflection is 75 ±5% of the screen height when the transducer is placed on an indication-free area of the forging.

(f) In angle beam examination by the contact method, a 1 in. × 1 in. (25 mm × 25 mm) or 1 in. × 1.5 in. (25 mm × 38 mm), 45 deg transducer shall be used at an appropriate frequency.

(g) In angle beam examination by the immersion method, a $^3\!/_4$ in. (19 mm) diameter transducer oriented at an appropriate angle of inclination shall be used at an appropriate frequency.

(h) Angle beam examination shall be calibrated with a notch of a depth equal to the lesser of $^3\!/_8$ in. (10 mm) or 3% of the nominal section thickness, a length of approximately 1 in. (25 mm), and a width not greater than two times the depth.

(i) Material shall be unacceptable (unless repaired in accordance with AM-421) if straight beam examination shows one or more discontinuities which produce indications accompanied by a complete loss of back reflection not associated with or attributable to the geometric configuration, or if angle beam examination results show one or more discontinuities which produce indications exceeding that of the calibration notch.

AM-410 CLAD PLATE AND PRODUCTS

Clad plate or products used in constructions in which the design calculations are based on the total thickness, including cladding, shall consist of base plate listed in one of the tables in this Part and shall conform to one of the following specifications:

SB-209 Specification for Aluminum Alloy Sheet and Plate;

SB-221 Specification for Aluminum Alloy Extruded Bars, Rods, Shapes, and Tubes.

AM-420 CASTINGS

AM-420.1 Examination. All nonferrous castings shall be examined in accordance with the following.

(a) Each casting shall be subjected to 100% visual examination and to liquid penetrant examination on all surfaces in accordance with AM-252.4. These examinations shall be performed following the final heat treatment applied to the casting.

(b) All parts of castings shall be subjected to complete radiographic examination and the radiographs shall be compared with the radiographic standards of ASTM E 272, Reference Radiographs for Inspection of High-Strength Copper-Base and Nickel-Copper Alloy Castings. Acceptable castings must meet Class 1 standards, if wall thickness is less than 1 in. (25 mm), or Class 2 standards, if 1 in. (25 mm) or over, as defined in the ASTM Specification.

(c) All parts of castings in excess of 12 in. (300 mm) in thickness shall be ultrasonically examined in accordance with the procedures given in SE-114. Any imperfections whose reflections do not exceed a height equal to 20% of the normal back reflection or do not reduce the height of the back reflection by more than 30% during movement of the transducer 2 in. (50 mm), in any direction, shall be considered acceptable. The above limits are established for the use of transducers having approximately 1 sq in. (650 mm^2) of area.

AM-420.2 Repairing of Castings. Upon approval by the vessel Manufacturer, castings subject to rejection because of these examinations may be repaired in accordance with AM-421.

AM-420.3 Identification and Marking. Each casting shall be marked with the name, trademark, or other traceable identification of the manufacturer and the casting identification, including material designation. The manufacturer shall furnish reports or certification that each casting conforms to all applicable requirements.

AM-421 Repair by Welding

(a) Castings having imperfections in excess of the maxima permitted in AM-420.1(a), (b), and (c) may be repaired by welding, if the imperfections are removed and provided prior approval is obtained from the vessel Manufacturer. To ensure complete removal of such imperfections, prior to making repairs, the base metal shall be reexamined by liquid penetrant examination.

(b) All weld repairs of depth exceeding 1 in. (25 mm) or 20% of the section thickness, whichever is the lesser, shall be examined by radiography in accordance with AM-420.1(b) and by liquid penetrant examination. Where the depth of repairs is less than 20% of the section thickness or 1 in. (25 mm), whichever is the lesser, and where the repaired section cannot be radiographed effectively, the first layer of each $\frac{1}{4}$ in. (6 mm) thickness of deposited weld metal and the finished weld surface shall be examined, as indicated previously, by liquid penetrant examination. The finished surface examination shall be made after any heat treating operations that are applied to the casting. Weld repairs resulting from ultrasonic examination shall be examined by ultrasonic methods.

(c) When repair welding is done after heat treatment of the casting, the casting shall be postweld heat treated.

(d) All welding shall be performed using welding procedures qualified in accordance with Section IX. The procedure qualification shall be performed on test specimens of cast material of the same specification and subject to the same heat treatments before and after welding as will be applied to the work. All welders and welding operators performing this welding shall also be qualified in accordance with Section IX.

(e) The location and extent of the weld repairs together with the repair procedure and examination results shall be recorded and transmitted as part of the certification.

ARTICLE M-5
SPECIAL REQUIREMENTS FOR BOLTING

AM-500 FOR ALL BOLTING MATERIALS

AM-501 Material Specifications and Stress Values

Specifications, supplementary rules, and maximum allowable stress values for acceptable bolting materials are given in Table 3 of Subpart 1 of Section II, Part D for ferrous materials and nonferrous materials for use with flanges designed in accordance with Appendix 3; for flanges designed in accordance with Appendices 4, 5, and 6, the specifications, supplementary rules, and allowable stress values for acceptable bolting materials are given in Table 4 of Subpart 1 of Section II, Part D for ferrous and nonferrous materials.

AM-501.1 Examination of Bolts, Studs, and Nuts. Examination of bolts, studs, and nuts bolting covered by Table 4 of Subpart 1 of Section II, Part D shall be subject to examinations as follows.

(a) Visual examination shall be applied to the areas of threads, shanks, and heads of final machined parts. Discontinuities such as laps, seams, or cracks are unacceptable.

(b) All bolts, studs, and nuts over 2 in. (50 mm) nominal bolt size shall be examined by the magnetic particle method of Article 9-1 or by the liquid penetrant method of Article 9-2. This examination shall be performed on the finished component after threading or on the material stock at approximately the finished diameter before threading and after heading (if involved). Linear nonaxial indications are unacceptable. Linear axial indications greater than 1 in. (25 mm) in length are unacceptable.

AM-502 Threading and Machining of Studs

Studs shall be threaded full length, or shall be machined down to the root diameter of the thread in the unthreaded portion provided that the threaded portions are at least $1\frac{1}{2}$ diameters in length.

Studs greater than 8 diameters in length may have an unthreaded portion which has the nominal diameter of the thread, provided the following requirements are met.

(a) The threaded portions shall be at least $1\frac{1}{2}$ diameters in length.

(b) The stud shall be machined down to the root diameter of the thread for a minimum distance of 0.5 diameters adjacent to the threaded portion.

(c) A suitable transition shall be provided between the root diameter and the unthreaded portion.

(d) Particular consideration shall be given to any dynamic loadings.

AM-503 Use of Washers

The use of washers is optional. When used, they shall be of wrought material.

AM-510 FOR FERROUS BOLTING

AM-511 Materials for Nuts and Washers

Materials for steel nuts and washers shall conform to SA-194, SA-563, or to the requirements for nuts in the specification for the bolting material with which they are to be used. Nuts of special design, such as wing nuts, may be made of any suitable wrought material listed in Tables ACS-1, AHA-1, or AQT-1 and shall be either: hot or cold forged; or machined from hot forged, hot rolled, or cold drawn bars.

AM-511.1 Selection of Materials for Nuts and Washers. Materials for nuts and washers shall be selected as follows.

(a) Carbon or alloy steel nuts and carbon or alloy steel washers of approximately the same hardness as the nuts may be used for metal temperatures not exceeding 900°F (480°C).

(b) Alloy steel nuts shall be used for metal temperatures exceeding 900°F (480°C). Washers, if used, shall be of alloy steel equivalent to the nut material.

(c) Nonferrous nuts and washers may be used with ferrous bolts and studs provided they are suitable for the application. Consideration shall be given to the differences in thermal expansion and possible corrosion

resulting from the combination of dissimilar metals. They shall conform to the requirements of AM-522 and AM-523.

AM-512 Requirements for Nuts

Nuts shall be semifinished, chamfered, and trimmed. Nuts shall be threaded to Class 2B or finer tolerances according to ASME B1.1.

AM-512.1 For Use With Flanges. For use with flanges conforming to the standards listed in AD-711, nuts shall conform at least to the dimensions given in ASME/ANSI B18.2.2 for Heavy Series Nuts.

AM-512.2 For Use With Other Connections. For use with connections designed in accordance with the rules in Part AD, nuts may be of the American National Standard Heavy Series or they may be of other dimensions provided their strength is equal to that of the bolting, giving due consideration to bolt hole clearance, bearing area, thread form and class of fit, thread shear, and radial thrust from threads.

AM-512.3 Depth of Nut Engagement. Nuts shall engage the threads for the full depth of the nut or, in the case of cap nuts, to a depth equivalent to the depth of a standard nut.

AM-512.4 Special Design. Nuts of special design may be used provided their strength is equal to that of the bolting (see AM-512.2).

AM-520 FOR NONFERROUS BOLTING

AM-521 Condition of Material Selected and Allowable Stress Value

(a) When nonferrous bolts are machined from heat treated, hot rolled, or cold worked material and are not subsequently hot worked or annealed, the allowable stress values in Table 3 of Subpart 1 of Section II, Part D to be used in design shall be based on the condition of the material selected.

(b) When nonferrous bolts are fabricated by hot heading, the allowable stress values for annealed materials in Table 3 of Subpart 1 of Section II, Part D shall apply unless the manufacturer can furnish adequate control data to show that the tensile properties of hot rolled or heat treated bars or hot finished or heat treated forgings are being met, in which case the allowable stress values for the material in the hot finished condition may be used.

(c) When nonferrous bolts are fabricated by cold heading, the allowable stress values for annealed materials in Table 3 of Subpart 1 of Section II, Part D shall apply unless the manufacturer can furnish adequate control data to show that higher design stresses, as agreed upon, may be used. In no case shall such stresses exceed the allowable stress values given in Table 3 of Subpart 1 of Section II, Part D for cold worked bar stock.

AM-522 Materials of Nuts and Washers

(a) Materials for steel nuts used with nonferrous bolting shall conform to AM-511.

(b) Nonferrous nuts and washers may be made of any suitable material listed in Table ANF-1.1, ANF-1.2, or ANF-1.3.

AM-523 Requirements for Nuts

See AM-512.

AM-523.1 For Use With Flanges. See AM-512.1.

AM-523.2 For Use With Other Connections. See AM-512.2.

AM-523.3 Depth of Nut Engagement. See AM-512.3.

AM-523.4 Special Design. See AM-512.4.

ARTICLE M-6
MATERIAL DESIGN DATA

AM-600 CONTENTS OF TABLES OF MATERIAL DESIGN DATA

Tables 2A, 2B, 3, and 4 in Subpart 1 of Section II, Part D, together with their maximum allowable design stress intensity values S_m over a range of temperatures (for limits see AD-130), give the data needed for design, as required by the rules of Part AD.

(a) The materials which may be used are listed in the Tables enumerated below:

ACS-1	ANF-1.4
AHA-1	ABM-1
AQT-1	ABM-1.2
ANF-1.1	ABM-1.3
ANF-1.2	ABM-2
ANF-1.3	

(b) Table Y-1 of Section II, Part D provides the values of yield strength for these same materials over an appropriate range of temperatures.

(c) At temperatures above 100°F (38°C), the design stress intensity values may exceed $^2\!/_3$ and may reach 90% of the yield strength (0.2% offset) at temperature. This may result in permanent strain of as much as 0.1%. When this amount of deformation is not acceptable, the designer should reduce the allowable stress to obtain an acceptable amount of deformation. Table Y-2 of Section II, Part D provides strain limiting factors for design use when employing high alloy steels or nonferrous materials and it is desired to limit the permanent strain below this.

(d) The coefficients of thermal expansion and the moduli of elasticity for all materials which may be used under the rules of this Division are given in the following Tables:

(1) coefficients of thermal expansion are given in Tables TE-1 through TE-5 of Section II, Part D;

(2) moduli of elasticity are given in Tables TM-1 through TM-5 of Section II, Part D.

(e) Coefficients of thermal conductivity and thermal diffusivity are listed in Table TCD of Section II, Part D.

(f) See also informative and nonmandatory guidance regarding metallurgical phenomena in Appendix A of Section II, Part D.

TABLE ACS-1 CARBON AND LOW ALLOY STEELS 04

Spec No.	Type/Grade	Spec No.	Type/Grade	Spec No.	Type/Grade
SA-36	. . .	SA-285	A, B, C	SA-516	55, 60, 65, 70
		SA-299	. . .	SA-524	I, II
SA-105	. . .			SA-533	A Cl. 1 & 2, B Cl. 1 &
SA-106	A, B, C	SA-302	A, B, C, D		2, C Cl. 1 & 2, D Cl.
SA-178	C	SA-333	1, 3, 4, 6, 9		2
SA-181	. . .	SA-334	1, 3, 9	SA-537	Cl. 1, Cl. 2, Cl. 3
SA-182	FR, F1, F2, F3V, F5, F5a, F9,	SA-335	P1, P2, P5, P5b, P5c, P9, P11,	SA-541	1, 1A, 2 Cl. 1 & 2, 3 Cl.
	F11 Cl. 1 & 2, F12 Cl. 1 &		P12, P21, P22, P91		1 & 2, 3V, 22 Cl. 3,
	2, F21, F22 Cl. 3, F22V, F91	SA-336	F1, F3V, F5, F5A, F9, F11 Cl.		22V
			2 & 3, F12, F21 Cl. 1 & 3,	SA-542	B Cl. 4, C Cl. 4a, D Cl.
SA-203	A, B, D, E, F		F22 Cl. 1 & 3, F22V		4a
SA-204	A, B, C	SA-350	LF1, LF2, LF3, LF9		
SA-209	T1, T1a, T1b	SA-352	LCB, LC1, LC2, LC3	SA-612	. . .
SA-210	A-1, C	SA-369	FP1, FP2, FP5, FP9, FP11,	SA-662	A, B, C
SA-213	T2, T5, T5b, T5c, T9, T11, T12,		FP12, FP21, FP22	SA-675	45, 50, 55, 60, 65, 70
	T21, T22, T91	SA-372	A, B, C, D		
SA-216	WCA, WCB, WCC	SA-387	2, 5, 11, 12, 21, 22, 91	SA-727	. . .
SA-217	C5, C12, WC1, WC4, WC5,			SA-737	B, C
	WC6, WC9	SA-420	WPL3, WPL6, WPL9	SA-738	A, B, C
SA-225	C	SA-423	1, 2	SA-739	B11, B22
SA-234	WPB, WPC, WP1, WP5, WP9,	SA-487	1 Cl. A, 4 Cl. A, 8 Cl. A	SA-765	I, II, III, IV
	WP11 Cl. 1, WP12 Cl. 1,				
	WP22 Cl. 1	SA-508	1, 1A, 2 Cl. 1 & 2, 3 Cl. 1 & 2,	SA-832	21V, 22V
SA-266	1, 2, 3, 4		3V, 4N Cl. 3, 22 Cl. 3		
SA-283	B, D	SA-515	60, 65, 70		

TABLE AHA-1
HIGH ALLOY STEELS

Spec No.	Type/Grade
SA-182	FXM-11, FXM-19, F6a, F304, F304H, F304L, F310, F316, F316H, F316L, F321, F321H, F347, F347H, F348, F348H
SA-213	TP304, TP304H, TP304L, TP304N, TP309Cb, TP309H, TP309S, TP310H, TP310MoLN, TP310S, TP316, TP316H, TP316L, TP316N, TP321, TP321H, TP347, TP347H, TP348, TP348H, XM-15
SA-217	CA15
SA-240	XM-15, XM-19, XM-29, 201LN, 302, 304, 304L, 304N, 309Cb, 309H, 309S, 310H, 310MoLN, 310S, 316, 316L, 316N, 317, 317L, 321, 321H, 347, 347H, 348, 405, 410, 410S, 429, 430, S44660
SA-249	TPXM-15, TPXM-19, TP304, TP304H, TP304L, TP304N, TP309Cb, TP309H, TP309S, TP310Cb, TP310H, TP310MoLN, TP310S, TP316, TP316H, TP316L, TP316N, TP317, TP321, TP321H, TP347, TP347H, TP348, TP348H
SA-268	TP405, TP410, TP429, TP430, 26-3-3
SA-312	TPXM-11, TPXM-15, TPXM-19, TP304, TP304H, TP304L, TP304N, TP309Cb, TP309H, TP309S, TP310Cb, TP310H, TP310MoLN, TP310S, TP316, TP316H, TP316L, TP316N, TP317, TP321, TP321H, TP347, TP347H, TP348, TP348H
SA-336	FXM-11, FXM-19, F6, F304, F304H, F304L, F304N, F310, F316, F316H, F316L, F316N, F321, F321H, F347, F347H
SA-351	CF3, CF8, CF8C, CF8M, CF10, CH8, CH20, CK20
SA-376	TP304, TP304H, TP304N, TP316, TP316H, TP316N, TP321, TP321H, TP347, TP347H, TP348
SA-403	XM-19, 304, 304H, 304L, 304N, 309, 310, 316, 316L, 316N, 317, 321, 321H, 347, 347H, 348, 348H
SA-430	FP304H, FP304N, FP316H, FP316N, FP321, FP321H, FP347H
SA-479	XM-19, 309H
SA-666	XM-11
SA-688	TP304, TP304L, TP316, TP316L
SA-789	S31500
SA-790	S31500
SA-803	26-3-3
SA-813	TP309Cb, TP309S, TP310Cb, TP310S
SA-814	TP309Cb, TP309S, TP310Cb, TP310S

TABLE AQT-1
QUENCHED AND TEMPERED STEELS

Spec No.	Type/Grade	Spec No.	Type/Grade	Spec No.	Type/Grade
SA-333	8	SA-508	4N Cl. 1 & 2	SA-645	. . .
SA-334	8	SA-517	A, B, E, F, J, P		
SA-353	. . .	SA-522	I	SA-723	1, 2, 3
SA-372	D, E Cl. 70, F Cl. 70, G Cl. 70, H Cl. 70, J Cl. 70 & 110	SA-533	B Cl. 3, D Cl. 3	SA-724	A, B, C
		SA-543	B, C		
		SA-553	I, II		
		SA-592	A, E, F		
SA-420	WPL8				

TABLE ANF-1.1
ALUMINUM ALLOYS

Spec No.	Alloy Designation/UNS No.	Spec No.	Alloy Designation/UNS No.
SB-209	A93003, A93004, A95052, A95083, A95086, A95454, A96061	SB-241	Alclad 3003, A93003, A95083, A95454, A96061, A96063
SB-210	Alclad 3003, A93003, A96061, A96063		
SB-221	A93003, A95083, A95454, A96061, A96063	SB-308	A96061

TABLE ANF-1.2
COPPER AND COPPER ALLOYS

Spec No.	UNS No.	Spec No.	UNS No.
SB-96	C65500	SB-169	C61400
SB-98	C65100, C65500, C66100	SB-171	C46400, C70600, C71500
		SB-187	C10200, C11000
SB-111	C28000, C44300, C44400, C44500, C60800, C70600, C71500	SB-395	C70600, C71500
SB-150	C61400, C62300, C63000, C64200		

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TABLE ANF-1.3
NICKEL AND NICKEL ALLOYS

Spec No.	UNS No.	Spec No.	UNS No.
SB-127	N04400	SB-511	N08330
SB-160	N02200, N02201	SB-514	N08800, N08810
SB-161	N02200, N02201	SB-515	N08800, N08810
SB-162	N02200, N02201	SB-516	N06600
SB-163	N02200, N02201, N04400, N06600, N08800, N08810, N08825	SB-517	N06600
SB-164	N04400, N04405	SB-535	N08330
SB-165	N04400	SB-536	N08330
SB-166	N06600	SB-564	N04400, N06022, N06059, N06600, N08800, N08810
SB-167	N06600	SB-572	N06002
SB-168	N06600	SB-573	N10003
SB-333	N10001, N10665	SB-574	N06022, N06059, N06455, N10276
SB-335	N10001, N10665	SB-575	N06022, N06059, N06455, N10276
SB-366	N06022, N06059	SB-581	N06007
SB-407	N08800, N08810	SB-582	N06007
SB-408	N08800, N08810	SB-619	N06002, N06007, N06022, N06059, N06455, N10001, N10276, N10665
SB-409	N08800, N08810	SB-622	N06002, N06007, N06022, N06059, N06455, N10001, N10276, N10665
SB-423	N08825	SB-626	N06002, N06007, N06022, N06059, N06455, N10001, N10276, N10665
SB-424	N08825		
SB-425	N08825		
SB-434	N10003		
SB-435	N06002		

TABLE ANF-1.4
TITANIUM AND TITANIUM ALLOYS

Spec No.	UNS No.	Spec No.	UNS No.
SB-265	R50250, R50400, R50550, R52400, R52402, R53400	SB-381	R50250, R50400, R50550, R52400, R52402, R53400
SB-338	R50250, R50400, R50550, R52400, R52402, R53400	SB-861	R50250, R50400, R50550, R52400, R53400
SB-348	R50250, R50400, R50550, R52400, R52402, R53400	SB-862	R50250, R50400, R50550, R52400, R53400

TABLE ABM-1 FERROUS BOLTING MATERIALS FOR USE WITH FLANGES DESIGNED IN ACCORDANCE WITH APPENDIX 3

Spec No.	Type/Grade	Diameter, in. (mm)	Min. Design Metal Temperature Without Impact Testing, °F (°C)
Low Alloy Steel Bolts			
SA-193	B5	Up to 4 (100), incl.	−20 (−29)
	B7	$2\frac{1}{2}$ (64) and under	−55 (−48)
		Over $2\frac{1}{2}$ to 4 (64 to 100), incl.	−40 (−40)
		Over 4 to 7 (100 to 175), incl.	−40 (−40)
	B7M	$2\frac{1}{2}$ (64) and under	−55 (−48)
	B16	$2\frac{1}{2}$ (64) and under	−20 (−29)
		Over $2\frac{1}{2}$ to 4 (64 to 100), incl.	−20 (−29)
		Over 4 to 7 (100 to 175), incl.	−20 (−29)
SA-320	L7	$2\frac{1}{2}$ (64) and under	See General Note (c) of Fig. AM-211
	L7A	Up to $2\frac{1}{2}$ (64), incl.	See General Note (c) of Fig. AM-211
	L7M	$2\frac{1}{2}$ (64) and under	See General Note (c) of Fig. AM-211
	L43	1 (25) and under	See General Note (c) of Fig. AM-211
SA-325	1	$\frac{1}{2}$ to $1\frac{1}{2}$ (13 to 38), incl.	−20 (−29)
SA-354	BC	Up to 4 (100), incl.	0 (−18)
	BD	Up to 4 (100), incl.	+20 (−7)
SA-437	B4B, B4C	All diameters	See General Note (c) of Fig. AM-211
SA-449	. . .	Up to 3 (75), incl.	−20 (−29)
SA-508	5 Cl. 2	All diameters	See General Note (c) of Fig. AM-211
SA-540	B21	All diameters	Impact test is required
	B23 Cl. 1 & 2	All diameters	Impact test is required
	B23 Cl. 3 & 4	Up to 6 (150), incl.	See General Note (c) of Fig. AM-211
		Over 6 to $9\frac{1}{2}$ (150 to 240), incl.	Impact test is required
	B23 Cl. 5	Up to 8 (200), incl.	See General Note (c) of Fig. AM-211
		Over 8 to $9\frac{1}{2}$ (200 to 240), incl.	Impact test is required
	B24 Cl. 1	Up to 6 (150), incl.	See General Note (c) of Fig. AM-211
		Over 6 to 8 (150 to 200), incl.	Impact test is required
	B24 Cl. 2	Up to 7 (175), incl.	See General Note (c) of Fig. AM-211
		Over 7 to $9\frac{1}{2}$ (175 to 240), incl.	Impact test is required
	B24 Cl. 3 & 4	Up to 8 (200), incl.	See General Note (c) of Fig. AM-211
		Over 8 to $9\frac{1}{2}$ (200 to 240), incl.	Impact test is required
	B24 Cl. 5	Up to $9\frac{1}{2}$ (240), incl.	See General Note (c) of Fig. AM-211
	B24V Cl. 3	All diameters	See General Note (c) of Fig. AM-211
Low Alloy Steel Nuts			
SA-194	2, 2H, 2HM, 3, 4, 7, 7M, 16	All diameters	−55 (−48)
SA-540	B21, B23, B24, B24V	All diameters	−55 (−48)
High Alloy Steels			
SA-193	B6	4 (100) and under	−20 (−29)
	B8 Cl. 1	All diameters	−425 (−254)
	B8 Cl. 2	Up to $1\frac{1}{2}$ (38), incl.	Impact test is required
	B8C Cl. 1	All diameters	−425 (−254)
	B8C Cl. 2	$\frac{3}{4}$ to $1\frac{1}{2}$ (19 to 38), incl.	Impact test is required

(continued)

TABLE ABM-1
FERROUS BOLTING MATERIALS FOR USE WITH FLANGES DESIGNED IN ACCORDANCE WITH APPENDIX 3 (CONT'D)

Spec No.	Type/Grade	Diameter, in. (mm)	Min. Design Metal Temperature Without Impact Testing, °F (°C)
High Alloy Steels (Cont'd)			
SA-193	B8M Cl. 1	All diameters	−425 (−254)
	B8M2	2 to $2\frac{1}{2}$ (50 to 64), incl.	Impact test is required
	B8MNA Cl. 1A	All diameters	−320 (−196)
	B8NA Cl. 1A	All diameters	−320 (−196)
	B8P Cl. 1	All diameters	Impact test is required
	B8P Cl. 2	Up to $1\frac{1}{2}$ (38), incl.	Impact test is required
	B8S, B8SA	All diameters	Impact test is required
	B8T Cl. 1	All diameters	−425 (−254)
	B8T Cl. 2	$\frac{3}{4}$ to 1 (19 to 25), incl.	Impact test is required
SA-320	B8 Cl. 1	All diameters	See General Note (c) of Fig. AM-211
	B8 Cl. 2	Up to 1 (25), incl.	See General Note (c) of Fig. AM-211
	B8A Cl. 1A	All diameters	See General Note (c) of Fig. AM-211
	B8C Cl. 1 & 1A	All diameters	See General Note (c) of Fig. AM-211
	B8C Cl. 2	Up to 1 (25), incl.	See General Note (c) of Fig. AM-211
	B8CA Cl. 1A	All diameters	See General Note (c) of Fig. AM-211
	B8F Cl. 1	All diameters	See General Note (c) of Fig. AM-211
	B8FA Cl. 1A	All diameters	See General Note (c) of Fig. AM-211
	B8M Cl. 1	All diameters	See General Note (c) of Fig. AM-211
	B8M Cl. 2	Up to $1\frac{1}{2}$ (38), incl.	See General Note (c) of Fig. AM-211
	B8MA Cl. 1A	All diameters	See General Note (c) of Fig. AM-211
	B8T Cl. 1	All diameters	See General Note (c) of Fig. AM-211
	B8T Cl. 2	Up to $1\frac{1}{2}$ (38), incl.	See General Note (c) of Fig. AM-211
	B8TA Cl. 1A	All diameters	See General Note (c) of Fig. AM-211
SA-453	651 Cl. A & B, 660 Cl. A & B	All diameters	Impact test is required
SA-479	XM-19	Up to 8 (200), incl.	Impact test is required
SA-564	630	Up to 8 (200), incl.	Impact test is required
SA-705	630	Up to 8 (200), incl.	Impact test is required

TABLE ABM-1.2
ALUMINUM ALLOY, COPPER, AND COPPER ALLOY BOLTING MATERIALS FOR USE WITH FLANGES DESIGNED IN ACCORDANCE WITH APPENDIX 3

Spec No.	UNS No.	Spec No.	UNS No.
SB-98	C65100, C65500, C66100	SB-187	C10200, C11000
SB-150	C61400, C62300, C63000, C64200	SB-211	A92014, A92024, A96061

GENERAL NOTE: Minimum design metal temperature for all bolting material listed in this Table is −320°F (−196°C).

TABLE ABM-1.3
NICKEL AND NICKEL ALLOY BOLTING MATERIALS FOR USE WITH FLANGES DESIGNED IN ACCORDANCE WITH APPENDIX 3

Spec No.	UNS No.	Spec No.	UNS No.	Spec No.	UNS No.
SB-160	N02200, N02201	SB-408	N08800, N08810	SB-574	N06022, N06455, N10276
SB-164	N04400, N04405	SB-425	N08825		
SB-166	N06600	SB-446	N06625	SB-581	N06007, N06030, N06975
		SB-572	N06002, R30556	SB-621	N08320
SB-335	N10001, N10665	SB-573	N10003	SB-637	N07718, N07750

GENERAL NOTE: Minimum design metal temperature for all bolting material listed in this Table is −320°F (−196°C).

TABLE ABM-2
BOLTING MATERIALS FOR USE WITH FLANGES DESIGNED IN ACCORDANCE WITH APPENDICES 4, 5, AND 6

Spec No.	Type/Grade/UNS No.	Spec No.	Type/Grade/UNS No.	Spec No.	Type/Grade/UNS No.
SA-193	B5, B6, B7, B7M, B8, B8C, B8M, B8MNA, B8NA, B8R, B8RA, B8S, B8SA, B8T, B16	SA-437	B4B, B4C	SA-705	630
		SA-453	651, 660	SB-164	N04400, N04405
		SA-540	B21, B22, B23, B24, B24V	SB-637	N07718, N07750
SA-320	L43	SA-564	630, 651, 660		

GENERAL NOTE: See AM-214.2 for impact testing requirements.

Part AD
DESIGN REQUIREMENTS

ARTICLE D-1
GENERAL

AD-100 SCOPE

(a) The requirements of Part AD provide specific design rules for some commonly used pressure vessel shapes under pressure loadings and, within specified limits, rules or guidance for treatment of other loadings. Simplified rules are also included for the approximate evaluation of design cyclic service life. This Part does not contain rules to cover all details of design.

(b) When rules are not provided for a vessel or vessel part, a complete stress analysis of the vessel or vessel part shall be performed considering all of the loadings specified in the User's Design Specification. This analysis shall be done in accordance with Appendix 4 for all applicable stress categories and in accordance with Appendix 5 when fatigue evaluation is required. Alternatively, an experimental stress analysis can be performed in accordance with Appendix 6. When either of these procedures is followed, the general principles, design requirements of Articles D-1, D-3, and D-4, and weld detail, fabrication, inspection, and testing requirements of this Division shall also be met.

(c) When the designer or user chooses, a detailed stress analysis may be used, in lieu of the design rules given in Part AD, to verify the design acceptability of a vessel or vessel part. Such an analysis shall consider all loadings specified in the User's Design Specification. This analysis shall be done in accordance with Appendix 4 for all applicable stress categories and in accordance with Appendix 5 when a fatigue evaluation is required (see AD-160). Except for local shell regions defined in AD-200, the wall thickness of a vessel or vessel part shall not be less than that computed by the formulas of AD-201 through AD-206. When this procedure is followed, all applicable weld detail, fabrication, inspection, and testing requirements of this Division shall also be met.

AD-101 MATERIALS IN COMBINATION

(a) Except as specifically prohibited by other rules of this Division, a vessel may be designed for and constructed of any combination of materials permitted in Part AM, provided the applicable rules are followed and the requirements in Section IX for welding dissimilar metals are met.

(b) A stress analysis of a vessel region shall be made in accordance with Appendix 4 unless all of the provisions of any one of the following numbered cases applies. This does not obviate the need for such analysis where required by other provisions of Part AD.

(1)(a) The junction is a girth seam between pressure parts.

(b) Any taper required because of different thickness is in material having the higher design stress intensity, or in weld deposit appropriate for the stronger material.

(c) No discontinuity is involved except that due to thickness and modulus of elasticity difference.

(d) $S_2 \leq 1.2S_1\ (E_2/E_1)$, where subscripts 1 and 2 denote the material having the lower and higher design stress intensity value, respectively, and S and E are as defined in Articles D-2 and D-3, respectively.

(2)(a) The junction is at a seam between pressure parts other than a girth seam covered by (b)(1) above and where the provisions of (b)(3) below do not apply.

(b) Any taper required because of different thickness is in material having the higher design stress intensity, or in weld deposit appropriate for the stronger material.

(c) $S_2 \leq 1.1S_1$ (E_2/E_1), where subscripts and symbols are as given in (1)(d) above.

(3) The combination is permitted by AD-551.

AD-102 COMBINATION UNITS

When a vessel unit consists of more than one independent pressure chamber, operating at the same or different pressures and temperatures, each such pressure chamber (vessel) shall be designed and constructed to withstand the most severe condition of coincident pressure and temperature expected. Chambers which come within the scope of this Division may be connected to chambers constructed to Division 1 rules, provided the connection between such chambers meets all of the requirements of the Division 2 rules. (See AG-121.3.)

AD-104 MINIMUM THICKNESS OF SHELL OR HEAD

The thickness after forming and without allowance for corrosion of any shell or head subject to pressure shall be not less than 1⁄4 in. (6 mm) for carbon and low alloy steels (Part AM, Tables ACS and AQT), or 1⁄8 in. (3 mm) for stainless steel and nonferrous materials (Part AM, Tables AHA and ANF). (See AF-105.1, AF-105.2, and AF-606.)

AD-105 SELECTION OF MATERIAL THICKNESS

The selected thickness of material shall be such that the forming, heat treatment, and other fabrication processes will not reduce the thickness of the material at any point below the minimum value required by the rules.

AD-106 CORROSION ALLOWANCE IN DESIGN FORMULAS

The dimensional symbols used in all design formulas throughout this Division represent dimensions in the corroded condition.

AD-110 LOADINGS

The loadings that shall be considered[1] and specified in the User's Design Specification shall include, but not be limited to, the following:

(a) internal and external pressure, including static head;

(b) weight of vessel and normal contents under operating or test conditions;

(c) superimposed loads, such as other vessels, operating equipment, insulation, corrosion resistant or erosion resistant linings and piping;

(d) wind loads, snow loads, and earthquake loads;

(e) reactions of supporting lugs, rings, saddles, or other types of vessel supports;

(f) impact loads, including rapidly fluctuating pressure;

(g) temperature conditions, introducing differential strain loadings, and strain induced reactions resulting from expansion or contraction of attached piping or other parts.

AD-115 CORROSION

Vessels or parts thereof subject to loss of metal by corrosion, erosion, mechanical abrasion, or other environmental effects shall have provisions made for such loss during the design or specified life of the vessel by a suitable increase in or addition to the thickness of the base metal over that determined by the design formulas or stress analysis. Material added or included for these losses need not be of the same thickness for all parts of the vessel, if different rates of attack are expected for the various parts. No additional thickness need be provided when previous experience in like service has shown that corrosion does not occur or is of only a superficial nature.

AD-116 CLADDING

Except as otherwise provided in AM-410 for integrally clad plate or overlay weld clad plate with credit for cladding thickness, the design calculations may be based on a thickness equal to the nominal thickness of the base plate plus S_c/S_b times the nominal thickness of the cladding, less any allowance provided for corrosion, provided the following conditions are met:

(a) the clad plate conforms to one of the specifications listed in the tables in Part AM or is overlay weld clad plate conforming to AF-563;

(b) the joints are completed by depositing corrosion resisting weld metal over the weld in the base plate to restore the cladding;

(c) the S_m value of the weaker material is at least 70% of the S_m value of the stronger where

S_c = design stress intensity value for the cladding or, for the weld overlay, that of the wrought material

[1] See AG-301.1 and AG-301.2.

whose chemistry most closely approximates that of the cladding, at the design temperature

S_b = design stress intensity value for the base plate at the design temperature

The design stress intensity value shall be that given for the base-plate material given in Part AM. When S_c is greater than S_b, the multiplier S_c/S_b shall be taken equal to unity.

The thickness of the corrosion resistant weld metal overlay cladding deposited by manual processes shall be verified by electrical or mechanical means. One examination shall be made for every head, shell course, or any other pressure retaining component for each welding process used. The location of examinations shall be chosen by the Inspector except that, when the Inspector has been duly notified in advance and cannot be present or otherwise make the selection, the fabricator may exercise his own judgment in selecting the locations.

AD-117 LININGS

Corrosion resistant or abrasion resistant linings are those not integrally attached to the vessel wall, i.e., they are intermittently attached or not attached at all. In either case, such linings shall not be given any credit when calculating the thickness of the vessel wall.

AD-120 DESIGN BASIS

(a) Table AD-120.1 sets forth the pressure, temperature, and static head relationships which must be considered by the designer.

(b) The design for a vessel part is usually controlled by coincident pressure and temperature at a point. The design shall take into account the maximum difference in fluid pressure, which exists under the specified conditions of operation (which may include pressure due to static head), between the inside and outside of the vessel at any point or between two chambers of a combination unit. The design thickness for pressure should not include any metal added as corrosion or erosion allowance or any metal required for any combination of loadings listed in AD-150 which are likely to occur coincident with the operating pressure and temperature.

AD-121 Definitions

AD-121.1 Design Pressure. Design pressure is the pressure at the top of the vessel and which, together with the applicable coincident (metal) temperature, is stamped on the nameplate. The pressure at the top of the vessel is also the basis for the pressure setting of the pressure relief devices protecting the vessel (see A-108).

AD-121.2 Design Temperature. The temperature used in design shall be based on the actual metal temperature expected under operating conditions for the part considered at the designated *coincident pressure.* When the occurrence of different metal temperatures during operation can be definitely predicted for different zones of a vessel, the design of the different zones may be based on their predicted temperatures.

(a) The temperature used in design shall be not less than the mean temperature through the thickness expected under operating conditions for the part considered (see footnotes of AS-100). If necessary, the metal temperature shall be determined by computations using accepted heat transfer procedures or by measurement from equipment in service under equivalent operating conditions. In no case shall the temperature at the surface of the metal exceed the maximum temperature listed in the stress intensity tables in Subpart 1 of Section II, Part D for materials or exceed the temperature limitations specified elsewhere in this Division.

(b) Design temperatures in excess of the maximum temperatures listed for each material specification and grade for design stress intensity values in tension given in the tables in Subpart 1 of Section II, Part D are not permitted.

(c) Design temperature limits for external pressure construction are as follows.

(1) Design temperatures in excess of the maximum temperatures given on the external pressure charts are not permitted.

(2) Design temperatures in excess of the maximum temperatures described in (b) above are not permitted.

(d) When sudden cyclic changes in temperature are apt to occur in normal operation with only minor pressure fluctuations, the design shall be governed by the highest probable operating metal temperature (or the coldest metal temperature) and the corresponding pressure.

(e) Suggested methods for determining the operating temperatures of the wall of vessels already in service are given in Appendix C.

(f) For ferrous materials, the minimum design metal temperature used shall be the coldest expected in normal service, except when colder temperatures are permitted by the rules of this Division (see AM-218). Considerations shall include the coldest operating temperature, operational upsets, autorefrigeration, atmospheric temperature, and any source of cooling. Different minimum design metal temperature zones are permitted. For hydrostatic and pneumatic test temperature provisions, see AT-352 and AT-422, respectively.

(g) The nonferrous materials listed in the tables in Subpart 1 of Section II, Part D, together with the

TABLE AD-120.1
PRESSURE AND TEMPERATURE RELATIONSHIPS

Condition	Pressure at Top of Vessel	Pressure Due to Static Head [Note (1)]	Temperature	Remarks
Condition 1				
For vessel as a whole	Design pressure	None	Coincident metal	Pressure and temperature to be stamped on nameplate
At any point	Coincident pressure	Pressure to point under consid- eration due to static head of vessel contents	Design coincident temperature	Temperature at various points may vary, in which case the maximum for these conditions should be used for the vessel as a whole or coincident conditions for spe- cific locations shall be listed on the Manufacturer's Data Report and stamping
Condition 2				
At any point	Coincident pressure	Coincident pres- sure to point under consid- eration due to static head	Design temperature	Higher temperature and lower pressure combinations (than Condition 1) must be checked or a part may be designed for the maximum design pressure and the design temperature (See footnote 1, AS-100)
Condition 3				
For vessel as a whole	Test pressure	None	Test temperature	. . .
At any point	Test pressure	Pressure at point under consid- eration due to static head	Test temperature	. . .
Condition 4				
For vessel as a whole or any part	Coincident pressure	. . .	Minimum design metal temper- ature	Minimum design metal temperature is used together with notch toughness tests or with low maximum stresses to determine suitability of material at service temperature
For vessel as a whole or any part	Safety valve setting	. . .	. . .	Usually set above the operating pressure but not over the limits set in AR-121 and AR-122

NOTE:
(1) Similar applications shall be made for other sources of pressure variation, such as that resulting from flow.

deposited weld metal within the range of composition for materials in those tables, do not undergo a marked drop in impact resistance at subzero temperature. Therefore, no additional requirements are specified for wrought aluminum alloys when they are used at temperatures not colder than −425°F (−254°C) and for copper and nickel alloys when they are used at temperatures not colder than −320°F (−196°C). The materials listed in the tables in Subpart 1 of Section II, Part D may be used at temperatures colder than those specified therein and for other weld metal compositions provided the user satisfies himself by suitable test results, such as determinations of tensile elongation and sharp-notch tensile strength (compared to unnotched tensile strength), that the material has suitable ductility at the design temperature.

AD-121.3 Operating Pressure. The operating pressure is the pressure at the top of the vessel at which it normally operates. The operating pressure shall not exceed the design pressure and is usually kept at a suitable level below it to prevent the frequent opening of pressure relieving devices.

AD-121.4 Test Pressure. The test pressure is the pressure to be applied at the top of the vessel during the test. This pressure plus any pressure due to static head at any point under consideration is used in the applicable formula to check the vessel under test conditions (see AT-300, AT-301, and AT-410).

AD-121.5 Safety Valve Setting. The pressure for which the safety or safety relief valves are set to open is established by AR-140.

AD-121.6 Terms Relating to Design and Stress Analysis. Definitions of design and analysis terminology are included in 4-112.

04 AD-130 DESIGN STRESS INTENSITY VALUES

The design stress intensity values S_m are given in Tables 2A, 2B, 3, and 4 in Subpart 1 of Section II, Part D for vessel materials. Beginning with the 2004 Edition, Section II, Part D has been issued as two separate publications. One publication contains values only in U.S. Customary units and the other contains values only in SI units. The selection of the version to use is dependent on the set of units selected for construction. Values for intermediate temperatures may be found by interpolation. For vessels designed to operate at a temperature colder than −20°F (−29°C), the allowable stress values to be used in design shall not exceed those given for temperatures of −20°F to 100°F (−29°C to 38°C). These S_m values form the basis for the various stress limits which are described in Appendix 4 and are used in determining the membrane stress intensity limits for the various load combinations given in Table AD-150.1. Lower values may be used at the discretion of the designer.

AD-131 Coefficients of Thermal Expansion and Moduli of Elasticity

Values of the coefficients of thermal expansion are in Tables TE-1, TE-2, TE-3, TE-4, and TE-5 in Section II, Part D; values of the moduli of elasticity are in Tables TM-1, TM-2, TM-3, TM-4, and TM-5 of Section II, Part D. For coefficients of thermal expansion and moduli of elasticity not included in Section II, Part D, these values shall be to authoritative source data.

AD-132 Special Stress Limits

The following deviations from the basic stress limits are provided to cover special conditions or configurations.

AD-132.1 Bearing Loads

(a) The average bearing stress for resistance to crushing under the maximum design load shall be limited to the yield strength S_y at temperature except that, when the distance to a free edge is greater than the distance over which the bearing load is applied, a stress of $1.5S_y$ at temperature is permitted. For clad surfaces, the yield strength of the base metal may be used if, when calculating the bearing stress, the bearing area is taken as the lesser of the actual contact area or the area of the base metal supporting the contact surface.

(b) When bearing loads are applied on parts having free edges, such as at a protruding edge, the possibility of a shear failure shall be considered. In the case of load stress only [see 4-112(k)], the average shear stress shall be limited to $0.6S_m$. In the case of load stress plus secondary stress [see 4-112(h)], the average shear stress shall not exceed the following:

(1) for materials to which AM-600(c) applies, the lower of $0.5S_y$ at 100°F (38°C) and $0.675S_y$ at all other temperatures;

(2) for all other materials, $0.5S_y$ at all temperatures.

For clad surfaces, if the configuration or thickness is such that a shear failure could occur entirely within the clad material, the allowable shear stress for the cladding shall be determined from the properties of the equivalent wrought material. If the configuration is such that a shear failure could occur across a path that is partially base metal and partially clad material, the allowable shear stresses for each material shall be used when evaluating the combined resistance to this type of failure.

(c) When considering bearing stresses in pins and similar members, the S_y-at-temperature value is applicable, except that a value of $1.5S_y$ may be used if no credit is given to bearing area within one pin diameter from a plate edge.

AD-132.2 Pure Shear. The average primary shear stress across a section loaded under design conditions in pure shear (for example, keys, shear rings, screw threads) shall be limited to $0.6S_m$. The maximum primary shear under design conditions, exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to $0.8S_m$.

AD-132.3 Progressive Distortion of Nonintegral Connections. Screwed-on caps, screwed-in plugs, shear ring closures, and breech lock closures are examples of nonintegral connections which are subject to failure by bell-mouthing or other types of progressive deformation.

If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operating cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can eventually lose engagement. Therefore, primary plus secondary stress intensities (see 4-134), which result in slippage between the parts of a nonintegral connection in which disengagement could occur as a result of progressive distortion, shall be limited to the value S_y given in Table Y-1 of Section II, Part D.

AD-140 DESIGN CRITERIA

The design requirements of this Part AD provide specific design rules for certain commonly used pressure vessel shapes under pressure loading and, within prescribed limits, rules for the treatment of other loadings. Simplified criteria are included for determining whether an analysis for cyclic operation must be made. The thickness of the vessel parts and attached supports covered by these rules shall be determined by the applicable formula using the most severe combination of loadings and allowable stress intensities kS_m expected to occur simultaneously during design and operation. Stress intensities during test shall not exceed the limits in AD-151. The basis for these formulas is given below. Table AD-150.1 lists values of k that are appropriate for various load combinations.

(a) The theory of failure used in this Division is the maximum shear stress theory except in the case of some specifically designated configurations, shapes, or design rules included as a part of this Division. Stress intensity is defined as two times the maximum shear stress.

(b) The average value of the general primary membrane stress intensity across the thickness of the section under consideration, due to any combination of design pressure and mechanical loadings expected to occur simultaneously, should not exceed the design stress intensity value kS_m.

(c) The local primary membrane stress intensity due to any combination of design pressure and mechanical loadings expected to occur simultaneously is limited to $1.5kS_m$. The distance over which the stress intensity exceeds $1.1kS_m$ shall not extend in the meridional direction more than $\sqrt{Rt}$, where R is the radius at the midsurface of the shell or head measured normal to the surface from the axis of revolution in the meridional plane, and t is the nominal thickness of the shell or head under consideration.

(d) The primary bending stress due to any combination of design pressure and mechanical loadings expected to occur simultaneously shall not exceed 1.5 kS_m. (See Appendix 4 when the design of components involves combinations of calculated stresses.)

AD-140.1 Secondary Stresses. Secondary stresses may exist in vessels designed and fabricated in accordance with these rules, but limitations are provided to restrict such stresses to levels consistent with the rules in Appendix 4. Where construction details are not covered or where design conditions exceed the formula limitations, a detailed stress analysis in accordance with the rules of Appendix 4 shall be made.

AD-150 LOAD COMBINATIONS

Vessels and their supports shall be designed for the load combinations and maximum stress intensity limits kS_m under the conditions of design and operation as given in Table AD-150.1; for test, the load combination in Table AD-150.1 and the stress intensity limits in AD-151. Wind loads and earthquake loads need not be assumed to occur simultaneously.

AD-151 Upper Limits of Test Pressure

If the test pressure at any point in a vessel, including static head, exceeds the required test pressure defined in AT-300, AT-301, and AT-410 by more than 6%, the upper limit shall be established by the design engineer using all the loadings that may exist during the test.

AD-151.1 For Hydrostatically Tested Vessels. The hydrostatic test pressure of a completed vessel shall not exceed that value which results in the following stress intensity limits:

(a) a calculated primary membrane stress intensity P_m of 90% of the tabulated yield strength S_y at test temperature as given in the applicable table of Subpart 1 of Section II, Part D;

(b) a calculated primary membrane plus primary bending stress intensity $P_m + P_b$ not to exceed the applicable limits given in (1) or (2) below:

(1) $P_m + P_b \le 1.35S_y$ for $P_m \le 0.67S_y$;

(2) $P_m + P_b \le 2.35S_y - 1.50P_m$ for $0.67S_y < P_m \le 0.90S_y$;

where

S_y = tabulated yield strength at test temperature

AD-151.2 For Pneumatically Tested Vessels. The pneumatic test pressure of a completed vessel shall not exceed that value which results in the following stress intensity limits:

TABLE AD-150.1
STRESS INTENSITY *k* FACTORS FOR VARIOUS LOAD COMBINATIONS

Condition	Load Combinations (See AD-110)	*k* Factors	Calculated Stress Limit Basis
Design	A The design pressure, the dead load of the vessel, the contents of the vessel, the imposed load of the mechanical equipment, and external attachment loads	1.0	Based on the corroded thickness at design metal temperature
	B Condition A above plus wind load	1.2	Based on the corroded thickness at design metal temperature
	C Condition A above plus earthquake load	1.2	Based on the corroded thickness at design metal temperature
	D Condition A above plus loads resulting from wave action [Note (1)] (NOTE: The condition of structural instability or buckling must be considered.)	1.2	Based on the corroded thickness at design metal temperature
Operation	A The actual operating loading conditions. This is the basis of fatigue life evaluation.	See AD-160 and Appendix 5	Based on corroded thickness at operating pressure and metal operating temperature
Test	A The required test pressure, the dead load of the vessel, the contents of the vessel, the imposed load of the mechanical equipment, and external attachment loads	See AD-151 for special limits	Based on actual design values at test temperature

NOTE:
(1) When the rules of this Division are used in design of pressure vessels installed in oceangoing ships, barges, and other floating craft [per AG-100(b)(2)], dynamic loads resulting from wave action included under Condition D shall be the most probable largest loads encountered during the vessel's life and having a probability level per wave encounter not greater than 10^{-8}, which corresponds to one occurrence in 20 years.

(a) a calculated primary membrane stress intensity P_m of 80% of the tabulated yield strength S_y at test temperature as given in the applicable table of Subpart 1 of Section II, Part D;

(b) a calculated primary membrane plus primary bending stress intensity $P_m + P_b$ not to exceed the applicable limits given in (1) or (2) below:

(1) $P_m + P_b \leq 1.20S_y$ for $P_m \leq 0.67S_y$;

(2) $P_m + P_b \leq 2.20S_y - 1.50P_m$ for $0.67S_y < P_m \leq 0.80S_y$;

AD-151.3 For Multichamber Vessels. In the case of multichamber vessels, pressure may be applied simultaneously to the appropriate adjacent chamber to maintain the stress intensity limits set forth in AD-151.1 and AD-151.2 (see AT-310).

AD-160 FATIGUE EVALUATION

When determining whether or not a vessel fatigue analysis shall be specified, the user may consider experience with comparable equipment operating under similar conditions in accordance with the provisions of AD-160.1. When not based upon significant applicable service experience, the need for a fatigue analysis shall be determined in accordance with the provisions of AD-160.2 and AD-160.3. Paragraphs AD-160.2 and AD-160.3 are not applicable to vessels for which the number of loading cycles exceeds 10^6.

AD-160.1 Operating Experience. When the user is considering experience with comparable equipment operating under similar conditions as related to the design and service contemplated, particular attention shall be given to the possible deleterious effects of the following design features:

(a) nonintegral construction, such as the use of pad type reinforcements or of fillet welded attachments, as opposed to integral construction;

(b) use of pipe threaded connections, particularly for diameters in excess of $2\frac{3}{4}$ in. (70 mm);

(c) stud bolted attachments;

(d) partial penetration welds;

(e) major thickness changes between adjacent members.

AD-160.2 Rules to Determine Need for Fatigue Analysis of Integral Parts of Vessels. A fatigue analysis need not be made provided *all* of Condition A or *all* of Condition B is met. If neither Condition A nor B is met, a detailed fatigue analysis shall be made in accordance with the rules of Appendices 4 and 5 for those parts which do not satisfy the conditions. The following rules are applicable to all integral parts of the vessel, including integrally reinforced type nozzles. For vessels having pad type nozzles or nonintegral attachments, the requirements of AD-160.3 apply.

Condition A. Fatigue analysis is not mandatory for materials having a specified minimum tensile strength not exceeding 80,000 psi (552 MPa) when the total of the expected number of cycles of types (a) plus (b) plus (c) plus (d), defined below, does not exceed 1,000 cycles.

(a) is *the expected (design) number of full-range pressure cycles* including startup and shutdown.

(b) is *the expected number of operating pressure cycles* in which the range of pressure variation exceeds 20% of the design pressure. (Cycles in which the pressure variation does not exceed 20% of the design pressure are not limited in number. Pressure cycles caused by fluctuations in atmospheric conditions need not be considered.)

(c) is *the effective number of changes in metal temperature*[2] *between any two adjacent points*[3] in the pressure vessel, including nozzles. The effective number of such changes is determined by multiplying the number of changes in metal temperature of a certain magnitude by the factor given in the following table, and by adding the resulting numbers. The factors are as follows.

Metal Temperature Differential, °F (°C)	Factor
50 or less (28 or less)	0
51 to 100 (28 to 56)	1
101 to 150 (57 to 83)	2
151 to 250 (84 to 139)	4
251 to 350 (140 to 194)	8
351 to 450 (195 to 250)	12
In excess of 450 (251)	20

For example, consider a design subjected to metal temperature differentials for the following number of times:

ΔT, °F (°C)	Cycles
50 (28)	1,000
90 (50)	250
400 (222)	5

The effective number of changes in metal temperature is

$$1{,}000\ (0) + 250\ (1) + 5\ (12) = 310$$

The number used as (c) in performing the comparison with 1,000 is then 310. Temperature cycles caused by fluctuations in atmospheric conditions need not be considered.

(d) the number of temperature cycles for components involving welds between materials having different coefficients of expansion is that which causes the value of $(\alpha_1 - \alpha_2)\ \Delta T$ to exceed 0.00034, where α_1 and α_2 are the mean coefficients of thermal expansion (see Tables TE-1, TE-2, TE-3, TE-4, and TE-5 of Section II, Part D) and ΔT is the operating temperature range, °F. This does not apply to cladding, which is covered by AD-116.

Condition B. Fatigue analysis is not mandatory when all of the following are met.

(a) The expected design number of full-range pressure cycles, including startup and shutdown, does not exceed the number of cycles in the applicable fatigue curve of Appendix 5 corresponding to an S_a value of three times the S_m value found in the tables of design stress intensity values in Subpart 1 of Section II, Part D for the material at the operating temperature.

(b) The expected (design) range of pressure cycles during normal operation[4] does not exceed the quantity one-third times the design pressure times (S_a/S_m), where

[2] Thermal protection devices, such as thermal sleeves in nozzles, may be used to reduce temperature differences or thermal shock.

[3] Adjacent points are defined as follows:

(a) For surface temperature differences:

(1) shells and dished heads in meridional direction, $L = 2.5\sqrt{Rt}$

(2) flat plates, $L = 3.5a$

where

L = minimum distance between adjacent points

R = radius measured normal to the surface from the midwall to the axis of revolution

a = radius of hot spot or heated area within a plate

t = thickness of the part at the point under consideration

If the product Rt varies, the average value of the points is used.

(b) For through-the-thickness temperature differences: Adjacent points are defined as any two points on a line normal to any surface.

[4] *Normal operation* is defined as any set of operating conditions other than startup and shutdown which are specified for the vessel to perform its intended function.

S_a is the value obtained from the applicable fatigue curve of Appendix 5 for the specified number of significant pressure fluctuations and S_m is the design stress intensity value found in Subpart 1 of Section II, Part D for the operating temperature. Significant pressure fluctuations are those for which the range exceeds the quantity design pressure times $\frac{1}{3}(S/S_m)$, where S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(c) The temperature difference in degrees F between any two adjacent points[3] of the vessel during normal operation and during startup and shutdown operation does not exceed $S_a/(2E\alpha)$, where S_a is the value obtained from the applicable design fatigue curve for the specified number of startup and shutdown cycles; α is the value of the instantaneous coefficient of thermal expansion at the mean value of the temperature at the two points, as given by Table TE-1, TE-2, TE-3, TE-4, or TE-5; and E is taken from Table TM-1, TM-2, TM-3, TM-4, or TM-5 at the mean value of the temperatures at the two points.

(d) The range of temperature difference in degrees F between any two adjacent points[3] of the vessel does not change during normal operation[4] by more than the quantity $S_a/(2E\alpha)$, where S_a is the value obtained from the applicable design fatigue curve for the total specified number of significant temperature difference fluctuations. A temperature difference fluctuation shall be considered to be significant if its total algebraic range exceeds the quantity $S/2E\alpha$, where S is defined as in (b) above.

(e) The total algebraic range of temperature fluctuation in degrees F for components fabricated from materials of differing moduli of elasticity and/or coefficients of thermal expansion and experienced by the vessel during normal operation does not exceed the magnitude $S_a/[2(E_1\alpha_1 - E_2\alpha_2)]$, where S_a is the value obtained from the applicable design fatigue curve for the total specified number of significant temperature fluctuations, E_1 and E_2 are the moduli of elasticity, and α_1 and α_2 are the values of the instantaneous coefficients of thermal expansion at the mean temperature value involved for the two materials of construction. (See Table TE-1, TE-2, TE-3, TE-4, TE-5, TM-1, TM-2, TM-3, TM-4, or TM-5.) A temperature fluctuation shall be considered to be significant if its total excursion exceeds the quantity $S[2(E\alpha_1 - E_2\alpha_2)]$, where S is defined as in (b) above. If the two materials used have different applicable design fatigue curves, the lower value of S_a shall be used in applying the rules of this paragraph. This does not apply to cladding, which is covered by AD-116.

(f) The specified full range of mechanical loads, excluding pressure but including piping reactions, does not result in load stress intensities whose range exceeds the S_a value obtained from the applicable design fatigue curve for the total specified number of significant load fluctuations. If the total specified number of significant load fluctuations exceeds the maximum number of cycles defined on the applicable design fatigue curve, the S_a value corresponding to the maximum number of cycles defined on the curve shall be used. A load fluctuation shall be considered to be significant if the total excursion of load stress intensity exceeds the value of S, where S is defined as in (b) above.

AD-160.3 Rules to Determine Need for Fatigue Analysis of Nozzles With Separate Reinforcement and Nonintegral Attachments. A fatigue analysis of pad type nozzles and nonintegral attachments need not be made provided *all* of Condition AP or *all* of Condition BP is met. The rules of Condition AP are applicable only to vessels constructed of materials covered by Figs. 5-110.1, 5-110.2.1, 5-110.2.2, 5-110.2.3, 5-110.3, and 5-110.4. (Fatigue analysis rules for other materials are in preparation.) If neither Condition AP nor BP is met, a detailed fatigue analysis must be made in accordance with the rules of Appendices 4 and 5. (See AD-570 for further limitations on pad type nozzles.)

Condition AP. Fatigue analysis of pad type nozzles and nonintegral[5] attachments is not mandatory for materials having specified minimum tensile strength not exceeding 80,000 psi (552 MPa) when the total of the expected number of cycles of types (a) plus (b) plus (c) plus (d), defined below, does not exceed 400.

(a) is *the expected (design) number of full-range pressure cycles* including startup and shutdown.

(b) is *the expected number of operating pressure cycles* in which the range of pressure variation exceeds 15% of the design pressure. (Cycles in which the pressure variation does not exceed 15% of the design pressure are not limited in number. Pressure cycles caused by fluctuations in atmospheric conditions need not be considered.)

(c) is *the effective number of changes in metal temperature*[6] *between any two adjacent points*[3] in the pressure vessel, including nozzles. In calculating the temperature difference between adjacent points, conductive heat transfer shall be considered only through welded or integral cross sections with no allowance for conductive heat transfer across unwelded contact surfaces. The effective number of changes is determined by multiplying the number of changes in metal temperature of a certain magnitude by the factor given in the following table, and by adding the resulting numbers. The factors are as follows.

[5] See AD-925 for attachment welds which require consideration.

[6] Thermal protection devices, such as thermal sleeves in nozzles, may be used to reduce temperature differences or thermal shock.

Metal Temperature Differential, °F (°C)	Factor
50 or less (28 or less)	0
51 to 100 (28 to 56)	1
101 to 150 (57 to 83)	2
151 to 250 (84 to 139)	4
251 to 350 (140 to 194)	8
351 to 450 (195 to 250)	12

For example, consider a design subjected to metal temperature differentials for the following number of times:

ΔT, °F (°C)	Cycles
50 (28)	1,000
90 (50)	250
400 (222)	5

The effective number of changes in metal temperature is

$$1{,}000\ (0) + 250\ (1) + 5\ (12) = 310$$

The number used as (c) in performing the comparison with 400 is then 310. Temperature cycles caused by fluctuations in atmospheric conditions need not be considered.

(d) the number of temperature cycles for components involving welds between materials having different coefficients of expansion is that which causes the value of $(\alpha_1 - \alpha_2)\ \Delta T$ to exceed 0.00034, where α_1 and α_2 are the mean coefficients of thermal expansion (see Tables TE-1, TE-2, TE-3, and TE-4) and ΔT is the operating temperature range, °F. This does not apply to cladding, which is covered by AD-116.

Condition BP. All of the requirements of AD-160.2, Condition B are met using the following adjusted values.

(a) Use a value of four instead of three in Condition B subparagraph (a).

(b) Use a value of one-fourth instead of one-third in Condition B subparagraph (b).

(c) Use a value of 2.7 instead of 2 in the denominator of Condition B subparagraphs (c), (d), and (e).

ARTICLE D-2
SHELLS OF REVOLUTION UNDER INTERNAL PRESSURE[1]

AD-200 SCOPE

The thicknesses of shells of revolution under internal pressure shall be not less than that computed by the formulas in AD-201 through AD-212, except for local shell regions as defined in (a) and (b) below. In addition, provision shall be made for the applicable load combinations listed in AD-150 in establishing the value of F as defined below.

(a) A reduction in vessel wall thickness is permitted in local regions on a vessel, provided a detailed stress analysis demonstrates the acceptability of the local thin area.

(1) An elastic stress analysis may be used to demonstrate that the requirements of 4-132 are satisfied. For the purposes of evaluating a local thin wall region of a cylindrical, spherical, or conical shell, a *local region* is defined as the surface area within a circle of a diameter of $1.0\sqrt{R_m t}$. The $2.5\sqrt{R_m t}$ limitation, as defined in 4-112(i), for the required distance between adjacent local regions shall also be taken to apply in all directions of the shell surface.

(2) Local thin regions that extend beyond the limits of (1) above may be evaluated by the design rules given in 4-136.

(b) A complete local circumferential band of reduced thickness at a weld joint in a cylindrical shell as shown in Fig. AD-200.1 is permitted providing all of the following requirements are met.

(1) The design of the local reduced thickness band is evaluated by plastic analysis methods of 4-136.3 or 4-136.5. All other applicable requirements of Appendices 4 and 5 for stress analysis and fatigue analysis shall be satisfied.

(2) The cylinder shall have an R_m/t ratio greater than 10.

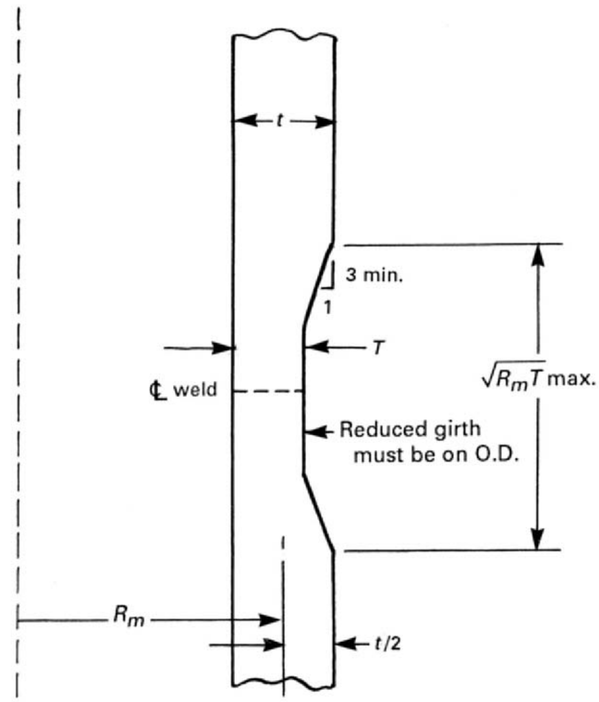


FIG. AD-200.1 CIRCUMFERENTIAL BAND OF REDUCED THICKNESS

(3) The thickness of the reduced shell region shall not be less than ⅔ of the cylinder thickness determined by AD-201.

(4) The reduced thickness region shall be on the outside of the vessel shell with a minimum taper transition of 3:1 in the base metal. The transition between the base metal and weld shall be designed to minimize stress concentrations.

(5) The total longitudinal length of each local thin region shall not exceed $\sqrt{R_m T}$.

(6) The minimum longitudinal distance from the thicker edge of the taper to an adjacent structural discontinuity shall be the greater of $2.5\sqrt{R_m t}$ or the distance

[1] For formed heads under pressure on the convex side, this may be either internal or external pressure, depending on the orientation of the head on the shell.

required to assure no overlapping of areas where the primary membrane stress intensity exceeds $1.1S_m$.

AD-200.1 Nomenclature. The symbols used in this Article are defined below. Except for test conditions, dimensions used or calculated shall be in the corroded condition (see AD-115).

D = inside diameter of a head skirt, or inside length of the major axis of an ellipsoidal head, or inside diameter of a conical head at the point under consideration measured perpendicular to the axis of revolution

F = meridional membrane force in the shell wall at the point under consideration resulting from primary loadings other than internal pressure, length of circumference. If this force is not uniform, as when resulting from wind or earthquake moment loading, the loading requiring the greatest shell thickness shall be used (tensile load is positive).

L = inside spherical or crown radius of torispherical and hemispherical heads

P = internal design pressure, plus any pressure due to the static head of the fluid, at any point under consideration (sum of columns 2 and 3 in Table AD-120.1)

Q = a factor in the formulas for cone-to-cylinder junctions depending on P/S and α

R = inside radius of the shell under consideration. This radius is measured normal to the surface from the axis of revolution.

R_L = inside radius of a cylinder at the large end of a cone-to-cylinder junction

R_m = midsurface radius of the shell

R_s = inside radius of a cylinder at the small end of a cone-to-cylinder junction

S = membrane stress intensity limit from tables of design stress intensity values in Subpart 1 of Section II, Part D multiplied by the stress intensity factor in Table AD-150.1

T = reduced shell thickness

h = one-half the length of the minor axis of an ellipsoidal head or the inside depth of an ellipsoidal head, measured from the tangent line (head bend line)

r = inside knuckle radius of torispherical and toriconical heads

t = minimum required thickness of shell

t_r = Q times the required thickness of a cylinder calculated in accordance with AD-201

α = one-half of the apex angle of a cone-to-cylinder junction

AD-201 Cylindrical Shells

The minimum required thickness of cylindrical shells shall be the greatest of the thicknesses determined by (a), (b), and (c) below.

(a)

$$t = \frac{PR}{S - 0.5P}$$

If $P > 0.4S$, the following formula may be used:

$$\ln \frac{(R + t)}{R} = \frac{P}{S}$$

ln is the natural log.

(b) If F is positive and exceeds $0.5PR$:

$$t = \frac{0.5PR + F}{S - 0.5P}$$

(c) If F is negative, the condition of axial structural instability or buckling shall be considered separately (see AD-340).

AD-202 Spherical Shells

The minimum required thickness of spherical shells shall be the greatest of the thicknesses determined by (a), (b), and (c) below.

(a)

$$t = \frac{0.5PR}{S - 0.25P}$$

If $P > 0.4S$, the following formula may be used:

$$\ln \frac{(R + t)}{R} = \frac{0.5P}{S}$$

(b) If F is positive:

$$t = \frac{0.5PR + F}{S - 0.25P}$$

(c) If F is negative, the condition of instability shall be considered. AD-340 for cylinders may be used for spheres, provided biaxial compression does not exist.

AD-203 Conical Shells

The minimum required thickness of conical shells shall be determined by the same formulas as for cylindrical shells in which R is the radius measured normal to the wall surface at the point under consideration (see AD-211 and AD-212 for cone-to-cylinder junctions of the large and small end, respectively).

(a)

$$t = \frac{PR}{S - 0.5P}$$

If $P > 0.4S$:

$$\ln \frac{(R + t)}{R} = \frac{P}{S}$$

(b) If F is positive and exceeds $0.5PR$:

$$t = \frac{0.5PR + F}{S - 0.5P}$$

(c) If F is negative, the condition of axial structural instability or buckling must be considered separately. AD-340 for cylinders may be used for conical sections with R defined as in AD-200.1.

AD-204 Formed Heads

The minimum required thickness at the thinnest point after forming of hemispherical, ellipsoidal, and torispherical heads under pressure on the concave side[2] shall be determined by the appropriate rule or formula in the following subparagraphs.

AD-204.1 Hemispherical Heads. For hemispherical heads, the minimum required thickness shall be as required for spherical shells (AD-202). For the required transition to cylindrical shells of different thickness, see AD-420 and Fig. AD-420.2.

AD-204.2 Torispherical Heads.[3] The minimum required thickness of a torispherical head having $t/L \geq 0.002$ up to a t/L where $P/S \leq 0.08$ (approximately $t/L = 0.04$ to 0.05) shall be established by using the curves in Fig. AD-204.1. Interpolation may be used for r/D values which fall within the range of the curves; however, no extrapolation of the curves is permitted. For designs where $P/S > 0.08$, which is above the upper limit of Fig. AD-204.1, the thickness shall be set by the following formula:

$$t = \frac{D}{2}\left(e^{P/S} - 1\right)$$

Where $t/L < 0.002$, which is below the lower limit of Fig. AD-204.1, the head design must be analyzed according to Appendix 4, 5, or 6. Transition joints to thicker or thinner shells shall be in accordance with AD-420 and Fig. AD-420.2.

[2] Pressure on the concave side may be caused by either internal or external pressure, depending upon the orientation of the head as it is attached to the shell.

[3] The head design curves of Fig. AD-204.1 have been developed considering membrane stress requirements, plastic collapse, cyclic load conditions, and the effects of maximum allowable tolerances per AF-135. See Article 4-4 of Appendix 4 for the design formulas for the curves of Fig. AD-204.1.

AD-204.3 Ellipsoidal Heads.[3,4] The minimum required thickness of a 2:1 ellipsoidal head shall be established using the procedures given in AD-204.2 and the curve of Fig. AD-204.1 which is labelled "2:1 ellipsoidal head." Ellipsoidal head designs which have $D/2h$ values different from 2 shall be analyzed as equivalent torispherical heads or according to Appendix 4, 5, or 6. (Rules are in preparation for designs above and below those limits.) Transition joints to thicker or thinner shells shall be in accordance with AD-420 and Fig. AD-420.2.

AD-204.4 Crown and Knuckle Radii. In connection with the design procedures of AD-204.2 and Fig. AD-204.1, the inside crown radius to which an unstayed head is formed shall not be greater than the outside diameter of the skirt of the head. The inside knuckle radius of a torispherical head shall not be less than:

(a) 6% of the outside diameter of the skirt; or

(b) three times the head thickness.

AD-204.5 Integral Head Skirts. When an integral head skirt is provided, the minimum required thickness of the skirt shall be not less than the minimum required thickness of a seamless shell of the same diameter. All transition joints shall be in accordance with AD-420 and Fig. AD-420.2.

AD-205 Composite Head Shapes

A head for a cylindrical shell may be built up of several head shapes, the thicknesses of which satisfy the requirements of the appropriate formulas above. The adjoining shapes must be so formed that they have a common tangent transverse to the joint. Any taper at a joint shall be within the boundary of the shape having the thinner wall (see Fig. AD-420.1).

AD-206 Loadings on Heads Other Than Pressure

Provision shall be made for other loadings given in AD-110. For torispherical and ellipsoidal heads the effect of other loadings must be determined in accordance with Appendix 4, 5, or 6. For the conical or spherical portions of heads, the effect of composite loading may be treated as in AD-201, AD-202, and AD-203.

AD-210 TRANSITION SHELL SECTIONS

AD-210.1 Rules for Concentric Reducers Transmitting Entire Longitudinal Loading. The rules of this

[4] Heads having $D/2h = 2$ have equivalent torispherical properties of a torisphere of $L/D = 0.90$ and $r/D = 0.17$.

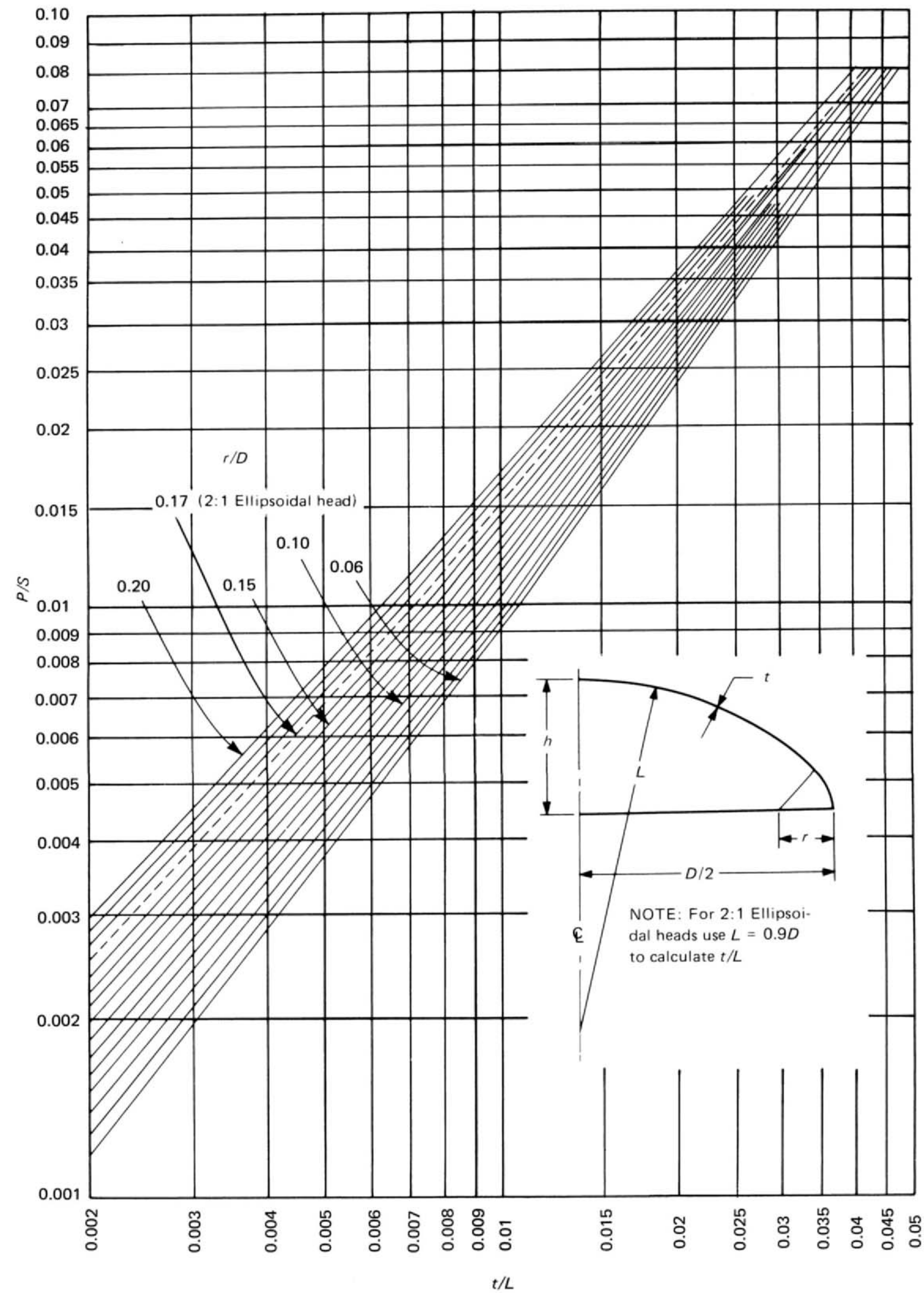


FIG. AD-204.1 DESIGN CURVES FOR TORISPHERICAL HEADS AND 2:1 ELLIPSOIDAL HEADS FOR USE WITH AD-204.2 AND AD-204.3

paragraph apply to concentric reducer sections wherein all the longitudinal loads are transmitted wholly through the shell of the reducer. Where loads are transmitted in part or as a whole by other elements, e.g., inner shells, stays, or tubes, the rules of this paragraph do not apply.

AD-210.2 Reducer Elements. The minimum required thickness of each element of a reducer, as defined below, under internal pressure shall not be less than that computed by the applicable formula. In addition, provisions shall be made for any of the other loadings listed in AD-110.

AD-210.3 Transition Section Reducers Joining Two Cylindrical Shells. A transition section reducer consisting of one or more elements may be used to join two cylindrical shell sections of different diameters but with a common axis, provided the requirements of this paragraph are met.

AD-210.4 Conical Shell Sections. The minimum required thickness of a conical shell shall be determined by the formula given in AD-203.

AD-210.5 Combination of Elements to Form a Reducer. When elements having different thicknesses are combined to form a reducer, the joints including the plate taper shall lie entirely within the limits of the thinner element being joined.

AD-210.6 Combination of Shapes to Form a Toriconical Reducer. A toriconical reducer may be shaped as a portion of a toriconical head or a portion of an ellipsoidal head plus a conical section, provided the design of the small end of the reducer element satisfies the requirements of Article D-5.

AD-210.7 Knuckle Tangent to the Larger Cylinder. When a knuckle is used at the large end of a reducer section, it shall have a shape that is a portion of an ellipsoidal, hemispherical, toriconical, or torispherical head. The thickness and other dimensions shall satisfy the requirements of AD-204.

AD-211 Cone-to-Cylinder Junction at Large End

The rules of this paragraph apply provided:

(a) the two parts to be joined have the same rotational axis;

(b) the load is internal pressure (see AD-206);

(c) the joint is a butt weld having its surfaces merge smoothly, both inside and outside, with the adjacent cone and cylinder surfaces without reducing the thickness (see AD-412.2);

(d) the weld at the junction is radiographed and meets the requirements of AI-510;

(e) the junction is not closer than $2.5\sqrt{R_L \times t_r}$ to another gross structural discontinuity.

AD-211.1 Adequate Minimum Thickness Cone-to-Cylinder Junction (Large End). The thickness of the cone and cylinder forming a junction at the large end for half apex angles not greater than 30 deg need not be thicker than required by AD-203 or AD-201, respectively, if the half apex angle α does not exceed the value given in Fig. AD-211.1.

AD-211.2 Cone-to-Cylinder Junction With Integral Reinforcement (Large End). When the half apex angle exceeds the maximum permitted by Fig. AD-211.1, the cone and cylinder must be reinforced in the area adjacent to the junction. Figure AD-211.2 gives Q values for ratios of design pressure P to S and values of α not greater than 30 deg. The junction may be reinforced by making both the cylinder and cone thickness equal to t_r and provided that:

(a) the increased cylinder thickness extends a minimum distance of $2.0\sqrt{R_L t_r}$ from the junction, where R_L is the radius of the cylinder at the large end of the cone;

(b) the increased cone thickness extends a minimum distance of $2.0\sqrt{R_L t_r / \cos \alpha}$ from the junction;

(c) in no case shall t be less than the thickness required for the cone in accordance with AD-203.

AD-212 Cone-to-Cylinder Junction at Small End

The rules of this paragraph apply provided:

(a) the two parts to be joined have the same rotational axis;

(b) the load is internal pressure (see AD-206);

(c) the joint is a butt weld having its surfaces merge smoothly, both inside and outside, with the adjacent cone and cylinder surfaces without reducing the thickness (see AD-412.2);

(d) the weld at the junction is radiographed and meets the requirements of AI-510;

(e) the junction is not closer than $2.5\sqrt{R_s t_r}$ to another gross structural discontinuity.

AD-212.1 Adequate Minimum Thickness Cone-to-Cylinder Junction (Small End). The thickness of the cone and cylinder forming a junction at the small end for half apex angles not greater than 30 deg need not be thicker than required by AD-203 and AD-201, respectively, if the point representing the junction lies in the "Adequate" region of Fig. AD-212.1.

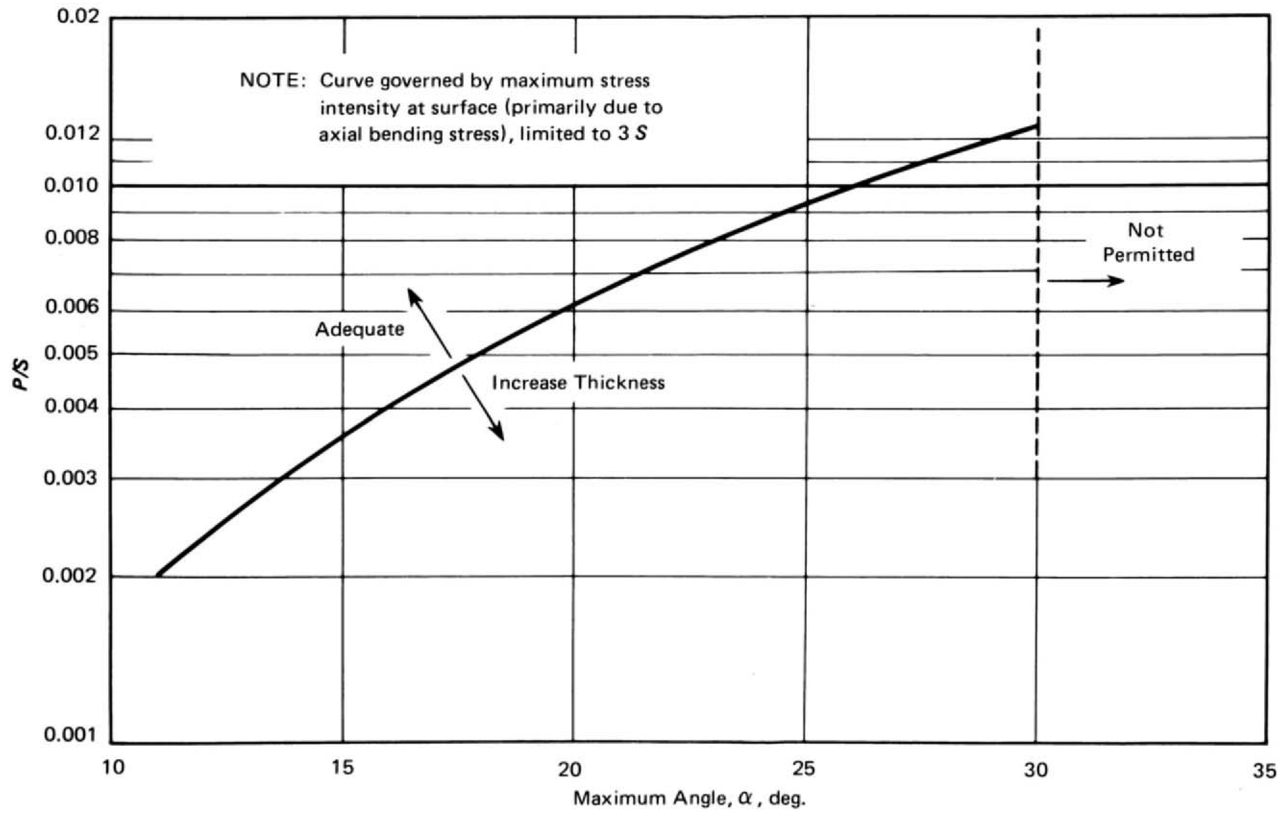


FIG. AD-211.1 INHERENT REINFORCEMENT FOR LARGE END OF CONE-TO-CYLINDER JUNCTION

AD-212.2 Cone-to-Cylinder Junction With Integral Reinforcement (Small End). When the half apex angle exceeds the maximum permitted by Fig. AD-212.1, the cone and cylinder must be reinforced in the area adjacent to the junction. Figure AD-212.2 gives Q values for ratios of design pressure P to S and values of α not greater than 30 deg. The junction may be reinforced by making both the cylinder and cone thickness equal to t_r and provided that:

(a) the increased cylinder thickness t_r extends a minimum distance $1.4\sqrt{R_s t_r}$ from the junction;

(b) the increased cone thickness t_r extends a minimum distance

$$1.4\sqrt{\frac{R_s t_r}{\cos\alpha}}$$

from the junction;

(c) in no case shall t_r be less than the thickness required for the cone in accordance with AD-203 at a distance

$$1.4\sqrt{\frac{R_s t_r}{\cos\alpha}}$$

from the junction.

AD-212.3 Cone-to-Cylinder Junctions at Small End Treated as Openings. Cone-to-cylinder junctions at the small ends of reducers may be treated as openings in conical heads provided:

(a) the diameter d of the small end is not more than one-half the diameter of the large end;

(b) the half apex angle α is greater than 30 deg but not greater than 60 deg;

(c) the reinforcement meets the requirements of AD-520 and AD-540.1, except the total cross-sectional area of reinforcement A required at the junction in any plane for a vessel under internal pressure shall not be less than

$$A = \frac{dt\tan\alpha}{2}$$

and two-thirds of this area shall be provided within a limit of

$$0.5\sqrt{\frac{dt}{2}}$$

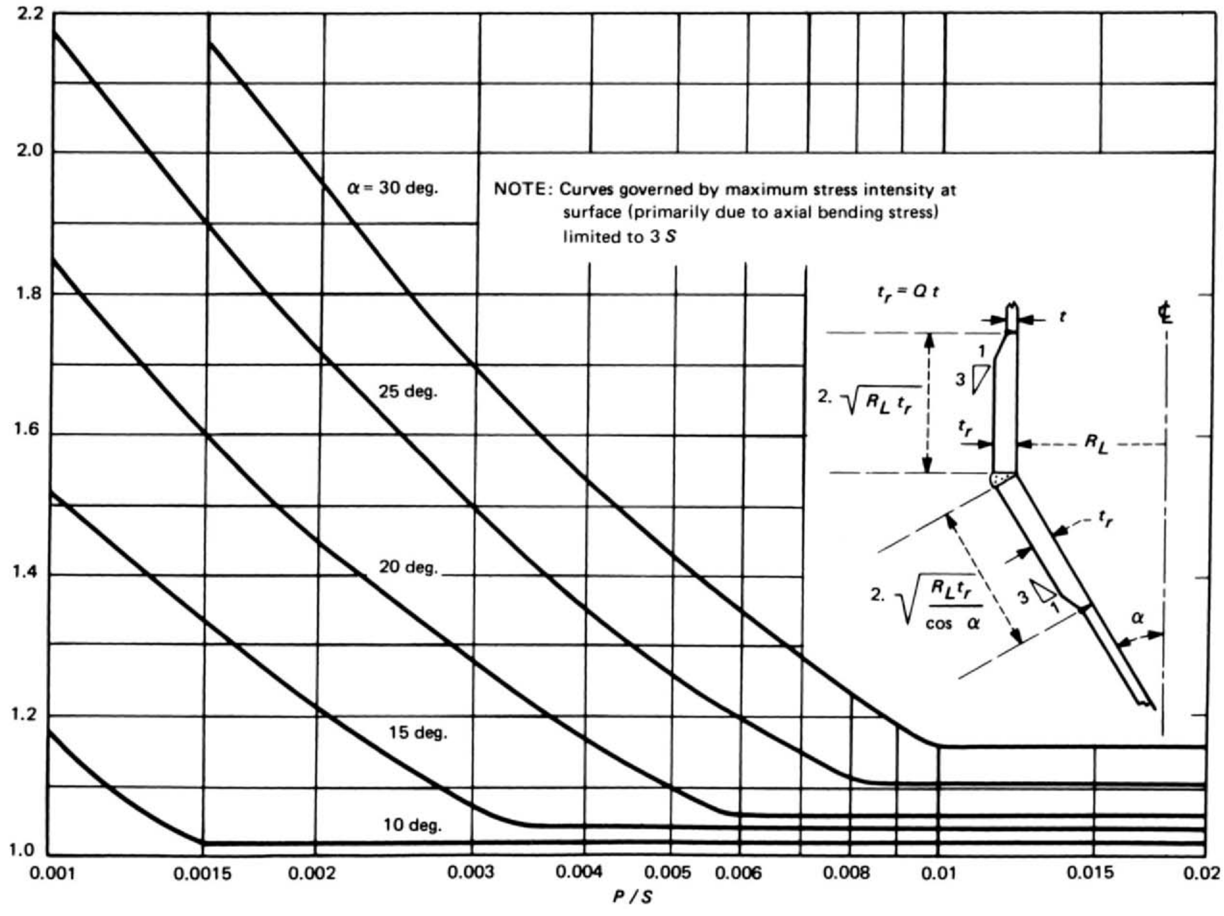


FIG. AD-211.2 VALUES OF Q FOR LARGE END OF CONE-TO-CYLINDER JUNCTION

measured along the cylinder and

$$0.5 \sqrt{\frac{dt}{2 \cos^2 \alpha}}$$

measured along the cone;

(d) reinforcement shall be integral with cone and/or cylinder and all other applicable requirements of Article D-5 met.

AD-213 Head-to-Shell and Head-to-Head Junctions 04

The rules of this paragraph apply to formed heads attached to cylindrical shells and to formed heads attached to each other to form a vessel.

(a) When formed heads (hemispherical, torispherical, and ellipsoidal) are attached to other formed heads to form a vessel, the rules of AD-420 shall be met.

(b) For the attachment of formed heads to cylindrical shells, see AD-420 and Fig. AD-420.1.

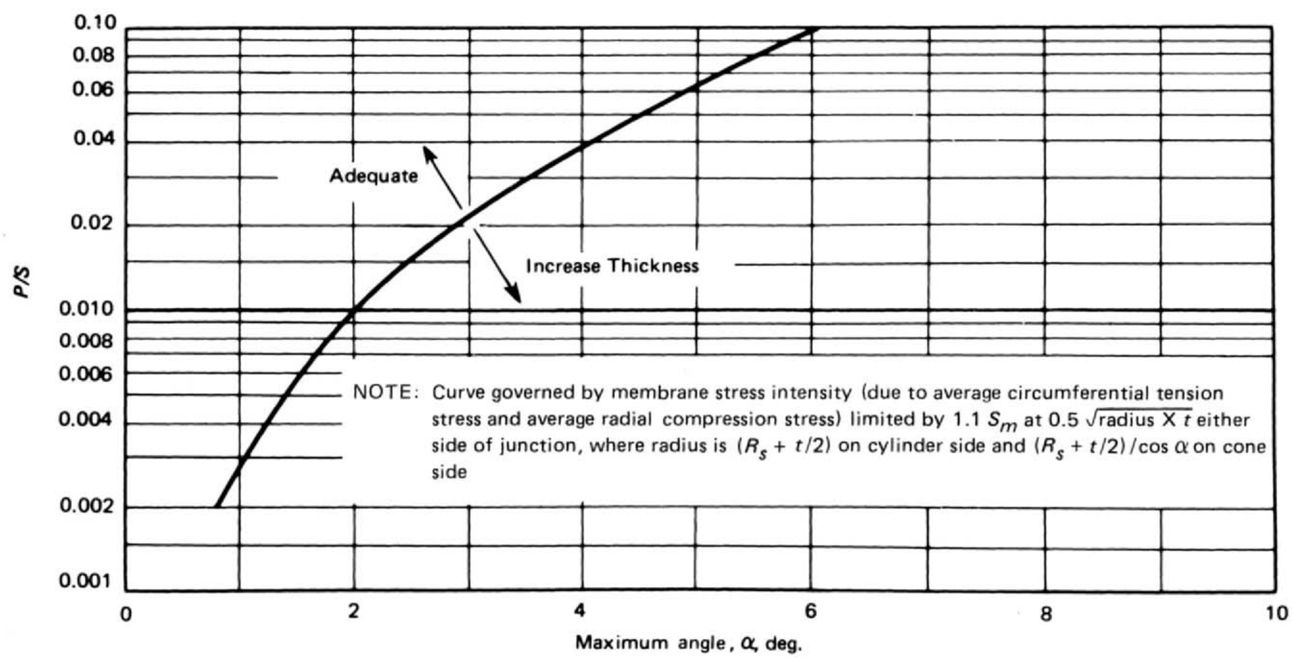


FIG. AD-212.1 INHERENT REINFORCEMENT FOR SMALL END OF CONE-TO-CYLINDER JUNCTION

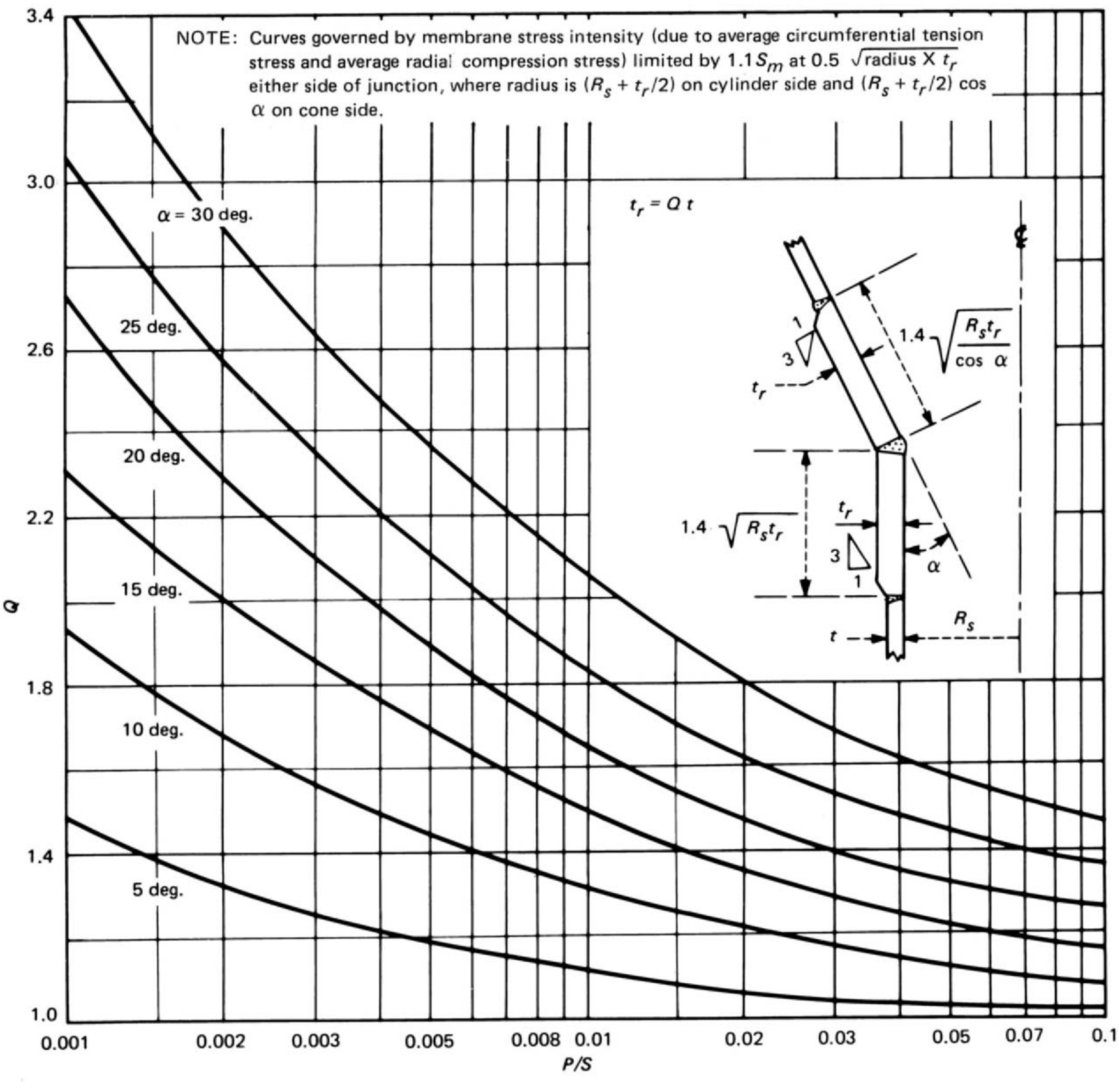


FIG. AD-212.2 VALUES OF Q FOR SMALL END OF CONE-TO-CYLINDER JUNCTION

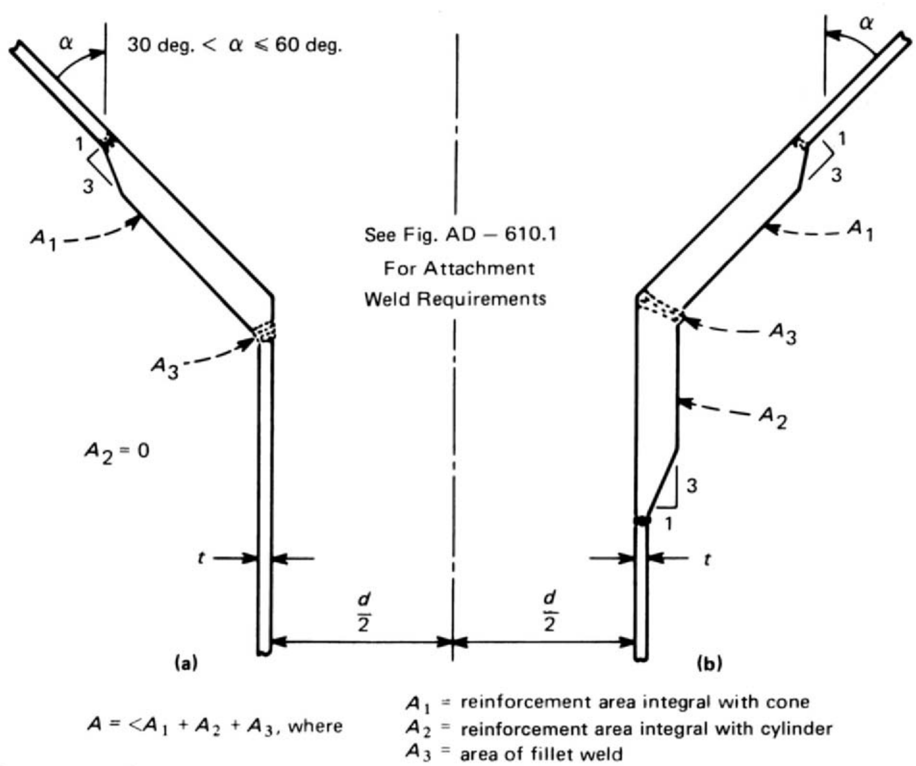

α
30 deg. < α ≤ 60 deg.
α
1
3
1
3
A1
A1
See Fig. AD – 610.1
For Attachment
Weld Requirements
A3
A3
A2
A2 = 0
3
1
t
t
d/2
d/2
(a)
(b)
A = <A1 + A2 + A3, where
A1 = reinforcement area integral with cone
A2 = reinforcement area integral with cylinder
A3 = area of fillet weld

FIG. AD-212.3

ARTICLE D-3
SHELLS OF REVOLUTION UNDER EXTERNAL PRESSURE[1]

AD-300 SCOPE

The rules given in this Article for determining the thicknesses of vessels under external pressure are applicable to spherical, conical, and cylindrical shells with or without stiffening rings, to formed heads, and to tubular products (see AF-130.2). Charts for use in determining the thicknesses of these components are given in Subpart 3 of Section II, Part D.

04 **AD-300.1 Nomenclature.** The symbols used in this Article are defined as follows:

A = factor determined from Fig. G in Subpart 3 of Section II, Part D and used to enter the applicable material chart in Subpart 3 of Section II, Part D. For the case of cylinders having D_o/t values less than 10, see AD-310.2. Also, factor determined from the applicable chart in Subpart 3 of Section II, Part D for the material used in a stiffening ring, corresponding to the factor B (see below) and the design metal temperature for the shell under consideration.

A_{eL} = effective area of reinforcement at large end intersection due to excessive metal thickness

A_{es} = effective area of reinforcement at small end intersection due to excessive metal thickness

A_{rL} = required area of reinforcement at large end of cone

A_{rs} = required area of reinforcement at small end of cone

A_s = cross-sectional area of the stiffening ring

A_T = equivalent area of cylinder, cone, and stiffening ring, where

$$A_{TL} = \frac{L_L t}{2} + \frac{L_c t_r}{2} + A_s \text{ for large end}$$

$$A_{TS} = \frac{L_{sm} t}{2} + \frac{L_c t_r}{2} + A_s \text{ for small end}$$

B = factor determined from the applicable chart or table in Subpart 3 of Section II, Part D for the material used in a shell or stiffening ring at the design metal temperature

D_L = outside diameter of large end of conical section under consideration

D_o = outside diameter of cylindrical shell (In conical shell calculations, the value of D_s or D_L should be used in calculations in place of D_o, depending on whether the small end D_s or large end D_L, is being examined.)

$D_o/2h_o$ = ratio of the major to the minor axis of ellipsoidal heads, which equals the outside diameter of the head skirt divided by twice the outside height of the head (see Table AD-350.2)

D_s = outside diameter of small end of conical section under consideration

E = modulus of elasticity of the material at design temperature. For external pressure and axial design in accordance with this Section, the modulus of elasticity to be used shall be taken from the applicable materials chart in Subpart 3 of Section II, Part D.[2] (Interpolation may be made between lines for intermediate temperatures.)

E_c = modulus of elasticity of cone material

E_r = modulus of elasticity of stiffening ring material

E_s = modulus of elasticity of shell material

f_1 = axial load at large end due to wind, dead load, etc., excluding pressure

f_2 = axial load at small end due to wind, dead load, etc., excluding pressure

h_o = one-half of the length of the outside minor axis of the ellipsoidal head, or the outside height of the ellipsoidal head measured from the tangent line (head-bend line)

[1] For formed heads under pressure on the convex side, this may be either internal or external pressure, depending on the orientation of the head on the shell.

[2] Note that the modulus of elasticity values listed in Subpart 3 of Section II, Part D for specific material groups may differ from those values listed in Table TM-1 of Section II, Part D and need only be applied for external pressure and axial compression design.

I = available moment of inertia of combined ring–shell–cone cross section about its neutral axis parallel to the axis of the shell. The width of shell which is taken as contributing to the moment of inertia of the combined section shall not be greater than $1.10\sqrt{D_o t_s}$ and shall be taken as lying one-half on each side of the centroid of the ring. Portions of the shell plate shall not be considered as contributing area to more than one stiffening ring.

CAUTIONARY NOTE: Stiffening rings may be subject to lateral buckling. This should be considered in addition to the requirements for I_s and I.

I_s = required moment of inertia of the combined ring–shell–cone cross section about its neutral axis parallel to the axis of the shell

If the stiffeners should be so located that the maximum permissible effective shell sections overlap on either or both sides of a stiffener, the effective shell section for that stiffener shall be shortened by one-half of each overlap.

k = 1 when additional area of reinforcement is not required
= y/S_rE_r when a stiffening ring is required, but k not less than 1.0

K_o = a factor depending on the ellipsoidal head proportions $D_o/2h_o$ (see Table AD-350.2)

L = total length of a tube between tubesheets, or the design length of a vessel section, taken as the largest of the following:
(a) the distance between head tangent lines plus one-third of the depth of each head if there are no stiffening rings (excluding conical heads and sections);
(b) the distance between cone-to-cylinder junctions for vessels with conical heads if there are no stiffening rings;
(c) the greatest center-to-center distance between any two adjacent stiffening rings;
(d) the distance from the center of the first stiffening ring to the head tangent line plus one-third of the depth of the head (excluding conical heads and sections), all measured parallel to the axis of the vessel; or
(e) the distance from the first stiffening ring in the cylinder to the cone-to-cylinder junction.

L_c = length of cone between stiffening rings measured along surface of cone. For cones without intermediate stiffeners,

$$L_c = \sqrt{L_x^2 + (R_L - R_s)^2}$$

L_e = equivalent length of conical section
= $(L_x/2)(1 + D_s/D_L)$

L_L = design length of a vessel section, taken as the larger of the following:
(a) the center-to-center distance between the cone-to-large-shell junction and an adjacent stiffening ring on the large shell;
(b) the distance between the cone-to-large-shell junction and one-third the depth of head on the other end of the large shell if no other stiffening rings are used.

L_s = one-half of the distance from the centerline of the stiffening ring to the next line of support on one side, plus one-half of the centerline distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the component. A line of support is:
(a) a stiffening ring that meets the requirements of this paragraph;
(b) a circumferential line on a head at one-third the depth of the head from the head tangent line;
(c) a circumferential connection to a jacket for a jacketed section of a cylindrical shell; or
(d) a cone-to-cylinder junction.

L_{sm} = design length of a vessel section, taken as the larger of the following:
(a) the center-to-center distance between the cone-to-small-shell junction and an adjacent stiffening ring on the small shell;
(b) the distance between the cone-to-small-shell junction and one-third the depth of head on the other end of the small shell if no other stiffening rings are used.

L_x = axial length of cone, per Fig. AD-300.1

P = external design pressure

P_a = maximum allowable external working pressure (gage or absolute, as required)

Q_L = algebraical sum of $PR_L/2$ and f_1

Q_s = algebraical sum of $PR_s/2$ and f_2

R_L = outside radius of large cylinder

R_o = for spherical shell, the outside radius
= for hemispherical head, the outside radius
= for ellipsoidal head, the equivalent outside spherical radius taken as K_oD_o
= for torispherical head, the outside radius of the crown portion of the head

R_s = outside radius of small cylinder

S = the lesser of $1.5S_m$ at design metal temperature from the tables in Subpart 1 of Section II, Part D, or 0.9 times the tabulated yield strength at design metal temperature from the tables in Subpart 1 of Section II, Part D

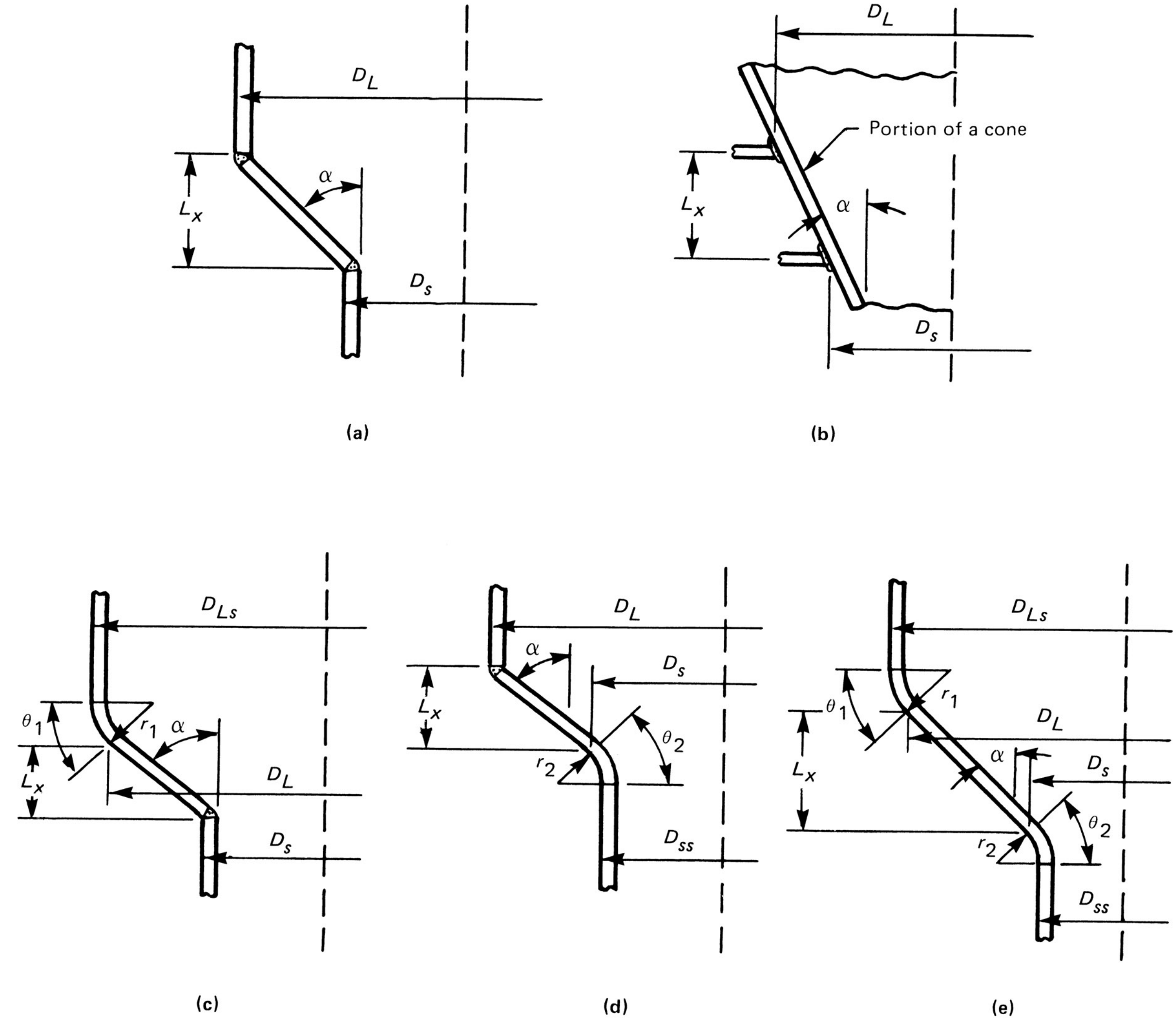


FIG. AD-300.1 LENGTH L_x OF SOME TYPICAL CONICAL SECTIONS FOR EXTERNAL PRESSURE

S_c = allowable stress intensity of cone
S_r = allowable stress intensity of stiffening ring material
S_s = allowable stress intensity of shell
t = minimum required thickness of cylindrical shell or tube, of spherical shell, or of formed head
t_c = nominal thickness of cone at cone-to-cylinder junction
t_e = effective thickness of conical section
= $t_r \cos \alpha$
t_r = minimum required thickness of cone at cone-to-cylinder junction
t_s = nominal thickness used, of a cylindrical shell or tube (for pipe, the tolerance requirements of AF-105.2 shall apply)
y = cone-to-cylinder factor
= S_sE_s for stiffening ring on shell
= S_cE_c for stiffening ring on cone
α = one-half the included (apex) angle of the cone at the centerline of the head
Δ = value to indicate need for reinforcement at cone-to-cylinder intersection having a half apex angle $\alpha \leq 60$ deg. When $\Delta \geq \alpha$, no reinforcement is required at the junction (see Table AD-360.3).

AD-310 CYLINDRICAL SHELLS AND TUBES

The minimum required thickness of a cylindrical shell or tube under external pressure, either seamless or with longitudinal butt joints, shall be determined by the following procedure.

04 **AD-310.1 Cylinders Having D_o/t Values ≥ 10**

Step 1. Assume a value for t and determine the ratios L/D_o and D_o/t.

Step 2. Enter Fig. G in Subpart 3 of Section II, Part D at the value of L/D_o determined in Step 1. For values of L/D_o greater than 50, enter the chart at a value of L/D_o of 50. For values of L/D_o less than 0.05, enter the chart at a value of $L/D_o = 0.05$.

Step 3. Move horizontally to the line for the value of D_o/t determined in Step 1. Interpolation may be made for intermediate values of D_o/t. From this intersection move vertically downwards and read the value of factor A.

Step 4. Using the value of A calculated in Step 3, enter the applicable material chart in Subpart 3 of Section II, Part D for the material/temperature under consideration. Move vertically to an intersection with the material-temperature line for the design temperature (see AD-121.2). Interpolation may be made between lines for intermediate temperatures. If tabular values in Subpart 3 of Section II, Part D are used, linear interpolation or any other rational interpolation method may be used to determine a B value that lies between two adjacent tabular values for a specific temperature. Such interpolation may also be used to determine a B value at an intermediate temperature that lies between two sets of tabular values, after first determining B values for each set of tabular values. In cases where the value at A falls to the right of the end of the material-temperature line, assume an intersection with the horizontal projection of the upper end of the material-temperature line. If tabular values are used, the last (maximum) tabulated value shall be used. For values at A falling to the left of the material line, see Step 7.

Step 5. From the intersection obtained in Step 4, move horizontally to the right and read the value of factor B.

Step 6. Using this value of B, calculate the value of the maximum allowable external working pressure P_a using the following formula:

$$P_a = \frac{4B}{3(D_o/t)}$$

Step 7. For values of A falling to the left of the applicable material-temperature line, the value of P_a can be calculated using the following formula:

$$P_a = \frac{2AE}{3(D_o/t)}$$

If tabular values are used, determine B as in Step 4 and apply it to the equation in Step 6.

Step 8. Compare P_a with P. If P_a is smaller than P, select a larger value for t and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P. An example illustrating the use of this procedure is given in G-112.

AD-310.2 Cylinders Having D_o/t Values < 10

Step 1. Using the same procedure as given in AD-310.1, obtain the value of B. For values of D_o/t less than four, the value of factor A can be calculated using the following formula:

$$A = \frac{1.1}{(D_o/t)^2}$$

For values of A greater than 0.10, use a value of 0.10.

Step 2. Using the value of B obtained in Step 1, calculate a value P_{a1} using the following formula:

$$P_{a1} = \left[\frac{2.167}{(D_o/t)} - 0.0833\right]B$$

Step 3. Calculate a value P_{a2} using the following formula:

$$P_{a2} = \frac{2S}{D_o/t}\left[1 - \frac{1}{D_o/t}\right]$$

where S is the lesser of $1.5S_m$ at design metal temperature from the applicable table in Subpart 1 of Section II, Part D, or 0.9 times the tabulated yield strength of the material at design metal temperature from the applicable table in Subpart 1 of Section II, Part D.

Step 4. The smaller of the values of P_{a1} calculated in Step 2 or P_{a2} calculated in Step 3 shall be used for the maximum allowable external working pressure P_a. Compare P_a with P. If P_a is smaller than P, select a larger value for t and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

AD-320 SPHERICAL SHELLS 04

The minimum required thickness of a spherical shell under external pressure, either seamless or of built-up construction with butt joints, shall be determined by the following procedure.

Step 1. Assume a value for t and calculate the value of factor A using the following formula:

$$A = 0.125/(R_o/t)$$

Step 2. Using the value of A calculated in Step 1, enter the applicable material chart in Subpart 3 of Section II, Part D for the material under consideration. Move vertically to an intersection with the material-temperature line for the design temperature (see AD-121.2). Interpolation may be made between lines for intermediate temperatures. If tabular values in Subpart 3 of Section II, Part D are used, linear interpolation or any other rational interpolation method may be used to determine a B value that lies between two adjacent tabular values for a specific temperature. Such interpolation may also be used to determine a B value at an intermediate temperature that lies between two sets of tabular values, after first determining B values for each set of tabular values. In cases where the value at A falls to the right of the end of the material-temperature line, assume an intersection with the horizontal projection of the upper end of the material-temperature line. If tabular values are used, the last (maximum) tabulated value shall be used. For values at A falling to the left of the material-temperature line, see Step 5.

Step 3. From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B.

Step 4. Using the value of B obtained in Step 3, calculate the value of the maximum allowable external working pressure P_a using the following formula:

$$P_a = B/(R_o/t)$$

Step 5. For values of A falling to the left of the applicable material-temperature line, the value of P_a can be calculated using the following formula:

$$P_a = \frac{0.0625E}{(R_o/t)^2}$$

If tabular values are used, determine B as in Step 2 and apply it to the equation in Step 4.

Step 6. Compare P_a obtained in Step 4 or 5 with P. If P_a is smaller than P, assume a larger value of t and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P. An example illustrating the use of this procedure is given in G-113.

AD-330 STIFFENING RINGS FOR CYLINDRICAL SHELLS

04 AD-331 Moment of Inertia for Circumferential Stiffening Rings

The required moment of inertia of the combined ring–shell section is given by the following formula:

$$I_s = \frac{D_o^2 L_s (t + A_s/L_s) A}{10.9}$$

The moment of inertia for a stiffening ring shall be determined by the following procedure.

Step 1. Assuming that the shell has been designed and D_o, L_s, and t are known, select a member to be used for the stiffening ring and determine its cross-sectional area A_s, and the value of I_s defined in AD-331. Then calculate B using the following formula:

$$B = \frac{3}{4}\left[\frac{PD_o}{t + A_s/L_s}\right]$$

Step 2a. If tabular values in Subpart 3 of Section II, Part D are used, linear interpolation or any other rational interpolation method may be used to determine an A value that lies between two adjacent tabular values for a specific temperature. Linear interpolation may also be used to determine an A value at an intermediate temperature that lies between two sets of tabular values, after first determining A values for each set of tabular values. The value of A so determined is then applied in the equation for I_s in Step 6.

Step 2b. If material charts in Subpart 3 of Section II, Part D are used, enter the right-hand side of the applicable material chart for the material under consideration at the value of B determined by Step 1. If different materials are used for the shell and stiffening ring, then use the material chart resulting in the larger value for factor A in Step 4 or 5 below.

Step 3. Move horizontally to the left to the material-temperature line for the design metal temperature. For values of B falling below the left end of the material-temperature line, see Step 5.

Step 4. Move vertically to the bottom of the chart and read the value of A.

Step 5. For values of B falling below the left end of the material-temperature line for the design temperature, the value of A can be calculated using the following formula:

$$A = 2B/E$$

Step 6. If the required I_s is greater than that computed for the combined ring–shell section I in Step 1, a new section with a larger moment of inertia must be selected and a new moment of inertia determined. If I_s is smaller than I computed for the section selected, then that section should be satisfactory.

An example of the use of this procedure is given in G-114.

AD-332 Arrangement of Stiffening Rings

Stiffening rings shall extend completely around the vessel except as provided in (c)(1), (2), and (3) below.

(a) Any joints between the ends or sections of such rings, as shown in Fig. AD-332.1 (A) and (B), and any connection between adjacent portions of a stiffening ring lying inside or outside the shell, as shown in (C), shall be made so that the required moment of inertia of the combined ring–shell section is maintained. For a strut section, as shown in Fig. AD-332.1 (D), the required moment of inertia shall be supplied by the strut alone.

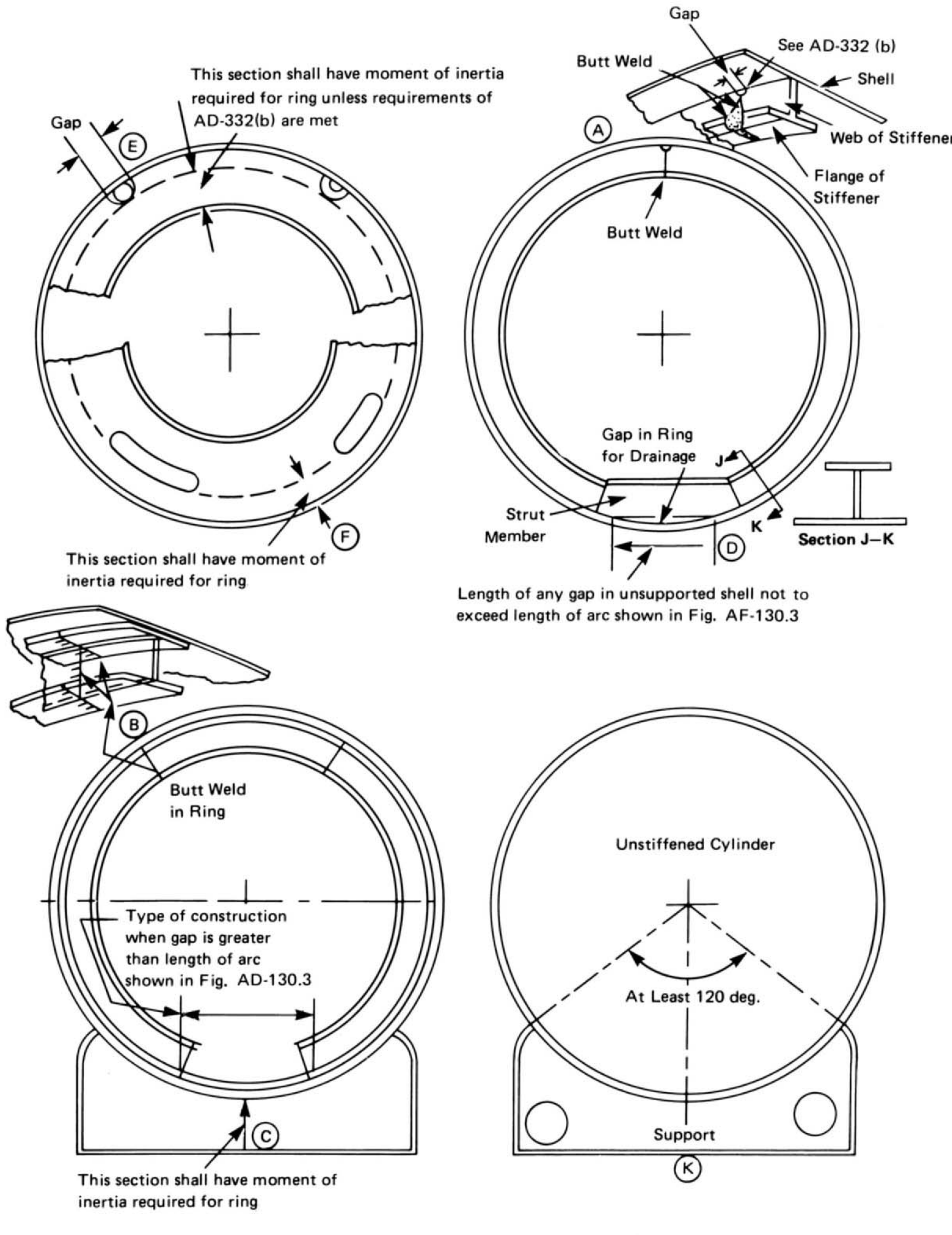


FIG. AD-332.1 VARIOUS ARRANGEMENTS OF STIFFENING RINGS FOR CYLINDRICAL VESSELS SUBJECTED TO EXTERNAL PRESSURE *(b)* Stiffening rings placed on the inside of a vessel may be arranged as shown in Fig. AD-332.1 (E) and (F) provided that the required moment of inertia of the ring in (E) or of the combined ring–shell section in (F) is maintained within the sections indicated. Where the gap at (A) or (E) does not exceed eight times the thickness of the shell plate, the combined moment of inertia of the shell and stiffener may be used.

(c) Any gap in that portion of a stiffening ring supporting the shell, as shown in Fig. AD-332.1 (D) and (E), shall not exceed the length of arc given in Fig. AF-130.3 unless additional reinforcement is provided as shown in (C) or unless:

(1) the length of unsupported shell arc does not exceed 90 deg; and

(2) the unsupported shell arcs in adjacent stiffening rings are staggered 180 deg; and

(3) the dimension L defined in AD-300.1 is taken as the larger of the distance between alternate stiffening rings or the distance from the head-bend line to the second stiffening ring plus one-third of the head depth.

(d) When internal plane structures perpendicular to the longitudinal axis of the cylinder, such as bubble trays or baffle plates, are used in a vessel, they may also be considered to act as stiffening rings provided they are designed to function as such.

(e) Any internal stays or supports used shall bear against the shell of the vessel through the medium of a substantially continuous ring.

AD-333 Permissible Methods of Attaching Stiffening Rings

Stiffening rings shall be attached to either the outside or the inside of the vessel by continuous welding (see Fig. AD-912.1). Where gaps occur in the stiffening ring, the attachment weld shall conform to the details in Fig. AD-912.1 sketch (e).

AD-340 CYLINDERS UNDER AXIAL COMPRESSION

The maximum allowable compressive stress to be used in the design of cylindrical shells and tubes subjected to loadings that produce longitudinal compressive stresses in the shell or tube shall be the smaller of the following values:

(a) the maximum allowable stress intensity at design metal temperature from the tables in Subpart 1 of Section II, Part D;

04 *(b)* the value of the factor B determined from the applicable chart in Subpart 3 of Section II, Part D, using the following definitions for the symbols on the charts:

R_o = outside radius of cylindrical shell or tube

t = minimum required thickness of cylindrical shell or tube

The value of B shall be determined from the applicable chart in Subpart 3 of Section II, Part D in the following manner.

Step 1. Using the selected values of t and R_o, calculate the value of factor A using the following formula:

$$A = 0.125/(R_o/t)$$

Step 2. Using the value of A calculated in Step 1, enter the applicable material chart in Subpart 3 of Section II, Part D for the material under consideration. Move vertically to an intersection with the material-temperature line for the design temperature (see AD-121.2). Interpolation may be made between lines for intermediate temperatures. If tabular values in Subpart 3 of Section II, Part D are used, linear interpolation or any other rational interpolation method may be used to determine a B value that lies between two adjacent tabular values for a specific temperature. Such interpolation may also be used to determine a B value at an intermediate temperature that lies between two sets of tabular values, after first determining B values for each set of tabular values. In cases where the value at A falls to the right of the end of the material-temperature line, assume an intersection with the horizontal projection of the upper end of the material-temperature line. If tabular values are used, the last (maximum) tabulated value shall be used. For values of A falling to the left of the material-temperature line, see Step 4.

Step 3. From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B. This is the maximum allowable compressive stress for the values of t and R used in Step 1.

Step 4. For values of A falling to the left of the applicable material temperature line, the value of B can be obtained using the following formula:

$$B = AE/2$$

If tabular values are used, determine B as in Step 2 and apply it to the equation in Step 4.

Step 5. Compare the value of B determined in Step 3 or 4 with the computed longitudinal compressive stress in the cylindrical shell or tube using the selected values of t and R_o. If the value of B is smaller than the computed compressive stress, a greater value of t must be selected and the design procedure repeated until a value of B is obtained which is greater than the compressive stress computed for the loading on the cylindrical shell or tube.

TABLE AD-350.2
VALUES OF SPHERICAL RADIUS FACTOR K_o FOR ELLIPSOIDAL HEAD WITH PRESSURE ON CONVEX SIDE
Interpolation Permitted for Intermediate Values

$D_o/2h_o$	. . .	3.0	2.8	2.6	2.4	2.2
K_o	. . .	1.36	1.27	1.18	1.08	0.99
$D_o/2h_o$	2.0	1.8	1.6	1.4	1.2	1.0
K_o	0.90	0.81	0.73	0.65	0.57	0.50

AD-350 FORMED HEADS

The minimum required thickness at the thinnest point after forming of hemispherical, ellipsoidal, or torispherical heads under pressure on the convex side[3] (minus heads) shall be determined by the appropriate rules or formulas in the following subparagraphs.

AD-350.1 Hemispherical Heads. The minimum required thickness of a hemispherical head having pressure on the convex side shall be determined in the same manner as given in AD-320 for determining the minimum required thickness for a spherical shell.

AD-350.2 Ellipsoidal Heads. The minimum required thickness of an ellipsoidal head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the same design procedure as is used for spherical shells in AD-320, except that the value of R_o for ellipsoidal heads shall be the equivalent outside spherical radius taken as K_oD_o in the corroded condition.

AD-350.3 Torispherical Heads. The minimum required thickness of a torispherical head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the same design procedure as is used for spherical shells in AD-320, except that the value of R_o for torispherical heads shall be the outside radius of the crown portion of the head in the corroded condition.

AD-360 CONICAL SHELLS AND HEADS

The required thickness of a conical head or section under pressure on the convex side, either seamless or of built-up construction with butt joints, shall be determined in accordance with AD-360.1 or AD-360.2. Stiffening rings shall be in accordance with AD-360.3.

[3] Pressure on the convex side may be caused by either internal pressure or external pressure, depending upon the orientation of the head as it is attached to the shell.

AD-360.1 Cone Angle $\alpha \leq 60$ deg

(a) Cones Having D_L/t_e Values ≥ 10

Step 1. Assume a value for t_e and determine the ratios L_e/D_L and D_L/t_e.

Step 2. Enter Fig. G in Subpart 3 of Section II, Part D at a value of L/D_o equivalent to the value of L_e/D_L determined in Step 1. For values of L_e/D_L greater than 50, enter the chart at a value of $L_e/D_L = 50$.

Step 3. Move horizontally to the line for the value of D_o/t equivalent to the value of D_L/t_e determined in Step 1. Interpolation may be made for intermediate values of D_L/t_e. From this point of intersection move vertically downwards to determine the value of factor A.

Step 4. Using the value of A calculated in Step 3, enter the applicable material chart in Subpart 3 of Section II, Part D for the material under consideration. Move vertically to an intersection with the material-temperature line for the design temperature (see AD-121.2). Interpolation may be made between lines for intermediate temperatures.

In cases where the value of A falls to the right of the end of the material-temperature line, assume an intersection with the horizontal projection of the upper end of the material-temperature line. For values of A falling to the left of the material-temperature line, see Step 7.

Step 5. From the intersection obtained in Step 4, move horizontally to the right and read the value of factor B.

Step 6. Using this value of B, calculate the value of the maximum allowable external working pressure P_a using the following formula:

$$P_a = \frac{4B}{3(D_L/t_e)}$$

Step 7. For values of A falling to the left of the applicable material-temperature line, the value of P_a can be calculated using the following formula:

$$P_a = \frac{2AE}{3(D_L/t_e)}$$

Step 8. Compare the calculated value of P_a obtained in Step 6 or 7 with P. If P_a is smaller than P, select a larger value for t and repeat the design procedure until a value of P_a is obtained that is equal to or greater than P.

Step 9. Provide adequate reinforcement of the cone-to-cylinder juncture according to AD-360.3.

(b) Cones Having D_L/t_e Values < 10

Step 1. Using the same procedure as given in (a) above, obtain the value of B. For values of D_L/t_e less than 4, the value of factor A can be calculated using the following formula:

$$A = \frac{1.1}{(D_L/t_e)^2}$$

For values of A greater than 0.10, use a value of 0.10.

Step 2. Using the value of B obtained in Step 1, calculate a value P_{a1} using the following formula:

$$P_{a1} = \left[\frac{2.167}{(D_L/t_e)} - 0.0833\right] B$$

Step 3. Calculate a value P_{a2} using the following formula:

$$P_{a2} = \frac{2S}{D_L/t_e}\left[1 - \frac{1}{D_L/t_e}\right]$$

where

S = the lesser of two times the maximum allowable stress value at design metal temperature, from the applicable table in Subpart 1 of Section II, Part D, or 0.9 times the yield strength of the material at design temperature

Step 4. The smaller of the values of P_{a1} calculated in Step 2 or P_{a2} calculated in Step 3 shall be used for the maximum allowable external working pressure P_a. Compare P_a with P. If P_a is smaller than P, select a larger value for t and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

Step 5. Provide adequate reinforcement of the cone-to-cylinder juncture according to AD-360.3.

AD-360.2 Cone Angle α > 60 deg. When α of the cone is greater than 60 deg, the thickness of the cone shall be the same as the required thickness for a flat head under external pressure, the diameter of which equals the largest diameter of the cone, or shall be designed by special analysis in accordance with AD-360.3(e).

AD-360.3 Rules for Reinforcement of Cone-to-Cylinder Junction Under External Pressure

(a) The formulas of (b) and (c) below provide for the design of reinforcement, if needed, at the cone-to-cylinder junctions for reducer sections and conical heads where all the elements have a common axis and the half apex angle α ≤ 60 deg. Subparagraph (e) below provides for special analysis in the design of cone-to-cylinder intersections with or without reinforcing rings, including those where α is > 60 deg.

In the design of reinforcement for a cone-to-cylinder juncture, the requirements of AD-551 for reinforcement material strength for nozzles are applicable to reinforcement for a cone-to-cylinder juncture.

(b) Reinforcement shall be provided at the junction of the cone with the large cylinder for conical heads and reducers without knuckles when the value of Δ obtained from Table AD-360.3 using the appropriate ratio P/S_s is less than α. Interpolation may be made in the Table.

TABLE AD-360.3
VALUES OF Δ FOR JUNCTIONS AT THE LARGE CYLINDER FOR α ≤ 60 deg

P/S_s	0	0.002	0.005	0.010	0.02
Δ, deg	0	5	7	10	15
P/S_s	0.04	0.08	0.10	0.125	0.15
Δ, deg	21	29	33	37	40
P/S_s	0.20	0.25	0.30	0.35	Note (1)
Δ, deg	47	52	57	60	

NOTE:
(1) Δ = 60 deg for greater values of P/S_s.

The cross-sectional area of the reinforcement ring shall be at least equal to that indicated by the following formula:

$$A_{rL} = \frac{kQ_LD_L \tan\alpha}{2S_s}\left[1 - \frac{1}{4}\left(\frac{PD_L - 2Q_L}{2Q_L}\right)\frac{\Delta}{\alpha}\right] \quad (1)$$

When the thickness of both the reducer and cylinder exceeds that required by the applicable design formulas, the minimum excess thickness may be considered to contribute to the required stiffening ring in accordance with the following formula:

$$A_{eL} = (t_s - t)\sqrt{\frac{D_Lt_s}{2}} + (t_c - t_r)\sqrt{\frac{D_Lt_c}{2\cos\alpha}} \quad (2)$$

Any additional area of stiffening which is required shall be situated within a distance of $\sqrt{D_Lt_s/2}$ from the junction of the reducer and the cylinder. The centroid of the added area shall be within a distance of 0.5 $\sqrt{D_Lt_s/2}$ from the junction.

The stiffening ring at the cone-to-cylinder junction shall also be considered as a stiffening ring.

The moment of inertia for a stiffening ring at the large end shall be determined by the following procedure.

Step 1. Assuming that the shell has been designed and D_L, L_L, and t are known, select a member to be used for the stiffening ring and determine cross-sectional area A_{TL}. Then calculate factor B using the following formula:

$$B = \frac{3}{4}\left(\frac{F_LD_L}{A_{TL}}\right)$$

where

$$F_L = PM + f_1 \tan\alpha$$

$$M = \frac{-D_L \tan\alpha}{4} + \frac{L_L}{2} + \frac{D_L^2 - D_s^2}{6D_L \tan\alpha}$$

Step 2. Enter the right-hand side of the applicable material chart in Subpart 3 of Section II, Part D for the material under consideration at the value of B determined by Step 1. If different materials are used for the shell and stiffening ring, use the material chart resulting in the larger value of A in Step 4 below.

Step 3. Move horizontally to the left to the material-temperature line for the design metal temperature. For values of B falling below the left end of the material-temperature line, see Step 5 below.

Step 4. Move vertically to the bottom of the chart and read the value of A.

Step 5. For values of B falling below the left end of the appropriate material-temperature curve, the value of A can be calculated using the formula $A = 2B/E_r$. For values of B falling above the appropriate material-temperature line, the design shall be adjusted by either changing the configuration, or changing the stiffener ring size or location, such that B is reduced to a value below or at the appropriate material-temperature curve. For values of B having multiple values of A, such as when B falls on a horizontal portion of the curve, the smallest value of A shall be used.

Step 6. Compute the value of the required moment of inertia from the formula for I_s. For the combined ring–shell–cone section:

$$I_s = \frac{AD_L^2 A_{TL}}{10.9}$$

Step 7. Determine the available moment of inertia I of the combined ring–shell–cone section.

Step 8. Evaluate the equation

$$I \geq I_s$$

If the equation is not satisfied, a new section with a larger moment of inertia must be selected, and the calculation shall be done again until the equation is met.

The requirements of AD-332 and AD-333 are to be met in attaching stiffening rings to the shell.

(c) The stiffening ring shall be provided at the junction of the conical shell of a reducer without a flare and the small cylinder. The cross-sectional area of the stiffening ring shall be at least equal to that indicated by the following formula:

$$A_{rs} = \frac{kQ_s D_s \tan \alpha}{2S_s} \qquad (3)$$

When the thickness of either the reducer or cylinder exceeds that required by the applicable design formula, the thickness may be considered to contribute to the required reinforcement ring in accordance with the following formula:

$$A_{es} = \sqrt{\frac{D_s t_c}{2 \cos \alpha}}\,(t_c - t_r) + \sqrt{\frac{D_s t_s}{2}}\,(t_s - t) \qquad (4)$$

Any additional area of stiffener which is required shall be situated within a distance $\sqrt{D_s t_s / 2}$ from the junction, and the centroid of the added area shall be within a distance $0.5\sqrt{D_s t_s / 2}$ from the junction.

The stiffening ring at the cone-to-cylinder junction shall also be considered as a stiffening ring.

The moment of inertia for a stiffening ring at the small end shall be determined by the following procedure.

Step 1. Assuming that the shell has been designed and D_s, L_{sm}, and t are known, select a member to be used for the stiffening ring and determine cross-sectional area A_{TS}. Then calculate factor B using the following formula:

$$B = \frac{3}{4}\left(\frac{F_s D_s}{A_{TS}}\right)$$

where

$$F_s = pN + F_2 \tan \alpha$$

$$N = \frac{D_s \tan \alpha}{4} + \frac{L_{sm}}{2} + \frac{D_L^2 - D_s^2}{12 D_s \tan \alpha}$$

Step 2. Enter the right-hand side of the applicable material chart in Subpart 3 of Section II, Part D for the material under consideration at the value of B determined by Step 1. If different materials are used for the shell and stiffening ring, use the material chart resulting in the larger value of A in Step 4 below.

Step 3. Move horizontally to the left to the material-temperature line for the design metal temperature. For values of B falling below the left end of the material-temperature line, see Step 5 below.

Step 4. Move vertically to the bottom of the chart and read the value of A.

Step 5. For values of B falling below the left end of the appropriate material-temperature curve, the value of A can be calculated using the formula $A = 2B/E_r$. For values of B falling above the appropriate material-temperature line, the design shall be adjusted by either changing the configuration, or changing the stiffener ring size or location, such that B is reduced to a value below or at the appropriate material-temperature curve. For values of B having multiple values of A, such as when B falls on a horizontal portion of the curve, the smallest value of A shall be used.

Step 6. Compute the value of the required moment of inertia from the formula for I_s. For the combined ring–shell–cone section:

$$I_s = \frac{AD_s^2 A_{TS}}{10.9}$$

Step 7. Determine the available moment of inertia I of the combined ring–shell–cone section.

Step 8. Evaluate the equation:

$$I \geq I_s$$

If the equation is not satisfied, a new section with a larger moment of inertia must be selected, and the calculation shall be done again until the equation is met.

The requirements of AD-332 and AD-333 are to be met in attaching stiffening rings to the shell.

(d) The reinforcement of reducers not described in AD-210, such as those made up of two or more conical frustums having different slopes, may be designed in accordance with (e) below.

(e) For conical sections with the half apex angle greater than 60 deg, and as an alternative to the rules provided in (b) and (c) above, the design may be based on special analysis such as numerical methods or the beam-on-elastic-foundation analysis of Timoshenko, Hetenyi, or Watts and Lang. The stresses at the junction shall meet all of the allowable stress limits of this Division. The effect of shell and cone buckling on the required area and moment of inertia at the joint shall also be considered in the analysis. The theoretical buckling pressure of the junction shall be at least 3.3 times the allowable external design pressure of the junction.

AD-360.4 Toriconical Heads and Shell Sections. The required thickness of a toriconical head having pressure on the convex side, either seamless or of built-up construction with butt joints within the head, shall not be less than that determined from AD-360.1 or AD-360.2, with the exception that L_e shall be determined as follows.

(a) For sketch (c) in Fig. AD-300.1,

$$L_e = r_1 \sin \theta_1 + \frac{L}{2}\left(\frac{D_L + D_s}{D_{Ls}}\right)$$

(b) For sketch (d) in Fig. AD-300.1,

$$L_e = r_2 \frac{D_{ss}}{D_L} \sin \theta_2 + \frac{L}{2}\left(\frac{D_L + D_s}{D_L}\right)$$

(c) For sketch (e) in Fig. AD-300.1,

$$L_e = r_1 \sin \theta_1 + r_2 \frac{D_{ss}}{D_{Ls}} \sin \theta_2 + \frac{L}{2} \frac{(D_L + D_s)}{D_{Ls}}$$

NOTE: Nomenclature is as defined in Fig. AD-300.1.

AD-360.5 Eccentric Cones. The thickness of an eccentric cone shall be taken as the greater of the two thicknesses obtained using both the smallest and largest α in the calculations.

AD-370 OPENINGS IN SHELLS AND HEADS

Openings in shells and heads convex to pressure shall comply with the requirements of AD-520.

ARTICLE D-4
WELDED JOINTS

AD-400 WELDED JOINT CATEGORIES

The term *category,* as used herein, defines the location of a joint in a vessel, but not the type of joint. The categories established by this paragraph are for use elsewhere in this Division in specifying special requirements regarding joint type and degree of examination for certain welded pressure joints. Since these special requirements, which are based on service, and thickness, do not apply to every welded joint, only those joints to which special requirements apply are included in categories. The joints included in each category are designated as joints of Categories A, B, C, and D below. Figure AD-400.1 illustrates typical joint locations included in each category.

AD-400.1 Category A Locations. Category A locations are longitudinal welded joints within the main shell, communicating chambers,[1] transitions in diameter, or nozzles; any welded joint within a sphere, within a formed or flat head, or within the side plates[2] of a flat-sided vessel; and circumferential welded joints connecting hemispherical heads to main shells, to transitions in diameter, to nozzles, or to communicating chambers.[1]

AD-400.2 Category B Locations. Category B locations are circumferential welded joints within the main shell, communicating chambers,[1] nozzles or transitions in diameter including joints between the transition and a cylinder at either the large or small end[3] and circumferential welded joints connecting formed heads other than hemispherical to main shells, to transitions in diameter, to nozzles, or to communicating chambers.[1]

AD-400.3 Category C Locations. Category C locations are welded joints connecting flanges, Van Stone laps, tubesheets or flat heads to main shell, to formed heads, to transitions in diameter, to nozzles, or to communicating chambers[1] and any welded joint connecting one side plate[2] to another side plate of a flat-sided vessel.

AD-400.4 Category D Locations. Category D locations are welded joints connecting communicating chambers[1] or nozzles to main shells, to spheres, to transitions in diameter, to heads, or to flat-sided vessels; nozzles at the small end of a transition in diameter when designed in accordance with AD-212.3; and those joints connecting nozzles to communicating chambers.[1]

AD-410 TYPES OF JOINTS PERMITTED

AD-411 Category A Locations

All joints of Category A shall be Type No. 1 butt joints (see AF-221).

AD-412 Category B Locations

All joints of Category B shall be Type No. 1 butt joints or, except as limited in AD-415, Type No. 2 butt joints (see AF-222).

AD-412.1 Removal of Backing Strips of Type No. 2 Joints. Backing strips shall be removed from Type No. 2 joints unless access conditions prevent their removal. When fatigue analysis of Type No. 2 joints, from which backing strips will not be removed, is required, stress concentration factors of 2.0 for membrane stresses and of 2.5 for bending stresses shall be applied.

AD-412.2 Angle Butt Joints for Transitions in Diameter at Category B Locations. When butt joints are required elsewhere in this Division for Category B, an angle joint connecting a transition in diameter to a cylinder shall be considered as meeting this requirement provided the angle α (see Fig. AD-400.1) does not exceed 30 deg and the requirements of Type No. 1 butt joints are met. All requirements pertaining to the butt joint shall apply to the angle joint.

[1] *Communicating chambers* are defined as appurtenances to the vessel which intersect the shell or heads of a vessel and form an integral part of the pressure containing enclosure, e.g., sumps.

[2] *Side plates of a flat-sided vessel* are defined as any of the flat plates forming an integral part of the pressure containing enclosure.

[3] See AD-400.4 for the joint category for the intersection of a cylinder and the small end of a transition designed in accordance with AD-212.3.

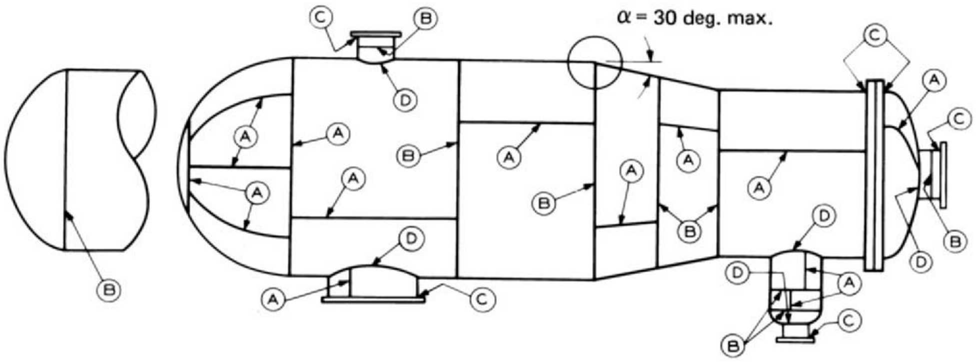


FIG. AD-400.1 ILLUSTRATION OF WELDED JOINT LOCATIONS TYPICAL OF CATEGORIES A, B, C, AND D

AD-413 Category C Locations

All joints of Category C shall be Type No. 1 butt joints, full penetration corner joints (see AF-223) except as limited in AD-415 and AD-416; or, for the limited applications permitted by AD-711.1, they may be fillet welded joints (see AF-225).

AD-413.1 Forged Flat Heads With Hubs for Butt Joints

(a) Hubs for butt weldings to the adjacent shell head, or other pressure parts such as hubbed tubesheets and flat heads as shown in Fig. AD-701.1, shall not be machined from flat plate. The hubs shall be forged in such a manner as to provide in the hub the full minimum tensile strength and elongation specified for the material in the direction parallel to the axis of the vessel. Proof of this shall be furnished by a tension test specimen (subsize, if necessary) taken in this direction and as close to the hub as is practical.[4] The minimum height of the hub shall be the greater of 1.5 times the thickness of the pressure part to which it is welded or $\frac{3}{4}$ in. (19 mm), but need not be greater than 2 in. (50 mm).

(b) Hubbed flanges as shown in Fig. 3-310.1 sketches (d), (e), and (f) shall not be machined from flat plate.

AD-413.2 Corner Welds. When shells, heads, or other pressure parts are welded to a forged or rolled plate to form a corner joint as shown in Fig. AD-701.3 for flat heads and in Fig. 3-310.1 sketch (h) for flanges, the welds shall meet the requirements given below.

(a) On the cross section through the welded joint, the line between the weld metal and the forged or rolled plate being attached shall be projected on planes both parallel to and perpendicular to the surface of the plate being attached, in order to determine the dimensions *a* and *b*, respectively.

(b) For flange rings of bolted flanged connections, and for flat heads and supported and unsupported tubesheets with a projection for a bolted connection, the sum of *a* and *b* shall be not less than three times the nominal wall thickness of the abutting pressure part.

(c) For other components, the sum of *a* and *b* shall be not less than two times the nominal wall thickness of the abutting pressure part. Examples of such components are flat heads and supported and unsupported tubesheets without a projection for a bolted connection and the side plates of a rectangular vessel.

(d) Joint details that have a dimension through the joint less than the thickness of the shell, head, or other pressure part or that provide attachment eccentric thereto are not permitted.

AD-414 Category D Locations

(a) The joints of Category D may be any of the following types:

(1) Type No. 1 butt joints;

(2) full penetration corner welds (see AF-223) except as limited in AD-415;

(3) full penetration corner welds at the nozzle neck and/or fillet welds (see AF-225) except as limited in AD-416.

(b) In addition to the requirements of this paragraph, see Article D-6 for specific requirements for the design of these welds.

AD-414.1 Locations at Which No External Load Is Imposed. Except as limited in AD-415, joints for attaching instrument connections and studded pad type connections that have no external loadings (such as instrumentation openings, inspection openings, etc.) may be made with partial penetration welds and/or fillet welds (see AD-621, AD-635, AF-224, and AF-225).

AD-414.2 Joints for Fittings With Internal Threads. Except as limited in AD-415, welded joints for

[4] One test specimen may represent a group of forgings provided they are of the same design, are from the same heat of material, and are forged in the same manner.

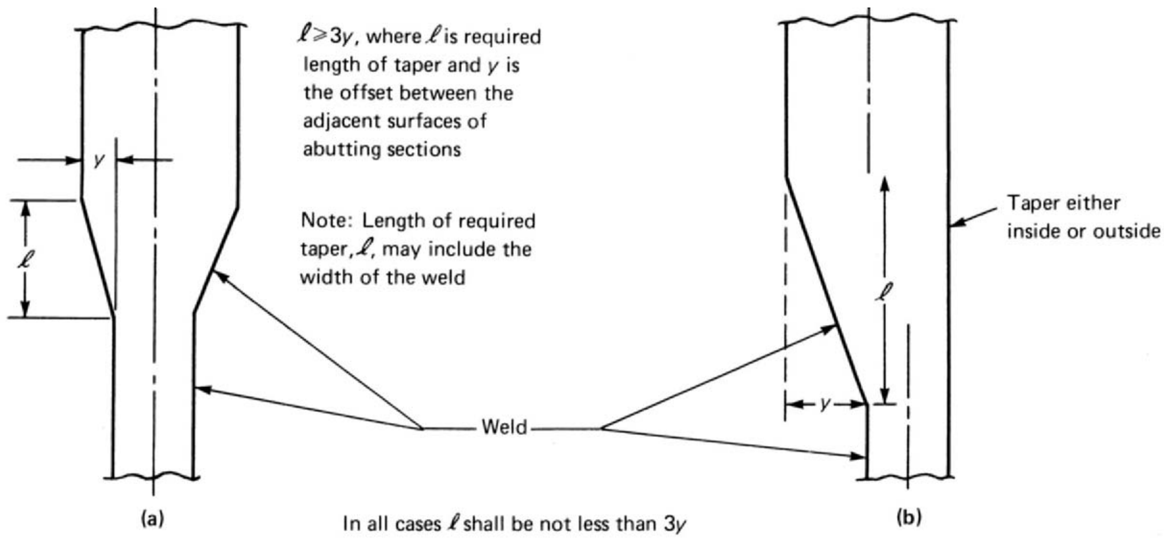


FIG. AD-420.1 BUTT WELDING OF SECTIONS OF UNEQUAL THICKNESS

internally threaded pipe fittings shall be full penetration groove welds or fillet welds as required by AD-620.

AD-415 Special Limitations for Joints of Materials Listed in Table AQT-1

(a) In vessels and vessel parts constructed of heat treated steels covered in Table AQT-1 except as permitted in (b) below, all joints of Categories A, B, and C, as defined in AD-400, and all other welded joints between parts of the pressure containing enclosure which are not defined by the category designation shall be Type No. 1 (see AF-221). All joints of Category D shall be in accordance with Type No. 1 (see AF-221) and Fig. AD-613.1 when the shell plate thickness is 2 in. (50 mm) or less. When the thickness exceeds 2 in. (50 mm), the weld detail may be as permitted for nozzles in Fig. AD-610.1 and Fig. AD-613.1.

(b) For materials SA-333 Grade 8, SA-334 Grade 8, SA-353, SA-522, SA-553, and SA-645 the joints of various categories (see AF-220) shall be as follows:

(1) all joints of Category A shall be Type No. 1 of AF-221;

(2) all joints of Category B shall be Type No. 1 of AF-221 or Type No. 2 of AF-221;

(3) all joints of Category C shall be full penetration welds extending through the entire section at the joint;

(4) all joints of Category D attaching a nozzle neck to the vessel wall and to a reinforcing pad, if used, shall be full-penetration groove welds.

AD-416 Special Limitations for Joints in Lethal Service

All joints in Category A shall be Type No. 1 (AF-221) and in Categories B and C shall be Type No. 1 or Type No. 2 (AF-222). All joints in Category D shall be Type No. 1 butt joint or full penetration corner weld through the vessel or nozzle wall (see AF-223).

AD-417 Joints Attaching Nonpressure Parts and Stiffeners

Welded joints attaching nonpressure parts and stiffeners may be butt welds, full penetration groove welds, partial penetration welds, fillet welds, or stud welds. In part, the type of weld permitted depends on the nature of the attachment and on the material to which the attachment is to be made. (For specific requirements see AD-900, AD-911, and AD-912.)

AD-420 TRANSITION JOINTS BETWEEN SECTIONS OF UNEQUAL THICKNESS

Unless the requirements of Appendices 4, 5, and 6 are shown to be satisfied, a tapered transition as shown in Fig. AD-420.1 shall be provided at joints of Categories A and B (see AD-400) between sections that differ in thickness by more than one-fourth of the thickness of the thinner section or by more than $\frac{1}{8}$ in. (3 mm). The transition may be formed by any process that will provide a

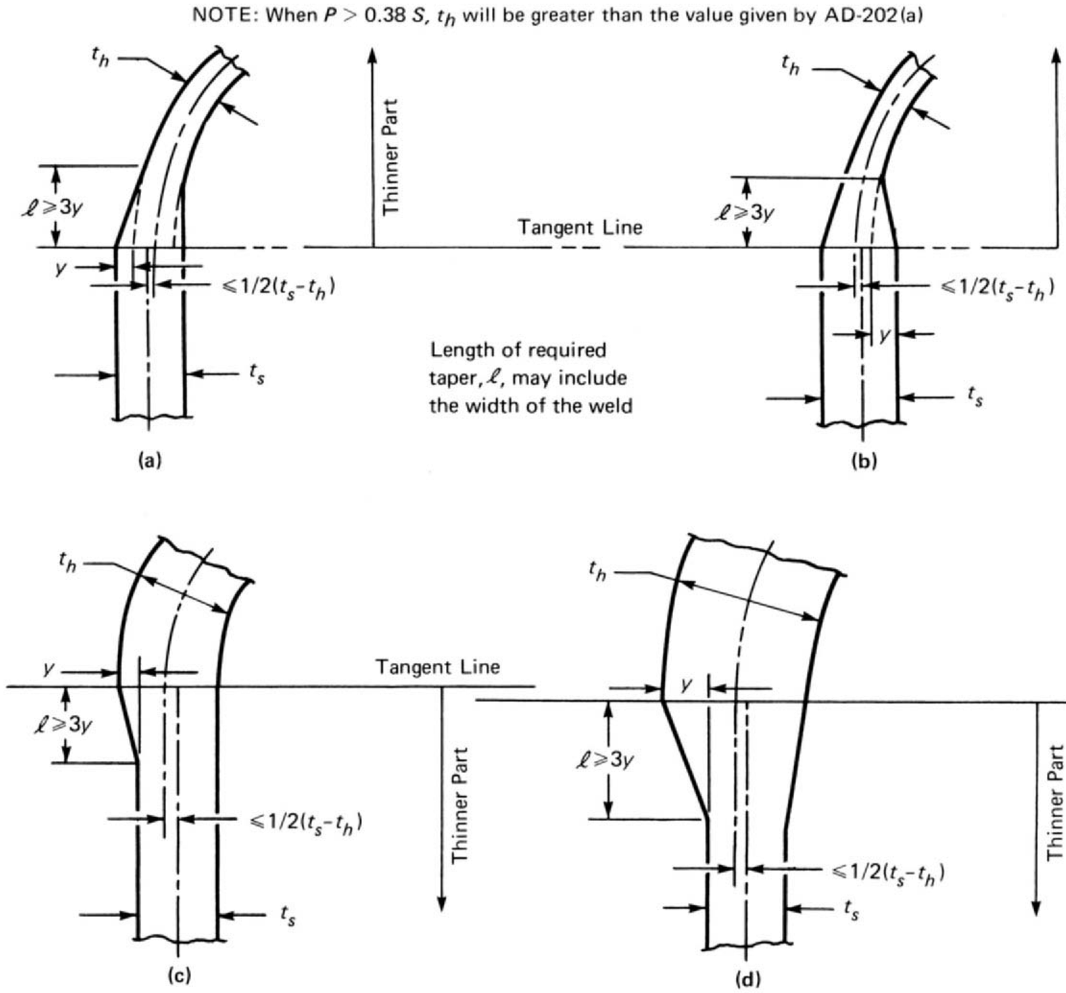


FIG. AD-420.2 JOINTS BETWEEN FORMED HEADS AND SHELLS

uniform taper. When the transition is formed by adding additional weld metal beyond what would otherwise be the edge of the weld, such additional weld metal buildup shall be subject to the requirements of AF-229. The butt weld may be partly or entirely in the tapered section as indicated in Figs. AD-420.1 and AD-420.2. When Appendices 4, 5, and 6 are not used, the following additional requirements shall also apply.

(a) The length of taper shall be not less than three times the offset between adjacent surfaces.

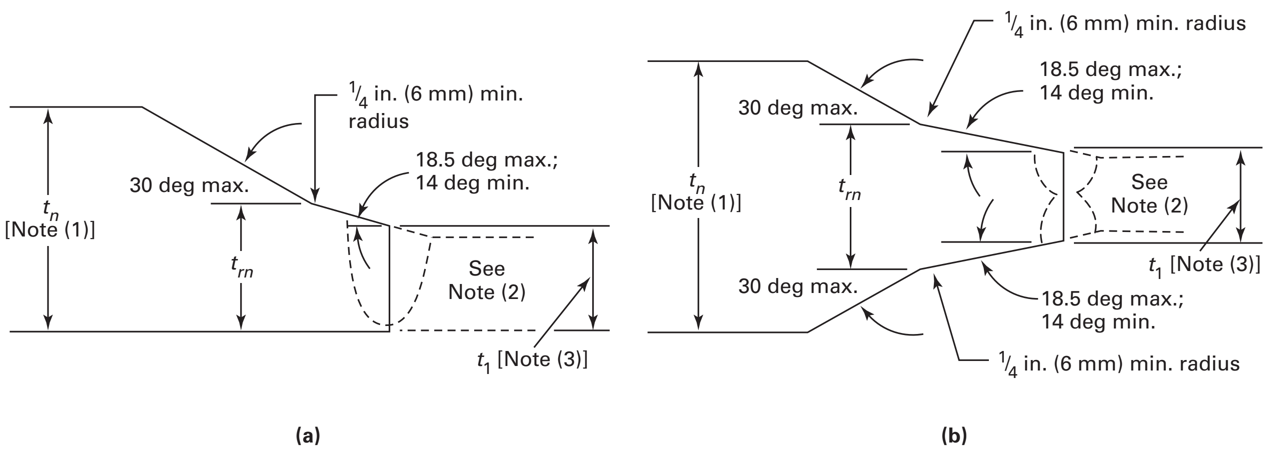
(b) Figure AD-420.1 shall apply to all joints of Categories A and B except joints connecting formed heads to main shells, for which case Fig. AD-420.2 shall apply.

(c) When a taper is required on any formed head intended for butt welded attachment, the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line.

(d) An ellipsoidal or hemispherical head which has a greater thickness than a cylinder of the same inside diameter may be machined to the outside diameter of the cylinder provided the remaining thickness is at least as great as that required for a shell of the same diameter.

The requirements of this paragraph do not apply to flange hubs.

AD-420.1 Nozzle Neck to Piping Transition. In the case of nozzle necks which attach to piping [see AG-120(a)(1) and AD-602] of a lesser wall thickness, a tapered transition from the weld end of the nozzle may be provided to match the piping thickness although the thickness is less than otherwise required by the rules of this Division. This tapered transition shall meet the limitations as shown in Fig. AD-420.3. 04



NOTES:
(1) As defined in AD-540.2.
(2) Weld bevel is shown for illustration only.
(3) t_1 is not less than the greater of:
  (a) $0.8t_{rn}$ where
    t_{rn} = required thickness of seamless nozzle wall
  (b) minimum wall thickness of connecting pipe

FIG. AD-420.3 NOZZLE NECKS ATTACHED TO PIPING OF LESSER WALL THICKNESS

ARTICLE D-5
OPENINGS AND THEIR REINFORCEMENT

AD-500 SCOPE

The rules contained in this Article provide for a satisfactory design in the vicinity of openings in the pressure shell, under pressure loading only, on the basis of opening shape, area replacement and its distribution, provided a fatigue analysis is not required. These rules do not include design requirements for piping loads that may be imposed on the nozzle and/or shell portion and that may be added to the pressure loadings. Such additional loadings should be carefully considered by the design engineer.

AD-501 Dimensions and Shape of Openings

(a) Openings except as permitted under (b) shall be circular, elliptical, or of any other shape which results from the intersection of a circular or elliptical cylinder with vessels of the shapes for which formulas are given in Article D-2, provided:

(1) the ratio of the diameter along the major axis to the diameter along the minor axis of the finished opening is 1.5 or less;

(2) the ratio $d/D \leq 0.50$, where d is the largest inside diameter of the intersecting vessel and D is the inside diameter of the intersected vessel;

(3) the distance between the centerlines of adjacent nozzles measured along the inside surface of the vessel shall be such that

$$\sqrt{(\ell_c/2)^2 + (\ell_\ell/3)^2}$$

is not less than the sum of their inside radii, where ℓ_c is the component of the centerline distance in the circumferential direction, and ℓ_ℓ is the component of the centerline distance in the longitudinal direction.

For openings in a head, or for openings along the longitudinal axis of a cylindrical shell, $\ell_c = 0$.

For openings around the circumference of a cylindrical shell, $\ell_\ell = 0$.

(4) reinforcement is provided around the edge of the opening in amount and distribution such that the area requirements for reinforcement are satisfied for all planes through the center of the opening and normal to the vessel surface as stipulated in AD-520.

(b) Openings of other shapes or dimensions may be used subject to the requirements of Appendix 4 or Appendix 5.

AD-502 Location of Openings in Welded Joints

Any type of opening permitted by these rules may be located in a butt welded joint.

AD-510 CIRCULAR OPENINGS NOT REQUIRING REINFORCEMENT

Circular openings need not be provided with reinforcement if all the following requirements are satisfied.

(a) A single opening has a diameter not exceeding 0.2 $\sqrt{R_m t}$, or if there are two or more openings within any circle of diameter 2.5 $\sqrt{R_m t}$, then the sum of the diameters of such unreinforced openings shall not exceed 0.25 $\sqrt{R_m t}$.

(b) No two unreinforced openings shall have their centers closer to each other, measured on the inside of the vessel wall, than 1.5 times the sum of their diameters.

(c) No unreinforced opening shall have its center closer than 2.5 $\sqrt{R_m t}$ to the edge of a locally stressed area in the shell, where R_m is the mean radius and t is the nominal thickness of the vessel shell or head at the location of the opening(s); locally stressed area means any area in the shell where the primary local membrane stress exceeds $1.1S_m$, but excluding those areas where such primary local membrane stress is due to an unreinforced opening.

AD-520 REQUIRED REINFORCEMENT FOR OPENINGS IN SHELLS AND FORMED HEADS

(a) Design for Internal Pressure. The total cross-sectional area of reinforcement A required in any given plane for a vessel under internal pressure shall be not less than

$$A = dt_r F$$

where

d = diameter in the given plane of the finished opening

t_r = minimum thickness which meets the requirements of Article D-2 in the absence of the opening, except that:

(1) when the opening and its reinforcement are entirely within the spherical portion of a torispherical head, t_r is the thickness required by AD-202 for spherical shells;

(2) when the opening is in a cone, t_r is the thickness required for a seamless cone of diameter D, measured where the nozzle axis pierces the inside wall of the cone;

(3) when the opening and its reinforcement are in a 2:1 elliptical head, located entirely within a circle, the center of which coincides with the center of the head and the diameter of which is equal to 80% of the shell diameter, t_r is the thickness required by AD-202 for spherical shells, using a radius of 0.9 times the shell diameter.

F = 1.00 when the plane under consideration is in the spherical portion of a head or when the given plane contains the longitudinal axis of a cylindrical shell. For other planes through a shell, use the value of F determined from Fig. AD-520.1, except that for reinforcing pads $F = 1$.

(b) Design for External Pressure. The reinforcement required for openings in vessels subject to external pressure need be only 50% of that required in (a) above, where t_r is the wall thickness required by the rules for vessels under external pressure (see Article D-3).

(c) Not less than half the required material shall be on each side of the centerline of the opening. [See also AD-540.1(b).]

AD-530 REQUIRED REINFORCEMENT FOR OPENINGS IN FLAT HEADS

Flat heads that have an opening with a diameter that does not exceed one-half of the head diameter shall have a total cross-sectional area of reinforcement not less than that given by the formula

$$A = 0.5dt_r$$

where

d = diameter of the finished opening

t_r = minimum thickness which meets the requirements of AD-702 in the absence of the opening

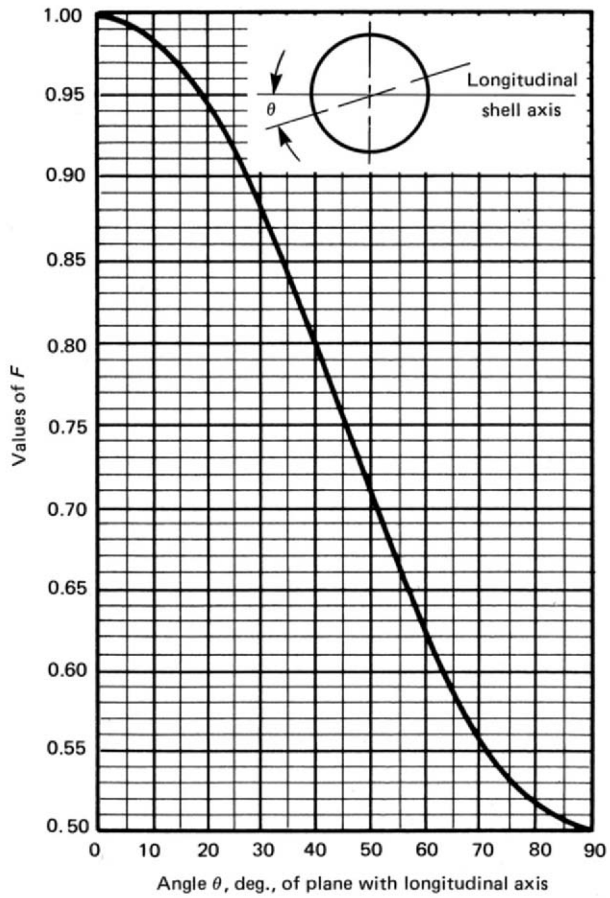


FIG. AD-520.1 CHART FOR DETERMINING VALUE OF F

AD-540 LIMITS OF REINFORCEMENT

The boundaries of the cross-sectional area in any plane normal to the vessel wall and passing through the center of the opening within which metal shall be located in order to have value as reinforcement are designated as the limits of reinforcement for that plane and are as described in AD-540.1 and AD-540.2.

AD-540.1 Boundary Along Vessel Wall. Two requirements on the limits of reinforcement measured along the midsurface of the nominal wall thickness shall be met as follows.

(a) 100% of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) the diameter of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus the thickness of the vessel wall plus the thickness of the nozzle wall.

(b) Two-thirds of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) $r + 0.5\sqrt{R_m t}$, where R_m is the mean radius of shell or head, t is the nominal vessel wall thickness, and r is the radius of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus the thickness of the vessel wall plus the thickness of the nozzle wall.

AD-540.2 Boundary Normal to Vessel Wall. The limits of reinforcement, measured normal to the vessel wall, shall conform to the contour of the surface at a distance from each surface equal to the following limits.

(a) For Fig. AD-540.1 sketches (a) and (b):

(1) when $h < 2.5t_n + K$, the limit is the larger of

$$0.5\sqrt{r_m t_n} + K \text{ or } 1.73x + 2.5t_p + K$$

but this limit shall not exceed either $2.5t$ or $L + 2.5t_p$;

(2) when $h \geq 2.5t_n + K$, the limit is the larger of

$$0.5\sqrt{r_m t_n} + K \text{ or } 2.5t_n$$

but this limit shall not exceed $2.5t$, where

r = inside radius of nozzle
t_n = nominal nozzle thickness
r_m = mean radius of nozzle
= $r + 0.5t_n$
r_2 = transition radius between nozzle and vessel wall
t_p = nominal thickness of connecting pipe
t = nominal vessel thickness
h = length along nozzle with thickness t_n
L = length along nozzle with thickness of t_n plus transition length
K = $0.73r_2$ when a transition radius r_2 is used and the smaller of the two legs when a fillet weld transition is used
x = slope offset distance
= $t_n - t_p$

(b) For Fig. AD-540.1 sketch (c):

(1) When 45 deg $\geq \theta \geq$ 30 deg, the limit is the larger of

$$0.5\sqrt{r_m t_n'} \text{ or } L' + 2.5t_p \leq 2.5t$$

(2) When $\theta <$ 30 deg, the limit is the larger of

$$0.5\sqrt{r_m t_n'} \text{ or } 1.73x + 2.5t_p \leq 2.5t$$

where

r = inside radius of nozzle
t_n' = $t_p + 0.667x$
θ = angle between vertical and slope (45 deg or less), deg
L' = length of tapered section along nozzle
r_m = $r + 0.5t_n'$

Other terms are given in (a) above.

(c) For Fig. AD-540.1 sketch (d), the limit is the larger of

$$0.5\sqrt{r_m t_n} + t_e + K \text{ or } 2.5t_n + t_e + K \leq 2.5t$$

In no case can the thickness t_e used to establish the limit exceed $1.5t$ or $1.73W$, where

W = width of added reinforcing element
t_e = thickness of added reinforcing element

Other terms are given in (a) above.

(d) For Fig. AD-612.1 sketches (d-1) and (d-2), and for Fig. AD-621.1 sketches (c-2) and (c-3), the limit is t_e, but not greater than $1.5t$ or $1.73W$. See (a) and (c) above for nomenclature.

AD-550 METAL AVAILABLE FOR REINFORCEMENT

Metal may be counted as contributing to the area of reinforcement called for in AD-520 and AD-530 provided it lies within the area of reinforcement specified in AD-540 and shall be limited to material which meets the following requirements:

(a) metal forming a part of the vessel wall which is in excess of that required on the basis of primary stress intensity (see AD-200 through AD-210, and AD-702), and is exclusive of corrosion allowance;

(b) similar metal in the nozzle wall provided the nozzle is integral with the vessel wall or is joined to it by a full penetration weld;

(c) weld metal which is fully continuous with the vessel wall;

(d) full penetration weld metal joining nozzle neck to separate reinforcing plate;

(e) metal not fully continuous with the shell, such as a pad continuously welded around its periphery, may be counted as reinforcement provided the requirements of AD-570 are met;

(f) The metal to be included as reinforcement under (b), (c), and (d) shall meet the following limit:

(U.S. Customary Units)

$$|(\alpha_R - \alpha_V)\Delta T| \leq 0.0008$$

(SI Units)

$$|(\alpha_R - \alpha_V)\Delta T| \leq 0.0004$$

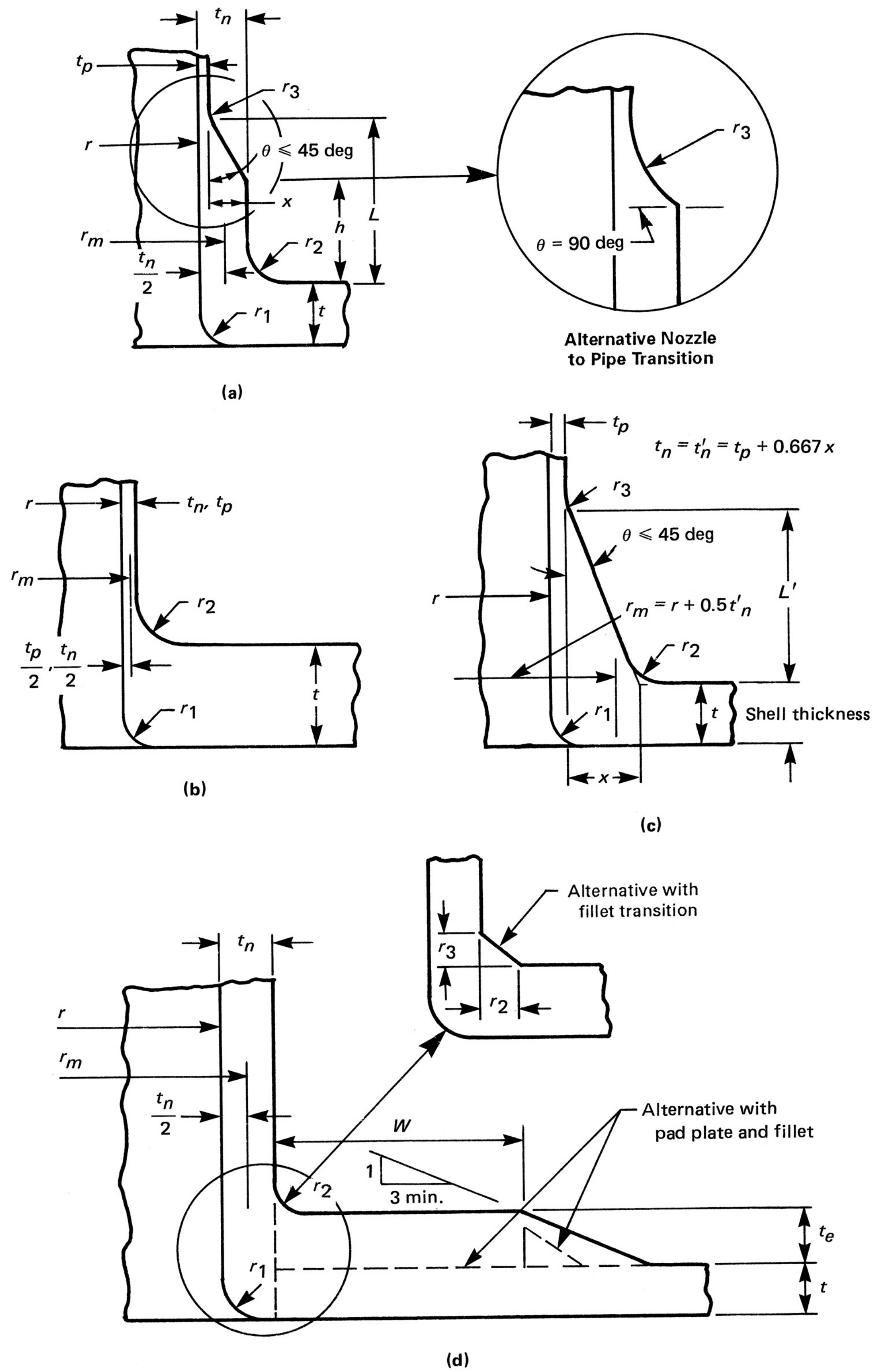


FIG. AD-540.1 NOZZLE NOMENCLATURE AND DIMENSIONS
(Depicts Configuration Only. See Article D-6 for Details of Construction.)

where

α_R = mean coefficient of the thermal expansion of reinforcing metal at design temperature, in./in.°F (mm/mm°C; see Tables TE-1, TE-2, TE-3, and TE-4 in Section II, Part D)

α_V = mean coefficient of thermal expansion of vessel metal at design temperature, in./in.°F (mm/mm°C; see Tables TE-1, TE-2, TE-3, and TE-4 in Section II, Part D)

ΔT = operating temperature range from 70°F (20°C) to the operating temperature, or the difference from the lowest operating temperature to the highest operating temperature, if greater

For designs exceeding this limit, no credit shall be taken for reinforcing potentially available in the nozzle neck within the limits of reinforcement, and no credit shall be taken for fillet weld metal area joining the nozzle neck to shell or separate reinforcing plate. For other reinforcing metal, requirements of (a) to (e) apply.

NOTE: It is extremely likely that for designs exceeding limit in (f), a fatigue analysis will be required by AD-160 rules.

AD-550.1 Metal Not Available for Reinforcement. Metal not fully continuous with the shell, as that in nozzles attached by partial penetration welds, shall not be counted as reinforcement (see also AD-621).

AD-550.2 Reinforcement Metal Limited to One Opening. Metal available for reinforcement shall not be considered as applying to more than one opening.

AD-551 Strength of Reinforcement Material

(a) Material in the nozzle wall used for reinforcement shall preferably have the same design stress intensity value as that used for the material in the vessel wall. In no case shall this value of design stress intensity be less than 80% of that value used for the vessel wall at the design temperature.

(b) If material with a lower design stress is used, the area provided by such material shall be increased in proportion to the inverse ratio of the stress intensity of the nozzle and the vessel wall material. No reduction in the reinforcement requirement may be made if the nozzle material or weld metal has a design stress intensity value higher than that of the material of the vessel wall. The strength of the material at the point under consideration shall be used in fatigue analyses.

AD-560 ALTERNATIVE RULES FOR NOZZLE DESIGN

The following is an acceptable alternative to the rules of AD-501 through AD-550 and Article 4-6 subject to the limitations of AD-560.1.

AD-560.1 Limitations. These alternative rules are applicable only to nozzles in vessels within the following limitations.

(a) The nozzle is circular in cross section and its axis is perpendicular to the vessel or head.

(b) The nozzle and reinforcing (if required) are welded integrally into the vessel with full penetration welds between all parts. Constructions such as those shown in Figs. AD-610.1 and AD-613.1 are acceptable. However, fillet welds must be ground to a radius in accordance with Fig. AD-560.1.

(c) The edge of the opening is at least $2.5\sqrt{R_m t}$ from the nearest edge of any other opening.

(d) The material(s) used in the nozzle, reinforcing, and vessel adjacent to the nozzle shall have a ratio of UTS/YS of not less than 1.5, where

UTS = specified minimum ultimate tensile strength
YS = specified minimum yield strength

(e) The following dimensional limitations are met:

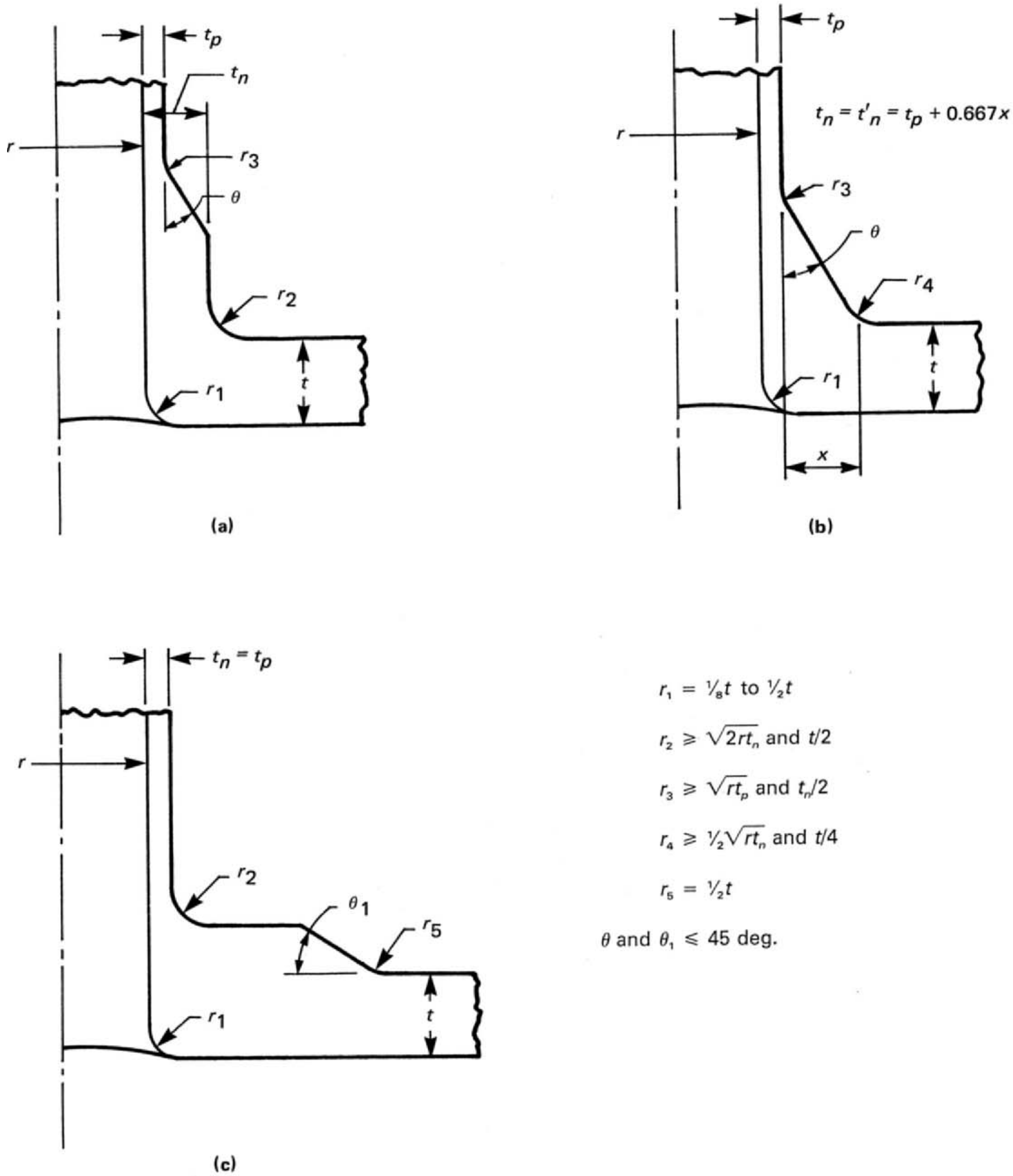
	Nozzles in Cylindrical Vessels	Nozzles in Spherical Vessels or Spherical Portion of Formed Heads
D / t	10 to 100	10 to 100
d / D	0.5 maximum	0.5 maximum
$d / \sqrt{Dt}$	. . .	0.80 maximum
$d / \sqrt{Dt_n r_2 / t}$	1.50 maximum	. . .

(f) In the case of spherical shells and formed heads, at least 40% of the reinforcement is located on the outside surface of the nozzle–shell juncture.

AD-560.2 Nomenclature

A_a = available reinforcing area
A_r = required minimum reinforcing area
D = inside diameter of cylindrical vessel, spherical vessel, or spherical head
d = inside diameter of nozzle
R = inside radius of cylindrical vessel, spherical vessel, or spherical portion of formed head
r = inside radius of nozzle
t = nominal wall thickness of vessel or head
t_n = nominal wall thickness of nozzle
t_p = nominal thickness of connecting pipe
t_r = wall thickness of vessel or head, computed by the equation given in AD-201 for cylindrical vessels; by AD-202 for spherical vessels or spherical portion of formed heads
t_{rn} = wall thickness of nozzle, computed by the equation given in AD-201

r_1, r_2, r_3, r_4, r_5, θ, θ_1: See Fig. AD-560.1.



$r_1 = \frac{1}{8}t$ to $\frac{1}{2}t$

$r_2 \geqslant \sqrt{2rt_n}$ and $t/2$

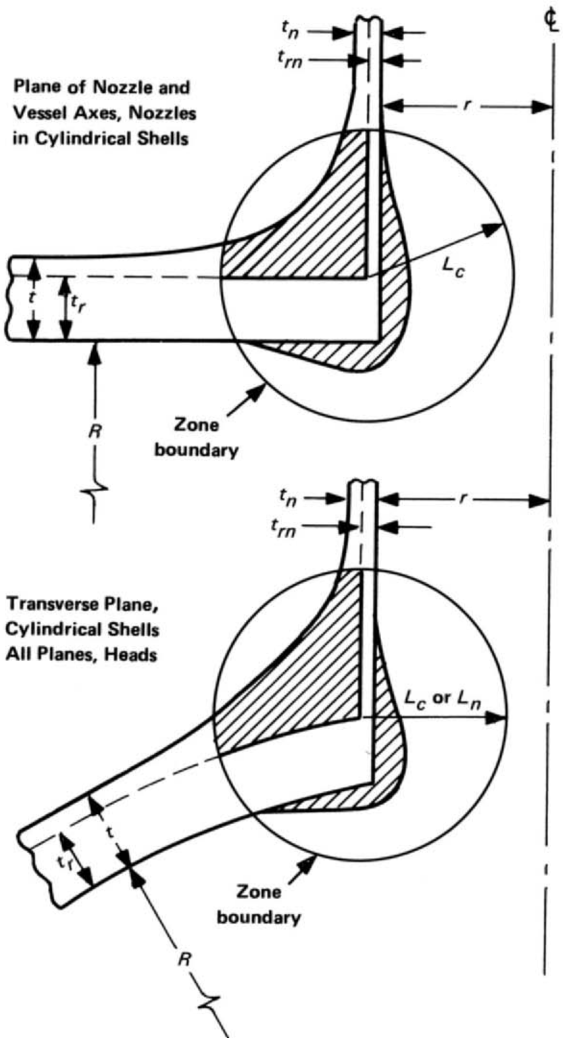
$r_3 \geqslant \sqrt{rt_p}$ and $t_n/2$

$r_4 \geqslant \frac{1}{2}\sqrt{rt_n}$ and $t/4$

$r_5 = \frac{1}{2}t$

θ and $\theta_1 \leqslant 45$ deg.

FIG. AD-560.1 EXAMPLES OF ACCEPTABLE TRANSITION DETAILS



(a) Reinforcing Zone Limit

(1) $L_c = 0.945\,(t_r/R)^{2/3}R$ for nozzles in cylindrical shells.

(2) $L_n = 1.26\,(t_r/R)^{2/3}\,[R\,(r/R + 0.5)]$ for nozzles in heads.

(3) The center of L_c or L_n is at the juncture of the outside surfaces of the shell and nozzles of thicknesses t_r and t_{rn}.

(4) In constructions where the zone boundary passes through a uniform thickness wall segment, the zone boundary may be considered as L_c or L_n through the thickness.

(b) Reinforcing Area

(1) Hatched areas represent available reinforcement area A_a.

(2) Metal area within the zone boundary, in excess of the area formed by the intersection of the basic shells, shall be considered as contributing to the required area A_r. The basic shells are defined as having inside radius R, thickness t_r, inside radius r, thickness t_{rn}.

(3) The available reinforcement area A_a shall be at least equal to $A_r/2$ on each side of the nozzle center line and in every plane containing the nozzle axis.

FIG. AD-560.4 LIMITS OF REINFORCING ZONE

L_c, L_n: See Fig. AD-560.4.
S, σ_t, σ_n, σ_r, σ: See Fig. 4-611.1 and AD-560.7.

AD-560.3 Required Reinforcement Area. The required minimum reinforcing area is related to the value of $d/\sqrt{Rt_r}$ as tabulated below.

	Required Minimum Reinforcing Area A_r	
Value of $d / \sqrt{Rt_r}$	Nozzles in Cylinders	Nozzles in Spherical Vessels or Spherical Portion of Formed Heads
<0.20	None[1]	None[1]
>0.20 and <0.40	$[4.05\,(d / \sqrt{Rt_r})^{1/2} - 1.81]dt_r$	$[5.40\,(d / \sqrt{Rt_r})^{1/2} - 2.41]dt_r$
>0.40	$0.75dt_r$	$dt_r \cos\phi$ $\phi = \sin^{-1}(d / D)$

NOTE:
(1) However, the transition radius r_2 (defined in Fig. AD-560.1), or equivalent thereof, is required.

The required minimum reinforcing area shall be provided in all planes containing the nozzle axis.

AD-560.4 Limits of Reinforcing Zone. Reinforcing metal included in meeting the minimum reinforcing area specified in AD-560.3 must be located within the reinforcing zone boundary shown in Fig. AD-560.4.

AD-560.5 Strength of Reinforcing Material Requirements. Material in the nozzle wall used for reinforcing shall preferably be the same as that of the vessel wall. If material with a lower design stress value S_m is used, the area provided by such material shall be increased in proportion to the inverse ratio of the stress values of the nozzle and the vessel wall material. No reduction in the reinforcing area requirement may be taken for the increased strength of nozzle material or weld metal which has a higher design stress value than that of the material of the vessel wall. The strength of the material at the point under consideration shall be used in fatigue analyses.

AD-560.6 Transition Details. Examples of acceptable transition tapers and radii are shown in Fig. AD-560.1. Other configurations which meet the reinforcing area requirements of AD-560.3 and with equivalent or less severe transitions are also acceptable, e.g., larger radius to thickness ratios.

AD-560.7 Stress Indices. The term stress index, as used herein, is defined as the numerical ratio of the stress components σ_t, σ_n, and σ_r under consideration to the computed stress S.

The symbols for the stress components are shown in Fig. 4-611.1 and are defined as follows:

TABLE AD-560.7
STRESS INDICES FOR INTERNAL PRESSURE LOADING

(a) Nozzles in Spherical Shells and Spherical Portions of Formed Heads

Stress	Inside Corner	Outside Corner
σ_n	2.0	2.0
σ_t	−0.2	2.0
σ_r	$-2t/R$	0
σ	2.2	2.0

(b) Nozzles in Cylindrical Shells

	Longitudinal Plane		Transverse Plane	
Stress	Inside Corner	Outside Corner	Inside Corner	Outside Corner
σ_n	3.1	1.2	1.0	2.1
σ_t	−0.2	1.0	−0.2	2.6
σ_r	$-t/R$	0	$-t/R$	0
σ	3.3	1.2	1.2	2.6

$S = P(2R + t)/4t$ for nozzles in spherical vessels or heads
$= P(2R + t)/2t$ for nozzles in cylindrical vessels
σ_t = the stress component in the plane of the section under consideration and parallel to the boundary of the section
σ_n = the stress component normal to the plane of the section (ordinarily the circumferential stress around the hole in the shell)
σ_r = the stress component normal to the boundary of the section
σ = the stress intensity (combined stress) at the point under consideration
P = range of pressure in cycle under consideration

When the conditions of AD-560.1 through AD-560.6 are satisfied, the stress indices given in Table AD-560.7 may be used. These stress indices deal only with the maximum stresses, at certain general locations, due to internal pressure. In the evaluation of stresses in or adjacent to vessel openings and connections, it is often necessary to consider the effect of stresses due to external loadings or thermal stresses. In such cases, the total stress at a given point may be determined by superposition. In the case of combined stresses due to internal pressure and nozzle loading, the maximum stresses should be considered as acting at the same point and added algebraically. If the stresses are otherwise determined by more accurate analytical techniques or by the experimental stress analysis procedure of Appendix 6, the stresses are also to be added algebraically.

AD-570 REQUIREMENTS FOR NOZZLES WITH SEPARATE REINFORCING PLATES

Except for nozzles at small ends of cones reinforced in accordance with the requirements of AD-212.3, added reinforcement in the form of separate reinforcing plates may be used, provided the vessel and the nozzles meet all of the following conditions.

(a) The materials of nozzle, pad, and vessel wall conform to those in Section IX, QW-422 for materials listed in Column 1 and Column 4 of Table AF-241.1.

(b) The specified minimum tensile strengths of said materials do not exceed 80,000 psi (550 MPa).

(c) The minimum elongation of each of said materials is 12% in 2 in. (50 mm).

(d) The thickness of the added reinforcement does not exceed $1\frac{1}{2}$ times the shell thickness.

(e) The requirements of AD-160 for pads in cyclic service are met.

ARTICLE D-6
NOZZLES AND OTHER CONNECTIONS

AD-600 REQUIREMENTS FOR NOZZLES AND OTHER CONNECTIONS

AD-601 PERMITTED TYPES OF NOZZLES AND OTHER CONNECTIONS

Nozzles and other connections may be any of the types for which rules are given in this Article provided:

(a) they meet its requirements as to location;

(b) the type of attachment weld is permitted by Article D-4, Welded Joints;

(c) the minimum size of weld is as required by Figs. AD-610.1, AD-612.1, AD-613.1, and AD-621.1;

(d) the requirements of Article D-5, Openings and Their Reinforcement, are complied with;

(e) Type No. 1 butt joints (see AF-221) or full penetration joints (see AF-223) are used when the openings are in shells $2\frac{1}{2}$ in. (63 mm) or more in thickness;

(f) the welded joints are examined by the methods stipulated in the applicable paragraph of Article F-2;

(g) studded connections conform to the requirements of AD-740;

(h) threaded connections meet the requirements of AD-640.

AD-601.1 Nomenclature. The symbols used in this paragraph and in Figs. AD-610.1, AD-612.1, AD-613.1, and AD-621.1 are defined as follows:

r = inside radius of nozzle in the corroded condition, in. (mm)

t = nominal thickness of vessel shell or head, in. (mm)

t_c = throat dimensions of corner welds between nozzle and vessel wall, not less than the smaller of $\frac{1}{4}$ in. (6 mm) or $0.7t_n$ (inside corner welds may be further limited by a lesser length of projection of the nozzle wall beyond the inside face of the vessel wall), in. (mm)

t_e = thickness of reinforcing element, in. (mm)

t_n = nominal thickness of nozzle wall, in. (mm)

t_w = depth of penetration of weld, in. (mm)

AD-602 MINIMUM THICKNESS OF NOZZLE NECKS AND OTHER CONNECTIONS

The wall thickness of a nozzle neck or other connection shall not be less than the thickness computed for the applicable loadings plus the thickness added for corrosion and erosion allowance and, except for access openings and openings for inspection only, not less than the smaller of the following:

(a) the required thickness of the shell or head to which the connection is attached plus the corrosion allowance provided in the shell or head adjacent to the connection;

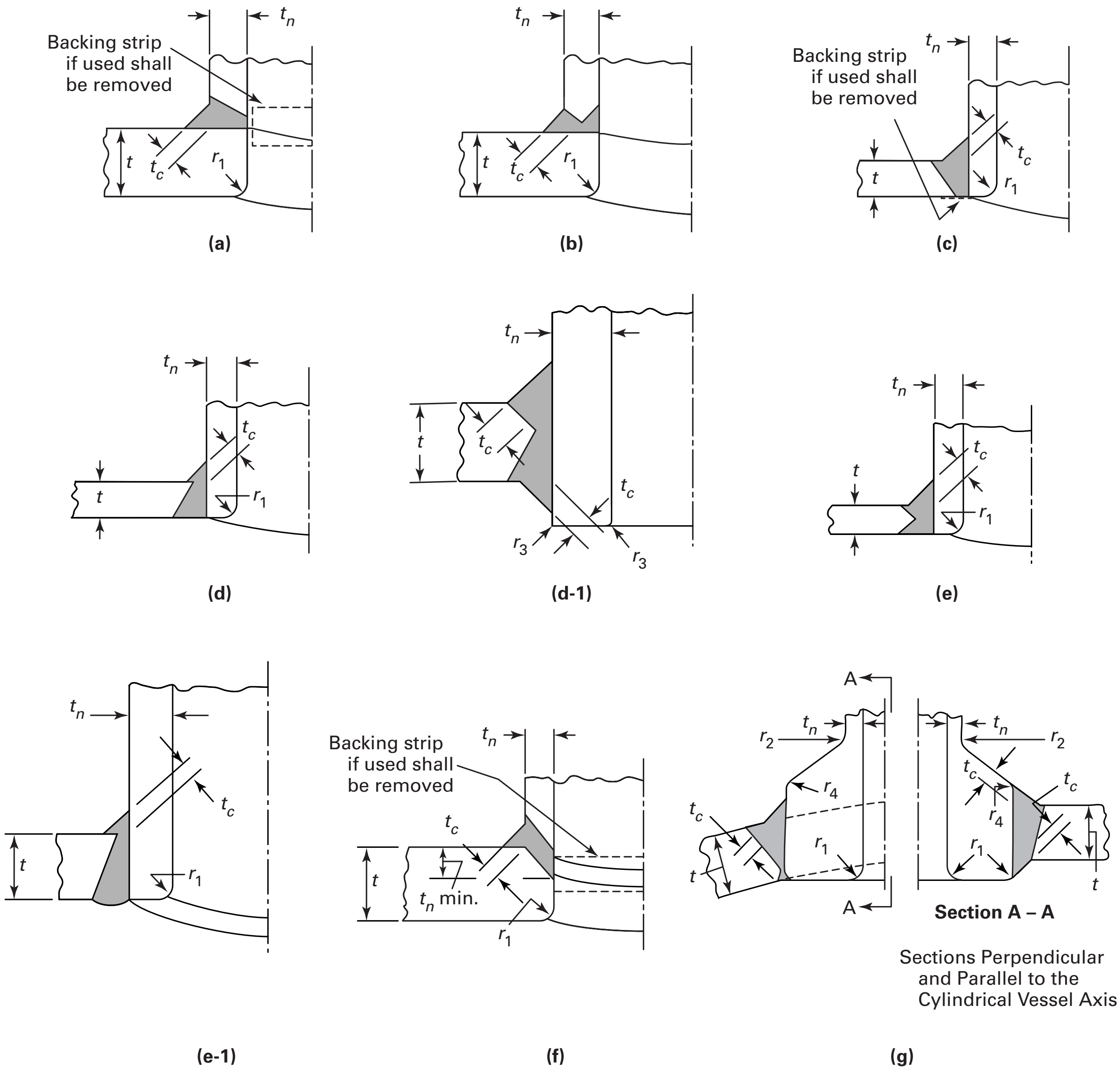
(b) the minimum thickness[1] of standard wall pipe plus the corrosion allowance on the connections.

See AD-420.1 for the thickness requirements of nozzle neck to piping transition.

AD-610 NOZZLE NECKS ABUTTING THE VESSEL WALL WITHOUT ADDED REINFORCING ELEMENT

Necks abutting the vessel wall shall be attached by a full penetration groove weld. Backing strips shall be used with welds deposited from only one side or when complete joint penetration cannot be verified by visual inspection. Backing strips, when used, shall be removed after welding. Permissible types of weld attachments are shown in Fig. AD-610.1 sketches (a) and (b).

[1] The minimum thickness for all materials is that wall thickness listed as standard (STD) in Table 2 of ASME B36.10M, less $12\frac{1}{2}\%$. For diameters other than those listed in the Table, this shall be based upon the next larger pipe size. When a material specification does not specify schedule weights conforming to ASME B36.10M, the pipe weight indicated as regular shall be used when so designated in the specification. If not so designated, the heaviest schedule listed shall be used even though this is less than the thickness of standard weight pipe of ASME B36.10M.



$^1/_8 t \le r_1 \le {}^1/_2 t$

$r_2 \ge {}^3/_4$ in. (19 mm)

$r_3 \ge$ smaller of $^1/_4$ in. (6 mm) or $t_n/2$ radius; alternatively, smaller of $^1/_4$ in. (6 mm) or $t_n/4$ chamfer at 45 deg

$r_4 \ge {}^1/_4$ in. (6 mm)

GENERAL NOTE: See Table AF-241.1 for limitations and examination requirements.

FIG. AD-610.1 SOME ACCEPTABLE FULL PENETRATION WELDED NOZZLE ATTACHMENTS NOT READILY RADIOGRAPHABLE

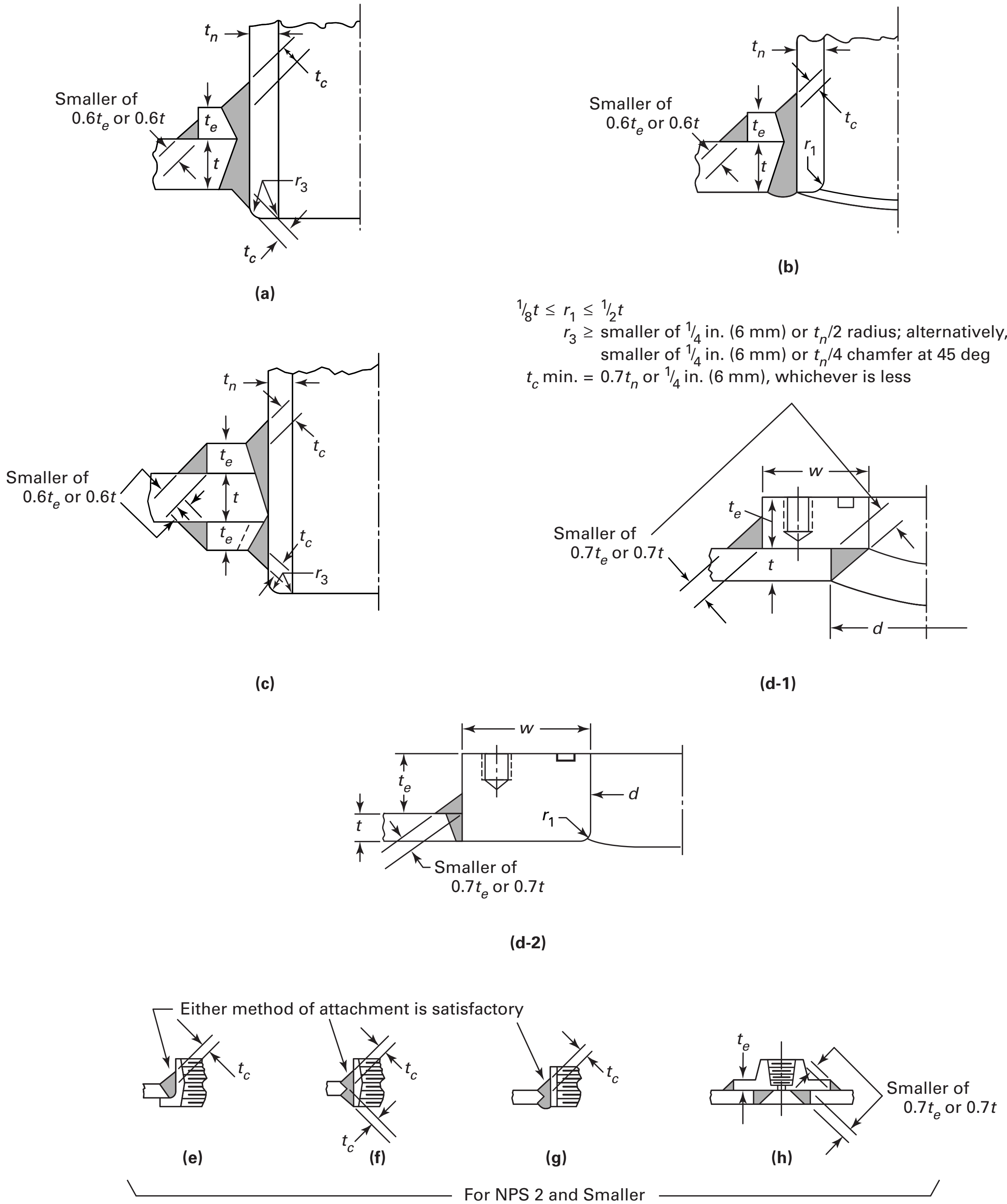


FIG. AD-612.1 SOME ACCEPTABLE PAD AND SCREWED FITTING TYPES OF WELDED NOZZLES AND OTHER CONNECTIONS TO SHELLS, DRUMS, AND HEADERS

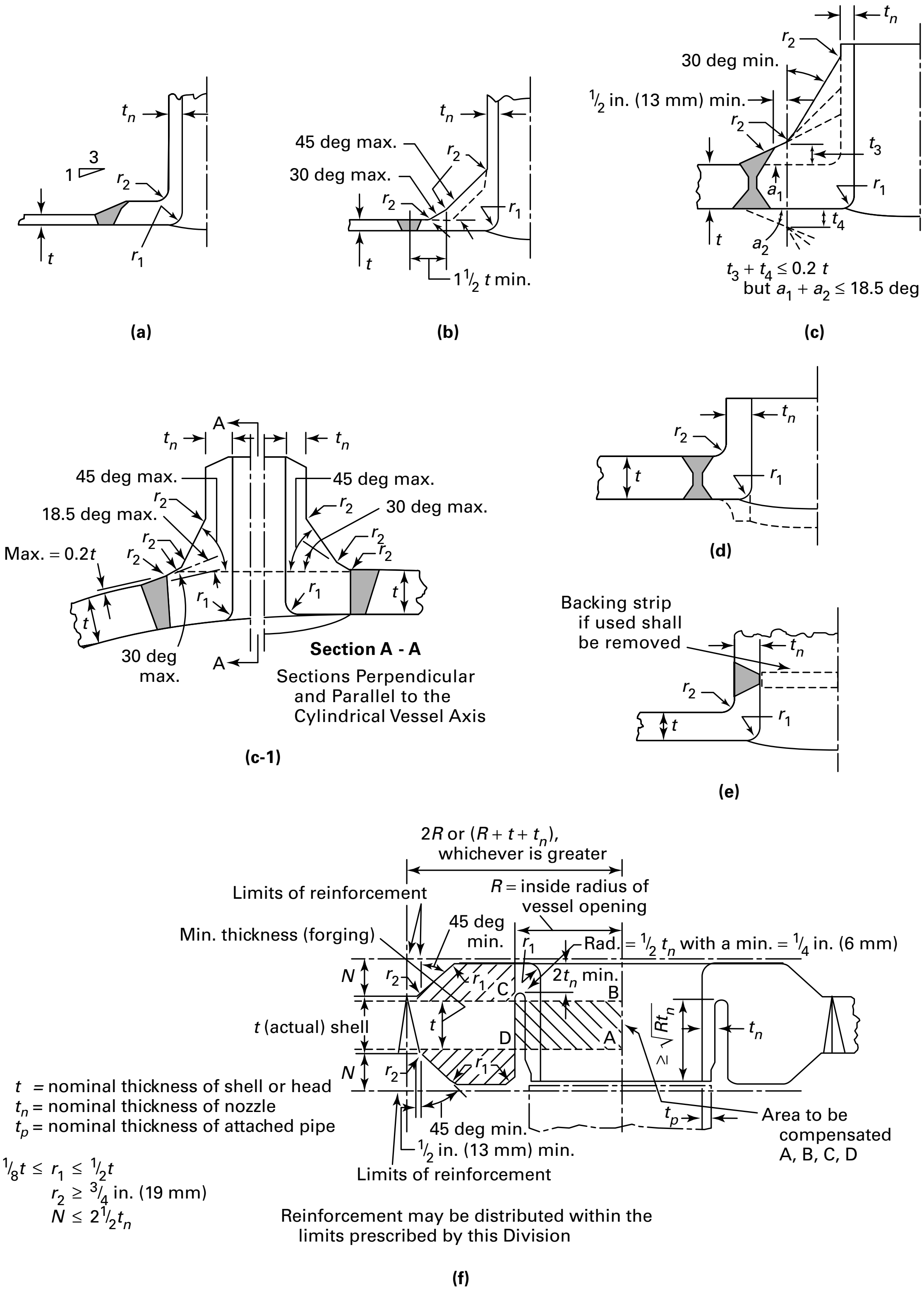


FIG. AD-613.1 ACCEPTABLE WELDED NOZZLE ATTACHMENT READILY RADIOGRAPHED TO CODE STANDARDS

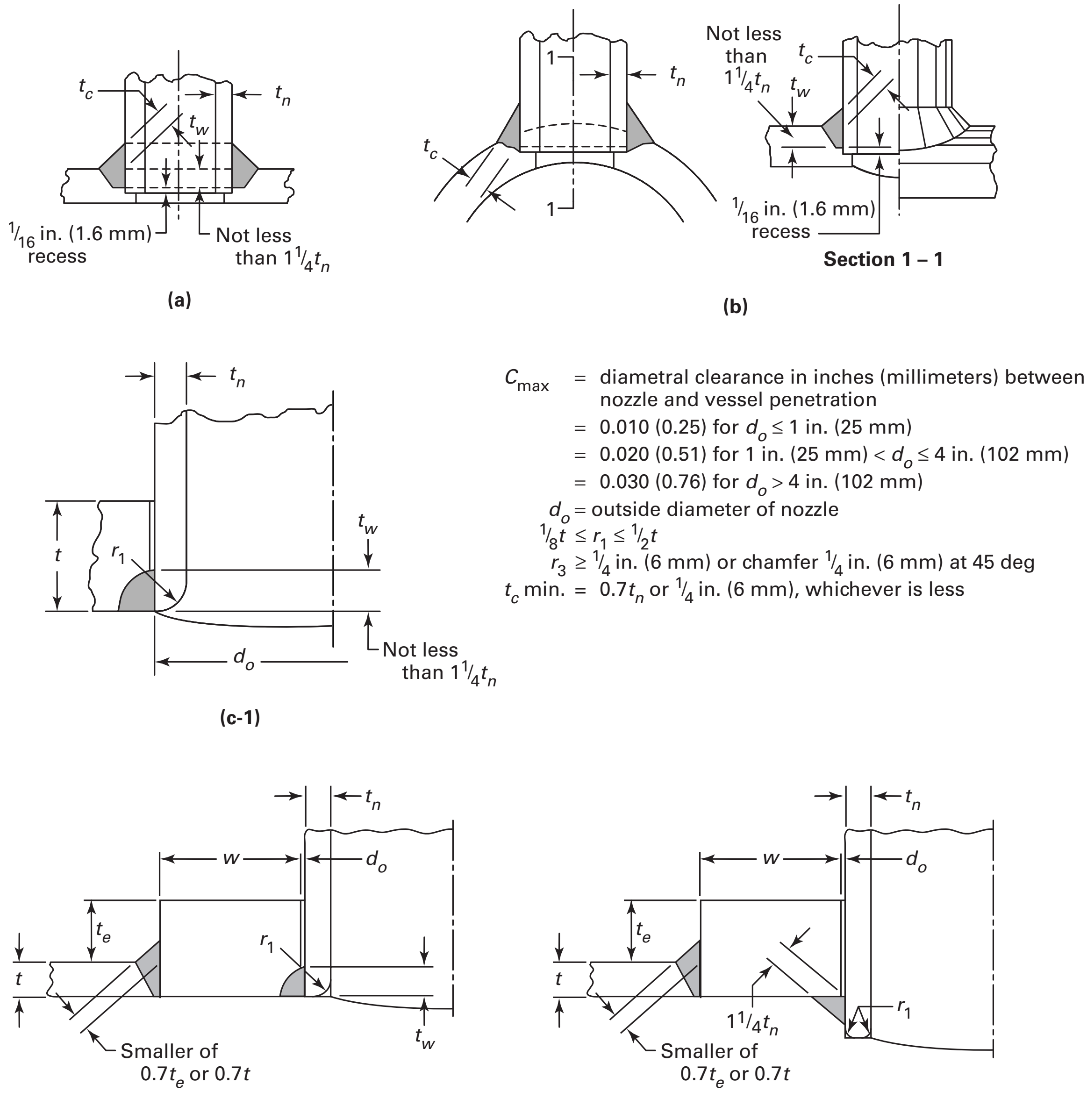


FIG. AD-621.1 PARTIAL PENETRATION WELD CONNECTIONS

AD-611 INSERTED NOZZLE NECKS WITHOUT ADDED REINFORCING ELEMENTS

Necks inserted partially into or through a hole cut in the vessel wall and without additional reinforcing elements shall be attached by a full penetration groove weld. Backing strips, when used, shall be removed after welding. Permissible types of weld attachments are shown in Fig. AD-610.1 sketches (c), (d), (d-1), (e), (e-1), (f), and (g).

AD-612 INSERTED NOZZLE NECKS WITH ADDED REINFORCING ELEMENT

Inserted type necks having added reinforcement in the form of one or more separate reinforcing plates shall be attached by welds at the outer edge of the reinforcement plate and at the nozzle neck periphery. The weld at the outer edge of the reinforcement shall be a fillet weld with a minimum throat dimension of the smaller of $0.6t_e$ or $0.6t$. The welds attaching the neck to the vessel wall and to the reinforcement shall be full penetration groove welds. Permissible types of weld attachments are shown in Fig. AD-612.1 sketches (a), (b), and (c).

AD-612.1 Provision of Telltale Holes for Air Testing. Reinforcing plates and saddles attached to the outside of a vessel shall be provided with at least one telltale hole (maximum size NPS $^1/_4$ tap) that may be tapped for a preliminary compressed air and soap solution (or equivalent) test for tightness of welds that seal off the inside of the vessel. These telltale holes may be left open or may be plugged when the vessel is in service. If the holes are plugged, the plugging material used shall not be capable of sustaining pressure between the reinforcing plate and the vessel wall. Telltale holes shall not be plugged during heat treatment.

AD-613 NOZZLES WITH INTEGRAL REINFORCEMENT

AD-613.1 Integral Reinforcement Employing Butt Welds. Nozzles having integral reinforcement may be attached using butt welds of Type No. 1. Permissible types are shown in Fig. AD-613.1 (see AF-221).

AD-613.2 Integral Reinforcement Employing Corner Welds. Nozzles or other connections with integral reinforcement and not covered by AD-613.1 shall be attached by means of full penetration corner welds (see AF-223). Permissible types of weld attachments are shown in Fig. AD-610.1.

AD-620 FITTINGS WITH INTERNAL THREADS

Internally threaded fittings shall be limited to NPS 2. They shall be attached by means of full penetration groove welds (see AF-223), as illustrated in Fig. AD-612.1 sketches (e), (f), and (g), except pad type fittings, such as shown in sketch (h), which may be used if attached by means of fillet welds having a minimum throat dimension of the smaller of $0.7t_e$ or $0.7t$, as shown in that sketch (see AF-225).

AD-621 WELDED CONNECTIONS NOT SUBJECT TO EXTERNAL LOADING

Partial penetration welds, as shown in Fig. AD-621.1, may be used only for attachments, such as instrumentation openings, inspection openings, etc., on which there are essentially no external mechanical loadings and on which there will be no thermal stresses greater than in the vessel itself. Such attachments shall satisfy the rules for reinforcement of openings, except that no material in the neck shall be used for reinforcement in the attachment illustrated in sketches (c-1), (c-2), and (c-3). The inside diameter of such openings shall not exceed 4 in. (100 mm).

(a) The weld size shall be such that the depth of penetration t_w will be at least $1^1/_4\ t_n$ and t_c will be not less than the smaller of $^1/_4$ in. (6 mm) or $0.7t_n$. For sketches (c-2) and (c-3), the fillet weld throat dimension at the outer edge of the reinforcement plate shall be at least the smaller of $0.7t_e$ or $0.7t$. For sketch (c-3), the fillet weld throat dimension at the inner edge of the reinforcement plate shall be at least $1^1/_4t_n$.

(b) Partial penetration welds shall be examined as required by Table AF-241.1.

AD-622 FORGED STEEL FITTINGS

ASME B16.11, Forged Steel Fittings, Socket Welding and Threaded, is acceptable for use under this Division in accordance with the requirements of AM-105. Pressure–temperature ratings for such fittings shall be calculated as for straight seamless pipe in accordance with the rules of this Division including the design stress intensity value for the material. The thickness tolerance of ASME B16.11 shall apply.

AD-623 DELETED 04

AD-630 STUDDED CONNECTIONS SUBJECT TO EXTERNAL LOADING

Studded connections which may have externally imposed loads shall have tapped holes complying with the requirements of AD-740. The vessel or integral weld buildup shall have a flat surface machined on the shell to receive the connection. Drilled holes to be tapped shall not penetrate within one-fourth of the wall thickness from the inside surface of the vessel after deducting corrosion allowance, unless at least the minimum thickness required, as above, is maintained by adding metal to the inside surface of the vessel.

AD-635 STUDDED PAD TYPE CONNECTIONS NOT SUBJECT TO EXTERNAL LOADING

Studded pad type connections may be used for connections on which there are essentially no external mechanical loads, such as manways and handholes used only as inspection openings, thermowell connections, etc., provided the requirements of AD-570 for pads are met. The pad shall be attached by a fillet weld along the outer edge and a single bevel weld along the inner edge. The throat dimensions of the outer and inner welds shall be not less than the smaller of $0.7t_e$ or $0.7t$. Permissible type of weld attachment is shown in Fig. AD-612.1 sketches (d-1) and (d-2). The tapped holes for stud threads shall comply with AD-740.

AD-640 THREADED CONNECTIONS

AD-640.1 Tapered Pipe Threads Not Over NPS 2. Pipes, tubes, and other threaded connections that conform to the ANSI Standard for Pipe Threads, ANSI/ASME B1.20.1, may be screwed into a threaded hole in a vessel wall provided the pipe engages the minimum number of threads specified in Table AD-640.1 after allowance has been made for curvature of the vessel wall. A built-up pad or a properly attached plate or fitting shall be used to provide the metal thickness and number of threads required in Table AD-640.1 or to furnish reinforcement when required.

TABLE AD-640.1
MINIMUM NUMBER OF PIPE THREADS FOR CONNECTIONS

Size of Pipe Connection, NPS (DN)	Threads Engaged	Minimum Plate Thickness Required, in. (mm)
$\frac{1}{2}$ & $\frac{3}{4}$ (15 & 20)	6	0.43 (10.9)
1, $1\frac{1}{4}$ & $1\frac{1}{2}$ (25, 32 & 40)	7	0.61 (15.5)
2 (50)	8	0.70 (17.8)

AD-640.2 Straight Threads. Straight threaded connections may be employed as provided for in AD-641.2.

AD-641 Restrictions on the Use of Threaded Connections

AD-641.1 Tapered Pipe Thread Connections. Internal taper pipe thread connections larger than NPS 2 (DN 50) shall not be used.

AD-641.2 Straight Threaded Connections

(a) Threaded connections employing straight threads shall provide for mechanical seating of the assembly by a shoulder or similar means. Straight threaded center openings in vessel heads, meeting the requirements of AF-761 and AF-762, shall be placed at a point where the calculated stress without a hole, due to any combination of design pressure and mechanical loadings expected to occur simultaneously, is not more than $0.5S_m$.

(b) Threaded connections above $2\frac{3}{4}$ in. (69 mm) in diameter may be used only if they meet the requirements of AD-160 or, if these requirements are not met, a detailed fatigue analysis must be made in accordance with the rules of Appendices 4 and 5.

ARTICLE D-7
FLAT HEADS, BOLTED, AND STUDDED CONNECTIONS

AD-700 FLAT HEADS, COVER PLATES, AND BLIND FLANGES

AD-701 General Requirements

The minimum thickness of flat heads, cover plates, and blind flanges of circular shape shall conform to the requirements given in this Article. Some acceptable types are shown in Figs. AD-701.1, AD-701.2, and AD-701.3. For complete stress analysis of flat circular plates, see Appendix 4.

AD-701.1 Nomenclature. The symbols used in this Article and its figures are defined as follows:

C = a factor depending upon the method of attachment of head, cover, flange, or tubesheet and on the shell dimensions, dimensionless (see Figs. AD-701.1, AD-701.2, and AD-701.3)
D = bolt circle diameter
L = distance from centerline of head-to-shell weld to tangent line on formed heads
P = internal design pressure (see AD-121.1)
S = membrane stress intensity limit for various load combinations (see Table AD-150.1). For bolted covers [Fig. AD-701.2, sketches (c), (d), and (e)], S is the maximum allowable stress value for material of flange (cover) at design temperature (operating condition) or atmospheric temperature (gasket seating), as may apply, given in Tables 1A and 1B of Subpart 1 of Section II, Part D
T = minimum required thickness of flat head, cover, or flange
W = total bolt load
d = diameter
h_G = gasket moment arm, equal to the radial distance from the centerline of the bolts to the centerline of the gasket reaction as shown in Fig. AD-701.2, sketches (c) and (d)
m = the ratio t_r/t_s, dimensionless
r = inside corner radius on a head formed by flanging, forging, or machining
t_c = throat dimension of corner welds
t_p = minimum distance from outside surface of flat head to edge of weld preparation measured as shown in Fig. AD-701.3
t_r = required thickness of shell or nozzle for pressure
t_s = nominal thickness of shell or nozzle

AD-702 Formulas for Minimum Thickness

(a) The minimum thickness of flat heads, as shown in Figs. AD-701.1, AD-701.2, and AD-701.3, shall be that calculated by the following formula:

$$T = d\sqrt{\frac{CP}{S}}$$

In any case, the thickness need not be greater than that computed by Formula (a) of UG-34(c)(2) of Section VIII, Division 1.

(b) The minimum thickness of cover plates and blind flanges attached by bolts causing an edge moment as shown in Fig. AD-701.2 shall be not less than that calculated by the following formula:

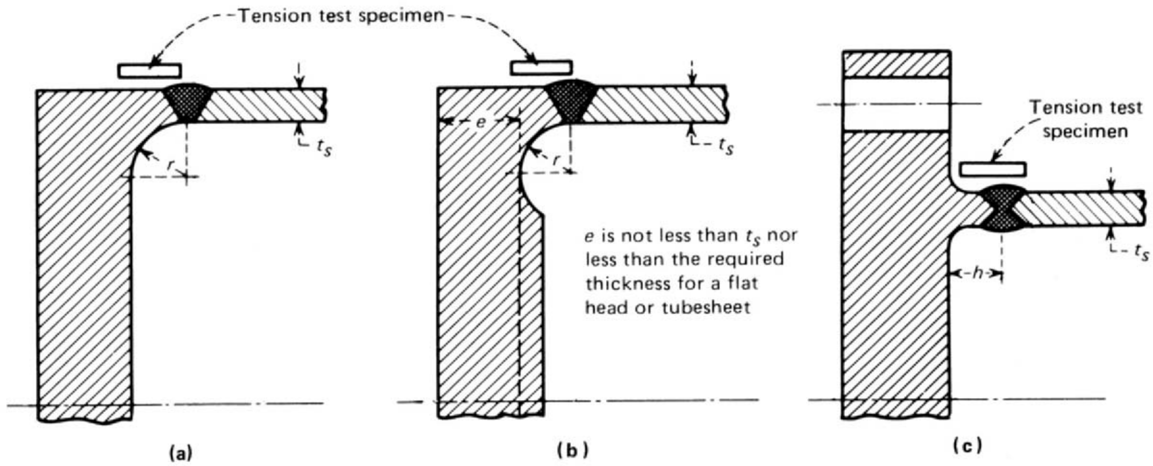
$$T = d\sqrt{CP/S + 1.9Wh_G/Sd^3}$$

NOTE: In some cases, the initial bolt load required to seat the gasket is larger than the operating bolt load. The thickness should be checked for both the operating condition and the initial bolt load required to seat the gasket.

AD-703 *C* Values for Various Constructions

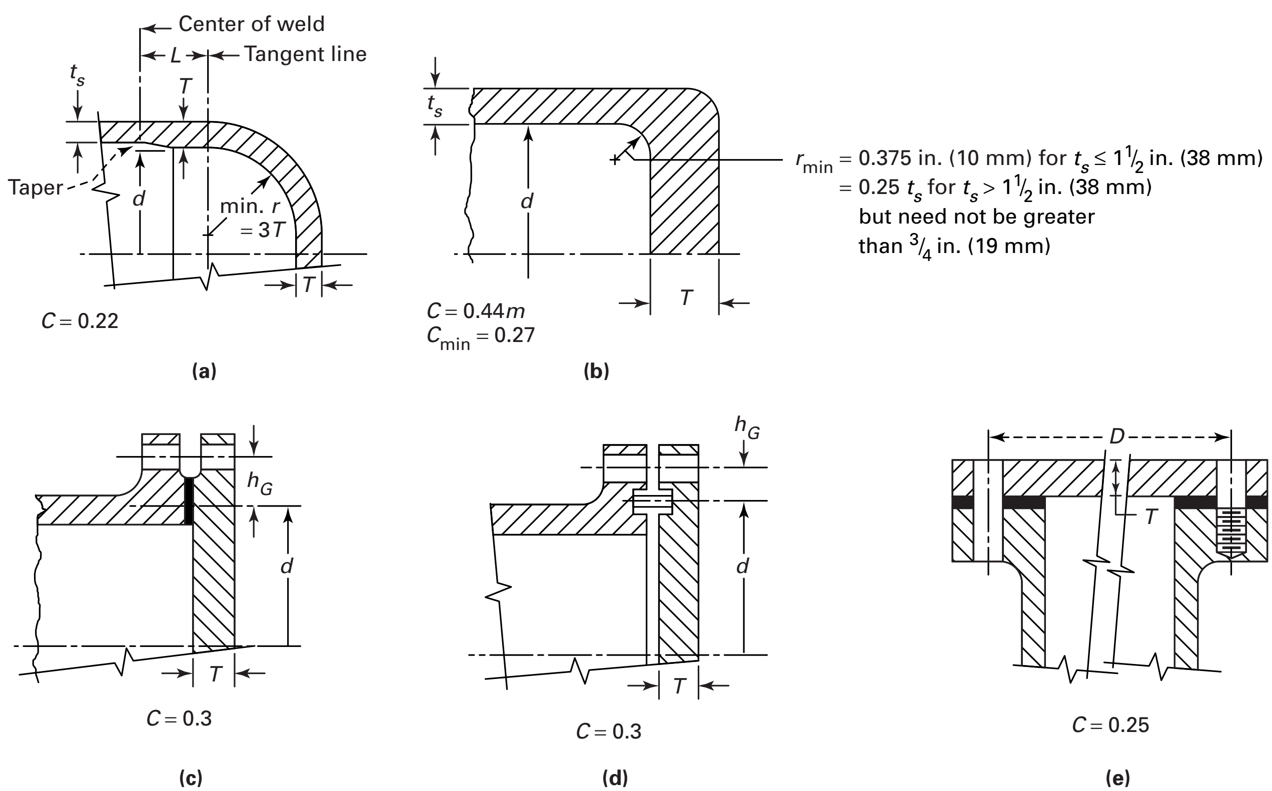
(a) For the type of construction shown in Fig. AD-701.2 sketch (a), the values of C to be used in the formula of AD-702(a) are:

C = 0.22 for flanged circular heads forged integral with or butt welded to the vessel with an inside corner



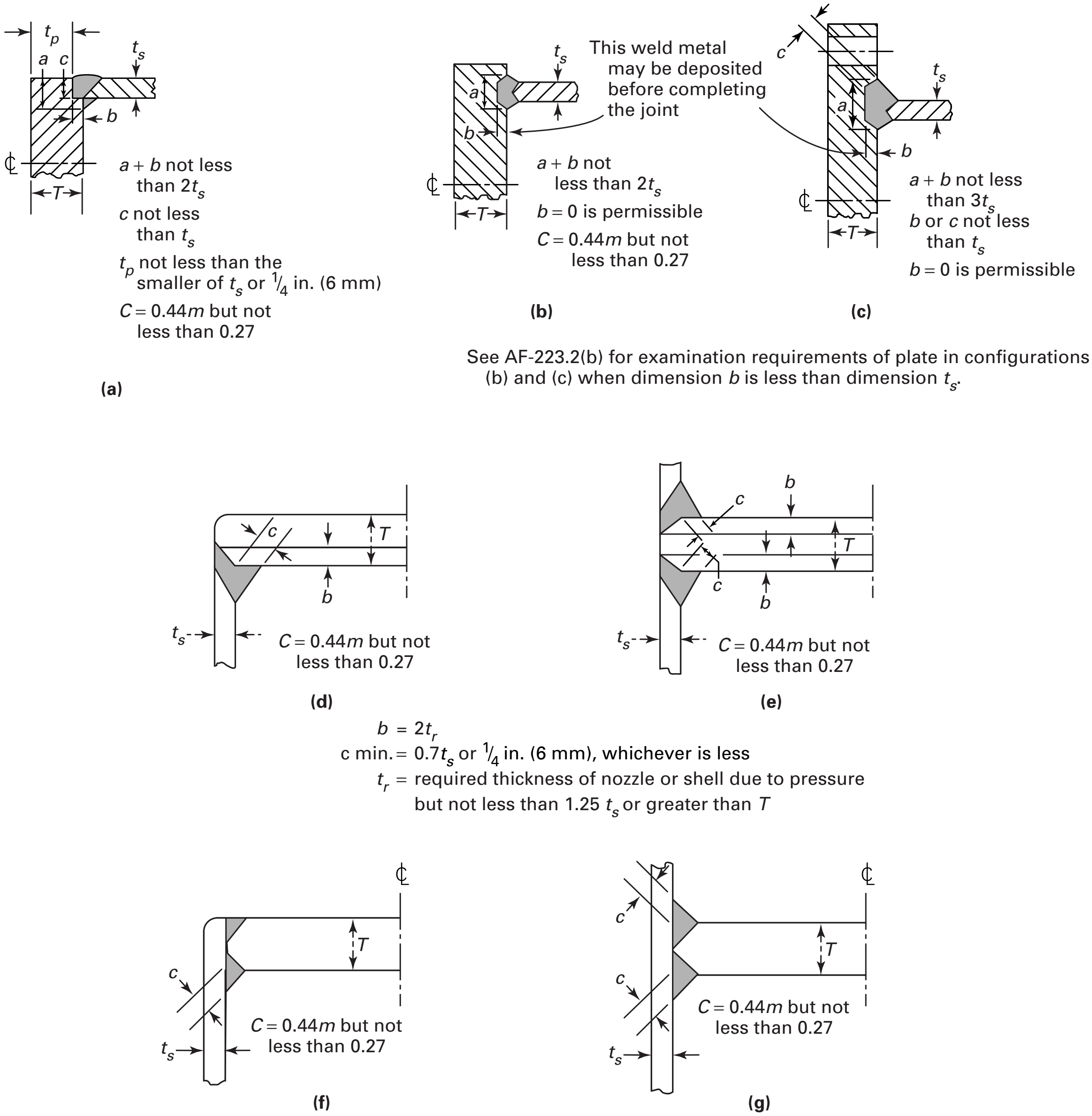
GENERAL NOTES:
(a) Not permissible if machined from plate unless the requirements of 20-200 are met.
(b) Tension test specimen may be located inside or outside the hub.
(c) r_{min} = 0.375 in. (10 mm) for $t_s \leq 1\frac{1}{2}$ in. (38 mm).
r_{min} = $0.25t_s$ for $t_s > 1\frac{1}{2}$ in. (38 mm), but need not be greater than $\frac{3}{4}$ in. (19 mm).
(d) h is the greater of $\frac{3}{4}$ in. (19 mm) or $1.5t_s$, but need not exceed 2 in. (50 mm).

FIG. AD-701.1 TYPICAL DETAILS READILY RADIOGRAPHABLE TO CODE STANDARDS FOR PRESSURE PARTS WITH BUTT WELDED HUBS



GENERAL NOTE: All these illustrations are diagrammatic only. Other designs that meet the requirements of AD-702 are acceptable.

FIG. AD-701.2 SOME ACCEPTABLE TYPES OF UNSTAYED FLAT HEADS AND COVERS



See Table AF-241.1 for limitations and examination requirements.

FIG. AD-701.3 ACCEPTABLE FULL PENETRATION CORNER JOINT DETAILS FOR ATTACHMENT OF PRESSURE PARTS TO PLATES TO FORM A CORNER JOINT

radius not less than three times the required head thickness, with no special requirement with regard to length of flange, and where the welding meets all of the requirements for circumferential joints given in Article F-2;

$C = 0.13$ for circular heads, when the flange length for heads of this design is not less than:

$$L = \left(1.1 - 0.8\,\frac{t_s^2}{T^2}\right)\sqrt{dT} \qquad (1)$$

$C = 0.13$ for circular heads, when the flange length L is less than the requirement in Eq. (1) above, but the shell thickness is not less than:

$$t_s = 1.12T\sqrt{1.1 - L/\sqrt{dT}} \qquad (2)$$

for a length of at least $2\sqrt{dt_s}$. When $C = 0.13$ is used, the taper shall be 1:3 minimum.

(b) For the type of construction shown in Fig. AD-701.2 sketch (b), the values of C to be used in the formula of AD-702(a) are:

$C = 0.44m$ but not less than 0.27 for forged circular heads integral with or butt welded to the vessel where the head thickness is not less than the shell thickness and the corner radius on the inside is not less than the following:

$$r_{\min} = 0.375 \text{ in. (10 mm) for } t_s \le 1\tfrac{1}{2} \text{ in. (38 mm)}$$

$$r_{\min} = 0.25t_s \text{ for } t_s > 1\tfrac{1}{2} \text{ in. (38 mm) but need not be greater than } \tfrac{3}{4} \text{ in. (19 mm)}$$

The welding shall meet all requirements for circumferential joints given in Article F-2.

(c) For the type of construction shown in Fig. AD-701.3 sketches (a), (b), (d), (e), (f), and (g), the values of C to be used in the formula of AD-702(a) are:

$C = 0.44m$ but not less than 0.27 for circular heads welded to the vessel when the head thickness is not less than the shell thickness and the inside fillet weld throat is not less than that shown in Fig. AD-701.3.

(d) For the types of construction shown in Fig. AD-701.2 sketches (c) and (d) and Fig. AD-701.3 sketch (c), the value of C to be used in the formula of AD-702(b) is:

$C = 0.3$ for circular heads and covers bolted to the vessel as indicated in the figures. Note that the formula in AD-702(b) shall be used because of the extra moment applied to the cover by the bolting.

When the cover plate is grooved for a peripheral gasket, as shown in Fig. AD-701.2 sketch (d), the net cover plate thickness under the groove or between the groove and the outer edge of the cover plate shall be not less than:

$$d\sqrt{1.9\,Wh_G/Sd^3} \qquad (3)$$

(e) For the type of construction shown in Fig. AD-701.2 sketch (e), for circular covers bolted with a full-face gasket to shells and flanges, the value of C to use in the formula of AD-702(a) is $C = 0.25$.

AD-710 BOLTED FLANGED CONNECTIONS

AD-711 Flanges and Flanged Fittings Conforming to ASME B16.5

It is recommended that the dimensional requirements of flanges used in bolted flange connections to external piping conform to ASME B16.5, Pipe Flanges and Flanged Fittings. In accordance with AM-105.1, such flanges and flanged fittings, with the exception of threaded and socket welding types, may be used at the pressure–temperature ratings specified in AM-105.1(b).

AD-711.1 Slip-On Flanges Conforming to ASME B16.5. Slip-on flanges conforming to ASME B16.5 may be used, provided all the following conditions are met.

(a) The materials of the flange and the part to which it is welded conform to those in Section IX, QW/QB-422 for materials listed in Column 1 of Table AF-241.1.

(b) The specified minimum tensile strengths of said materials do not exceed 80,000 psi (550 MPa).

(c) The minimum elongation of each of said materials is 12% in 2 in. (51 mm).

(d) The thickness of the materials to which the flange is welded does not exceed $1\tfrac{1}{4}$ in. (32 mm).

(e) The throat thickness, taken as the minimum thickness in any direction through the attaching fillet welds, is at least 0.7 times the thickness of the material to which the flange is welded.

(f) The fatigue analysis required for nozzles with separate reinforcement and nonintegral attachments, as set forth in AD-160.3, is applied to the design.

AD-712 Large Diameter Flanges Conforming to ASME B16.47

For bolted flanged connections, it shall be permissible to use flanges conforming to ASME B16.47, Large Diameter Steel Flanges. The pressure–temperature rating used shall not exceed that specified in ASME B16.47 except where these flanges, including specified gaskets and bolting, satisfy the rules of Article D-7 or Appendix 3 of this Division for the vessel design conditions.

AD-720 NONSTANDARD FLANGES

Flanges which do not conform to ASME B16.5 or ASME B16.47, or do not satisfy AM-105.1, shall be designed in accordance with Appendix 3, Rules for Bolted Flange Connections, or with the rules of Appendices 4, 5, and 6.

AD-730 FORGED NOZZLE FLANGES

A forged nozzle flange may use the ASME B16.5 pressure–temperature ratings for the flange material being used, provided both of the following are met:

(a) The forged nozzle flange shall meet all dimensional requirements of a flanged fitting given in ASME B16.5 with the exception of the inside diameter. The inside diameter of the forged nozzle flange shall not exceed the inside diameter of the same size and class lap joint flange given in ASME B16.5.

(b) The outside diameter of the forged nozzle neck shall be at least equal to the hub diameter of the same size and class ASME B16.5 lap joint flange; larger hub diameters shall be limited to nut stop diameter dimensions. See Fig. 3-310.1, sketches (i-1) and (i-2).

AD-740 STUDDED CONNECTIONS

Where tapped holes are provided for studs, the threads shall be full and clean and shall engage the stud for a length not less than the larger of d_s or

$$0.75d_s \times \frac{\text{design stress-intensity value of stud material at design temp.}}{\text{design stress-intensity value of tapped material at design temp.}}$$

where d_s is the root diameter of the stud, except that the thread engagement need not exceed $1\frac{1}{2}d_s$.

ARTICLE D-8
QUICK-ACTUATING CLOSURES

AD-800 GENERAL DESIGN REQUIREMENTS

Closures other than the multibolted type designed to provide access to the contents space of a pressure vessel shall have the locking mechanism or locking device so designed that failure of any one locking element or component in the locking mechanism cannot result in the failure of all other locking elements and the release of the closure. Quick-actuating closures shall be so designed and installed that it may be determined by visual external observation that the holding elements are in good condition and that their locking elements, when the closure is in the closed position, are in full engagement.

AD-801 Specific Design Requirements

Quick-actuating closures that are held in position by positive locking devices and that are fully released by partial rotation or limited movement of the closure itself or the locking mechanism and any closure that is other than manually operated shall be so designed that when the vessel is installed, the following conditions are met.

(a) The closure and its holding elements are fully engaged in their intended operating position before pressure can be built up in the vessel.

(b) Pressure tending to force the closure clear of the vessel will be released before the closure can be fully opened for access.

(c) In the event that compliance with (a) and (b) is not inherent in the design of the closure and its holding elements, provision shall be made so that devices to accomplish this can be added when the vessel is installed. It is recognized that it is impractical to write detailed requirements to cover the multiplicity of devices used for quick access or to prevent negligent operation or the circumventing of safety devices. Any device or devices which will provide the safeguards broadly described in these subparagraphs (a), (b), and (c) will meet the intent of the Code.

AD-801.1 Permissible Design Deviations for Manually Operated Closures. Quick-actuating closures that are held in position by a locking device or mechanism that requires manual operation and are so designed that there will be leakage of the contents of the vessel prior to disengagement of the locking elements and release of closure need not satisfy AD-801(a), (b), and (c). However, such closures shall be equipped with an audible and/or visible warning device that will serve to warn the operator if pressure is applied to the vessel before the closure and its holding elements are fully engaged in their intended position and, further, will serve to warn the operator if an attempt is made to operate the locking mechanism or device before the pressure within the vessel is released.

AD-802 Required Pressure Indicating Devices

All vessels having quick-actuating closures shall be provided with a pressure indicating device visible from the operating station.

ARTICLE D-9
ATTACHMENTS AND SUPPORTS

AD-900 GENERAL REQUIREMENTS

(a) Supports, lugs, brackets, stiffeners, and other attachments may be welded or stud bolted to the outside or inside of a vessel wall. All stud bolted attachments require a detailed fatigue analysis in accordance with the requirements of Appendices 4 and 5 unless the conditions of AD-160 are met. Attachments shall conform reasonably to the curvature of the shell to which they are to be attached.

(b) Resistance welded studs may be used for minor nonpressure attachments only to materials other than those listed in Table AQT-1 and are prohibited for use with materials listed in Table AQT-1.

(c) Other types of welds are illustrated in Fig. AD-912.1 and limitations are given in AD-911 and AD-912. Minimum weld sizes for the various types shall conform to Fig. AD-912.1 except for welds covered by AD-901.1.

(1) All welds joining nonpressure parts to pressure parts shall be continuous except as permitted in (2) below. Fillet or partial penetration welds where permitted shall be continuous on all sides.

(2) Welds joining minor attachments[1] to pressure parts constructed of materials other than those listed in Table AQT-1 need not be continuous.

(3) Attachments may be welded directly to weld deposit cladding without restriction.

For clad construction where design credit is taken for cladding thickness, attachment may be made directly to the cladding for loadings producing primary stresses in the attachment weld not exceeding 10% of the design stress intensity value of the attachment or the cladding material, whichever is less; for higher loadings there shall be sufficient attachment welding either directly to the base metal or to weld overlay cladding to develop the strength for the primary stress loadings (portions of weld not required for strength, e.g., for weld continuity or sealing, may be welded directly to the cladding).

For other integral clad construction the preceding practice is a recommended guide with due consideration to the degree of assurance of the lining bond and the desired reliability of performance in service.

For applied linings, attachments should generally be made directly to the base metal or to weld overlay cladding; careful analysis and tests should be made to establish the adequacy and reliability of attachment before making any attachments directly to the lining (successful experience with similar linings in comparable service may provide a basis for judgment).

(d) For postheat treatment after welding, the fabrication requirements of the vessel base metal apply.

AD-901 Materials for Attachments to Pressure Parts

Those attachments welded directly to pressure parts shall be of a material listed in Part AM. See AF-623 for limitations for quenched and tempered materials. Exceptions to the material requirements of AF-623.1 are given in the next paragraph. The material and the deposited weld metal shall be compatible with that of the pressure part.

Lightly loaded attachments, as defined in AD-912(a), of nonhardenable austenitic stainless steels conforming to either SA-240, SA-312, or SA-479 are permitted to be fillet welded to pressure parts conforming to either SA-353, SA-553 Type 1 and Type 2, or SA-645.

AD-901.1 Materials for Minor Attachments to Pressure Parts. Except as limited by AF-623 or for forged fabrication, AF-741, where no welding is permitted, minor attachments[1] may be of noncertified material and may be welded directly to the pressure part provided:

(a) the material is identified and is suitable for welding;

(b) the material is compatible insofar as welding is concerned with that to which the attachment is to be made;

(c) the welds are postweld heat treated when required in Part AF.

[1] Parts of small size [not over $\frac{3}{8}$ in. (10 mm) thick or 5 cu in. (78 cm^3) volume] carrying no load or insignificant load requiring no stress calculation in designer's judgment, such as nameplates, insulation supports, and locating lugs.

AD-902 Materials for Attachments Welded to Nonpressure Parts

Attachments welded to nonpressure parts may be of noncertified material, provided the material is identified, is suitable for welding, and is compatible with the material to which attachment is made.

AD-910 TYPES OF ATTACHMENT WELDS

AD-911 For Attachment to Pressure Parts of Materials Listed in Columns 1 and 4 of Table AF-241.1

Welds attaching nonpressure parts or stiffeners to pressure parts shall be one of the following:

(a) a fillet weld not over $\frac{1}{2}$ in. (13 mm) leg dimension and not closer than $\sqrt{Rt_s}$ from a gross structural discontinuity,[2] where

R = radius measured normal to the surface from the midwall to the axis of rotation
t_s = nominal shell thickness

(b) a partial penetration weld plus fillet weld; this is limited to the attachment of parts not exceeding $1\frac{1}{2}$ in. (38 mm) thickness;

(c) a full penetration groove weld plus a fillet weld on each side;

(d) a full penetration butt weld[3]

(e) for attachment of support skirts or other supports involving similar attachment orientation, in addition to the weld types of (c) and (d), welds of greater effective throat dimension than 90 deg fillet welds, as obtained by increased leg dimension or angle and bevel of parts joined, may be used where the effective throat is t_{min} (see Fig. AD-912.1 for illustration). However, the same limitation on thickness as item (b) applies.

AD-912 For Attachment to Pressure Parts of Materials Listed in Columns 2 and 3 of Table AF-241.1

Welds attaching nonpressure parts or stiffeners to pressure parts shall be one of the following:

(a) except as permitted below, fillet welds are permissible only for seal welds or for lightly loaded[4] attachments with weld size not over $\frac{3}{8}$ in. (10 mm) leg dimension and shall not be located closer than $\sqrt{Rt_s}$ from a gross structural discontinuity. For materials SA-333 Grade 8, SA-334 Grade 8, SA-353, SA-522, SA-553, and SA-645, fillet welds are permissible, provided that the fillet weld leg dimension does not exceed $\frac{1}{2}$ in. (13 mm) and the weld is not closer than $\sqrt{Rt_s}$ from another gross structural discontinuity;

(b) a partial penetration weld plus fillet weld; this is limited to the attachment of parts not exceeding $\frac{3}{4}$ in. (19 mm) in thickness;

(c) a full penetration groove weld plus a fillet weld on each side;

(d) a full penetration butt weld [see footnote 3 to AD-911(d)];

(e) for attachment of support skirts or other supports involving similar attachment orientation, in addition to welds permitted by (d), welds of greater effective throat dimension than 90 deg fillet welds may be used where the throat is a minimum of t (see Fig. AD-912.1 for illustration). This detail is limited to attachment of parts not exceeding $\frac{3}{4}$ in. (19 mm) in thickness unless the attachment weld is double welded.

AD-920 STRESS VALUES FOR WELD MATERIAL

(a) Attachment weld strength shall be based on the nominal weld area and the design stress intensity values in Part AM and stress criteria in Part AD for the weaker of the two materials joined, multiplied by the following reduction factors:

0.5 for fillet welds such as covered by AD-911(a);

0.75 for partial penetration groove or partial penetration groove plus fillet welds, such as covered by AD-911(b) and AD-912(b);

1.0 for welds covered by AD-911(c), (d), and (e) and AD-912(c) to (e), inclusive.

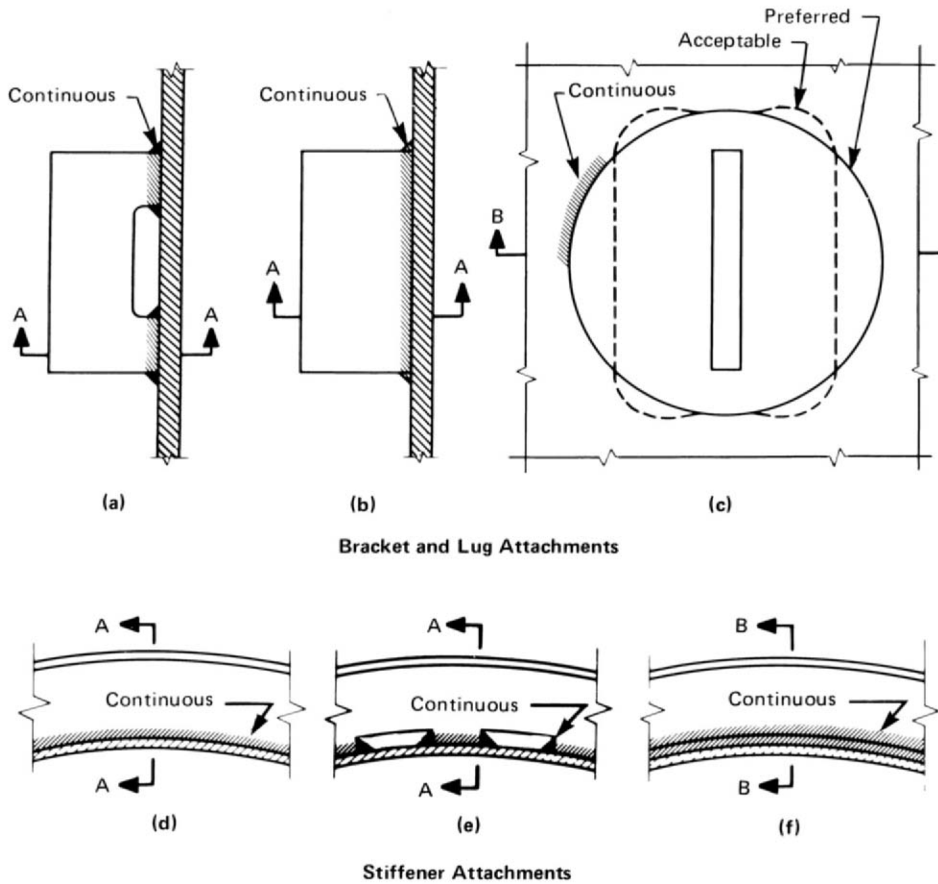
For welds attaching austenitic stainless steel internals to low alloy steel vessels at design temperatures exceeding 800°F (427°C), the design stress intensity values may be taken equal to the allowable stress values in Division 1, Table 1A of Section II, Part D, for the austenitic material to be attached.

(b) The nominal weld area for fillet welds is the throat area; for groove welds, the depth of penetration times

[2] A gross structural discontinuity is a source of stress or strain intensification which affects a relatively large portion of a structure and has a significant effect on the overall stress or strain pattern or on the structure as a whole. Examples of gross structural discontinuities are head-to-shell and flange-to-shell junctions, nozzles, and junctions between shells of different diameters or thicknesses.

[3] The prior deposition of weld metal to provide a boss for the butt weld is permissible provided it is checked for soundness by suitable nondestructive examination. The fabricator shall also give due consideration to heat treatment of the buildup.

[4] Weld stress due to mechanical loads on attached member not over 25% of allowable stress for fillet welds and temperature difference between shell and attached member not expected to exceed 25°F (14°C) shall be considered lightly loaded.



GENERAL NOTES:
(a) See AD-900, AD-911, and AD-912 for limitations.
(b) For continuously attached pads consider need for vent holes.
(c) For (e) design, a minimum of 50% of the web must be welded, evenly spaced around the circumference, to the shell.
(d) See Fig. AD-912.1 (Cont'd) for sectional views.

FIG. AD-912.1 SOME ILLUSTRATIVE WELD ATTACHMENT DETAILS AND MINIMUM WELD SIZES

the length of weld; and for groove welds with fillet welds, the combined throat and depth of penetration, exclusive of reinforcement, times the length of weld.

AD-925 ATTACHMENT WELDS — EVALUATION OF NEED FOR FATIGUE ANALYSIS

In applying Condition AP or BP of AD-160, fillet welds and non-full-penetration welds are nonintegral attachments, except that the following welds need not be considered because of the limitations of their use:

(a) welds covered by AD-901.1, AD-911(a), and AD-912(a);

(b) welds covered by AD-911(e) and AD-912(e) may be considered integral as covered by Conditions A and B of AD-160.

AD-930 DESIGN OF ATTACHMENTS

The effects of attachments, including external and internal piping connections, shall be taken into account in checking for compliance with design criteria.

AD-940 DESIGN OF SUPPORTS

(a) All vessels shall be so supported and the supporting members so arranged and attached to the vessel as to

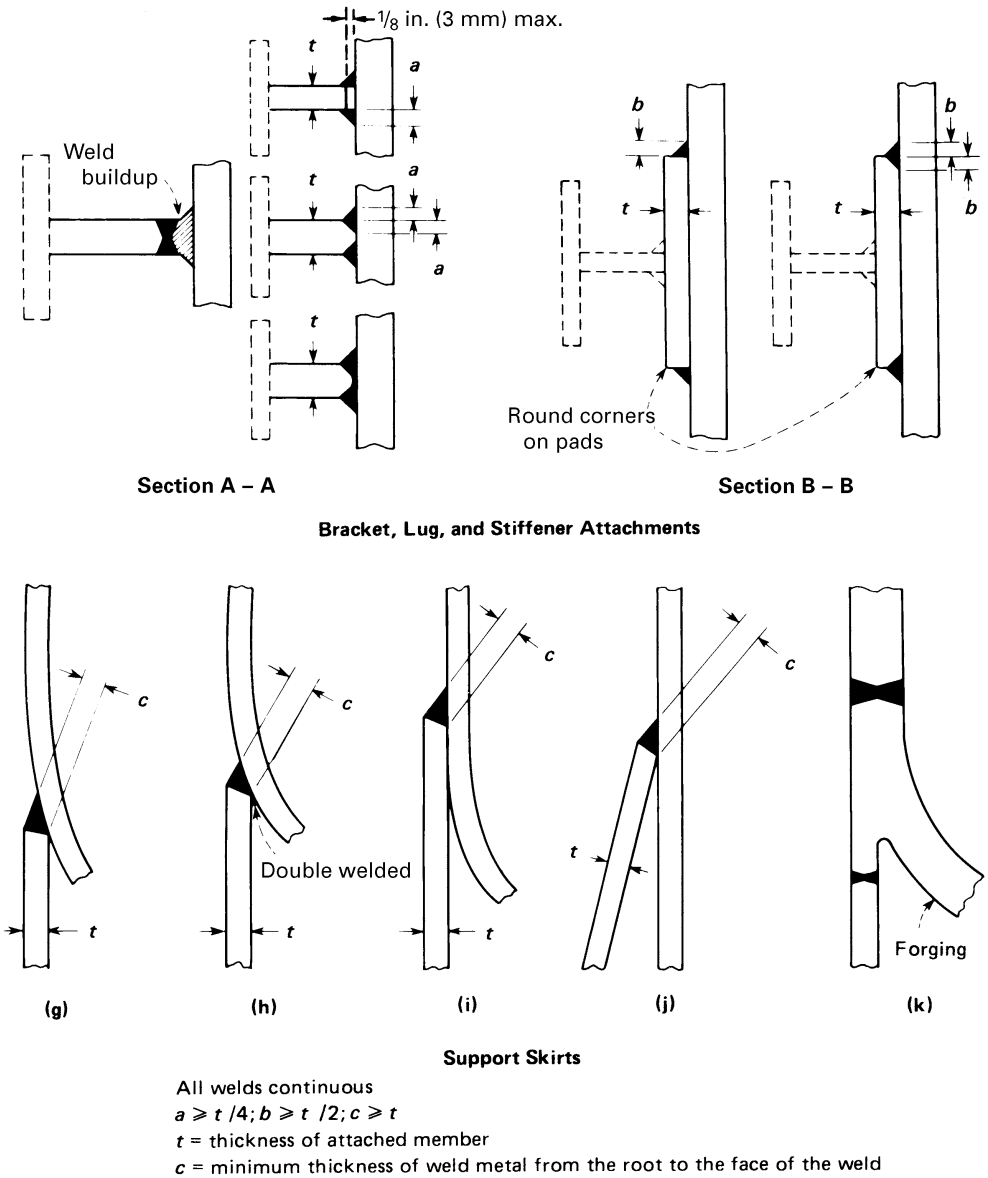


FIG. AD-912.1 SOME ILLUSTRATIVE WELD ATTACHMENT DETAILS AND MINIMUM WELD SIZES (CONT'D)

provide for the maximum imposed loadings. The imposed loadings include those due to pressure, the weight of the vessel and its contents, to machinery and piping loads, wind, earthquake, etc. (see AD-150). Wind and earthquake loads need not be assumed to occur simultaneously.

(b) All supports should be designed to prevent excessive localized stresses due to temperature changes in the vessel or deformations produced by the internal pressure.

(c) The membrane stress intensity in that part of the support within the jurisdiction of this Division [see AG-120(b)] shall not exceed the limits established in Table AD-150.1.

(d) Horizontal vessels supported by saddles shall use saddles such that they afford bearing to extend over at least one-third of the shell circumference.

ARTICLE D-10
ACCESS AND INSPECTION OPENINGS

AD-1000 GENERAL REQUIREMENTS

(a) All pressure vessels for use with compressed air, and those subject to internal corrosion or having parts subject to erosion or mechanical abrasion (see AD-115), except as permitted otherwise in this paragraph, shall be provided with suitable manhole, handhole, or other inspection openings for examination and cleaning.

(b) Compressed air as used in this Article is not intended to include air which has had moisture removed to provide an atmospheric dew point of −50°F (−46°C) or less.

(c) Inspection openings may be omitted in the shell side of fixed tubesheet heat exchangers.

When inspection openings are not provided, the Manufacturer's Data Report shall include one of the following notations under Remarks:

(1) "AD-1000 (c)" when inspection openings are omitted in fixed tubesheet heat exchangers;

(2) "AD-1001" or "AD-1003" when provision for inspection is made in accordance with one of these paragraphs;

(3) the statement "for noncorrosive service."

AD-1001 Requirements for Vessels 12 in. (300 mm) in Inside Diameter[1] and Smaller

For vessels 12 in. (300 mm) or less in inside diameter, openings for inspection only may be omitted if there are at least two removable pipe connections not less than NPS $^3\!/_4$ (DN 20).

AD-1003 Requirements for Vessels Less Than 16 in. (400 mm) and Over 12 in. (300 mm) in Inside Diameter

Vessels less than 16 in. (400 mm) and over 12 in. (300 mm) in inside diameter shall have at least two handholes or two threaded pipe plug inspection openings of not less than NPS $1^1\!/_2$ (DN 40) except as permitted by the following: When vessels less than 16 in. (400 mm) and over 12 in. (300 mm) in inside diameter are to be installed so that inspection cannot be made without removing the vessel from the assembly, openings for inspection only may be omitted provided there are at least two removable pipe connections of not less than NPS $1^1\!/_2$ (DN 40).

AD-1010 EQUIPMENT OF VESSELS REQUIRING ACCESS OR INSPECTION OPENINGS

Vessels that require access or inspection openings shall be equipped as follows.[1]

(a) All vessels less than 18 in. (450 mm) and over 12 in. (300 mm) in inside diameter shall have at least two handholes or two plugged, threaded inspection openings of not less than NPS $1^1\!/_2$ (DN 40).

(b) All vessels 18 to 36 in. (450 to 900 mm), inclusive, in inside diameter shall have a manhole or at least two handholes or two plugged, threaded inspection openings of not less than NPS 2 (DN 50).

(c) All vessels over 36 in. (900 mm) in inside diameter shall have a manhole (see AD-1020.1), except that those whose shape or use makes one impracticable shall have at least two handholes or other openings that may be used for inspection; in either case the openings shall measure at least 4 in. × 6 in. (100 mm × 150 mm).

(d) When handholes or pipe plug openings are permitted for inspection openings in place of a manhole, one handhole or one pipe plug opening shall be in each head or in the shell near each head.

(e) Openings with removable heads or cover plates intended for other purposes may be used in place of the required inspection openings.

(f) A single opening with removable head or cover plate may be used in place of all the smaller inspection openings provided it is of such size and location as to afford at least an equal view of the interior.

(g) Flanged connections from which piping, instruments, or similar attachments can be removed may be

[1] Diameters of vessels and sizes of openings are nominal.

used in place of the required inspection openings provided that:

(1) the connections are at least equal to the size of the required openings; and

(2) the connections are sized and located to afford at least an equal view of the interior as the required inspection openings.

AD-1020 SIZE AND TYPE OF ACCESS AND INSPECTION OPENINGS

When inspection or access openings are required, they shall comply at least with the requirements of this paragraph.

AD-1020.1 Type and Minimum Size of Manhole. An elliptical or obround manhole shall be not less than 12 in. × 16 in. (300 mm × 400 mm). A circular manhole shall be not less than 16 in. (400 mm) in inside diameter.

AD-1020.2 Minimum Size of Handholes. A handhole opening shall be not less than 2 in. × 3 in. (50 mm × 75 mm) in size, but should be as large as is consistent with the size of the vessel and the location of the opening.

AD-1021 Design of Access and Inspection Openings in Shells and Heads

All access and inspection openings in a shell or unstayed head shall be designed in accordance with the rules of this Division for openings.

AD-1022 Minimum Gasket Bearing Widths for Manhole Cover Plates

Manholes of the type in which the internal pressure forces the cover plate against a flat gasket shall have a minimum gasket bearing width of $^{11}/_{16}$ in. (17 mm).

AD-1025 Threaded Openings

AD-1025.1 Materials for Threaded Plugs or Caps. When a threaded opening is to be used for inspection or cleaning purposes, the closing plug or cap shall be of a material suitable for the pressure, and no material shall be used at a temperature exceeding the maximum temperature allowed in this Division for that material.

AD-1025.2 Permissible Types of Threads. The thread shall be a standard taper pipe thread, except that a straight thread of at least equal strength may be used if other sealing means to prevent leakage are provided.

ARTICLE D-11
SPECIAL REQUIREMENTS FOR LAYERED VESSELS

AD-1100 GENERAL

The design for layered pressure vessels shall conform to the general design requirements given in Article D-1, except that reinforcing is required as illustrated in Fig. AD-1118.1. AD-160.3 is not applicable to layered pressure vessels.

AD-1101 SHELLS OF REVOLUTION UNDER INTERNAL PRESSURE

(a) The thickness of shells of revolution under internal pressure shall not be less than that computed by the formulas in AD-201 through AD-212.

(b) The inner shell or inner head material which has a lower allowable design stress than the layer materials may only be included as credit for part of the total wall thickness if S_1 is not less than $0.50 S_L$ by considering its effective thickness to be:

$$t_{\mathrm{eff}} = t_{\mathrm{act}} \frac{S_1}{S_L}$$

where

t_{eff} = effective thickness of inner shell or inner head
t_{act} = actual thickness of inner shell or inner head
S_1 = design stress of inner shell or inner head
S_L = design stress of layers

(c) Layers in which the stress intensity value of the materials is within 20% of the other layers may be used by prorating the allowable stress intensity value of the layers in the thickness formula, provided the materials are compatible in modulus of elasticity and coefficient of thermal expansion (see AD-101).

(d) The minimum thickness of any layer shall not be less than $^1\!/_8$ in. (3 mm).

AD-1102 SHELLS OF REVOLUTION UNDER EXTERNAL PRESSURE

(a) When layered shells are used for external pressure, the requirements of Article D-3 shall be in accordance with the following.

(1) The thickness used for establishing external pressure applied to the outer layer shall be the thickness of the total layers, except as given in (2) below. The design of the vent holes shall be such that the external pressure is not transmitted through the vent holes in the outer layer.

(2) Layered vessels of helically wound interlocking strip construction shall not be used for external pressure above that permitted by the inner shell.

(3) The thickness used for establishing vacuum pressure shall be only the thickness of the inner shell or inner head, except that for vessels of helically wound interlocking strip construction, only the inner shell thickness shall be used.

(b) Cylinders Under Axial Compression. Layered shells under axial compression shall be calculated per AD-340, utilizing the total layered shell thickness.

AD-1110 DESIGN OF WELDED JOINTS

The design of welded joints shall conform to the requirements given in Article D-4 except as modified herein.

(a) Category A and B joints of inner shells and inner heads of layered sections shall be as follows.

(1) Category A joints shall be Type No. 1 of Table AF-810.1.

(2) Category B joints shall be Type No. 1 or Type No. 2 of Table AF-810.1.

(b) Category A joints of layered sections shall be as follows.

(1) Category A joints of layers over $^7\!/_8$ in. (22 mm) in thickness shall be Type No. 1 of Table AF-810.1.

(2) Category A joints of layers $^7\!/_8$ in. (22 mm) or less in thickness shall be of Type No. 1 or 2 of Table AF-810.1, except the final outside weld joint of spiral wrapped layered shells may be a single lap weld.

(3) Welds joining the ends of helically wound interlocking strips shall be of Type No. 1 of Table AF-810.1 and shall comply with the requirements of AF-810.20(b)(5).

(c) Category B joints of layered shell sections to layered shell sections, or layered shell sections to solid shell sections, shall be of Type 1 or 2 of Table AF-810.1.

(1) Category B joints of layered sections to layered sections of unequal thickness shall have transitions as shown in Fig. AD-1117.1 sketch (a) or (b).

(2) Category B joints of layered sections to solid sections of unequal thickness shall have transitions as shown in Fig. AD-1117.1 sketch (c), (d), (e), or (f).

(3) Category B joints of layered sections to layered sections of equal thickness shall be as shown in Fig. AD-1117.6 sketch (b), (c), (d), (f), or (g).

(4) Category B joints of layered sections to solid sections of equal thickness shall be as shown in Fig. AD-1117.6 sketch (a) or (e).

(d) Category A joints of solid hemispherical heads to layered shell sections shall be of Type 1 or 2 of Table AF-810.1.

(1) Transitions shall be as shown in Fig. AD-1117.2 sketch (a), (b-1), (b-2), or (b-3) when the hemispherical head thickness is less than the thickness of the layered shell section and the transition is made in the layered shell section.

(2) Transitions shall be as shown in Fig. AD-1117.2 sketch (c), (d-1), or (e) when the hemispherical head thickness is greater than the thickness of the layered shell section and the transition is made in the layered shell section.

(3) Transition shall be as shown in Fig. AD-1117.2 sketch (f) when the hemispherical head thickness is less than the thickness of the layered shell section and the transition is made in the hemispherical head section.

(e) Category B joints of solid elliptical, torispherical, or conical heads to layered shell sections shall be of Type 1 or 2 of Table AF-810.1. Transitions shall be as shown in Fig. AD-1117.2 sketch (c), (d-1), (d-2), (e), or (f).

(f) Category C joints of solid flat heads and tubesheets to layered shell sections shall be of Type 1 or 2 of Table AF-810.1 as indicated in Fig. AD-1117.3. Transitions, if applicable, shall be used as shown in Fig. AD-1117.1 sketch (c), (d), (e), or (f).

(g) Category C joints attaching solid flanges to layered shell sections and layered flanges to layered shell sections shall be of Type 1 or 2 of Table AF-810.1 as indicated in Fig. AD-1117.4.

(h) Category A joints of layered hemispherical heads to layered shell sections shall be of Type 1 or 2 of Table AF-810.1 with transition as shown in Fig. AD-1117.5 sketch (a-1) or (a-2).

(i) Category B joints of layered conical heads to layered shell sections shall be of Type 1 or 2 of Table AF-810.1 with transitions as shown in Fig. AD-1117.5 sketch (b-1).

(j) Category B joints of layered shell sections to layered shell sections or layered shells to solid heads or shells may be butt joints as shown in Fig. AD-1117.6 sketches (c), (d), and (e), or step welds as shown in Fig. AD-1117.6 sketches (a), (b), (f), and (g).

(k) Category D joints of solid nozzles, manholes, and other connections to layered shell or layered head sections shall be full penetration welds as shown in Fig. AD-1118.1 except as permitted in sketch (i), (j), (k), or (l). Category D joints between layered nozzles and shells or heads are not permitted.

(l) When layers of Category A joints as shown in Fig. AD-1117.2 sketches (a), (b-1), (b-2), and (b-3) and Fig. AD-1117.5 sketches (a-1) and (a-2) are welded with fillet welds having a taper less than 3:1, an analysis of the head-to-shell junction shall be done in accordance with Appendix 4. No resistance due to friction shall be considered in the analysis. The longitudinal load resisted by the weld shall consider the load transferred from the remaining outer layers.

AD-1115 OPENINGS AND THEIR REINFORCEMENT

(a) All openings, except as provided in (b), shall meet the requirements for reinforcing per Article D-5. All reinforcements required for openings shall be integral with the nozzle or provided in the layered section or both. Additional layers may be included for required reinforcement.

(b) Openings, NPS 2 (DN 50) and smaller, need not be reinforced when installed in layered construction, but may be welded on the inside as shown in Fig. AD-1118.1 sketch (j). The nozzle nominal wall thickness shall not be less than Schedule 80 pipe as fabricated, in addition to meeting the requirements of AD-602.

(c) Openings are not permitted in the shell of helically wound interlocking strip construction.

AD-1116 NOZZLES AND OTHER CONNECTIONS

Some acceptable nozzle geometries and attachments are shown in Fig. AD-1118.1.

(a) Openings up to and including 6 in. (150 mm) nominal pipe size (DN 150) may be constructed as shown in Fig. AD-1118.1 sketches (k) and (l). Such partial penetration weld attachments may only be used for instrumentation openings, inspection openings, etc. on which there are no external mechanical loadings provided the following requirements are met.

(1) The requirements for reinforcing specified in AD-1115(a) above apply except that the diameter of the finished openings in the wall shall be d' as specified in Fig. AD-1118.1 sketches (k) and (l), and the thickness t_r is the required thickness of the layered shells computed by the design requirements.

(2) Additional reinforcement, attached to the inside surface of the inner shell, may be included after the corrosion allowance is deducted from all exposed surfaces. The attachment welds shall comply with AD-621 and Fig. AD-1118.1 sketch (k) or (l).

(3) Metal in the nozzle neck available for reinforcement shall be limited by the boundaries specified in AD-540 and AD-550 except that the inner layer shall be considered the shell.

(b) Openings greater than 2 in. (50 mm) may be constructed as shown in Fig. AD-1118.1 sketch (i). The requirements for reinforcing specified in (a) above apply except that:

(1) the diameter of the finished openings in the walls shall be d' as specified in Fig. AD-1118.1 sketch (i), and the thickness t_r is the required thickness of the layered shells computed by the design requirements;

(2) additional reinforcement may be included in the solid hub section as shown in Fig. AD-1118.1 sketch (i);

(3) metal in the nozzle neck available for reinforcement shall be limited by the boundaries specified in AD-540 and AD-550, except that the inner layer shall be considered the shell.

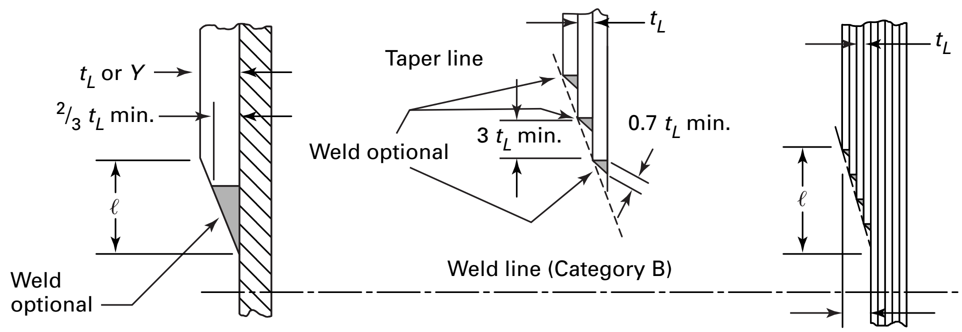
(c) The bolt circle in a layered flange shall not exceed the outside diameter of the shell. Weld overlay as shown in Fig. AD-1117.4 sketches (e), (e-1), (f), (f-1), (g), and (g-1) shall be provided to tie the overwraps and layers together.

AD-1120 FLAT HEADS, BOLTED AND STUDDED CONNECTIONS

Design criteria shall meet the requirements of Article D-7, except that design of welded joints shall be in accordance with AD-1110(f) and (g).

AD-1125 ATTACHMENTS AND SUPPORTS

Supports for layered pressure vessels may be designed per Article D-9. However, when attaching supports or other connections to the outside or inside of layered pressure vessels, only the immediate layer shall be used in the calculation, except where provisions are made to transfer the load to other layers. For some acceptable supports, see Fig. AD-1122. When jacketed closures are used, provisions shall be made for extending layer vents through the jacket (see AF-817). Partial jackets covering only a portion of the circumference are not permitted on layered shells.

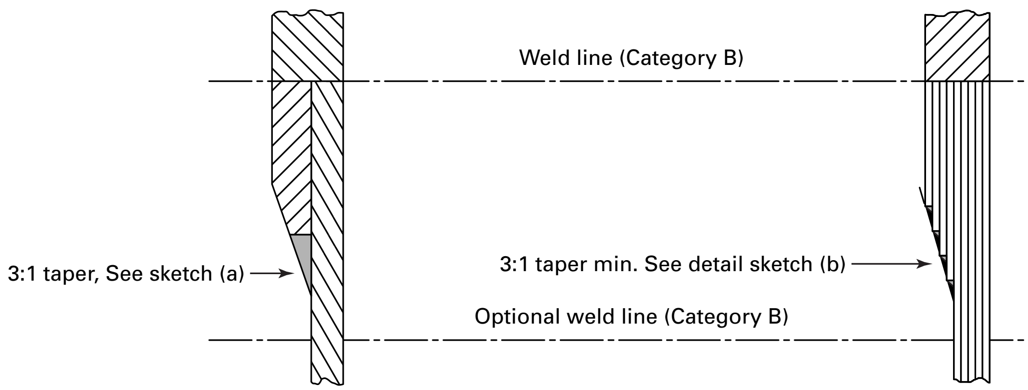


For Layers Over $^5/_8$ in. (16 mm) Thickness

(a)

Details of Taper for Layers $^5/_8$ in. (16 mm) or Less in Thickness

(b)

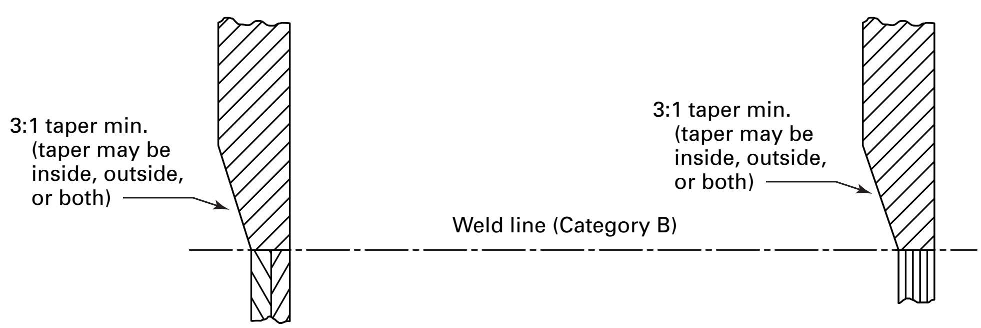


For Layers Over $^5/_8$ in. (16 mm) Thickness

(c)

For Layers $^5/_8$ in. (16 mm) or Less in Thickness

(d)



For Layers Over $^5/_8$ in. (16 mm) Thickness

(e)

For Layers $^5/_8$ in. (16 mm) or Less in Thickness

(f)

GENERAL NOTE: $\ell \geq 3Y$, where ℓ is required length of taper and Y is the offset. t_L is the thickness of one layer. The length of required taper may include the width of the weld. The transition may be on either or both sides.

FIG. AD-1117.1 TRANSITIONS OF LAYERED SHELL SECTIONS

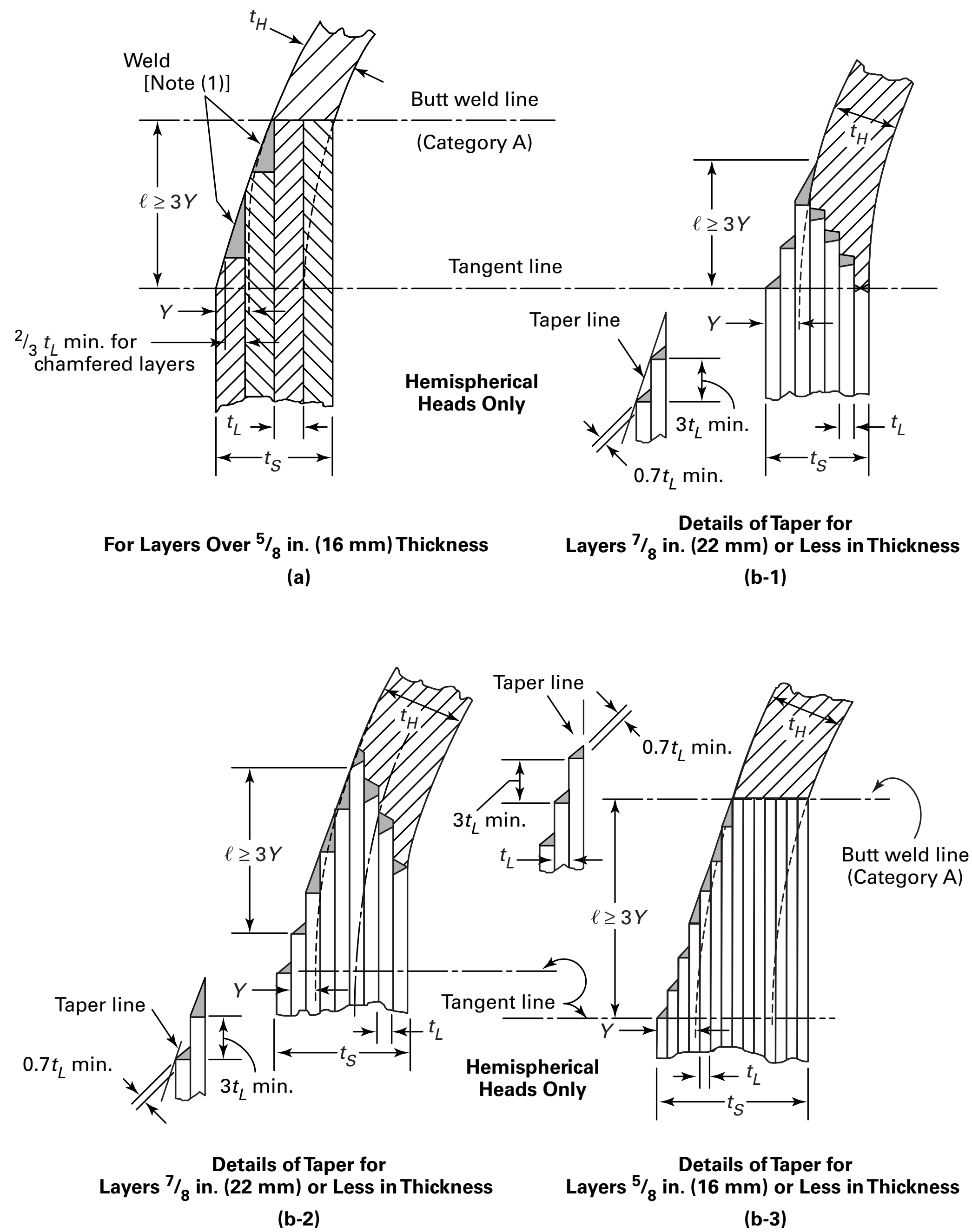
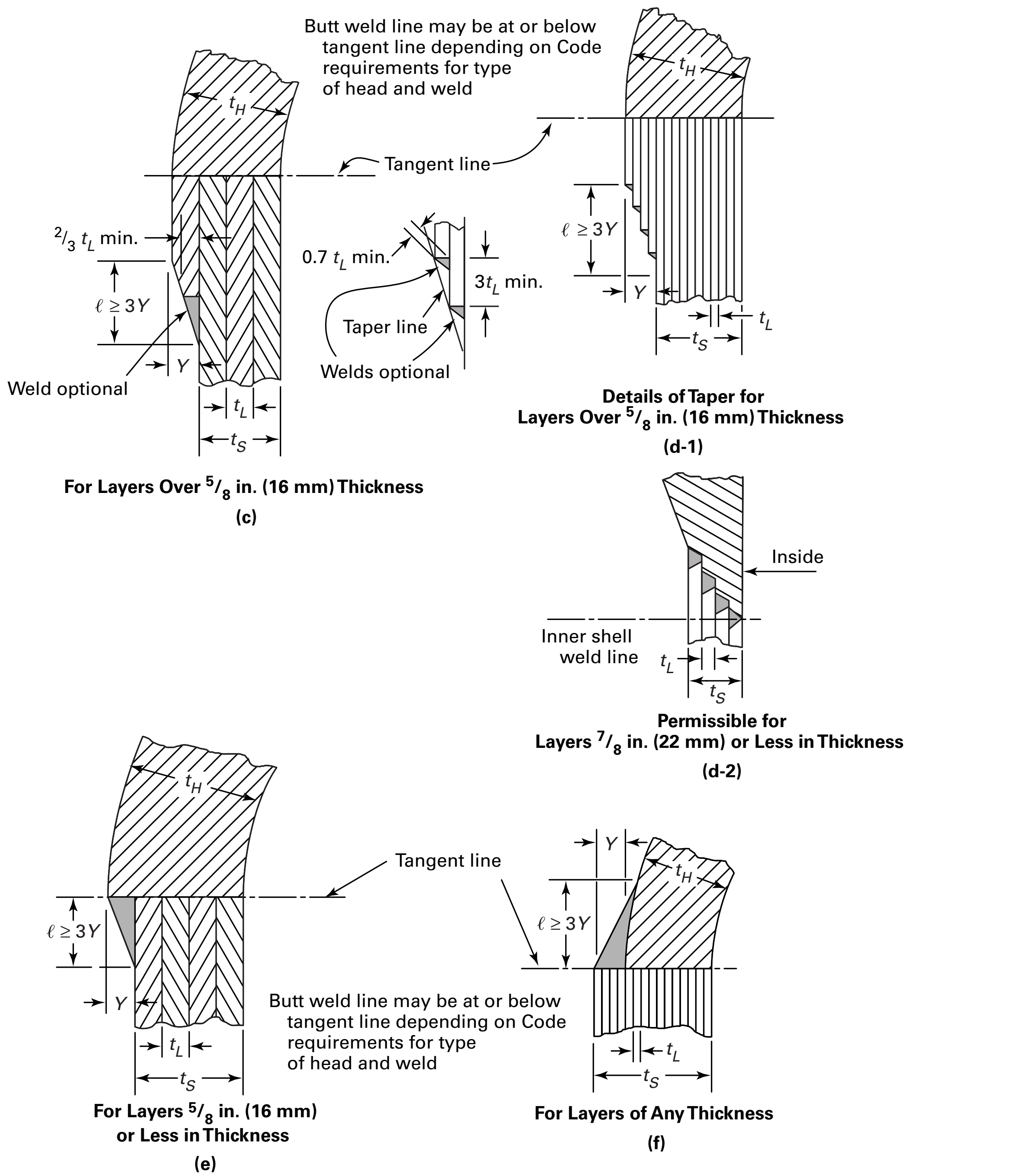


FIG. AD-1117.2 SOME ACCEPTABLE SOLID HEAD ATTACHMENTS TO LAYERED SHELL SECTIONS



GENERAL NOTES:

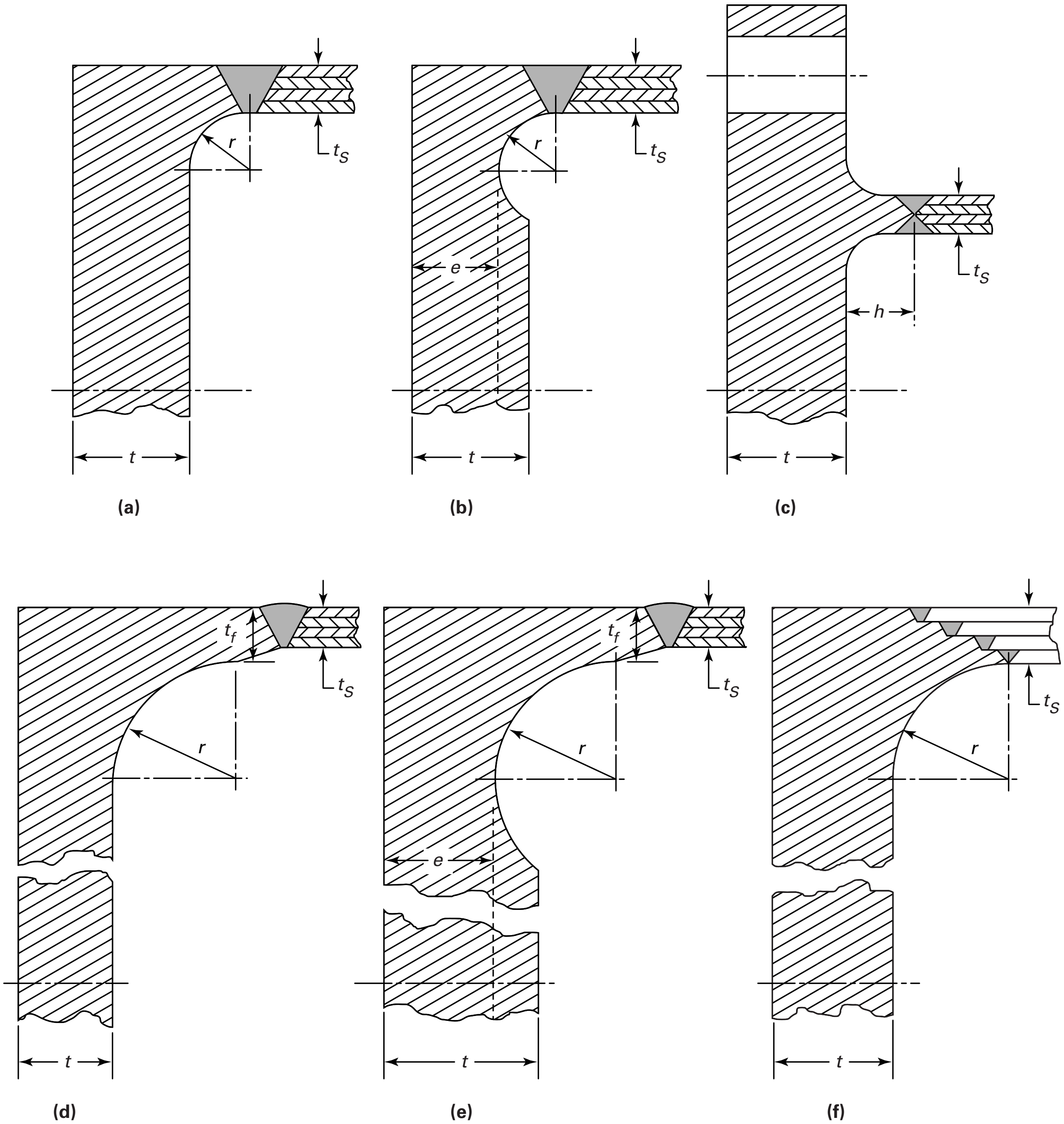
(a) t_H = thickness of head at joint, in. (mm)
t_L = thickness of one layer, in. (mm)
t_S = thickness of layered shell, in. (mm)
Y = offset, in. (mm)

(b) In sketch (e), Y shall not be larger than t_L. In sketch (f), Y shall not be larger than $^1/_2\ t_S$. In all cases, ℓ shall not be less than 3 times Y. The shell centerline may be on either side of the head centerline by a maximum of $^1/_2\ (t_S - t_H)$. The length of required taper may include the width of the weld.

NOTE:

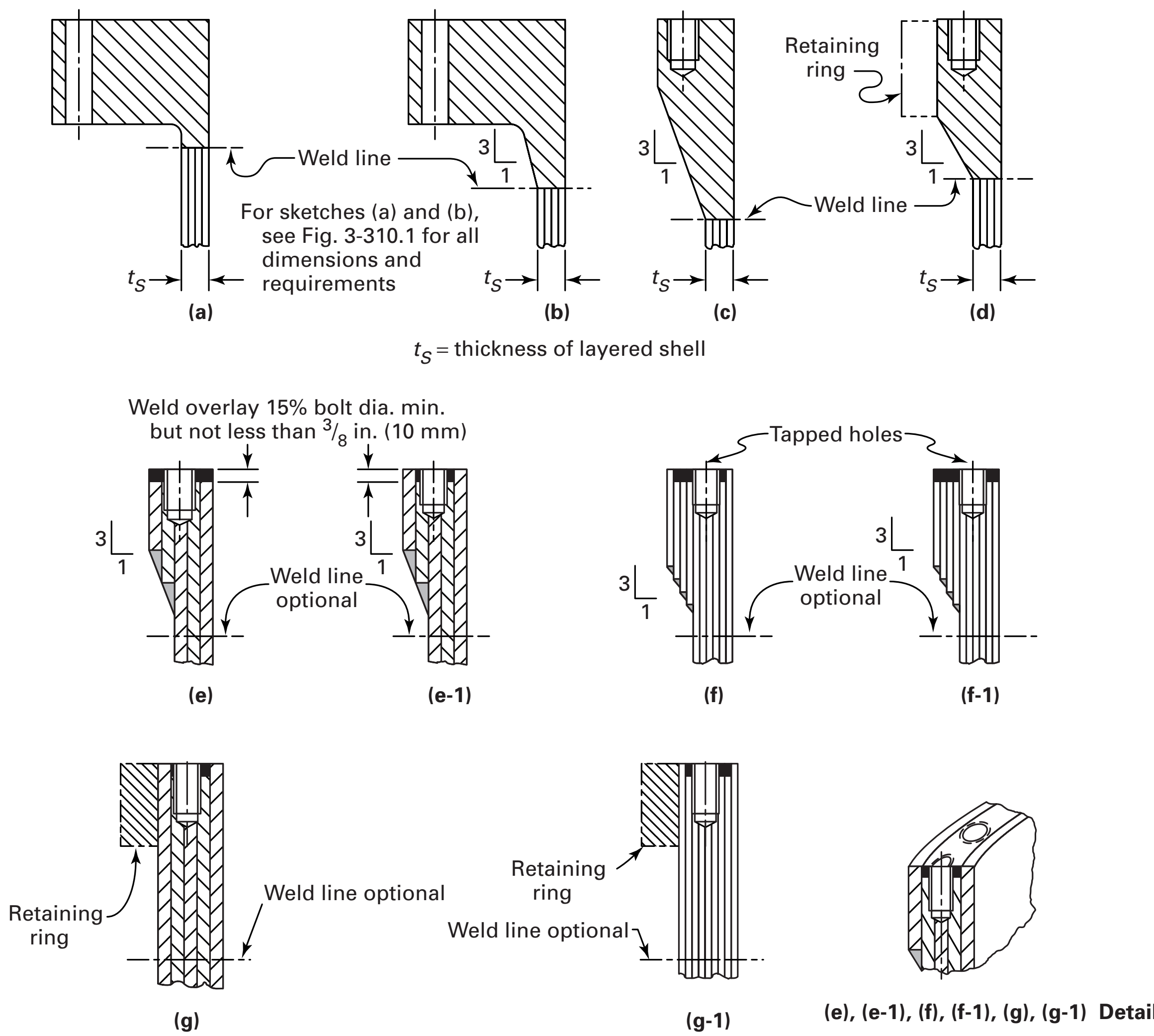
(1) Actual thickness shall not be less than theoretical head thickness.

FIG. AD-1117.2 SOME ACCEPTABLE SOLID HEAD ATTACHMENTS TO LAYERED SHELL SECTIONS (CONT'D)



GENERAL NOTES:
(a) t_S = thickness of layered shell [see AD-1110(f)], in. (mm)
(b) t = thickness of flat head or tubesheet (see AD-700), in. (mm)
(c) For all other dimensions, see Fig. AD-701.1.

FIG. AD-1117.3 SOME ACCEPTABLE FLAT HEADS AND TUBESHEETS WITH HUBS JOINING LAYERED SHELL SECTIONS



GENERAL NOTES:

(a) The following limitations apply to sketches (e), (e-1), (f), (f-1), (g), and (g-1):
  (1) the weld overlay shall tie the overlay, the overwraps, and layers together; and
  (2) the bolt circle shall not exceed the outside diameter of the shell.

(b) For sketches (e), (e-1), (f), and (f-1), the angle of transition and size of fillet welds are optional. The bolt circle diameter shall be less than the outside diameter of the layered shell.

FIG. AD-1117.4 SOME ACCEPTABLE FLANGES FOR LAYERED SHELLS **04**

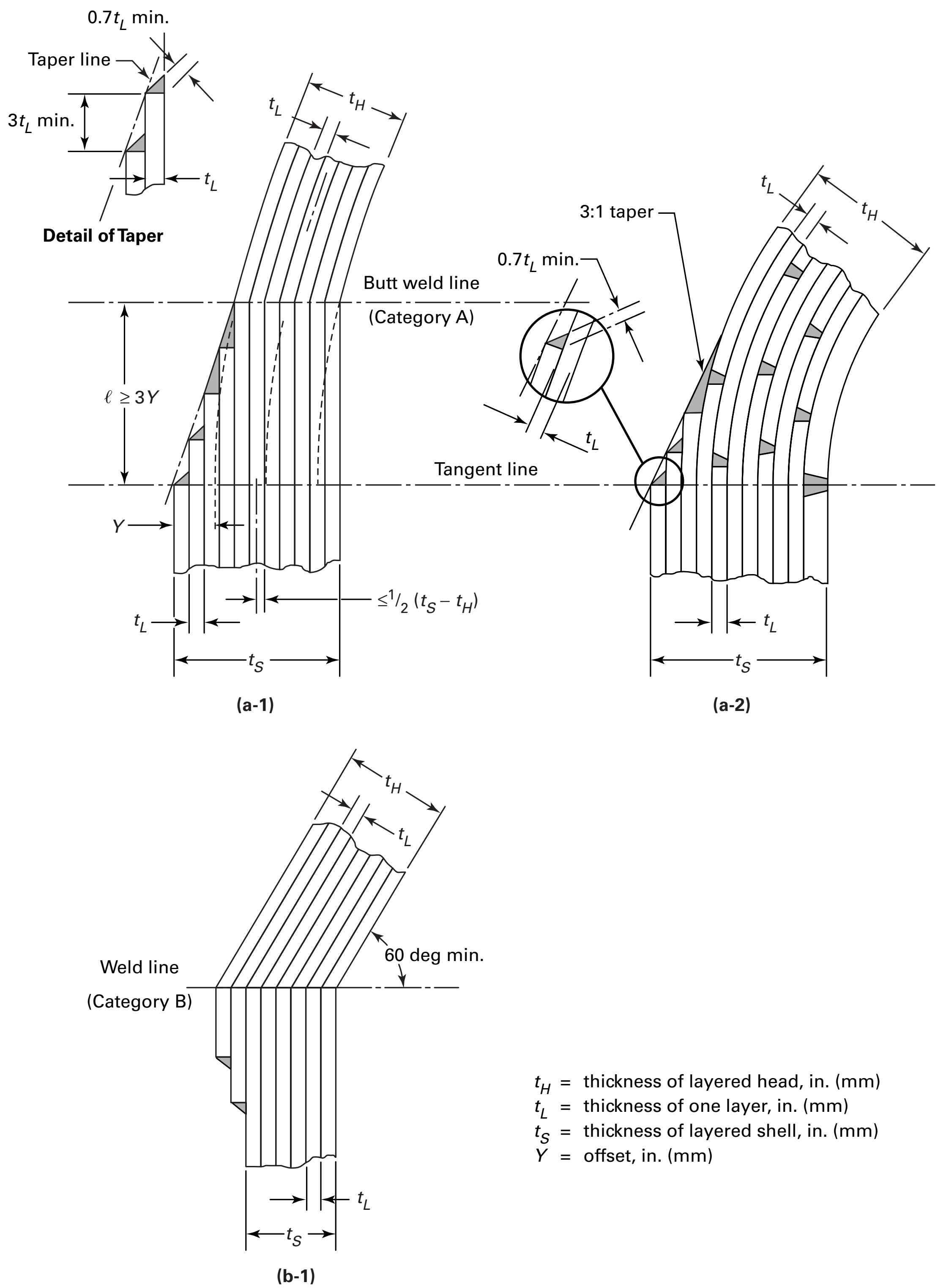


FIG. AD-1117.5 SOME ACCEPTABLE LAYERED HEAD ATTACHMENTS TO LAYERED SHELLS

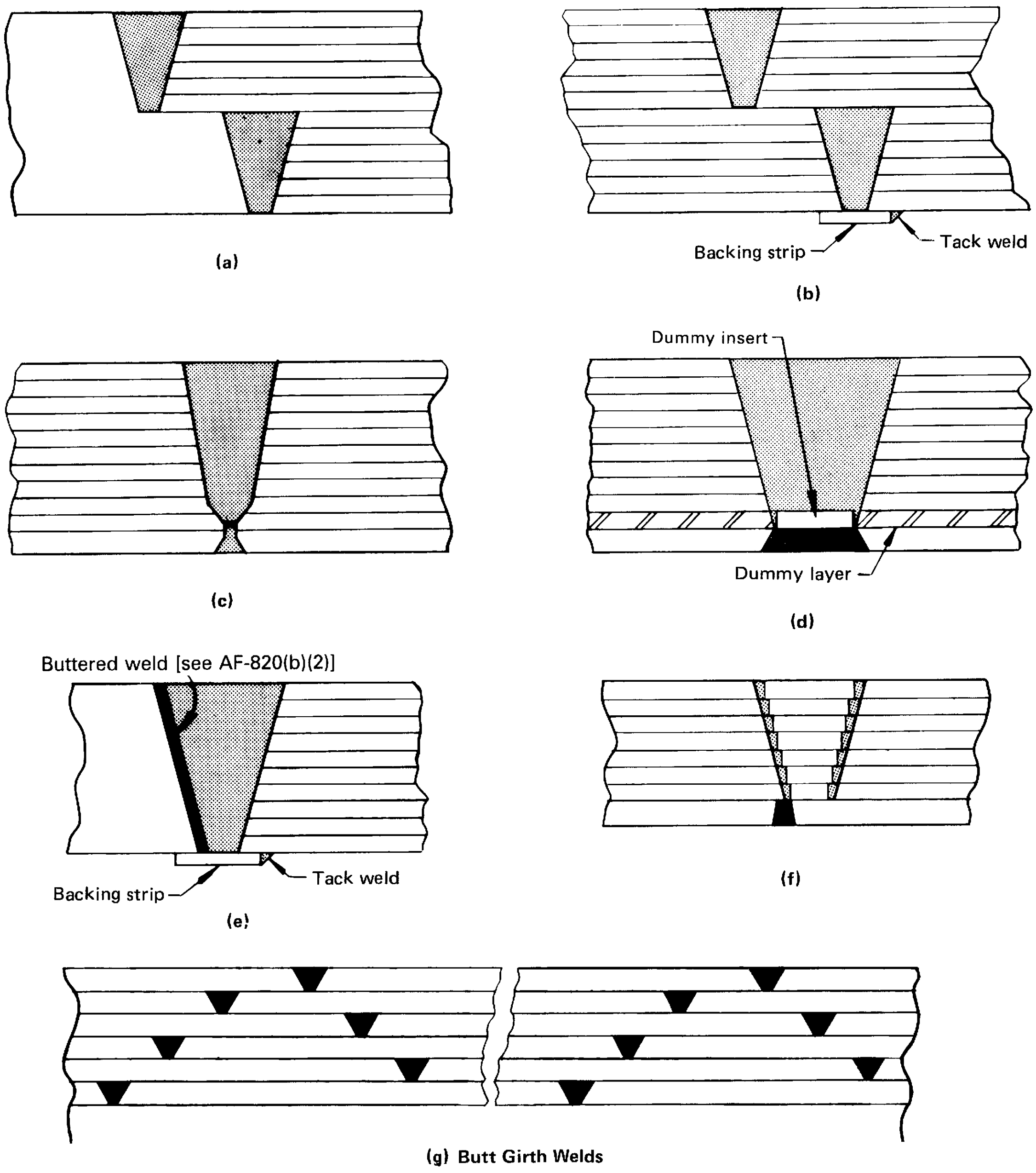


FIG. AD-1117.6 SOME ACCEPTABLE WELDED JOINTS OF LAYERED-TO-LAYERED AND LAYERED-TO-SOLID SECTIONS 04

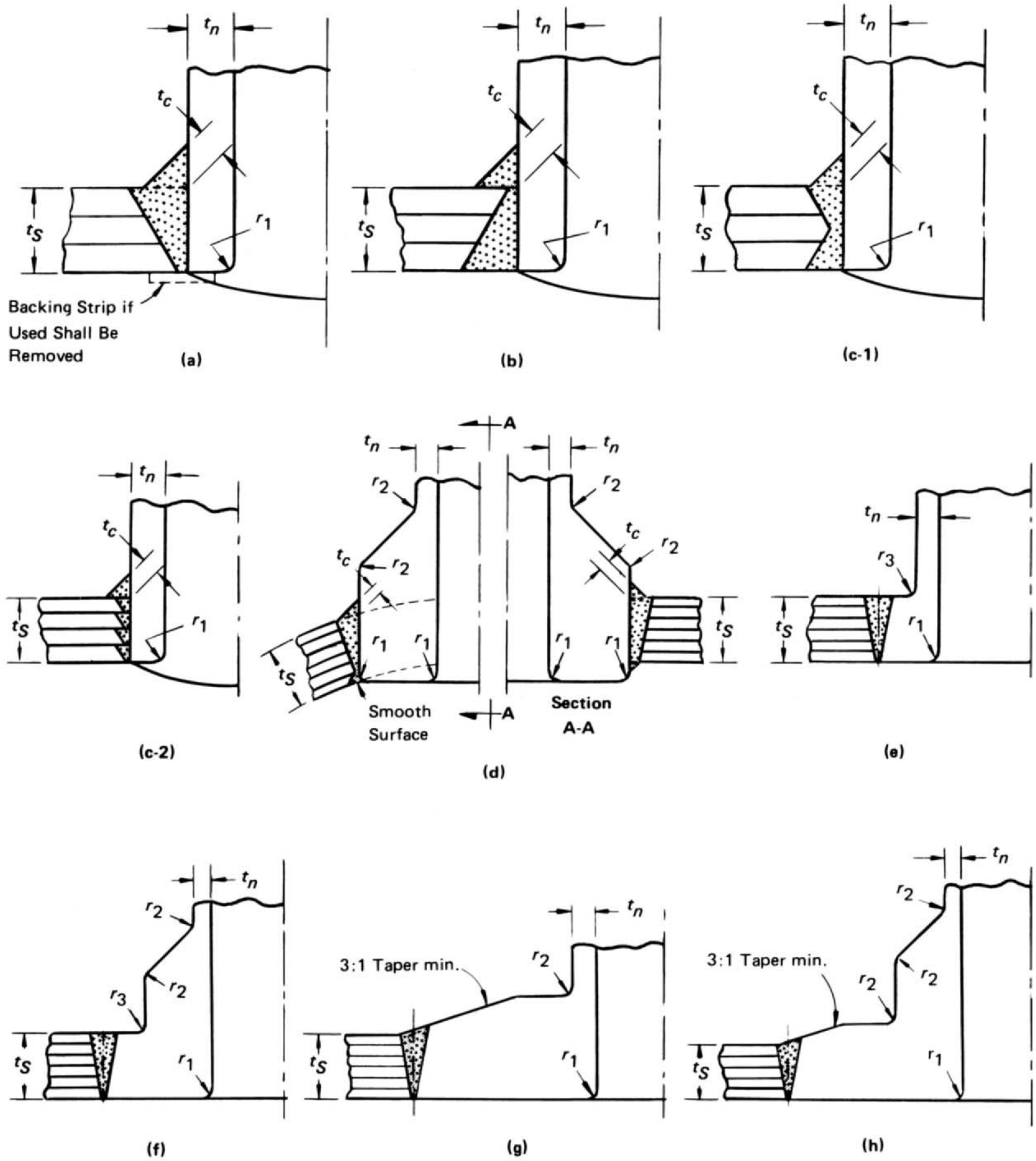
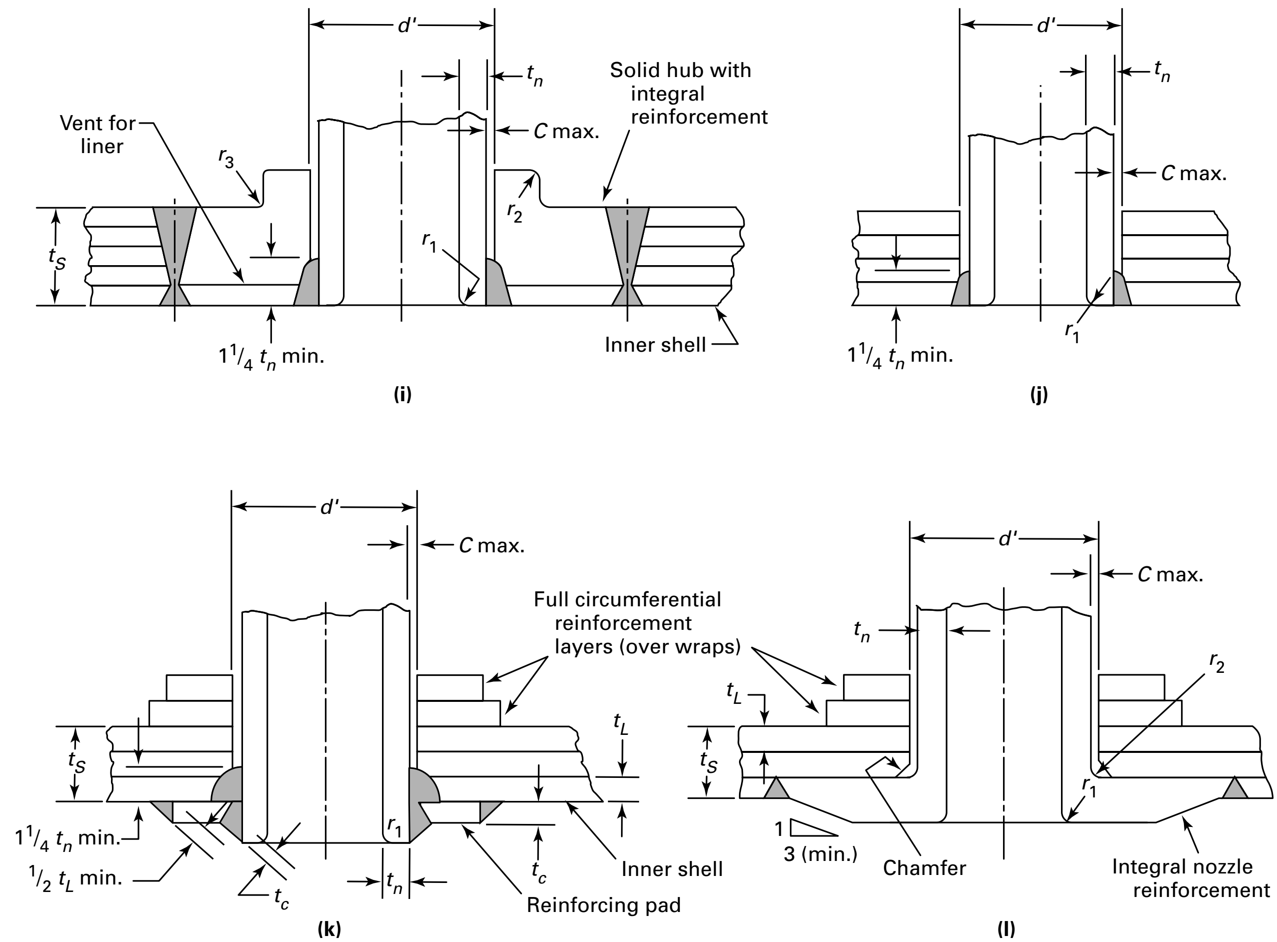


FIG. AD-1118.1 SOME ACCEPTABLE NOZZLE ATTACHMENTS IN LAYERED SHELL SECTIONS



C max. = $\frac{1}{8}$ in. (3 mm) radial clearance between nozzle neck and vessel opening
d' = finished opening in the wall (refer to AD-1116 for max. permissible diameter)
r_1 min. = $\frac{1}{4}$ t_n or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2 = $\frac{1}{4}$ in. (6 mm) minimum
r_3 min. = r_1 minimum
t min. = the smaller of $\frac{3}{4}$ in. (19 mm) or t_n
t_c = not less than $\frac{1}{4}$ in. (6 mm) or 0.7 of the smaller of $\frac{3}{4}$ in. (19 mm) or t_n
t_L = thickness of one layer, in. (mm)
t_n = nominal thickness of nozzle wall less corrosion allowance, in. (mm)
t_S = thickness of layered shell, in. (mm)

GENERAL NOTE: Provide means, other than seal welding, to prevent entry of external foreign matter into the annulus between the layers and the nozzle neck O.D. for sketches (i), (j), (k), and (l).

FIG. AD-1118.1 SOME ACCEPTABLE NOZZLE ATTACHMENTS IN LAYERED SHELL SECTIONS (CONT'D)

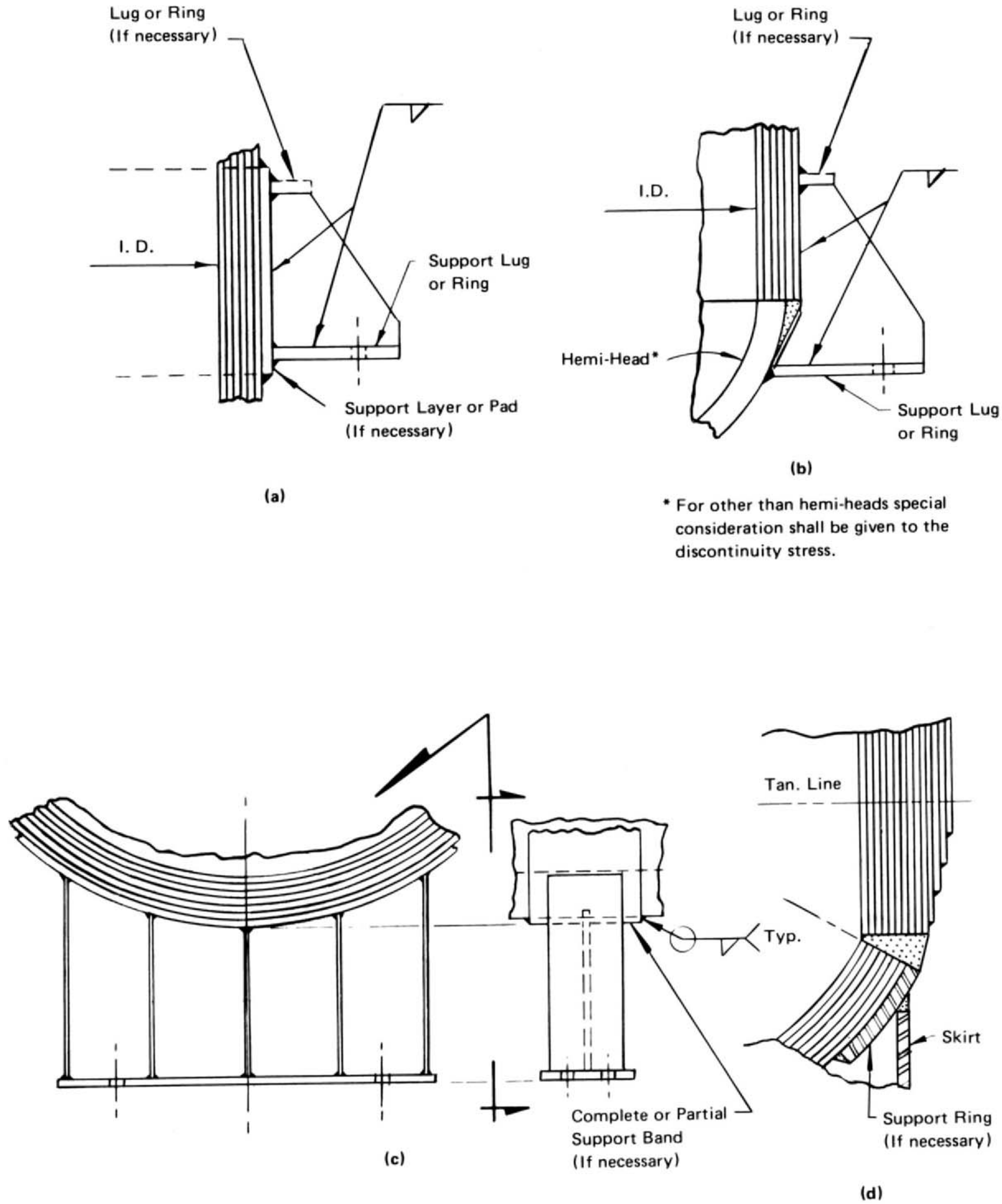


FIG. AD-1122 SOME ACCEPTABLE SUPPORTS FOR LAYERED VESSELS

Part AF
FABRICATION REQUIREMENTS

ARTICLE F-1
GENERAL FABRICATION REQUIREMENTS

AF-100 MATERIALS

AF-101 Certification of Materials

The vessel Manufacturer shall certify compliance with the special requirements of Part AM for any of the treatments, tests, or examinations specified therein that he performs. The certification shall include certified reports of the results of all tests and examinations performed on the materials by the vessel Manufacturer.

AF-102 Material Identification

Material for pressure parts preferably should be laid out so that when the vessel is completed, one complete set of the original identification markings required in the specifications for the material will be plainly visible. In case the original identification markings are unavoidably cut out or the material is divided into two or more parts, one set shall either be accurately transferred prior to cutting by the pressure vessel Manufacturer to a location where the markings will be visible on the completed vessel, or a coded marking, acceptable to the Inspector, shall be used to assure identification of each piece of material during fabrication and subsequent identification of the markings on the completed vessel. In either case an as-built sketch or a tabulation of materials shall be made, identifying each piece of material with the certified test report or certificate of compliance and the coded marking. Except as indicated in AF-102.1, material may be marked by any method acceptable to the Inspector. The Inspector need not witness the transfer of the marks but shall satisfy himself that it has been correctly done.

AF-102.1 Method of Transferring Markings. Where the service conditions prohibit die stamping for material identification, and when so specified by the user, the material manufacturer and the vessel fabricator shall mark the required data on the plates in a manner which will allow positive identification upon delivery. The markings must be recorded so that each plate will be positively identified in its position in the finished vessel to the satisfaction of the Inspector. Transfer of markings for material that is to be divided shall be done as in AF-102.2.

AF-102.2 Transfer of Markings by Other Than the Manufacturer. When material is formed into shapes by anyone other than the Manufacturer of the completed pressure vessel and the original markings as required by the applicable material specification are unavoidably cut out, or the material is divided into two or more parts, the manufacturer of the shape shall either:

(a) transfer the original identification markings to another location on the shape; or

(b) provide for identification by the use of a coded marking traceable to the original required marking, using a marking method agreed upon and described in the Quality Control System of the Manufacturer of the completed pressure vessel.

The mill certification of the physical and chemical requirements of this material, in conjunction with the above modified marking requirements, shall be considered sufficient to identify these shapes. Manufacturer's Partial Data Reports and parts stamping are not a requirement unless there has been fabrication to the shapes that includes welding, except as exempted by AM-105.1.

AF-104 Repair of Defective Materials

Defects may be removed and the material repaired by the vessel Manufacturer or, unless prohibited by the material specification, may also be repaired by the material manufacturer with the approval of the vessel Manufacturer. Material repairs that exceed those permitted by the material specification shall be made to the satisfaction of the Inspector. All repairs shall be in accordance with the following paragraphs.

AF-104.1 Examination of Defective Areas. Areas from which defects have been removed shall be examined by either a magnetic particle method in accordance with Article 9-1 or by a liquid penetrant method in accordance with Article 9-2 to insure complete removal of the defect.

AF-104.2 Repair by Welding. For the repair of materials by welding, the procedures and welds must be qualified in accordance with Section IX of the Code; where the base metal requires impact testing in accordance with AM-204, a procedure test plate shall be welded and the deposited weld metal impact tested in accordance with AT-201 and shall meet the same minimum requirements as established for the base material. The repaired material shall be heat treated in accordance with the heat treatment requirements of AF-402, when required.

AF-104.3 Examination of Finished Weld-Repaired Surfaces

(a) The finished weld-repaired surface shall be prepared and inspected by either a magnetic particle method in accordance with Article 9-1 or by a liquid penetrant method in accordance with Article 9-2.

(b) The area repaired by welding shall be examined by radiography in accordance with Article I-5 when the depth of the weld deposit exceeds either $^3/_8$ in. (10 mm) or one-half the material thickness.

AF-105 Permissible Mill Underthickness Tolerances

AF-105.1 For Plate. Plate material shall be ordered not thinner than the design thickness. Vessels made of plate furnished with an undertolerance of not more than the smaller value of 0.01 in. (0.3 mm) or 6% of the ordered thickness may be used at the full design pressure for the thickness ordered if the material specification permits such undertolerance. If the specification to which the plate is ordered allows a greater undertolerance, the ordered thickness of the material shall be sufficiently greater than the design thickness so that the thickness of the material furnished is not more than the smaller of 0.01 in. (0.3 mm) or 6% under the design thickness.

AF-105.2 For Pipe and Tube. If pipe or tube is ordered by its nominal wall thickness, the manufacturing undertolerance on wall thickness shall be taken into account. The manufacturing undertolerances are given in Part AM. After the minimum required wall thickness is determined, it shall be increased by an amount sufficient to provide the manufacturing undertolerance allowed in the pipe or tube specification.

AF-110 FORMING

AF-111 Forming Shell Sections and Heads

All materials for shell sections and for heads shall be formed to the required shape by any process that will not unduly impair the mechanical properties of the material.

AF-112 Base Metal Preparation

AF-112.1 Examination of Materials

(a) All materials to be used in constructing a pressure vessel shall be examined before fabrication for the purpose of detecting, as far as possible, defects which would affect the safety of the vessel. As fabrication progresses, the vessel Manufacturer shall carefully examine the edges of base materials (including the edges of openings cut through the thickness), to detect defects that have been uncovered during fabrication, and they shall be repaired in accordance with AF-104.

(b) Except as required in (d) below, cut edges which are to be welded in base materials with thicknesses over $1^1/_2$ in. (38 mm) shall be examined for discontinuities by a magnetic particle method in accordance with Article 9-1 or by a liquid penetrant method in accordance with Article 9-2.

(c) For openings, cut edges in base materials of all thicknesses shall be examined for discontinuities by a magnetic particle method in accordance with Article 9-1 or by a liquid penetrant method in accordance with Article 9-2 as specified below.

(1) Examination is required for openings shown in Fig. AD-610.1, sketches (a), (b), and (f).

(2) For other types of openings, this examination is not required for the cut edges of openings 3 in. (75 mm) in diameter or smaller.

(3) Nonlaminar discontinuities (having length not parallel to the material surface) shall be removed.

(4) Discontinuities parallel to the surface, such as inclusions, which are disclosed by either method, are acceptable without repair if they do not exceed 1 in. (25 mm) in length.

CAUTIONARY NOTE: For those services in which laminar discontinuities may be harmful, additional testing of materials prior to fabrication should be specified by the vessel purchaser, for example, ultrasonic testing of plate to SA-435, and of forgings to SA-388.

(d) When a pressure part is to be welded to a flat plate thicker than $\frac{1}{2}$ in. (13 mm) to form a corner joint under the provisions of AD-413.2, the weld joint preparation in the flat plate shall be examined before welding as specified in (1) below by either magnetic particle method in accordance with Article 9-1 or liquid penetrant method in accordance with Article 9-2, except as otherwise provided in AF-223.2(b). After welding, the peripheral edge of the flat plate and any remaining exposed surface of the weld joint preparation shall be reexamined as specified in (1) below.

(1) For Fig. AD-701.3 and Fig. 3-310.1, sketch (h), the weld joint preparation and the peripheral edges of the flat plate forming a corner joint shall be examined as follows:

(a) the weld edge preparation of typical joint preparations in flat plate as shown in Fig. AD-701.3, sketches (a), (b), and (c), and Fig. 3-310.1, sketch (h);

(b) the outside peripheral edge of the flat plate after welding as shown in Fig. AD-701.3, sketch (a);

(c) the outside peripheral edge of the flat plate after welding as shown in Fig. AD-701.3, sketch (b), if the distance from the edge of the completed weld to the peripheral edge of the flat plate is less than the thickness of the flat plate;

(d) the inside peripheral surface of the flat plate after welding as shown in Fig. 3-310.1, sketch (h);

(e) no examination is required on the outside peripheral edge of the flat plate as shown in Fig. AD-701.3, sketch (c), and Fig. 3-310.1, sketch (h).

AF-112.2 Cutting Plates and Other Stock

(a) Plates, edges of heads, and other parts may be cut to shape and size by mechanical means such as machining, shearing, grinding, or by thermal cutting. After thermal cutting, all slag and detrimental discoloration of material which has been molten shall be removed by mechanical means prior to further fabrication or use. When thermal cutting is used, the effect on mechanical properties shall be taken into consideration. The edges to be welded shall be uniform and smooth.

(b) In general, nonferrous materials cannot be cut by the conventional oxyacetylene equipment commonly used for steels. They may be melted and cut by oxyacetylene, powder cutting, carbon arc, oxygen arc, and other means. When such thermal means for cutting are employed, a shallow contaminated area adjacent to the cut results. This contamination shall be removed by grinding, machining, or other mechanical means after thermal cutting and prior to use or further fabrication.

AF-112.3 Shearing of Nozzles and Manhole Necks. Ends of nozzles or manhole necks which are to remain unwelded in the completed vessel may be cut by shearing provided sufficient additional material is removed by any other method that produces a smooth finish. The cut edges shall be examined by a magnetic particle method in accordance with Article 9-1 or liquid penetrant method in accordance with Article 9-2.

AF-112.4 Finish of Exposed Inside Edges. Exposed inside edges other than as provided for in Figs. AD-610.1, AD-612.1, AD-613.1, and AD-621.1 shall be rounded (grinding permitted) to at least $\frac{1}{4}\,t$ or $\frac{3}{4}$ in. (19 mm), whichever is less, when the inner end of the nozzle neck is flush with the inside wall of the shell. When the inner end of the nozzle neck protrudes beyond the inside wall of the shell towards the center of curvature, it shall be rounded off (grinding permitted) on both inner and outer surfaces of the neck end to at least $\frac{1}{4}\,t_n$ or $\frac{3}{8}$ in. (10 mm), whichever is smaller, or chamfered to 45 deg to at least $\frac{5}{16}$ in. (8 mm) (see Figs. AD-610.1, AD-612.1, AD-613.1, and AD-621.1).

AF-112.5 Examination of Cut Edges of Base Materials. After final edge preparation, the cut edges of base materials shall be examined in accordance with AF-112.1(b).

AF-120 PRELIMINARY SHAPING OF EDGES OF PLATES TO BE ROLLED

If the plates are to be rolled, the adjoining edges of longitudinal joints of cylindrical vessels shall first be shaped to the proper curvature by preliminary rolling or forming in order to avoid having objectionable flat spots along the completed joints (see AF-130).

AF-130 TOLERANCES FOR SHELLS

Cylindrical, conical, and spherical shells of a completed vessel (except formed heads covered by AF-135 and forgings covered by AF-712.2) shall meet the requirements of AF-130.1 to AF-130.4, inclusive, at all cross sections.

AF-130.1 Shells for Internal Pressure. The difference in inches between the maximum and minimum inside diameters at any cross section shall not exceed 1% of *D,* where *D* is the nominal inside diameter in inches at the cross section under consideration. The diameters may be measured on the inside or outside of the vessel. If measured on the outside, the diameters shall be corrected for the plate thickness at the cross section under consideration (see Fig. AF-130.1). When the cross section passes through an opening or within 1 I.D. of the opening measured from the center of the opening, the permissible

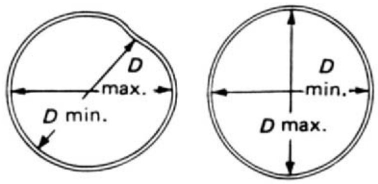


FIG. AF-130.1 EXAMPLES OF DIFFERENCES BETWEEN MAXIMUM AND MINIMUM DIAMETERS IN CYLINDRICAL SHELLS

difference in inside diameters given above may be increased by 2% of the inside diameter of the opening.

AF-130.2 Shells for External Pressure. Shells shall meet the out-of-roundness requirements of AF-130.1 and, in addition, shall meet the requirements of (a), (b), and (c) below.

(a) The maximum plus-or-minus deviation from the true circular form of cylinders or the theoretical form of other shapes, measured radially on the outside or inside of the vessel, shall not exceed the maximum permissible deviation obtained from Fig. AF-130.2. Use $e = 1.0t$ or $e = 0.2t$, respectively, for points which fall above or below these curves. Measurements shall be made from a segmental circular template having the design inside or outside radius (depending on where the measurements are taken) and a chord length equal to twice the arc length obtained from Fig. AF-130.3.

(b) The value of t in inches at any cross section is the nominal plate thickness less corrosion allowance for sections of constant thickness and the nominal thickness of the thinnest plate less corrosion allowance for sections having plates of more than one thickness.

(c) The value of L in Figs. AF-130.2 and AF-130.3 is determined as follows:

(1) for cylinders, L as given in AD-300.1;

(2) for cones or conical sections, D_o is the outside diameter, in inches, at the large end of the cone, taken perpendicular to the axis of revolution, and L is the design length of the cone or conical section, using the following applicable definitions:

(a) the axial length of the cone or the greatest center-to-center distance between any two adjacent stiffening rings, if used; or

(b) the distance from the end of the cone, or the bend line if a transition knuckle is used, to the centerline of the first stiffening ring.

(3) for spheres, L is one-half the outside diameter D_o, in inches.

AF-130.3 Deviations From Specified Shell Tolerances. Fabrication deviations from the above tolerances are prohibited, unless the following requirements are met.

(a) Provision is made for the deviations in the design calculations and they are agreed to by the user, Manufacturer, and Inspector.

(b) If the nominal thickness of plate used for a cylindrical vessel exceeds the minimum thickness required by AD-310 for the external design pressure, and if such excess thickness is not required for corrosion allowance or loadings causing compressive forces, the maximum permissible deviation e determined for the nominal plate thickness used may be increased by the ratio of Factor B for the nominal plate thickness used divided by Factor B for the minimum required plate thickness, and the chord length for measuring e_{max} shall be determined by D_o/t for the nominal plate thickness used.

AF-130.4 Tolerances for Shells Fabricated From Pipe. Vessel shells fabricated from pipe, meeting all other requirements of this Part, may have variations of diameter permitted by the specification for such pipe.

AF-135 TOLERANCE FOR FORMED HEADS

(a) The inner surface of a torispherical, toriconical, hemispherical, or ellipsoidal head shall neither deviate outside of the specified shape by more than $1\frac{1}{4}$% of D nor inside the specified shape by more than $\frac{5}{8}$% of D, where D is the nominal inside diameter of the vessel. Such deviations shall be measured perpendicular to the specified shape and shall not be abrupt. The knuckle radius shall not be less than that specified.

(b) Hemispherical heads and any spherical portion of a formed head designed for external pressure shall, in addition to satisfying (a) above, meet the local tolerances for spheres given in AF-130.2.

(c) Deviation measurements shall be taken on the surface of the base metal and not on welds.

(d) The skirt or cylindrical end of a formed head shall match the cylindrical edge of the adjoining part within the tolerance specified in AF-142 and shall be circular to the extent that the difference between the maximum and minimum diameters does not exceed 1% of D, where D is the nominal inside diameter.

AF-136 PEAKING OF WELDS IN SHELLS AND HEADS FOR INTERNAL PRESSURE

For vessels that are not exempt from the fatigue analysis requirements of AD-160, the peaking height d at Category A weld joints shall be measured by either an inside or outside template, as appropriate (see Fig. AF-136). The chord length of the template shall be based on the

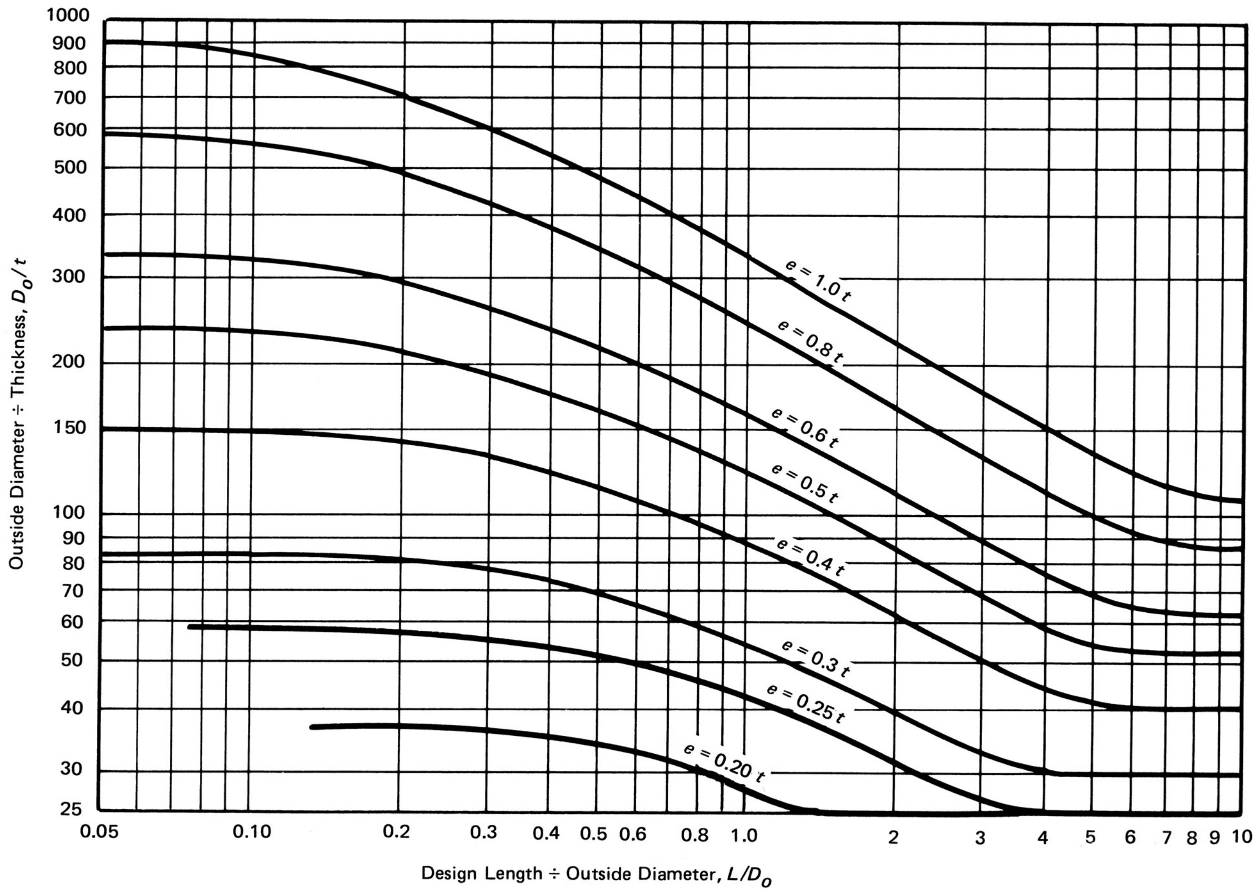


FIG. AF-130.2 MAXIMUM PERMISSIBLE DEVIATION FROM A CIRCULAR FORM *e* FOR VESSELS UNDER EXTERNAL PRESSURE

inside diameter *D* at the cross section under consideration. This chord length shall be the larger of *D*/6 or 12 in. (300 mm), but need not exceed 36 in. (900 mm). For weld joints in torispherical and ellipsoidal heads, *D* shall be equal to the diameter of the spherical portion of the head. For 2:1 ellipsoidal heads, *D* shall be equal to 1.8 times the nominal inside diameter of the attaching cylindrical shell. The allowable value of *d* shall be shown on the Manufacturer's Design Report.

AF-140 FITTING AND ALIGNMENT

Parts that are being welded shall be fitted, aligned, and retained in position during the welding operation. When joining two parts by the inertia and continuous drive friction welding processes, one of the two parts must be held in a fixed position and the other part rotated. The two faces to be joined must be essentially symmetrical with respect to the axis of rotation. Some of the basic types of applicable joints are solid round to solid round, tube to tube, solid round to tube, solid round to plate, and tube to plate.

AF-140.1 Means for Maintaining Alignment During Welding. Bars, jacks, clamps, tack welds, or other appropriate means may be used to maintain the alignment of the edges to be welded. Tack welds, if used to maintain alignment, shall either be removed completely when they have served their purpose, or their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the final weld. Tack welds shall be made by qualified procedures and welders, shall be examined visually for defects, and, if found to be defective, shall be removed.

Provided that the work is done under the provisions of AG-302.1, it is not necessary that a subcontractor making such tack welds for a vessel or parts manufacturer be a holder of a Code Certificate of Authorization.

AF-140.2 Aligning Edges of Butt Joints. The edges of butt joints shall be held during welding so that the

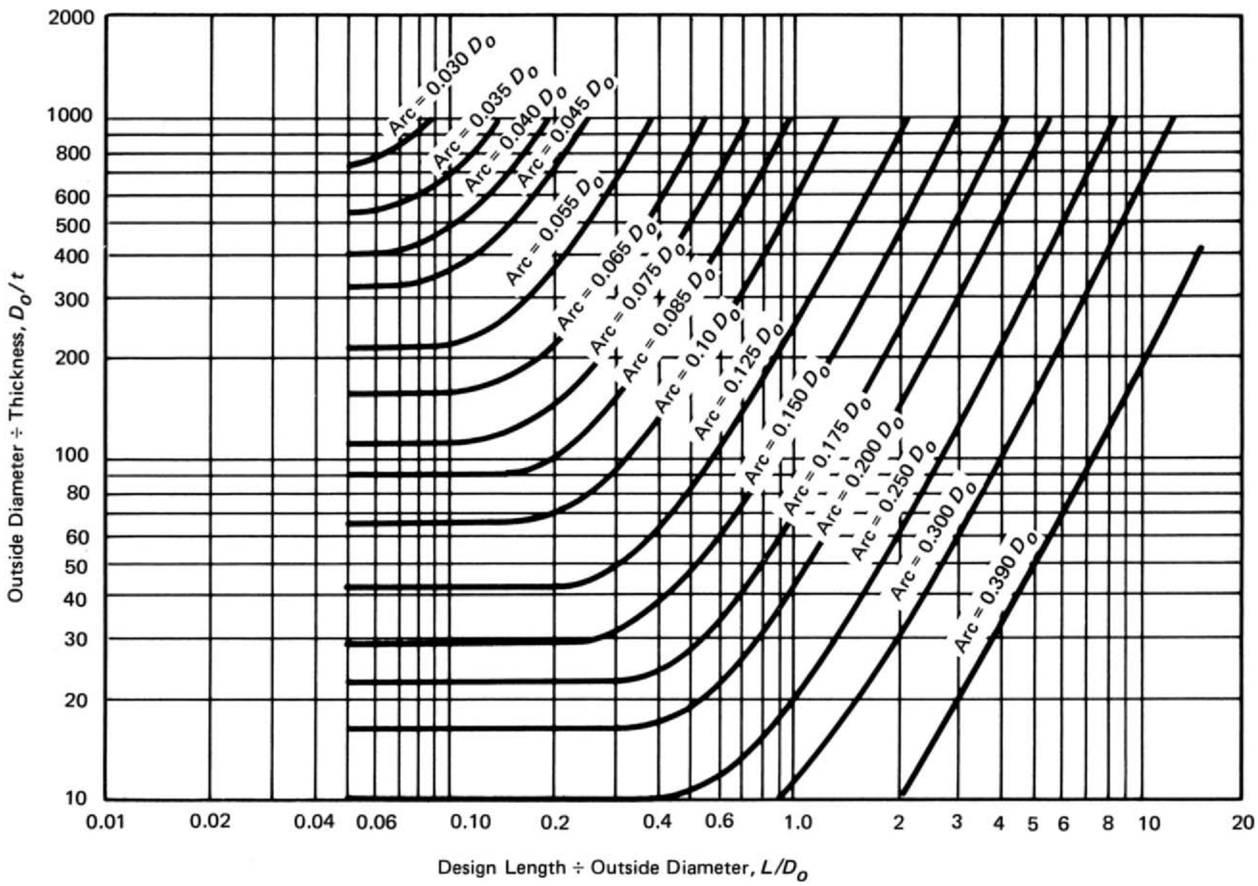


FIG. AF-130.3 MAXIMUM ARC LENGTH FOR DETERMINING PLUS OR MINUS DEVIATION

tolerances of AF-142 are not exceeded in the completed joint. When fitted girth joints have deviations exceeding the permitted tolerances, the head or shell ring, whichever is out-of-true, shall be reformed until the errors are within the limits allowed (see AF-142.1).

AF-140.3 Removal of Temporary Attachments. The areas from which temporary attachments have been removed shall be dressed smooth and be examined by a magnetic particle method in accordance with Article 9-1 or by a liquid penetrant method in accordance with Article 9-2. Defects shall be removed and the material shall be inspected to insure that the defects have been removed. If weld repairs are necessary, they shall be made using qualified welding procedures and welders and shall be examined as outlined in AF-253.

AF-141 Cleaning of Surfaces to Be Welded

(a) The surfaces to be welded shall be clean and free of scale, rust, oil, grease, slag, detrimental oxides, and other deleterious foreign material. The method and extent of cleaning should be determined based on the material to be welded and the contaminants to be removed. When weld metal is to be deposited over a previously welded surface, all slag shall be removed by a roughing tool, chisel, chipping hammer, or other suitable means so as to prevent inclusion of impurities in the weld metal.

(b) Cast surfaces to be welded shall be machined, chipped, or ground to remove foundry scale and to expose sound metal.

(c) The requirements in (a) and (b) above are not intended to apply to any process of welding by which proper fusion and penetration are otherwise obtained and by which the weld remains free from defects.

AF-142 Alignment Tolerances for Edges to Be Butt Welded

Alignment of sections at edges to be butt welded shall be such that the maximum offset is not greater than allowed in AF-142.1 and AF-142.2. Alternatively, offsets greater than permitted by AF-142.1 and AF-142.2 are

TABLE AF-142.1
MAXIMUM ALLOWABLE OFFSET IN WELDED JOINTS
See AF-614.1 for Special Requirements for Quenched and Tempered Steels

Section Thickness, in. (mm)	Direction of Joints in Cylindrical Shells [Note (1)] Longitudinal	Circumferential
Up to $\frac{1}{2}$ (13), incl.	$\frac{1}{4}t$	$\frac{1}{4}t$
Over $\frac{1}{2}$ to $\frac{3}{4}$ (13 to 19), incl.	$\frac{1}{8}$ in. (3 mm)	$\frac{1}{4}t$
Over $\frac{3}{4}$ to $1\frac{1}{2}$ (19 to 38), incl.	$\frac{1}{8}$ in. (3 mm)	$\frac{3}{16}$ in. (5 mm)
Over $1\frac{1}{2}$ to 2 (38 to 50), incl.	$\frac{1}{8}$ in. (3 mm)	$\frac{1}{8}t$
Over 2 (50)	$\frac{1}{16}t$ [$\frac{3}{8}$ in. (10 mm) max.]	$\frac{1}{8}t$ [$\frac{3}{4}$ in. (19 mm) max.]

NOTE:
(1) t = nominal thickness of the thinner section at the joint.

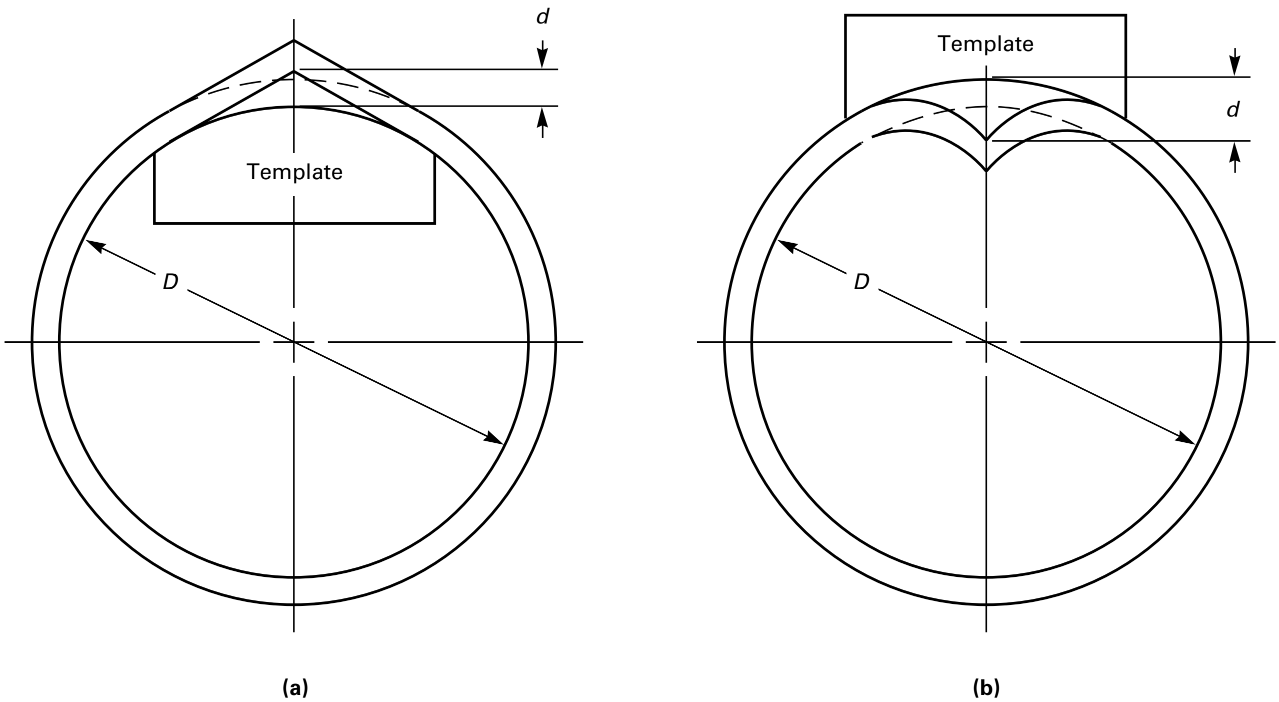


FIG. AF-136 PEAKING HEIGHT AT CATEGORY A WELD JOINTS

allowable provided that the maximum offset is acceptable to the Inspector prior to welding and the requirements of Appendix 4 and AF-142.3 are met. See AF-614 for alignment requirements for quenched and tempered steels.

AF-142.1 For Cylindrical Shells. The maximum allowable offset in welded joints in cylindrical shells shall be as given in Table AF-142.1.

AF-142.2 For Spherical Shells and for Hemispherical Heads Welded to Cylindrical Shells. Joints in spherical vessels, joints within heads, and joints between cylindrical shells and hemispherical heads shall meet the requirements in Table AF-142.1 for longitudinal joints in cylindrical shells.

AF-142.3 Fairing of Offsets Within Allowable Tolerances. Any offset within the allowable tolerance provided above shall be faired at a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal beyond what would have been the edge of the weld. Such additional weld metal buildup shall be subject to the requirements of AF-229.

ARTICLE F-2
WELDING FABRICATION REQUIREMENTS

AF-200 WELDING PROCESSES

(a) The welding processes that may be used in the construction of vessels under this Part of this Division are restricted as follows.

(1) Arc welding processes: atomic hydrogen, electrogas, gas metal arc, gas tungsten arc, plasma arc, shielded metal arc, stud, and submerged arc.

(2) Other than arc welding processes: electron beam, electroslag, explosive,[1] induction, inertia and continuous drive friction, laser beam, oxyfuel gas, resistance, and thermit.

(b) The welding processes to be used in welding of titanium are restricted to electron beam, gas metal arc, gas tungsten arc, laser beam, and plasma arc.

(c) The electroslag and electrogas processes may be used for butt welds only in ferritic steels and the following austenitic steels which are welded to produce a ferrite containing weld metal: SA-240 TP304, TP304L, TP316, and TP316L; SA-182 F304, F304L, F316, and F316L; SA-351 CF3, CF3A, CF3M, CF8, CF8A, and CF8M. For electroslag welds in ferritic materials over 1½ in. (38 mm) in thickness at the joint, or electrogas welds in ferritic materials with any single pass greater than 1½ in. (38 mm), the joint shall be given a grain refining (austenitizing) heat treatment.

(d) Definitions are given in Section IX which include variations of these processes.

(e) Arc stud welding and resistance stud welding may be used only for nonpressure-bearing attachments, having a load- or non-load-carrying function, except for materials listed in Table AQT-1 provided that, in the case of ferrous materials, heat treatment requirements of AF-401 and AF-402 for the materials used in the vessel are met. Studs shall be limited to 1 in. (25 mm) diameter maximum for round studs and an equivalent cross-sectional area for studs with other shapes.

[1] *explosive welding* — a solid state welding process wherein coalescence is produced by the application of pressure by means of an explosion.

(f) The inertia and continuous drive friction welding processes shall only be used on materials assigned P-Numbers in Section IX and shall not include rimmed or semikilled steel.

AF-210 WELDING QUALIFICATIONS AND RECORDS

AF-210.1 Manufacturer's Responsibility

(a) Each Manufacturer or parts manufacturer is responsible for the welding done by his organization and shall establish the procedure and be responsible for the tests required in Section IX or, if not included in Section IX, the additional tests required herein to qualify the welding procedures and the performance of welders and welding operators who apply these procedures.

(b) The Manufacturer (certificate holder) may engage individuals, by contract or agreement, for their services as welders[2] at the shop location shown on the Certificate of Authorization and at field sites (if allowed by the Certificate of Authorization) for the construction of pressure vessels or vessel parts, provided all of the following conditions are met. 04

(1) All Code construction shall be the responsibility of the Manufacturer.

(2) All welding shall be performed in accordance with the Manufacturer's Welding Procedure Specifications, in accordance with the requirements of Section IX.

(3) All welders shall be qualified by the Manufacturer in accordance with the requirements of Section IX.

(4) The Manufacturer's Quality Control System shall include as a minimum:

(a) a requirement for complete and exclusive administrative and technical supervision of all welders by the Manufacturer;

(b) evidence of the Manufacturer's authority to assign and remove welders at his discretion without involvement of any other organization;

[2] *Welder* includes brazer, welding and brazing operator.

(c) a requirement for assignment of welder identification symbols;

(d) evidence that this program has been accepted by the Manufacturer's authorized Inspection Agency which provides the inspection service.

(5) The Manufacturer shall be responsible for Code compliance of the completed pressure vessel or part, including Code symbol stamping and providing Data Report Forms properly executed and countersigned by the Inspector.

AF-210.2 Qualification Test Limitations. Welding of all test coupons shall be conducted by the Manufacturer. Testing of all test coupons shall be the responsibility of the Manufacturer. Alternatively, AWS Standard Welding Procedure Specifications that have been accepted by Section IX may be used, provided they meet all other requirements of this Division. Qualification of welding procedure by one Manufacturer shall not qualify that procedure for use by any other Manufacturer, except as provided for in QW-201 of Section IX. A performance qualification test conducted by one Manufacturer shall not qualify a welder or welding operator to do work for any other Manufacturer, except as provided for in QW-300 of Section IX.

AF-210.3 Production Welding Prior to Qualification. No production welding shall be undertaken until after the welding procedures which are to be used have been qualified.

AF-210.4 Qualification of Welding Procedure

(a) Each procedure of welding that is to be followed in construction shall be recorded in detail by the Manufacturer.

(b) The procedure used in welding pressure parts and in joining load-carrying nonpressure parts (attachments) to pressure parts shall be qualified in accordance with Section IX.

(c) When making procedure test plates for butt welds in accordance with Section IX, consideration should be given to the effect of angular, lateral, and end restraint on the weldment. This applies particularly to material and weld metal of 80,000 psi (552 MPa) strength or higher and thick sections of both low and high tensile strength material. The addition of restraint during the welding may result in cracking difficulties that otherwise might not occur.

(d) The procedure used in welding nonpressure-bearing attachments, which have essentially no load-carrying function (such as extended heat transfer surfaces, insulation support pins, etc.), to pressure parts shall meet the following requirements.

(1) When the welding process is manual, machine, or semiautomatic, procedure qualification is required in accordance with Section IX.

(2) When the welding is any automatic welding process performed in accordance with a Welding Procedure Specification (in compliance with Section IX as far as applicable), procedure qualification testing is not required.

AF-210.5 Tests of Welders and Welding Operators

(a) The welders and the welding operators used in welding pressure parts and in joining load-carrying nonpressure parts (attachments) to pressure parts shall be qualified in accordance with Section IX.

(1) The qualification test for welding operators of machine welding equipment shall be performed on a separate test plate prior to the start of welding or on the first workpiece.

(2) When stud welding is used to attach load-carrying studs, a production stud weld test of the procedure and welding operator shall be performed on a separate test plate or tube prior to the start of welding on each work shift. This weld test shall consist of five studs, welded and tested in accordance with either the bend or torque stud weld testing described in Section IX.

(b) The welders and welding operators used in welding nonpressure-bearing attachments, which have essentially no load-carrying function (such as extended heat transfer surfaces, insulation support pins, etc.), to pressure parts shall comply with the following.

(1) When the welding process is manual, machine, or semiautomatic, qualification in accordance with Section IX is required.

(2) When welding is done by any automatic welding process, performance qualification testing is not required.

(3) When stud welding is used, a production stud weld test, appropriate to the end use application requirements, shall be specified by the Manufacturer and carried out on a separate test plate or tube at the start of each shift.

AF-210.6 Maintenance of Qualification and Production Records. The Manufacturer shall maintain a record of the welding procedures and the welders and welding operators employed by him, showing the date and results of tests and the identification mark assigned to each welder. These records shall be certified by the Manufacturer or contractor and shall be accessible to the Inspector. The welder or welding operator shall stamp the identification mark assigned to him by the Manufacturer adjacent to all welded joints made by him, at 3 ft (0.9 m) or smaller intervals with stamping procedures that meet the requirements of AF-102.1 and AF-601; or as an alternative, the Manufacturer shall keep a record of the welded joints in a vessel and of the welders and welding operators used in making each of the joints.

AF-215 Precautions to Be Taken Before Welding

AF-215.1 Identification, Handling, and Storing of Electrodes and Other Welding Materials. The Manufacturer is responsible for control of the welding electrodes and other materials which are to be used in the fabrication of the vessel. Suitable identification, storage, and handling of electrodes, flux, and other welding materials shall be maintained. Precautions shall be taken to minimize absorption of moisture by low hydrogen electrodes and flux.

AF-215.2 Lowest Permissible Temperature for Welding. It is recommended that no welding of any kind be done when the temperature of the metal is lower than 0°F (−18°C). At temperatures between 32°F (0°C) and 0°F (−18°C), the surface of all areas within 3 in. (75 mm) of the point where a weld is to be started should be heated to a temperature at least warm to the hand [estimated to be above 60°F (16°C)] before welding is started. It is recommended also that no welding be done when surfaces are wet or covered with ice, when snow is falling on the surfaces to be welded, or during periods of high wind unless the welders or welding operators and the work are properly protected.

AF-220 SPECIFIC REQUIREMENTS FOR WELDED JOINTS

AF-221 Type No. 1 Butt Joints

Type No. 1 butt joints are those produced by double welding or by other means which produce the same quality of deposited weld metal on both inside and outside weld surfaces. Welds using backing strips which remain in place do not qualify as Type No. 1 butt joints.

AF-221.1 Weld Penetration and Reinforcement

(a) Butt welded joints shall have complete penetration and full fusion. As-welded surfaces are permitted; however, the surface of the welds shall be sufficiently free from coarse ripples, grooves, overlaps, and abrupt ridges and valleys to permit proper interpretation of radiographic and other required nondestructive examinations. If there is a question regarding the surface condition of the weld when interpreting a radiographic film, the film shall be compared to the actual weld surface for determination of acceptability.

(b) A reduction in thickness due to the welding process is acceptable provided all of the following conditions are met.

(1) The reduction in thickness shall not reduce the material of the adjoining surfaces below the minimum required thickness at any point.

(2) The reduction in thickness shall not exceed 1/32 in. (0.8 mm) or 10% of the nominal thickness of the adjoining surface, whichever is less.[3]

AF-221.2 Examination Requirements. Note (1) to Column 1 of Table AF-241.1 permits reduced examination requirements under certain conditions. Otherwise, Type No. 1 butt joints, whether longitudinal or circumferential, shall be fully radiographed for their entire length or periphery in accordance with the requirements of Article I-5. All welds made by the inertia and continuous drive friction welding processes that require radiography shall also be ultrasonically examined in accordance with the requirements of Article 9-3. In addition, all welds made by the electroslag welding process, or the electrogas process with any single pass greater than 1½ in. (38 mm), in ferritic materials shall be ultrasonically examined in accordance with the requirements of Article 9-3. This ultrasonic examination shall be done following the grain refining (austenitizing) heat treatment or postweld heat treatment. All welds made by the electron beam welding process shall also be ultrasonically examined for their entire length in accordance with the requirements of Article 9-3.

AF-221.3 To assure that the weld grooves are completely filled so that the surface of the weld metal at any point does not fall below the surface of the adjoining base materials,[4] weld metal may be added as reinforcement on each face of the weld. The thickness of the weld reinforcement on each face shall not exceed the following:

Material Nominal Thickness, in. (mm)	Max. Reinforcement Thickness, in. (mm) — Circumferential Joints in Pipe and Tubing	Max. Reinforcement Thickness, in. (mm) — Other Welds
Less than 3/32 (2.5)	3/32 (2.5)	1/32 (0.8)
3/32 to 3/16 (2.5 to 5), incl.	3/32 (2.5)	1/16 (1.5)
Over 3/16 to 1/2 (5 to 13), incl.	1/8 (3.0)	3/32 (2.5)
Over 1/2 to 1 (13 to 25), incl.	5/32 (4.0)	3/32 (2.5)
Over 1 to 2 (25 to 50), incl.	5/32 (4.0)	1/8 (3.0)
Over 2 to 3 (50 to 75), incl.	5/32 (4.0)	5/32 (4.0)
Over 3 to 4 (75 to 100), incl.	7/32 (5.5)	7/32 (5.5)
Over 4 to 5 (100 to 125), incl.	1/4 (6.0)	1/4 (6.0)
Over 5 (125)	5/16 (8.0)	5/16 (8.0)

[3] It is not the intent of this paragraph to require measurement of reductions in thickness due to the welding process. If a disagreement between Manufacturer and the Inspector exists as to the acceptability of any reduction in thickness, the depth shall be verified by actual measurement.

[4] Concavity due to the welding process on the root side of a single welded circumferential butt weld is permitted when the resulting thickness of the weld is at least equal to the thickness of the thinner member of the two sections being joined and the contour of the concavity is smooth.

AF-222 Type No. 2 Butt Joints

Type No. 2 butt joints are single-welded butt joints having backing strips which remain in place. See AD-412.1 for stress concentration factors to be applied to Type No. 2 joints when a fatigue analysis is required.

AF-222.1 Penetration and Reinforcement. When Type No. 2 butt joints are used, particular care shall be taken in aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joints for their full length. However, for assuring complete filling of the weld grooves, weld reinforcement in accordance to the limits specified in AF-221.3 need be supplied only on the side opposite the backing strip.

AF-222.2 Backing Strips. Backing strips shall be continuous and any splices shall be butt welded. Circumferential single-welded butt joints with one plate offset to form a backing strip are prohibited.

AF-222.3 Examination Requirements. Note (1) to Column 1 of Table AF-241.1 permits reduced examination requirements under certain conditions. Otherwise, Type No. 2 butt joints shall be radiographically examined throughout their entire periphery in accordance with the requirements of Article I-5. In addition, all welds made by the electroslag welding process in ferritic materials shall be ultrasonically examined in accordance with the requirements of Article 9-3. This ultrasonic examination shall be done following the grain refining (austenitizing) heat treatment or postweld heat treatment. All welds made by the electron beam welding process shall also be ultrasonically examined for their entire length in accordance with the requirements of Article 9-3.

AF-223 Full Penetration Corner Joints

Corner joints are those connecting two members at right angles to each other in the form of an L or T, and shall be made with full penetration welds.

AF-223.1 Penetration and Fusion. Welds in full penetration corner joints shall be groove welds extending completely through at least one of the parts being joined and shall be fully fused to each part [see Fig. AD-610.1; Fig. AD-612.1 sketches (b), (c), (e), (f), and (g); Fig. AD-701.3; and Fig. 3-310.1 sketches (g) and (h)].

AF-223.2 Examination Requirements

(a) For nozzle connections with necks abutting vessel wall [see Fig. AD-610.1 sketches (a) and (b)], the radially disposed surface of the opening cut in the vessel wall thickness to the approximate inside diameter of the nozzle shall be magnetic particle or liquid penetrant examined in accordance with the requirements of Article 9-1 or 9-2, whichever is applicable.

(b) For corner joint constructions as illustrated in Fig. AD-701.3 sketches (b) and (c), except when dimension b is equal to or greater than t_s, the unstayed flat head, prior to welding, shall be 100% examined by the ultrasonic method in accordance with the requirements of SA-435, except that no lamination in the head is acceptable.

(c) The welds shall be examined on both interior and exterior surfaces by either the magnetic particle or liquid penetrant method, in accordance with the requirements of Article 9-1 or 9-2, except:

(1) for Category C joints when the shell material is greater in thickness than $2\frac{1}{2}$ in. (63 mm), the examination shall be performed by the ultrasonic method in accordance with the requirements of Article 9-3 or, except for welds made by the inertia and continuous drive friction welding processes, by radiography in accordance with the requirements of Article I-5;

(2) for Category D joints when an opening is greater than 6 in. (150 mm) in diameter in shell material greater than $2\frac{1}{2}$ in. (63 mm) in thickness, the examination shall be by the ultrasonic or, except for welds made by the inertia and continuous drive friction welding processes, radiographic procedures in accordance with the methods stated in (1) above.

(d) The required magnetic particle or liquid pene- trant examination shall be performed after postweld heat treatment, if done, for materials covered by Column 2 of Table AF-241.1.

AF-224 Partial Penetration Joints for Nozzle Attachments

Partial penetration welds of the groove type may be used for connections not subject to external loadings, as permitted by AD-414.1.

AF-224.1 Penetration Requirements. Partial penetration welds shall have a minimum depth of penetration equal to that required by AD-621 and Fig. AD-621.1.

AF-224.2 Examination Requirements. Partial penetration welds shall be examined by a magnetic particle method in accordance with the requirements of Article 9-1 or a liquid penetrant method in accordance with the requirements of Article 9-2. The required magnetic particle or liquid penetrant examination shall be performed after postweld heat treatment, if done, for materials covered by Column 2 of Table AF-241.1.

AF-225 Fillet Welded Joints

Fillet welded joints, permitted by the rules of this Division, are those of approximately triangular cross section, joining two surfaces at approximately right angles to each other. For connection attachments, fillet welds shall meet the requirements of AD-612 and Fig. AD-612.1, AD-620, AD-635, or AD-711.1. For attachment of nonpressure parts, fillet welds shall meet the requirements of AD-911 or AD-912, whichever is applicable, and of AF-227.

AF-225.1 Quality Requirements. The reduction of the thickness of the base metal due to the welding process at the edges of the fillet weld shall meet the same requirements as for butt welds. (See AF-221.1.)

AF-225.2 Examination Requirements

(a) The radially disposed surfaces of the openings cut in the vessel walls to the approximate inside diameters of nozzles to be attached by means of fillet welds shall be examined by either a magnetic particle method in accordance with the requirements of Article 9-1 or a liquid penetrant method in accordance with the requirements of Article 9-2. Unacceptable defects thus discovered shall be removed and repaired as required by the applicable Article.

(b) Note (1) to Column 1 of Table AF-241.1 permits reduced examination requirements under certain conditions. Otherwise, after completion, the surface of fillet welds shall also be magnetic particle or liquid penetrant examined in accordance with the requirements of Articles 9-1 or 9-2, whichever is applicable.

(c) Fillet welds used to connect nonpressure parts shall be examined in accordance with the requirements of AF-227.1.

AF-226 Welds Attaching Nozzles and Other Connections

The design requirements for welds attaching nozzle necks and other connections are set forth in Article D-6. The applicable paragraphs and figures governing the various types of construction are shown in Table AF-226.1.

AF-227 Welds Attaching Nonpressure Parts and Stiffeners

The rules governing the types of welds which may be used to join supports, lugs, brackets, stiffeners, and other attachments to the vessel wall are set forth in Article D-9. See AD-911 and AD-912 for rules governing welds for attachment to pressure parts. Only minor nonpressure parts may be attached by welding to forged vessels or forged parts when the carbon content of the material exceeds 0.35% by ladle analysis. See AF-741.

AF-227.1 Examination Requirements for Welds Attaching Nonpressure Parts and Stiffeners

(a) Note (1) to Column 1 of Table AF-241.1 permits reduced examination requirements under certain conditions. Otherwise, all welds attaching supports, lugs, brackets, stiffeners, and other nonpressure attachments to pressure parts (see Article D-9) shall be examined on all exposed surfaces by the magnetic particle or the liquid penetrant method in accordance with the requirements of Articles 9-1 or 9-2, whichever is applicable.

(b) The examination required in (a) above shall be made after postweld heat treatment, if performed, for attachment to materials covered by Column 2 of Table AF-241.1.

AF-228 Liquid Penetrant Examination

All austenitic chromium–nickel alloy steel welds, both butt and fillet, in vessels whose shell thickness exceeds $^3/_4$ in. (19 mm) shall be examined by the liquid penetrant method (see Article 9-2). This examination shall be made following heat treatment, if heat treatment is performed. All cracks shall be eliminated.

AF-229 Surface Weld Metal Buildup

Construction in which deposits of weld metal are applied to the surface of base metal for the purpose of:

(a) restoring the thickness of the base consideration; or

(b) modifying the configuration of weld joints in order to provide the tapered transition requirements of AD-420 or AF-142.3 shall be performed in accordance with the requirements of AF-229 and AF-229.2.

AF-229.1 Procedure Qualification. A butt welding procedure qualification in accordance with the provisions of Section IX must be performed for the thickness of weld metal deposited, prior to production welding.

AF-229.2 Examination Requirements

(a) All weld metal buildup must be examined over the full surface of the deposit by either a magnetic particle method in accordance with Article 9-1 or by a liquid penetrant method in accordance with Article 9-2.

(b) When such surface weld metal buildup is used in welded joints which require radiographic examination, the weld metal buildup shall be included in the examination.

AF-230 MISCELLANEOUS WELDING REQUIREMENTS

AF-231 Preparation of Reverse Side of Double-Welded Joints

The reverse side of double-welded joints shall be prepared by chipping, grinding, or melting out, so as to

TABLE AF-226.1

Type of Construction	Applicable Paragraph	Applicable Fig. No.
Nozzle necks abutting vessel wall without added reinforcing element	AD-610	AD-610.1 sketches (a) and (b)
Inserted nozzles without added reinforcing element	AD-611	AD-610.1 sketches (c), (d), (d-1), (e), (e-1), (f), and (g)
Inserted nozzles with added reinforcing element	AD-612	AD-612.1 sketches (a), (b), and (c)
Nozzles with integral reinforcement	AD-613	AD-613.1 sketches (a), (b), (c), (c-1), (d), (e), and (f); AD-610.1 all sketches
Fittings with internal threads attached by welds	AD-620	AD-612.1 sketches (e), (f), (g), and (h)
Welded connections not subject to external loadings	AD-621	AD-621.1
Studded connections subject to external loadings	AD-630	. . .
Studded pad connections not subject to external loading	AD-635	AD-612.1 sketch (d)

secure sound metal at the base of weld metal first deposited, before applying weld metal from the reverse side. These requirements are not intended to apply to any process of welding by which proper fusion and penetration are otherwise obtained and by which the base of the weld remains free from impurities.

AF-232 Aligning and Separating Components of Single-Welded Joints

Where single-welded joints are used, particular care shall be taken in aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joint for its full length.

AF-233 Precautions to Be Taken When Welding Is Restarted

If the welding is stopped for any reason, extra care shall be taken in restarting to get the required penetration and fusion.

AF-234 Peening

(a) Weld metal and heat affected zones may be peened by manual, electric, or pneumatic means when it is deemed necessary or helpful to control distortion, to relieve residual stresses, or to improve the quality of the weld. Peening shall not be used on the initial (root) layer of weld metal nor on the final (face) layer unless the weld is subsequently postweld heat treated. In no case, however, is peening to be performed in lieu of any postweld heat treatment required by these rules.

(b) Controlled shot peening and other similar methods, which are intended only to enhance surface properties of the vessel or vessel parts, shall be performed after any nondestructive examinations and pressure tests required by these rules.

AF-235 Identification Markings or Records for Welders and Welding Operators

(a) Each welder and welding operator shall stamp the identifying number, letter, or symbol, assigned by the Manufacturer, on or adjacent to and at intervals of not more than 3 ft (1.0 m) along the welds which he makes in plates $^1/_4$ in. (6 mm) and over in thickness, or a record shall be kept by the Manufacturer of those employed on welding each joint, which shall be available to the Inspector.

(b) When a multiple number of permanent nonpressure part load bearing attachment welds, nonload-bearing welds, such as stud welds, or special welds, such as tube-to-tubesheet welds, are made on a vessel, the Manufacturer need not identify the welder or welding operator that welded each individual joint, provided:

(1) the Manufacturer's Quality Control System includes a procedure that will identify the welders or welding operators that made such welds on each vessel so that the Inspector can verify that the welders or welding operators were all properly qualified;

(2) the welds in each category are all of the same type and configuration and are welded with the same Welding Procedure Specification.

(c) Permanent identification of welders or welding operators making tack welds that become part of the final pressure weld is not required, provided the Manufacturer's Quality Control System includes a procedure to permit the Inspector to verify that such tack welds were made by qualified welders or welding operators.

AF-236 Friction Welding Visual Examination

The welded joint between two members joined by the inertia and continuous drive friction welding processes shall be a full penetration weld. Visual examination of the as-welded flash roll of each weld shall be made as an in-process check. The weld upset shall meet the specified amount within ±10%. The flash shall be removed to sound metal.

AF-237 Capacitor Discharge Welding

Capacitor discharge welding may be used for welding temporary attachments and permanent nonstructural attachments without postweld heat treatment, provided the following requirements are met.

(a) A Welding Procedure Specification shall be prepared in accordance with Section IX, insofar as possible describing the capacitor discharge equipment, the combination of materials to be joined, and the technique of application. Qualification of the Welding Procedure is not required.

(b) The energy output shall be limited to 125 W–sec (425 Btu/hr).

AF-240 SUMMARY OF JOINTS PERMITTED AND THEIR EXAMINATION

AF-241 Types of Joints Permitted

Article D-4 establishes the types of joints permitted, according to location, in vessels and their components. Article D-6 establishes rules for attaching nozzles and other pressure connections by welding. Likewise, Article D-9 gives rules for attaching nonpressure parts and stiffeners. The requirements of these Articles are summarized in Table AF-241.1.

AF-241.1 Examination Requirements. In addition to summarizing the types of joints permitted, Table AF-241.1 gives the concomitant examination requirements as set forth in AF-221 through AF-228, AF-652, and AF-653. Unless specifically exempted, all welds shall be examined as required by these paragraphs and by Table AF-241.1.

AF-250 REPAIR OF WELD DEFECTS

AF-251 Removal of Unacceptable Defects

Unacceptable defects detected visually or by the examinations described in Articles I-5, 9-1, 9-2, or 9-3 and defects detected by leakage tests shall be removed by mechanical means or by thermal gouging processes.

AF-252 Rewelding of Areas to Be Repaired

The areas to be repaired shall be rewelded by qualified welders using qualified welding procedures.

AF-253 Examination of Repaired Welds

Repaired welds shall be reexamined by the methods of the original examination of the weld. The repaired weld shall not be accepted unless the examination shows the repair to be satisfactory.

AF-254 Postweld Heat Treatment of Repaired Welds

The postweld heat treating rules in Article F-4 shall apply to all weld repairs.

AF-260 WELDING TEST PLATES

AF-261 Nonferrous Vessels

If a vessel of welded titanium construction incorporates joints of Categories A and B as described in AD-400, a production test plate of the same specification, grade, and thickness shall be made of sufficient size to provide at least one face and one root bend specimen or two side bend specimens dependent upon plate thickness. Where longitudinal joints are involved, the test plate shall be attached to one end of the longitudinal joint and welded continuously with the joint. Where circumferential joints only are involved, the test plate need not be attached but shall be welded along with the joint, and each welder or welding operator shall deposit weld metal in the test plate at the location and proportional to that deposited in the production weld. Test plates shall represent each welding

TABLE AF-241.1
PERMITTED TYPES OF WELDS AND REQUIRED EXAMINATION

COLUMN 1 [Notes (1), (2)]					
	Materials P-No. 1 Groups 1, 2, and 3; P-No. 8 Groups 1 and 2; P-No. 9A Group 1; SA-387 Grade 12 Only of P-No. 4 Group 1; and P-No. 3 Group 3 Except SA-302				
Joint Category or Type of Connection	Joint Design			Fabrication and Examination	
	Type Weld	Applicable Paragraphs	Applicable Figures	Exam. Method	Remarks
Category A	No. 1 B	AD-411	. . .	RT	See AF-221.2
Category B	No. 1 or 2 B	AD-412	. . .	RT	See AF-221.2 and AF-222.3
Category C	No. 1 B	AD-413	AD-701.1 3-310.1	RT	See AF-221.2
	FP	AD-413	AD-701.3 3-310.1	RT or UT	Shell thk. > $2\frac{1}{2}$ in. (63 mm) See AF-223.2(c)
	FP	AD-413	AD-701.3 3-310.1	MT or PT	Shell thk. ≤ $2\frac{1}{2}$ in. (63 mm) See AF-223.2(c)
	FW	AD-413	3-310.1(b)	MT or PT	See AF-225 and AD-711.1 for limitations
Category D	No. 1 B	AD-414	AD-613.1	RT	See AF-221.2
	FP	AD-414 AD-601	AD-610.1	RT or UT	Openings > 6 in. (150 mm) ϕ in shells > $2\frac{1}{2}$ in. (63 mm) thk. See AF-223.2(c)
	FP	AD-414 AD-601	AD-610.1	MT or PT	Openings ≤ 6 in. (150 mm) ϕ or openings > 6 in. (150 mm) ϕ in shells ≤ $2\frac{1}{2}$ in. (63 mm) thk. See AF-223.2(c)
	FP + FW (pads)	AD-414	AD-612.1	MT or PT	See AD-570 for limitations
	FW	AD-414	AD-612.1	MT or PT	See AD-620 or AD-635 for limitations
	PP	AD-414.1	AD-621.1	MT or PT	See AD-621 for limitations

process or combination of processes or a change from machine to manual or vice versa. At least one test plate is required for each vessel, provided not over 100 ft (30 m) of Category A or B joints are involved. An additional test plate, meeting the same requirements as outlined above, shall be made for each additional 100 ft (30 m) of Category A or B joints involved. The bend specimens shall be prepared and tested in accordance with Section IX, QW-160. Failure of either bend specimen constitutes rejection of the weld.

TABLE AF-241.1
PERMITTED TYPES OF WELDS AND REQUIRED EXAMINATION (CONT'D)

COLUMN 1 [Notes (1), (2)]					
	Materials P-No. 1 Groups 1, 2, and 3; P-No. 8 Groups 1 and 2; P-No. 9A Group 1; SA-387 Grade 12 Only of P-No. 4 Group 1; and P-No. 3 Group 3 Except SA-302				
Joint Category or Type of Connection	Joint Design			Fabrication and Examination	
	Type Weld	Applicable Paragraphs	Applicable Figures	Exam. Method	Remarks
Attachments	B FP FP + FW PP + FW FW	AD-911	. . .	MT or PT	See AF-227.1
Austenitic Welds	All	. . .	. . .	PT	P-No. 8 shells > $3/4$ in. (19 mm) After PHWT, if done, see AF-228
Nonferrous Welds	. . .	. . .	. . .	. . .	. . .

TABLE AF-241.1
PERMITTED TYPES OF WELDS AND REQUIRED EXAMINATION (CONT'D)

COLUMN 2 [Note (2)]					
	Materials Not Listed in Columns 1, 3, and 4				
	Joint Design			Fabrication and Examination	
Joint Category or Type of Connection	Type Weld	Applicable Paragraphs	Applicable Figures	Exam. Method	Remarks
Category A	No. 1 B	AD-411	. . .	RT	See AF-221.2
Category B	No. 1 or 2 B	AD-412	. . .	RT	See AF-221.2 and AF-222.3
Category C	No. 1 B	AD-413 AD-601	AD-701.1 3-310.1	RT	See AF-221.2
	FP	AD-413 AD-601	AD-701.3 3-310.1	RT or UT	Shell thk. > $2\frac{1}{2}$ in. (63 mm) See AF-223
	FP	AD-413	AD-701.3 3-310.1	MT or PT	Shell thk. < $2\frac{1}{2}$ in. (63 mm) After PWHT, if done, see AF-223.2(c) and (d)
Category D	No. 1 B	AD-414	AD-613.1	RT	See AF-221.2
	FP	AD-414 AD-601	AD-610.1	RT or UT	Openings > 6 in. (150 mm) ϕ in shells > $2\frac{1}{2}$ in. (63 mm) thk. See AF-223.2(c)
	FP	AD-414 AD-601	AD-610.1	MT or PT	Openings in shells ≤ $2\frac{1}{2}$ in. (63 mm) After PWHT, if done, see AF-223.2(c) and (d)
	PP	AD-414.1	AD-621.1	MT or PT	See AD-621 for limitations After PWHT, if done, see AF-223.2(d)
Attachments	B FP FP + FW PP + FW FW	AD-912	. . .	MT or PT	See AF-227.1 After PWHT, if done, see AF-223.2(d)
Austenitic Welds	. . .	. . .	. . .	. . .	. . .
Nonferrous Welds	. . .	. . .	. . .	. . .	. . .

TABLE AF-241.1
PERMITTED TYPES OF WELDS AND REQUIRED EXAMINATION (CONT'D)

COLUMN 3 [Note (2)]

	Materials in Table AQT-1 Except SA-372 Types IV & V for Forged Bottles [Note (3)]				
	Joint Design			Fabrication and Examination	
Joint Category or Type of Connection	Type Weld	Applicable Paragraphs	Applicable Figures	Exam. Method	Remarks
Category A	No. 1 B	AD-411	. . .	RT + MT or PT	See AF-651 and AF-653
Category B	No. 1 B	AD-415	. . .	RT + MT or PT	See AF-651 and AF-653
Category C	No. 1 B	AD-415	AD-701.1 3-310.1	RT + MT or PT	See AF-651 and AF-653
Category D	No. 1 B	AD-415	AD-613.1	RT + MT or PT	See AF-651 and AF-653
	FP	AD-415	AD-610.1	RT + UT + MT or PT	Openings in shells. Over 2 in. (50 mm) thk. only; see AF-652. See AF-653.
Attachments	B FP FP + FW PP + FW FW	AD-912	. . .	MT or PT	See AF-653
Austenitic Welds	. . .	. . .	. . .	. . .	. . .
Nonferrous Welds	. . .	. . .	. . .	. . .	. . .

TABLE AF-241.1
PERMITTED TYPES OF WELDS AND REQUIRED EXAMINATION (CONT'D)

COLUMN 4 [Note (2)]					
	Materials P-No. 21 to P-No. 25 Inclusive, P-No. 31 to P-No. 35 Inclusive, P-No. 41 to P-No. 45 Inclusive				
Joint Category or Type of Connection	Joint Design			Fabrication and Examination	
	Type Weld	Applicable Paragraphs	Applicable Figures	Exam. Method	Remarks
Category A	No. 1 B	AD-411	. . .	RT	See AF-221.2
Category B	No. 1 or 2 B	AD-412	. . .	RT	See AF-221.2 and AF-222.3
Category C	No. 1 B	AD-413	AD-701.1 3-310.1	RT	See AF-221.2
	FP	AD-413	AD-701.3 3-310.1	RT or UT	Shell thk. > $2\frac{1}{2}$ in. (63 mm) See AF-223.2(c)
	FP	AD-413	AD-701.3 3-310.1	PT	Shell thk. < $2\frac{1}{2}$ in. (63 mm) See AF-223.2(c)
Category D	No. 1 B	AD-414	AD-613.1	RT	See AF-221.2
	FP	AD-414 AD-601	AD-610.1	RT or UT	Openings > 6 in. (150 mm) ϕ in shells > $2\frac{1}{2}$ in. (63 mm) thk. See AF-223.2(c)
	FP	AD-414 AD-601	AD-610.1	PT	Openings ≤ 6 in. (150 mm) ϕ or openings > 6 in. (150 mm) ϕ in shells ≤ $2\frac{1}{2}$ in. (63 mm) thk. See AF-223.2(c)
	FP + FW (pads)	AD-414	AD-612.1	PT	See AD-570 for limitations
	FW	AD-414	AD-612.1	PT	See AD-620 or AD-635 for limitations
	PP	AD-414.1	AD-621.1	PT	See AD-621 for limitations
Attachments	B FP FP + FW PP + FW FW	AD-911	. . .	PT	See AF-227.1
Austenitic Welds	. . .	. . .	. . .	. . .	. . .
Nonferrous Welds	All	. . .	. . .	PT	P-No. 43, P-No. 44, and P-No. 45 After PWHT, if done

(Notes to Table AF-241.1 follow on next page)

TABLE AF-241.1
PERMITTED TYPES OF WELDS AND REQUIRED EXAMINATION (CONT'D)

NOMENCLATURE:

TYPE OF JOINT
- B = butt weld: Type No. 1 — see AF-221; Type No. 2 — see AF-222
- FP = full penetration weld except butt weld — see AF-223
- PP = partial penetration weld — see AF-224
- FW = fillet weld — see AF-225

METHOD OF EXAMINATION
- RT = complete radiography
- MT = magnetic particle
- PT = liquid penetrant
- UT = ultrasonic

TIME OF EXAMINATION
- PWHT = postweld heat treatment

NOTES:

(1) For vessels for which a fatigue analysis is not required and when materials over $1/2$ in. (13 mm) thick do not include SA-515 Gr. 70, SA-204, and SA-299, examination method substitutions may be made as follows.

(a) Visual examination may be substituted for MT or PT as follows:

Category	Weld Type	Conditions
C	FP & PP	When thinner of materials joined ≤ $1/2$ in. (13 mm)
D	FP	When thinner of materials joined ≤ $1/2$ in. (13 mm) and thicker of materials joined ≤ $1\frac{1}{4}$ in. (31 mm)
	Pad FW	Wherever pads are permitted
Attachments	All	When thinner of materials joined ≤ $1/2$ in. (13 mm) and thicker of materials joined ≤ $1\frac{1}{4}$ in. (31 mm)

(b) MT or PT may be substituted for RT or UT for butt type welds in Category C locations when the thinner of the materials does not exceed $1/2$ in. (13 mm) and the nominal diameter of the opening does not exceed 10 in. (254 mm).

(c) All welds made by the electron beam welding process shall also be ultrasonically examined for their entire length in accordance with the requirements of Article 9-3.

(2) Ultrasonic examination in accordance with Article 9-3 may be substituted for radiography for the final closure seam of a pressure vessel if the construction of the vessel does not permit interpretable radiographs in accordance with Code requirements. The absence of suitable radiographic equipment shall not be justification for such substitution. The written examination procedure shall be available to the Inspector and shall be proven by actual demonstration to the satisfaction of the Inspector to be capable of detecting and locating discontinuities described in this Division.

(3) Welding on forged bottles of SA-372 Types IV & V materials is limited to seal welds after final heat treatment. See AF-741 for minor attachment and repair welds permitted before final heat treatment. All welds permitted shall be examined before and after pressure test.

ARTICLE F-3
SPECIAL REQUIREMENTS FOR TUBE-TO-TUBESHEET WELDS

AF-300 MATERIAL REQUIREMENTS

Tubes may be attached to tubesheets by welding provided the tubes and tubesheets or tubesheet facings are of weldable materials covered by this Division.

AF-301 Preparing Holes in Tubesheets

Tube holes in tubesheets shall be drilled full size or they may be punched to three-quarters size and then drilled, reamed, or finished full size with a rotating cutter.

AF-301.1 Clearance Between Tubes and Tube Holes. The clearance between the outside surface of the tubes and the inside surfaces of the tube holes shall not exceed clearance used in the welding procedure qualification tests.

AF-301.2 Finish of Holes. The edges of the tubesheet at the tube holes on the side to be welded shall be free of burrs, and the edges of the tubesheet at the tube hole on the side opposite the weld shall have sharp corners removed. The surfaces of tube holes in tubesheets shall have a workmanship-like finish.

AF-310 WELD DESIGN AND JOINT PREPARATION

The weld dimensions and weld detail, and joint preparation, if used, shall comply with the details included in the Welding Procedure Specification.

AF-320 QUALIFICATION OF WELDING PROCEDURE AND OF WELDER OR WELDING OPERATOR

The welding procedure qualification and welder or welding operator qualification shall be in accordance with the rules in AF-321.

AF-321 Essential Variables

The welding procedure shall be set up as a new procedure specification and shall be completely requalified when any of the changes listed below are made in the procedure. Changes other than those given below may be made in a procedure without the necessity for requalification, provided the procedure specification is amended to show these changes.

AF-321.1 For All Welding Processes

(a) A change from one welding process to any other welding process or combination of welding processes.

(b) A change in P-Number classification of tube material in QW/QB-422 of Section IX. A separate qualification is required for each tube material which is not included under any P-Number.

(c) A change in the P-Number of the tubesheet material. The tubesheet may be of homogeneous material or have a cladding of wrought material or weld overlay. If welding is performed between the tube and cladding, the cladding shall be considered the base material. A separate qualification is required for welding tubes to base material or cladding material which is not included under any P-Number.

(d) Any of the following changes in the analysis of the weld metal to be deposited:

(1) a change from any A-Number in QW/QB-422 of Section IX to any other A-Number or to any F-Number in QW-432 or to any analysis not listed in the tables; except that each AISI type of A-No. 7 or A-No. 8 of QW/QB-422 shall require separate qualification;

(2) a change from any F-Number in QW-432 to any other F-Number or to any A-Number in QW/QB-422 or to any analysis not listed in the tables.

(e) For tubes of specified wall thickness of 0.100 in. or less, an increase or decrease of 10% of specified wall thickness or specified diameter. For specified wall thicknesses greater than 0.100 in. (2.5 mm), only one qualification test is required.

(f) A decrease of 10% or more in the specified width of the ligament between tube holes when the specified width of the ligament is less than the greater of $^3/_8$ in. (10 mm) or three times the specified tube wall thickness.

(g) The addition of other welding positions than those already qualified (see QW-461.1 of Section IX).

(h) A change in the specified preheating temperature range.

(i) A change in the specified postweld heat treating temperature.

(j) A change from multiple-pass to single-pass welding or vice versa.

AF-321.2 For Shielded Metal Arc Welding

(a) An increase in electrode diameter.

(b) A change from one F-Number in QW-432 to any other F-Number (QW-404.4 and QW-404.5 shall apply).

AF-321.3 For Inert Gas Consumable or Nonconsumable Electrode Welding

(a) A change in the configuration of the tubesheet at the tube hole edges, including the addition or omission of preplaced metal inserts.

(b) A change in the size or shape of preplaced metal inserts.

(c) A change from inert gas to another inert gas or to a mixture of inert gases.

(d) When using mixed inert gas shielding, a change of ±25% or 5 cu ft/hr (0.14 m^3/hr), whichever is the larger, in the rate of flow of the minor gas constituent.

(e) A change from inert gas or a mixture of inert gases to a shielding gas containing noninert gases; e.g., oxygen. This includes any deliberate change in the quantity of noninert gases.

(f) For inert gas tungsten arc process, the addition or omission of filler metal.

(g) A change in the nominal diameter of the electrode or filler metal.

AF-321.4 For Explosive Welding

(a) An increase or decrease in the specified tube wall thickness or diameter of 10% for all diameters and wall thicknesses instead of the provisions of AF-321.1(e).

(b) A change in the method of pressure application.

(c) A change in the type of explosive or a change in energy content of ±10%.

(d) A change of ±0.010 in. (±0.25 mm) in the placement of the charge from the tubesheet face.

(e) A change in the specified clearance between the tube and the tubesheet of ±10%.

AF-330 TEST ASSEMBLY

The procedure qualification shall be made on a test assembly which simulates the conditions to be used in production with respect to the tube hole pattern and the essential variables listed in AF-321. In addition, the thickness of the tubesheet in the test assembly shall be as thick as the production tubesheet, except it need not exceed 2 in. (50 mm). The minimum required number of weld joints shall be ten.

AF-334 Examination

The test assembly shall be examined by a liquid penetrant method in accordance with Article 9-2. Following this test, the assembly shall be sectioned longitudinally through each tube. [The thickness of the assembly may be reduced to $\frac{1}{2}$ in. (13 mm) prior to this.] The four faces of each tube exposed by sectioning shall be polished and etched with a suitable etchant and shall be visually examined for cracks. The weld throats of all sections (minimum leakage path) shall be not less than two-thirds of the specified tube wall thickness and shall be free from cracks on visual examination with 10× magnification.

AF-336 Performance Tests

The requirements for the performance qualification test for welders and welding operators shall be the same as those for the procedure qualification, except that the minimum required number of tubes in the test assembly shall be six. Any welder or welding operator who makes a procedure test that passes satisfactorily is thereby qualified.

ARTICLE F-4
HEAT TREATMENT OF WELDMENTS

AF-400 HEAT TREATMENT OF WELDMENTS

AF-401 Requirements for Preheating

The Welding Procedure Specification for the material being welded shall specify the minimum preheating requirements in accordance with the weld procedure qualification requirements of Section IX. Where preheating is not required by the welding procedure, preheating may be employed during welding to assist in completion of the welded joint. The need for and temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of the parts being joined, elevated temperature physical properties, and material thicknesses. Specific rules for preheating are not given in this Division. Some practices used for preheating are given in nonmandatory Appendix D, as a general guide for the materials listed by P-Numbers of Section IX. It is cautioned that the preheating listed therein does not necessarily ensure satisfactory completion of the welded joint, and requirements for individual materials within the P-Number listing may have preheating more or less restrictive than this general guide.

AF-402 Requirements for Postweld Heat Treatment[1]

Before applying the detailed requirements and exemptions in these paragraphs, satisfactory qualification of the welding procedures to be used shall be performed in accordance with all the variables of Section IX and AF-321, including conditions of postweld heat treatment or its omission, and the restrictions listed below. Except for nonferrous materials and except as otherwise provided in Table AF-402.1 and Table AF-402.2 for ferrous materials, all welds in pressure vessels or pressure vessel parts shall be given a postweld heat treatment at a temperature not less than that specified in those Tables when the nominal thickness as defined in AF-402.3, including corrosion allowance, exceeds the limits in those Tables. The exemptions for postweld heat treatment, as provided for in Tables AF-402.1 and AF-402.2, are not permitted when the vessel is designed for lethal service as defined in footnote 3 to AG-301.1(c), or when welding ferritic materials greater than $\frac{1}{8}$ in. (3.2 mm) thick with the electron beam welding process, or when welding P-No. 3, P-No. 4, P-No. 5A, P-No. 5B, P-No. 5C, P-No. 6, P-No. 7 (except for Type 405 and Type 410S), and P-No. 10 materials using the inertia and continuous drive friction welding process. The materials in Table AF-402.1 are listed in accordance with QW/QB-422 of Section IX and are also listed in the tables of stress intensity values in Subpart 1 of Section II, Part D.

AF-402.1 When Holding Temperatures and Times May Be Exceeded. Except where prohibited in Table AF-402.1, holding temperatures and/or holding times in excess of the minimum values given in Table AF-402.1 may be used (see AM-202). A time–temperature recording of all postweld heat treatments shall be provided for review by the Inspector. The holding time at temperature specified in Table AF-402.1 need not be continuous. It may be an accumulation of time of multiple postweld heat treat cycles.

AF-402.2 Heat Treatment of Pressure Parts Consisting of Different P-Number Groups. When pressure parts of two different P-Number groups are joined by welding, the postweld heat treatment shall be that specified in Table AF-402.1 with applicable notes for the material requiring the higher postweld heat treatment temperature. When nonpressure parts are welded to pressure parts, the postweld heat treatment temperature of the pressure part shall control.

AF-402.3 Definition of Nominal Thickness Governing Postweld Heat Treatment. Nominal thickness as used in Tables AF-402.1, AF-402.2, and AF-630.1 is the thickness of the welded joint as defined below. For

[1] Additional postweld heat treatment requirements may result from the requirements of Article T-2.

TABLE AF-402.1
REQUIREMENTS FOR POSTWELD HEAT TREATMENT OF PRESSURE PARTS AND ATTACHMENTS

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness (See AF-402.1)		
		Up to 2 in. (50 mm)	Over 2 to 5 in. (50 to 125 mm)	Over 5 in. (125 mm)
P-No. 1 Group Nos. 1, 2, 3	1,100 (593)	1 hr/in. (1 hr/25 mm), 15 min minimum	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)

NOTES:

(1) When it is impractical to postweld heat treat at the temperature specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures for longer periods of time in accordance with Table AF-402.2.

(2) Postweld heat treatment is mandatory under the following conditions:

(a) for welded joints over 1½ in. (38 mm) governing nominal thickness. Postweld heat treatment is mandatory for welded joints over 1¼ in. (31 mm) governing nominal thickness through 1½ in. (38 mm) governing nominal thickness unless preheat is applied at a minimum temperature of 200°F (93°C) during welding.

(b) for welded joints of all thicknesses if required by AG-301.1(c), except heat treatment is not mandatory under the conditions specified below:

(1) for groove welds not over ½ in. (13 mm) in size and fillet welds with a throat not over ½ in. (13 mm) that attach nozzle connections that have a finished inside diameter not greater than 2 in. (50 mm), provided the connections do not form ligaments that require an increase in shell or head thickness, and preheat to a minimum temperature of 200°F (93°C) is applied;

(2) for groove welds not over ½ in. (13 mm) in size or fillet welds with a throat thickness of ½ in. (13 mm) or less used for attaching nonpressure parts to pressure parts, provided preheat to a minimum temperature of 200°F (93°C) is applied when the thickness of the pressure part exceeds 1¼ in. (31 mm);

(3) for studs welded to pressure parts provided preheat to a minimum temperature of 200°F (93°C) is applied when the thickness of the pressure part exceeds 1¼ in. (31 mm);

(4) for corrosion resistant weld metal overlay cladding or for welds attaching corrosion resistant applied lining (see AF-551), provided preheat to a minimum temperature of 200°F (93°C) is maintained during application of the first layer when the thickness of the pressure part exceeds 1¼ in. (31 mm).

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness (See AF-402.1)		
		Up to 2 in. (50 mm)	Over 2 to 5 in. (50 to 125 mm)	Over 5 in. (125 mm)
P-No. 3 Group Nos. 1, 2, 3	1,100 (593)	1 hr/in. (1 hr/25 mm), 1 hr minimum	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)

NOTES:

(1) When it is impractical to postweld heat treat at the temperature specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures for longer periods of time in accordance with Table AF-402.2. When postweld heat treatment is performed in accordance with this Note, the vessel test plate required by Article T-2 shall receive the same heat treatment.

(2) Postweld heat treatment is mandatory for P-No. 3, Gr. No. 3 material in all thicknesses.

(3) Except for the exemptions in Note (4), postweld heat treatment is mandatory under the following conditions:

(a) on P-No. 3, Gr. No. 1 and P-No. 3, Gr. No. 2 material over ⅝ in. (16 mm) nominal thickness. For these materials, postweld heat treatment is mandatory on material up to and including ⅝ in. (16 mm) nominal thickness unless a welding procedure qualification described in AF-210.4 has been made in equal or greater thickness than the production weld.

(b) on material of all thicknesses if required by AG-301.1(c) or if for pressure parts subject to direct firing.

(4) For welding connections and attachments to pressure parts, postweld heat treatment is not mandatory under the conditions specified below:

(a) for attaching to pressure parts which have a specified maximum carbon content of not more than 0.25% (SA Material Specification carbon content, except when further limited by the purchaser to a value within the Specification limits) or to nonpressure parts with groove welds not over ½ in. (13 mm) in size or fillet welds having a throat thickness of ½ in. (13 mm) or less, provided preheat to a minimum temperature of 200°F (93°C) is applied;

(b) for circumferential butt welds in pipe or tube where the pipe or tube has both a nominal wall thickness of ½ in. (13 mm) or less and a specified maximum carbon content of not more than 0.25% (SA Material Specification carbon content, except when further limited by the purchaser to a value within the Specification limits);

(c) for studs welded to pressure parts which have a specified maximum carbon content of not more than 0.25% (SA Material Specification carbon content, except when further limited by the purchaser to a value within the Specification limits), provided preheat to a minimum temperature of 200°F (93°C) is applied;

(d) for corrosion resistant weld metal overlay cladding or for welds attaching corrosion resistant applied lining (see AF-551) when welded to pressure parts which have a specified maximum carbon content of not more than 0.25% (SA Material Specification carbon content, except when further limited by the purchaser to a value within the Specification limits), provided preheat to a minimum temperature of 200°F (93°C) is maintained during application of the first layer.

(5) If during the holding period of postweld heat treatment, the maximum time or temperature of any vessel component exceeds the provisions of AM-202, additional test coupons shall be made and tested.

(continued)

TABLE AF-402.1
REQUIREMENTS FOR POSTWELD HEAT TREATMENT OF PRESSURE PARTS AND ATTACHMENTS (CONT'D)

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness (See AF-402.1)		
		Up to 2 in. (50 mm)	Over 2 to 5 in. (50 to 125 mm)	Over 5 in. (125 mm)
P-No. 4 Group Nos. 1, 2	1,100 (593)	1 hr/in. (1 hr/25 mm), 1 hr minimum	1 hr/in. (1 hr/25 mm)	5 hr plus 15 min for each additional inch (25 mm) over 5 in. (125 mm)

NOTES:

(1) Except for exemptions in Note (2), postweld heat treatment is mandatory under the following conditions:

(a) on material of SA-202 Grades A and B over 5/8 in. (16 mm) nominal thickness. For these materials, postweld heat treatment is mandatory up to and including 5/8 in. (16 mm) nominal thickness unless a welding procedure qualification described in AF-210.4 has been made in equal or greater thickness than the production weld.

(b) on material of all thicknesses for pressure parts subject to direct firing or if required by AG-301.1(c);

(c) on all other P-No. 4 Gr. Nos. 1 and 2 materials.

(2) Postweld heat treatment is not mandatory under the conditions specified below:

(a) for circumferential butt welds in pipe or tube of P-No. 4 materials where the pipe or tubes comply with all of the following conditions:

(1) a maximum nominal outside diameter of 4 in. (100 mm);

(2) a maximum nominal thickness of 5/8 in. (16 mm);

(3) a maximum specified carbon content of not more than 0.15% (SA Material Specification carbon content, except when further limited by the purchaser to a value within the Specification limits);

(4) a minimum preheat of 250°F (121°C).

(b) for P-No. 4 pipe or tube materials meeting the requirements of (a)(1), (a)(2), and (a)(3) above, having nonpressure attachments fillet welded to them provided:

(1) the fillet welds have a maximum throat thickness of 1/2 in. (13 mm);

(2) a minimum preheat temperature of 250°F (121°C) is applied.

(c) for P-No. 4 pipe or tube materials meeting the requirements of (a)(1), (a)(2), and (a)(3) above, having studs welded to them provided a minimum preheat temperature of 250°F (121°C) is applied.

(3) If during the holding period of postweld heat treatment, the maximum time or temperature of any vessel component exceeds the provisions of AM-202, additional test coupons shall be made and tested.

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness (See AF-402.1)		
		Up to 2 in. (50 mm)	Over 2 to 5 in. (50 to 125 mm)	Over 5 in. (125 mm)
P-Nos. 5A, 5B Group No. 1, and 5C Group No. 1	1,250 (677)	1 hr/in. (1 hr/25 mm), 1 hr minimum	1 hr/in. (1 hr/25 mm)	5 hr plus 15 min for each additional inch (25 mm) over 5 in. (125 mm)
P-No. 5B, Group No. 2	1,300 (704)			

NOTES:

(1) Except for exemptions in Note (2), postweld heat treatment is mandatory.

(2) Postweld heat treatment is not mandatory under the following conditions:

(a) for circumferential butt welds in pipe or tubes where the pipe or tubes comply with all of the following conditions:

(1) a maximum specified chromium content of 3.0%;

(2) a maximum nominal outside diameter of 4 in. (100 mm);

(3) a maximum nominal thickness of 5/8 in. (16 mm);

(4) a maximum specified carbon content of not more than 0.15% (SA Material Specification carbon content, except when further limited by the purchaser to a value within the Specification limits);

(5) a minimum preheat of 300°F (149°C) is applied.

(b) for pipe or tube materials meeting the requirements of (a)(1), (a)(2), (a)(3), and (a)(4) above, having nonpressure attachments fillet welded to them provided:

(1) the fillet welds have a maximum throat thickness of 1/2 in. (13 mm);

(2) a minimum preheat temperature of 300°F (149°C) is applied.

(c) for pipe or tube materials meeting the requirements of (a)(1), (a)(2), (a)(3), and (a)(4) above, having studs welded to them provided a minimum preheat temperature of 300°F (149°C) is applied.

(3) If during the holding period of postweld heat treatment, the maximum time or temperature of any vessel component exceeds the provisions of AM-202, additional test coupons shall be made and tested.

(4) When it is impractical to postweld heat treat P-Nos. 5A, 5B Group No. 1, and 5C Group No. 1 materials at the temperature specified in this Table, it is permissible to perform the postweld heat treatment at 1,200°F (649°C) minimum provided that, for material up to 2 in. (50 mm) nominal thickness, the holding time is increased to the greater of 4 hr minimum or 4 hr/in. (4 hr/25 mm) of thickness; for thickness over 2 in. (50 mm), the specified holding times are multiplied by 4. The requirements of AT-112 must be accommodated in this reduction in postweld heat treatment.

(continued)

TABLE AF-402.1
REQUIREMENTS FOR POSTWELD HEAT TREATMENT OF PRESSURE PARTS AND ATTACHMENTS (CONT'D)

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness (See AF-402.1)		
		Up to 2 in. (50 mm)	Over 2 to 5 in. (50 to 125 mm)	Over 5 in. (125 mm)
P-No. 6 Group Nos. 1, 2, 3	1,250 (677)	1 hr/in. (1 hr/25 mm), 1 hr minimum	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)

NOTES:

(1) Postweld heat treatment is not required for vessels constructed of Type 410 material with carbon content not to exceed 0.08% and welded with electrodes that produce an austenitic chromium-nickel weld deposit or a nonair-hardening nickel-chromium iron weld deposit, provided the plate thickness at the welded joint does not exceed 3/8 in. (10 mm), and for thicknesses over 3/8 in. (10 mm) to 1 1/2 in. (38 mm) provided a preheat of 450°F (232°C) is maintained during welding and that the joints are completely radiographed.

(2) If during the holding period of postweld heat treatment, the maximum time or temperature of any vessel component exceeds the provisions of AM-202, additional test coupons shall be made and tested.

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness (See AF-402.1)		
		Up to 2 in. (50 mm)	Over 2 to 5 in. (50 to 125 mm)	Over 5 in. (125 mm)
P-No. 7 Group Nos. 1, 2	1,350 (732)	1 hr/in. (1 hr/25 mm), 1 hr minimum	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)

NOTES:

(1) Postweld heat treatment shall be performed as prescribed in AF-402 except that the cooling rate shall be a maximum of 100°F (38°C) per hour in the range above 1,200°F (649°C), after which the cooling rate shall be sufficiently rapid to prevent embrittlement. Postweld heat treatment is not required for vessels constructed of Type 405 material with carbon content not to exceed 0.08%, welded with electrodes that produce an austenitic chromium-nickel weld deposit or a nonair-hardening nickel-chromium-iron weld deposit, provided the plate thickness at the welded joint does not exceed 3/8 in. (10 mm), and for thicknesses over 3/8 in. (10 mm) to 1 1/2 in. (38 mm) provided a preheat of 450°F (232°C) is maintained during welding and that the joints are completely radiographed.

(2) If during the holding period of postweld heat treatment, the maximum time or temperature of any vessel component exceeds the provisions of AM-202, additional test coupons shall be made and tested.

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness (See AF-402.1)		
		Up to 2 in. (50 mm)	Over 2 to 5 in. (50 to 125 mm)	Over 5 in. (125 mm)
P-No. 8	...	...	...	...

NOTE:

(1) Postweld heat treatment is neither required nor prohibited for joints between austenitic stainless steels of the P-No. 8 group. See Nonmandatory Appendix D.

(continued)

TABLE AF-402.1
REQUIREMENTS FOR POSTWELD HEAT TREATMENT OF PRESSURE PARTS AND ATTACHMENTS (CONT'D)

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness (See AF-402.1)
P-No. 9A Group No. 1	1,100 (593)	1 hr minimum, plus 15 min/in. (15 min/25 mm) for thickness over 1 in. (25 mm)

NOTES:
(1) When it is impractical to postweld heat treat at the temperature specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures [1,000°F (538°C) minimum] for longer periods of time in accordance with Table AF-402.2. When postweld heat treatment is performed in accordance with this Note, the vessel test plate required by Article T-2 shall receive the same heat treatment.
(2) Except for exemptions in Note (3), postweld heat treatment is mandatory under the following conditions:
(a) on material over $^5/_8$ in. (16 mm) nominal thickness. For material up to and including $^5/_8$ in. (16 mm) nominal thickness, postweld heat treatment is mandatory unless a welding procedure qualification described in AF-210.4 has been made in equal or greater thickness than the production weld.
(b) on material of all thicknesses if required by AG-301.1(c) or if for pressure parts subject to direct firing.
(3) Postweld heat treatment is not mandatory under the conditions specified below:
(a) for circumferential butt welds in pipe or tubes where the pipe or tubes comply with all of the following conditions:
(1) a maximum nominal outside diameter of 4 in. (100 mm);
(2) a maximum thickness of $^1/_2$ in. (13 mm);
(3) a maximum specified carbon content of not more than 0.15% (SA Material Specification carbon content, except when further limited by the purchaser to a value within the Specification limits);
(4) a minimum preheat of 250°F (121°C).
(b) for pipe or tube materials meeting the requirements of (a)(1), (a)(2), and (a)(3) above, having attachments fillet welded to them, provided:
(1) the fillet welds have a throat thickness of $^1/_2$ in. (13 mm) or less;
(2) the material is preheated to 250°F (121°C) minimum. A lower preheating temperature may be used provided specifically controlled procedures necessary to produce sound welded joints are used. Such procedures shall include but not be limited to the following:
(a) the throat thickness of fillet welds shall be $^1/_2$ in. (13 mm) or less;
(b) the maximum continuous length of fillet welds shall be not over 4 in. (100 mm);
(c) the thickness of the test plate used in making the welding procedure qualification of Section IX shall not be less than that of the material to be welded.
(c) for attaching nonpressure parts to pressure parts with groove welds not over $^1/_2$ in. (13 mm) in size or fillet welds that have a throat thickness of $^1/_2$ in. (13 mm) or less, provided preheat to a minimum temperature of 200°F (93°C) is applied;
(d) for studs welded to pressure parts provided preheat to a minimum temperature of 200°F (93°C) is applied;
(e) for corrosion resistant weld metal overlay cladding or for welds attaching corrosion resistant applied lining (see AF-551), provided preheat to a minimum temperature of 200°F (93°C) is maintained during application of the first layer.
(4) If during the holding period of postweld heat treatment, the maximum time or temperature of any vessel component exceeds the provisions of AM-202, additional test coupons shall be made and tested.
(5) When the heating rate is less than 50°F/hr (28°C/hr) between 800°F (427°C) and the holding temperature, the additional 15 min/in. (15 min/25mm) holding time is not required. Additionally, where the manufacturer can provide evidence that the minimum temperature has been achieved throughout the thickness, the additional 15 min/in. (15 min/25 mm) holding time is not required.

(continued)

TABLE AF-402.1
REQUIREMENTS FOR POSTWELD HEAT TREATMENT OF PRESSURE PARTS AND ATTACHMENTS (CONT'D)

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness (See AF-402.1)
P-No. 9B Group No. 1	1,100 (593)	1 hr minimum, plus 15 min/in. (15 min/25 mm) for thickness over 1 in. (25 mm)

NOTES:

(1) When it is impractical to postweld heat treat at the temperature specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures [1,000°F (538°C) minimum] for longer periods of time in accordance with Table AF-402.2. When postweld heat treatment is performed in accordance with this Note, the vessel test plate required by Article T-2 shall receive the same heat treatment.

(2) The holding temperature for postweld heat treatment shall not exceed 1,175°F (635°C).

(3) Except for exemptions in Note (4), postweld heat treatment is mandatory under the following conditions:

(a) on material over $^5/_8$ in. (16 mm) nominal thickness. For material up to and including $^5/_8$ in. (16 mm) nominal thickness, postweld heat treatment is mandatory unless a welding procedure qualification described in AF-210.4 has been made in equal or greater thickness than the production weld.

(b) on material of all thicknesses if required by AG-301.1(c) or if for pressure parts subject to direct firing.

(4) Postweld heat treatment is not mandatory under the conditions specified below:

(a) for attaching nonpressure parts to pressure parts with groove welds not over $^1/_2$ in. (13 mm) in size or fillet welds that have a throat thickness of $^1/_2$ in. (13 mm) or less, provided preheat to a minimum temperature of 200°F (93°C) is applied;

(b) for studs welded to pressure parts provided preheat to a minimum temperature of 200°F (93°C) is applied;

(c) for corrosion resistant weld metal overlay cladding or for welds attaching corrosion resistant applied lining (see AF-551), provided preheat to a minimum temperature of 200°F (93°C) is maintained during application of the first layer.

(5) If during the holding period of postweld heat treatment, the maximum time or temperature of any vessel component exceeds the provisions of AM-202, additional test coupons shall be made and tested.

(6) When the heating rate is less than 50°F/hr (28°C/hr) between 800°F (427°C) and the holding temperature, the additional 15 min/in. (15 min/25 mm) holding time is not required. Additionally, where the manufacturer can provide evidence that the minimum temperature has been achieved throughout the thickness, the additional 15 min/in. (15 min/25 mm) holding time is not required.

(continued)

TABLE AF-402.1
REQUIREMENTS FOR POSTWELD HEAT TREATMENT OF PRESSURE PARTS AND ATTACHMENTS (CONT'D)

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness (See AF-402.1)
P-No. 10A Group No. 1	1,100 (593)	1 hr minimum, plus 15 min/in. (15 min/25 mm) for thickness over 1 in. (25 mm)

NOTES:

(1)(*a*) When it is impractical to postweld heat treat at the temperature specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures for longer periods of time in accordance with Table AF-402.2. When postweld heat treatment is performed in accordance with this Note, the vessel test plate required by Article T-2 shall receive the same heat treatment.

(*b*) Consideration should be given for possible embrittlement of materials containing up to 0.15% vanadium when postweld heat treating at the minimum temperature and at lower temperatures for longer holding times.

(2) Except for the exemptions in Note (3), postweld heat treatment is mandatory under the following conditions:

(*a*) on all thicknesses of SA-487 Cl. 1A material;

(*b*) on all other P-No. 10A materials over $\frac{5}{8}$ in. (16 mm) nominal thickness. For these materials, postweld heat treatment is mandatory on material up to and including $\frac{5}{8}$ in. (16 mm) nominal thickness, unless a welding procedure qualification described in AF-210.4 has been made in equal or greater thickness than the production weld.

(*c*) on material of all thicknesses if required by AG-301.1(c) or if for pressure parts subject to direct firing.

(3) Postweld heat treatment is not mandatory under the conditions specified below:

(*a*) for attaching to pressure parts which have a specified maximum carbon content of not more than 0.25% (SA Material Specification carbon content, except when further limited by the purchaser to a value within the Specification limits) or to nonpressure parts with groove welds not over $\frac{1}{2}$ in. (13 mm) in size or fillet welds having a throat thickness of $\frac{1}{2}$ in. (13 mm) or less, provided preheat to a minimum temperature of 200°F (93°C) is applied;

(*b*) for circumferential butt welds in pipes or tube where the pipe or tube has both a nominal wall thickness of $\frac{1}{2}$ in. (13 mm) or less and a specified maximum carbon content of not more than 0.25% (SA Material Specification carbon content, except when further limited by the purchaser to a value within the Specification limits), provided preheat to a minimum temperature of 200°F (93°C) is applied;

(*c*) for studs welded to pressure parts which have a specified maximum carbon content of not more than 0.25% (SA Material Specification carbon content, except when further limited by the purchaser to a value within the Specification limits), provided preheat to a minimum temperature of 200°F (93°C) is applied;

(*d*) for corrosion resistant weld metal overlay cladding or for welds attaching corrosion resistant applied lining (see AF-551) when welded to pressure parts which have a specified maximum carbon content of not more than 0.25% (SA Material Specification carbon content, except when further limited by the purchaser to a value within the Specification limits), provided preheat to a minimum temperature of 200°F (93°C) is maintained during application of the first layer.

(4) If during the holding period of postweld heat treatment, the maximum time or temperature of any vessel component exceeds the provisions of AM-202, additional test coupons shall be made and tested.

(5) When the heating rate is less than 50°F/hr (28°C/hr) between 800°F (427°C) and the holding temperature, the additional 15 min/in. (15 min/25 mm) holding time is not required. Additionally, where the manufacturer can provide evidence that the minimum temperature has been achieved throughout the thickness, the additional 15 min/in. (15 min/25 mm) holding time is not required.

(continued)

TABLE AF-402.1
REQUIREMENTS FOR POSTWELD HEAT TREATMENT OF PRESSURE PARTS AND ATTACHMENTS (CONT'D)

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness (See AF-402.1)
P-No. 10B Group No. 2	1,100 (593)	1 hr minimum, plus 15 min/in. (15 min/25 mm) for thickness over 1 in. (25 mm)

NOTES:
(1) Postweld heat treatment is mandatory for P-No. 10B materials for all thicknesses.
(2) If during the holding period of postweld heat treatment, the maximum time or temperature of any vessel component exceeds the provisions of AM-202, additional test coupons shall be made and tested.
(3) When the heating rate is less than 50°F/hr (28°C/hr) between 800°F (427°C) and the holding temperature, the additional 15 min/in. (15 min/25 mm) holding time is not required. Additionally, where the manufacturer can provide evidence that the minimum temperature has been achieved throughout the thickness, the additional 15 min/in. (15 min/25 mm) holding time is not required.

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness (See AF-402.1)
P-No. 10C Group No. 1	1,000 (538)	1 hr minimum, plus 15 min/in. (15 min/25 mm) for thickness over 1 in. (25 mm)

NOTES:
(1) When it is impractical to postweld heat treat at the temperatures specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures for longer periods of time in accordance with Table AF-402.2.
(2) Except for the exemptions in Note (3), postweld heat treatment is mandatory under the following conditions:
(a) for material over 1½ in. (38 mm) nominal thickness. Postweld heat treatment is mandatory on materials over 1¼ in. (31 mm) nominal thickness through 1½ in. (38 mm) nominal thickness unless preheat is applied at a minimum temperature of 200°F (93°C) during welding.
(b) on material of all thicknesses if required by AG-301.1(c).
(3) Postweld heat treatment is not mandatory under the conditions specified below:
(a) for groove welds not over ½ in. (13 mm) in size and fillet welds with throat not over ½ in. (13 mm) that attach nozzle connections that have a finished inside diameter not greater than 2 in. (50 mm), provided the connections do not form ligaments that require an increase in shell or head thickness and preheat to a minimum temperature of 200°F (93°C) is applied;
(b) for groove welds not over ½ in. (13 mm) in size or fillet welds having throat thickness of ½ in. (13 mm) or less used for attaching nonpressure parts to pressure parts and preheat to a minimum temperature of 200°F (93°C) is applied when the thickness of the pressure part exceeds 1¼ in. (31 mm);
(c) for studs welded to pressure parts, provided preheat to a minimum temperature of 200°F (93°C) is applied when the thickness of the pressure part exceeds 1¼ in. (31 mm);
(d) for corrosion resistant weld metal overlay cladding or for welds attaching corrosion resistant applied lining (see AF-551), provided preheat to a minimum temperature of 200°F (93°C) is maintained during application of the first layer when the thickness of the pressure part exceeds 1¼ in. (31 mm).
(4) When the heating rate is less than 50°F/hr (28°C/hr) between 800°F (427°C) and the holding temperature, the additional 15 min/in. (15 min/25 mm) holding time is not required. Additionally, where the manufacturer can provide evidence that the minimum temperature has been achieved throughout the thickness, the additional 15 min/in. (15 min/25 mm) holding time is not required.

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness (See AF-402.1)
P-No. 10F Group No. 6	1,100 (593)	1 hr minimum, plus 15 min/in. (15 min/25 mm) for thickness over 1 in. (25 mm)

NOTES:
(1) Postweld heat treatment is mandatory for P-No. 10F materials for all thicknesses.
(2) If during the holding period of postweld heat treatment, the maximum time or temperature of any vessel component exceeds the provisions of AM-202, additional test coupons shall be made and tested.
(3)cWhen the heating rate is less than 50°F/hr (28°C/hr) between 800°F (427°C) and the holding temperature, the additional 15 min/in. (15 min/25 mm) holding time is not required. Additionally, where the manufacturer can provide evidence that the minimum temperature has been achieved throughout the thickness, the additional 15 min/in. (15 min/25 mm) holding time is not required.

(continued)

TABLE AF-402.1
REQUIREMENTS FOR POSTWELD HEAT TREATMENT OF PRESSURE PARTS AND ATTACHMENTS (CONT'D)

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness (See AF-402.1)		
		Up to 2 in. (50 mm)	Over 2 to 5 in. (50 to 125 mm)	Over 5 in. (125 mm)
P-No. 10H Group No. 1	. . .	. . .	. . .	. . .

NOTE:
(1) For the austenitic–ferritic wrought or cast duplex stainless steels listed below, postweld heat treatment is neither required nor prohibited, but any heat treatment applied shall be performed as listed below and followed by liquid quenching or rapid cooling by other means:

Alloy	Postweld Heat Treatment Temperature, °F	Postweld Heat Treatment Temperature, °C
S32550	1,900–2,050	1 038–1 121
S31803	1,870–2,010	1 021–1 099
S32900 (0.08 max. C)	1,725–1,750	941–954
S31200	1,900–2,000	1 038–1 093
S31500	1,785–1,875	974–1 024
S32304	1,740–1,920	949–1 049
J93345	2,050 minimum	1 121 minimum
S32750	1,800–2,060	982–1 127
S32950	1,825–1,875	996–1 024

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness (See AF-402.1)
P-No. 10I Group No. 1	1,350 (732)	1 hr minimum, plus 15 min/in. (15 min/25 mm) for thickness over 1 in. (25 mm)

NOTES:
(1) The cooling rate shall be a maximum of 100°F/hr (56°C/hr) in the range above 1,200°F (649°C), after which the cooling rate shall be rapid to prevent embrittlement.
(2) Postweld heat treatment is neither required nor prohibited for a thickness of $^1\!/_2$ in. (13 mm) or less.
(3) For alloy S44635, the rules for ferritic chromium stainless steel shall apply, except that postweld heat treatment is neither prohibited nor required. If heat treatment is performed after forming or welding, it shall be performed at 1,850°F (1 010°C) minimum followed by rapid cooling to below 800°F (427°C).
(4) If during the holding period of postweld heat treatment, the maximum time or temperature of any vessel component exceeds the provisions of AM-202, additional test coupons shall be made and tested.
(5) When the heating rate is less than 50°F/hr (28°C/hr) between 800°F (427°C) and the holding temperature, the additional 15 min/in. (15 min/25 mm) holding time is not required. Additionally, where the manufacturer can provide evidence that the minimum temperature has been achieved throughout the thickness, the additional 15 min/in. (15 min/25 mm) holding time is not required.

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness (See AF-402.1)		
		Up to 2 in. (50 mm)	Over 2 to 5 in. (50 to 125 mm)	Over 5 in. (125 mm)
P-No. 10K Group No. 1	. . .	. . .	. . .	. . .

NOTES:
(1) For alloy S44660, the rules for ferritic chromium stainless steel shall apply, except that postweld heat treatment is neither required nor prohibited. If heat treatment is performed after forming or welding, it shall be performed at 1,500°F to 1,950°F (816°C to 1 066°C) for a period not to exceed 10 min followed by rapid cooling.
(2) If during the holding period of postweld heat treatment, the maximum time or temperature of any vessel component exceeds the provisions of AM-202, additional test coupons shall be made and tested.

TABLE AF-402.2
ALTERNATIVE POSTWELD
HEAT TREATMENT REQUIREMENTS FOR
CARBON AND LOW ALLOY STEELS
OF PRESSURE PARTS
AND ATTACHMENTS
(Applicable Only When Permitted in Table AF-402.1)

Decrease in Temperature Below Minimum Specified Temperature, °F (°C)	Minimum Holding Time at Decreased Temperature, hr [Note (1)]
50 (28)	2
100 (56)	4
150 (84) [Note (2)]	10
200 (111) [Note (2)]	20

NOTES:
(1) Minimum holding time for 1 in. (25 mm) thickness or less. Add 15 min/in. (15 min/25 mm) of thickness for thicknesses greater than 1 in. (25 mm).
(2) These lower postweld heat treatment temperatures permitted only for P-No. 1 Groups 1 and 2 materials.

pressure vessels or parts of pressure vessels being postweld heat treated in a furnace charge, it is the greatest weld thickness in any vessel or vessel part which has not previously been postweld heat treated.

(a) When the welded joint connects parts of the same thickness, using a full penetration butt weld, the nominal thickness is the total depth of the weld exclusive of any permitted weld reinforcement.

(b) For groove welds, the nominal thickness is the depth of the groove.

(c) For fillet welds, the nominal thickness is the throat dimension. If a fillet weld is used in conjunction with a groove weld, the nominal thickness is the depth of the groove or the throat dimension, whichever is greater.

(d) For stud welds, the nominal thickness shall be the diameter of the stud.

(e) When a welded joint connects parts of unequal thicknesses, the nominal thickness shall be the following:

(1) the thinner of two adjacent butt welded parts including head to shell connections;

(2) the thickness of the shell in connections to tubesheets, flat heads, covers, flanges, or similar constructions;

(3) in Figs. AD-610.1, AD-612.1, AD-613.1, and AD-621.1, the thickness of the weld across the nozzle neck or shell or head or reinforcing pad or attachment fillet weld, whichever is the greater;

(4) the thickness of the nozzle neck at the joint in nozzle neck to flange connections;

(5) the thickness of the weld at the point of attachment when a nonpressure part is welded to a pressure part;

(6) the thickness of the weld in tube-to-tubesheet connections.

(f) For repairs, the nominal thickness is the depth of the repair weld.

AF-402.4 Heat Treatment of Welds. Electroslag welds in ferritic materials over $1\frac{1}{2}$ in. (38 mm) in thickness at the joint shall be given a grain refining (austenitizing) heat treatment. For P-No. 1 materials only, the heating and cooling rate restrictions of AF-415(b) and (e) do not apply when the heat treatment following welding is in the austenitizing range.

AF-410 Heating Portions Before Joining and Local Heating of Circumferential Joints After Joining

The postweld heat treatment shall be performed in accordance with one of the procedures of this paragraph. In the procedures that follow, the soak band is defined as the volume of metal required to meet or exceed the minimum PWHT temperatures listed in Table AF-402.1. As a minimum, the soak band shall contain the weld, heat affected zone, and a portion of base metal adjacent to the weld being heat treated. The minimum width of this volume is the widest width of weld plus t or 2 in. (50 mm), whichever is less, on each side or end of the weld. The term t is the nominal thickness as defined in AF-402.3.

AF-410.1 Heating Vessel in a Furnace in One Heat. Heating the vessel as a whole in a closed furnace. This procedure is preferable and should be used whenever practicable.

AF-410.2 Heating Vessel Portions in a Furnace in More Than One Heat. Heating the vessel in more than one heat in a furnace, provided the overlap of the heated sections of the vessel is at least 5 ft (1.5 m). When this procedure is used, the portion outside of the furnace shall be shielded so that the temperature gradient is not harmful. The cross section where the vessel projects from the furnace shall not intersect a nozzle or other structural discontinuity.

AF-410.3 Heating Shell Sections, Heads, and Other Portions Before Joining. Heating of shell sections, heads, and/or portions of vessels for postweld heat treatment of longitudinal joints or complicated welded details before joining to make the completed vessel. When it is not practicable to postweld heat treat the complete vessel as a whole or in two or more heats as provided in AF-410.2, any circumferential joints not previously postweld heat treated may be locally postweld heat treated by any appropriate means that will assure the required uniformity. For such local heating, the soak band shall extend around the full circumference. The portion outside the soak band shall be protected so that the temperature gradient is not harmful. This procedure may also be used to postweld heat treat portions of new vessels after repairs.

AF-410.4 Heating Vessel Internally. The vessel may be heated internally by any appropriate means when adequate indicating and recording temperature devices are utilized to aid in the control and maintenance of a uniform distribution of temperature in the vessel wall. Previous to this operation, the vessel should be fully enclosed with insulating material.

AF-410.5 Local Heating of Nozzles to Vessels and External Attachments

(a) Heating a circumferential band containing nozzles or other welded attachments that require postweld heat treatment in such a manner that the entire band shall be brought up uniformly to the required temperature and held for the specified time. Except as modified in this paragraph below, the soak band shall extend around the entire vessel and shall include the nozzle or welded attachment. The portion of the vessel outside of the circumferential soak band shall be protected so that the temperature gradient is not harmful; this procedure may also be used for local heat treatment of circumferential joints in pipe, tubing, or nozzle necks. In the latter case, proximity to the shell increases thermal restraint, and the designer should provide adequate length to permit heat treatment without harmful gradients at the nozzle attachment, or heat a full circumferential band around the shell, including the nozzle.

The circumferential soak band width may be varied away from the nozzle or attachment weld requiring PWHT, provided the required soak band around the nozzle or attachment weld is heated to the required temperature and held for the required time. As an alternative to varying the soak band width, the temperature within the circumferential band away from the nozzle or attachment may be varied and need not reach the required temperature, provided the required soak band around the nozzle or attachment weld is heated to the required temperature, held for the required time, and the temperature gradient is not harmful throughout the heating and cooling cycle. The portion of the vessel outside of the circumferential soak band shall be protected so that the temperature gradient is not harmful.

(b) The procedure in (a) may also be used to postweld heat treat portions of vessels after repairs.

AF-410.6 Local Area Heating of Double Curvature Heads or Shells. Heating a local area around nozzles or welded attachments in the larger radius sections of a double curvature head or a spherical shell or head in such a manner that the area is brought up uniformly to the required temperature and held for the specified time. The soak band shall include the nozzle or welded attachment. The minimum soak band size shall be a circle whose radius is the widest width of the weld attaching the nozzle, reinforcing plate, or structural attachment to the shell, plus t or 2 in. (50 mm), whichever is less. The portion of the vessel outside of the soak band shall be protected so that the temperature gradient is not harmful.

AF-410.7 Heating of Other Configurations. Local area heating of other configurations not addressed in AF-410.1 through AF-410.6 is permitted provided that other measures (based upon sufficiently similar documented experience or evaluation) are taken that consider the effect of thermal gradients, all significant structural discontinuities (such as nozzles, attachments, head-to-shell junctions), and any mechanical loads which may be present during PWHT. The portion of the vessel outside of the soak band shall be protected so that the temperature gradient is not harmful. The soak band shall include a circle that extends beyond the edges of the attachment weld in all directions by a minimum of t or 2 in. (50 mm), whichever is less.

AF-415 Operation of Postweld Heat Treatment

The operation of postweld heat treatment shall be carried out by one of the procedures given in AF-410 in accordance with the following requirements.

(a) The temperature of the furnace shall not exceed 800°F (427°C) at the time the vessel or part is placed in it.

(b) Above 800°F (427°C), the rate of heating shall be not more than 400°F/hr (222°C/hr) divided by the maximum metal thickness of the shell or head plate in inches, but in no case more than 400°F/hr (222°C/hr) and in no case need it be less than 100°F/hr (56°C/hr). During the heating period there shall not be a greater variation in temperature throughout the portion of the vessel being heated than 250°F (139°C) within any 15 ft (4.6 m) interval of length.

(c) The vessel or vessel part shall be held at or above the temperature specified in Table AF-402.1 or Table AF-402.2 for the period of time specified in the Tables. During the holding period, there shall not be a difference greater than 150°F (83°C) between the highest and lowest temperatures throughout the portion of the vessel being heated, except where the range is further limited in Table AF-402.1.

(d) During the heating and holding periods, the furnace atmosphere shall be so controlled as to avoid excessive oxidation of the surface of the vessel. The furnace shall

be of such design as to prevent direct impingement of the flame on the vessel.

(e) Above 800°F (427°C), cooling shall be done in a closed furnace or cooling chamber at a rate not greater than 500°F/hr (278°C/hr) divided by the maximum metal thickness of the shell or head plate in inches, but in no case need it be less than 100°F/hr (56°C/hr). From 800°F (427°C) the vessel may be cooled in still air.

AF-420 Postweld Heat Treatment After Repairs or Alterations

Except as permitted in AF-420.1, vessels or parts of vessels that have been postweld heat treated, in accordance with the requirements of this Article, shall again be postweld heat treated after repairs have been made.

AF-420.1 Weld Repairs Made After Postweld Heat Treatment. Weld repairs to P-No. 1 Gr. Nos. 1–3 materials and to P-No. 3 Gr. Nos. 1–3 materials and to the weld metals used to join these materials may be made after the final PWHT but prior to the final hydrostatic test, without additional PWHT, provided that PWHT is not required as a service requirement in accordance with AG-301.1(c), except for the exemptions in Table AF-402.1, or provided that the material is not required to be impact tested to qualify for toughness properties per AM-204. The welded repairs shall meet the requirements of (a) through (f) below. These requirements do not apply when the welded repairs are minor restorations of the material surface such as those required after the removal of construction fixtures and provided that the surface is not exposed to the vessel contents.

(a) The Manufacturer shall give prior notification of the repair to the user or to his designated agent and shall not proceed until acceptance has been obtained. Such repairs shall be recorded on the Data Report.

(b) The total repair depth shall not exceed $1\frac{1}{2}$ in. (38 mm) for P-No. 1 Gr. Nos. 1–3 materials and $\frac{5}{8}$ in. (16 mm) for P-No. 3 Gr. Nos. 1–3 materials. The total depth of a weld repair shall be taken as the sum of the depths for repairs made from both sides of a weld at a given location.

(c) After removal of the defect, the groove shall be examined, using either the magnetic particle or the liquid penetrant examination methods, in accordance with Article 9-1 for MT and Article 9-2 for PT.

(d) In addition to the requirements of Section IX for qualification of Welding Procedure Specifications for groove welds, the following requirements shall apply.

(1) The weld shall be deposited by the manual shielded metal arc process using low hydrogen electrodes. The electrodes shall be properly conditioned in accordance with Section II, Part C, SFA-5.5, A5.6. The maximum bead width shall be four times the electrode core diameter.

(2) For P-No. 1 Gr. Nos. 1–3 materials, the repair area shall be preheated and maintained at a minimum temperature of 200°F (93°C) during welding.

(3) For P-No. 3 Gr. Nos. 1–3 materials, the repair weld method shall be limited to the half bead weld repair and weld temper bead reinforcement technique. The repair area shall be preheated and maintained at a minimum temperature of 350°F (177°C) during welding. The maximum interpass temperature shall be 450°F (232°C). The initial layer of weld metal shall be deposited over the entire area using $\frac{1}{8}$ in. (3 mm) maximum diameter electrodes. Approximately one-half the thickness of this layer shall be removed by grinding before depositing subsequent layers. The subsequent weld layers shall be deposited using $\frac{5}{32}$ in. (4 mm) maximum diameter electrodes in such a manner as to assure tempering of the prior weld beads and their heat affected zones. A final temper bead weld shall be applied to a level above the surface being repaired without contacting the base material but close enough to the edge of the underlying weld bead to assure tempering of the base material heat affected zone. After completing all welding, the repair area shall be maintained at a temperature of 400°F (204°C) to 500°F (260°C) for a minimum of 4 hr. The final temper bead reinforcement layer shall be removed substantially flush with the surface of the base material.

(e) After the finished repair weld has reached ambient temperature, it shall be inspected using the same nondestructive examination that was used in (c) above, except that for P-No. 3 Gr. No. 3 materials, the examination shall be made after the material has been at ambient temperature for a minimum period of 48 hr to determine the presence of possible delayed cracking of the weld. If the examination is by magnetic particle method, only the alternating current yoke type is acceptable. In addition, welded repairs greater than $\frac{3}{8}$ in. (10 mm) deep in materials and in welds that are required to be radiographed by the rules of this Division shall be radiographically examined to the requirements of AI-500.

(f) The vessel shall be hydrostatically tested after making the welded repair.

ARTICLE F-5
SPECIAL REQUIREMENTS FOR WELDING CORROSION RESISTANT INTEGRAL OR WELD METAL OVERLAY CLAD OR LINED PARTS AND FOR COMPOSITE WELDS

AF-500 MATERIAL

AF-501 Corrosion Resistant Integral or Weld Metal Overlay Clad Base Material or Parts

Integral or weld metal overlay clad base material or parts having applied corrosion resistant linings shall conform to the requirements of AM-220 and AM-230.

AF-503 Inserted Strips in Clad Materials

The nominal thickness of inserted strips used to restore cladding at joints shall be equal to that of the nominal minimum thickness of cladding specified for the plates, backed if necessary with corrosion resistant weld metal deposited in the groove to bring the insert flush with the surface of the adjacent cladding. Insert strips shall not be used when cladding is considered part of the shell for strength purposes.

AF-505 Weld Metal Composition

Welds that are exposed to the corrosive action of the contents of the vessel should have a resistance to corrosion that is not substantially less than that of the corrosion resistant integral or weld metal overlay cladding or lining. The use of filler metal that will deposit weld metal with practically the same composition as the material joined is recommended. Weld metal of different composition may be used provided it has better mechanical properties, in the opinion of the Manufacturer, and the user is satisfied that its resistance to corrosion is satisfactory for the intended service. The columbium content of columbium-stabilized austenitic stainless steel weld metal shall not exceed 1.00%, except when a higher content is permitted in the material being welded.

AF-510 JOINTS IN CORROSION RESISTANT INTEGRAL OR WELD METAL OVERLAY CLADDING AND APPLIED LININGS

The types of joints and welding procedures used shall be such as to minimize the formation of brittle weld composition by the mixture of metals of corrosion resistant alloy and base material.

NOTE: Because of the different thermal coefficients of expansion of dissimilar metals, caution should be exercised in design and construction under provisions of these paragraphs in order to avoid difficulties in service under extreme temperature conditions or with unusual restraint of parts such as may occur at points of stress concentration.

AF-520 WELDING PROCEDURES

Welding procedures for corrosion resistant weld overlay, composite (clad) metals, and attachment of applied linings shall be prepared and qualified in accordance with the requirements of Section IX.

AF-540 METHODS TO BE USED IN ATTACHING APPLIED LININGS

Applied linings may be attached to the base material and other parts by any method and process of welding that is not excluded by the rules of this Division.

AF-550 POSTWELD HEAT TREATMENT[1] OF CLAD AND LINED WELDMENTS

AF-551 Requirements When Base Metal Must Be Postweld Heat Treated

Vessels or parts of vessels constructed of corrosion resistant integral or weld metal overlay clad or applied corrosion resistant lining material shall be postweld heat treated when the base material is required to be postweld heat treated. In applying these rules, the determining thickness shall be the total thickness of the base material.

When the thickness of the base material requires postweld heat treatment, it shall be performed after the application of corrosion resistant weld metal overlay cladding or applied corrosion resistant lining unless exempted by the notes of Table AF-402.1.

AF-552 Requirements When Base Metal or Lining Is Chromium Alloy Steel

Vessels or parts of vessels constructed of chromium alloy stainless steel cladded base material and those lined with chromium alloy stainless steel applied linings shall be postweld heat treated in all thicknesses, except that vessels clad or lined with Type 405 or Type 410S and welded with an austenitic electrode or non-air-hardening nickel–chromium–iron electrode need not be postweld heat treated unless required by AF-551.

AF-560 REQUIREMENTS FOR BASE MATERIAL WITH CORROSION RESISTANT INTEGRAL OR WELD METAL OVERLAY CLADDING

AF-561 Procedure Qualification for Groove Welds in Base Material With Corrosion Resistant Integral or Weld Metal Overlay Cladding

The requirements in Section IX, QW-217 for procedure qualification shall be followed.

AF-561.1 When the Integral or Weld Overlay Cladding Thickness Is Included in Design Thickness. The welding procedure for groove welds in integral or weld overlay shall be qualified as provided in AF-520 when any part of the cladding thickness of the cladded base material is included in the design calculations in accordance with AD-116.

AF-561.2 When the Integral or Weld Overlay Cladding Thickness Is Not Included in Design Thickness. When the cladding thickness is not included in the design calculations, the procedure for groove welds may be qualified as in AF-520, or the weld in the base joint or cladding joint may be qualified by itself with the rules in Section IX.

AF-562 Procedure Qualification for Alloy Welds in Base Metal

AF-562.1 For Groove Joints. Groove joints in basemetal plates and parts may be made with corrosion resistant alloy steel filler metal or groove joints may be made between corrosion resistant alloy steel and carbon or low alloy steel, provided the welding procedure and the welders have been qualified in accordance with the requirements of Section IX for the combination of materials used. Some applications of this rule are base metal welded with alloy steel electrodes and alloy nozzles welded to carbon steel shells.

AF-562.2 For Fillet Welds. Fillet welds of corrosion resistant metal deposited in contact with two materials of dissimilar composition may be used for attachments covered by Article F-3 and for any other use permitted by this Division. The qualification of welding procedures and welders to be used on fillet welds for a given combination of materials and alloy weld metal shall be made in accordance with AF-321.

AF-563 Performance Qualification for Groove Welds in Base Material With Corrosion Resistant Integral or Weld Metal Overlay Cladding

Welders and welding operators shall be qualified in accordance with the requirements of Section IX.

AF-570 EXAMINATION REQUIREMENTS

AF-571 Examination of Chromium Alloy Cladding or Lining

The joints between chromium alloy cladding layers or liner sheets shall be examined for cracks as follows.

(a) Joints welded with straight chromium alloy filler metal shall be examined throughout their full length. Chromium alloy welds in continuous contact with the welds in the base metal shall be examined by the radiographic methods. Liner welds that are attached to the base metal, but merely cross the seams in the base metal, may be examined by any method that will disclose surface cracks.

(b) Joints welded with austenitic chromium–nickel steel filler metal or non-air-hardening nickel–chromium–

[1] Postweld heat treatment temperatures may be in the carbide precipitation range for unstabilized austenitic chromium–nickel steel, as well as within the range where a sigma phase may form. Improper treatment could result in material of inferior physical properties and inferior corrosion resistance and could result in the ultimate failure of the vessel.

iron filler metal shall be given a radiographic spot examination in accordance with the methods described in Article I-5. For lined construction, at least one spot examination shall include a portion of the liner weld that contacts weld metal in the base plate.

AF-572 Examination of Vessels and Parts

Vessels or parts of vessels constructed of integral or weld metal overlay clad base material and those having applied corrosion resistant linings shall have welded joints radiographed as required by the rules in Article F-2. In addition, all welds made by the electroslag welding process in ferritic materials shall be ultrasonically examined in accordance with the requirements of Article 9-3. This ultrasonic examination shall be done following the grain refining (austenitizing) heat treatment or postweld heat treatment. Ultrasonic examination for the final closure seam of a vessel may be substituted for radiography if construction does not permit interpretable radiography. See Note (3) to Table AF-241.1 for requirements. All welds made by the electron beam welding process shall also be ultrasonically examined for their entire length in accordance with the requirements of Article 9-3.

AF-572.1 Examination of Base Plates Protected by a Strip Covering. When the base material weld in integral or weld metal overlay clad or lined construction is protected by a covering strip or sheet of corrosion resistant material applied over the weld in the base material to complete the cladding or lining, any radiographic examination required by the rules in Article F-2 may be made on the completed weld in the base plate before the covering is attached.

AF-572.2 Examination of Base Plates Protected by an Alloy Weld. The radiographic examination required by the rules in Article F-2 shall be made after the joint, including the corrosion resistant layer, is complete, except that the radiographic examination may be made on the weld in the base material before the alloy cover weld is deposited, provided the following requirements are met.

(a) The thickness of the base material at the welded joint is not less than that required by the design calculation.

(b) The corrosion resistant alloy weld deposit is non-air-hardening.

(c) The completed alloy weld deposit is examined by any method that will detect cracks.

AF-580 INSPECTION AND TESTS

AF-581 General Requirements

The rules in the following paragraphs apply specifically to the inspection and testing of unfired pressure vessels and vessel parts constructed of integral or weld metal overlay clad base material and those having applied corrosion resistant linings, and shall be used in conjunction with the general requirements for inspection in Part AI and for testing in Part AT that pertain to the method of fabrication used.

AF-582 Tightness of Applied Lining

A test for pressure tightness of the applied lining that will be appropriate for the intended service is recommended, but the details of the test shall be a matter for agreement between the user and the Manufacturer. The test should be such as to assure freedom from damage to the load-carrying base material. When rapid corrosion of the base material is to be expected from contact with the contents of the vessel, particular care should be taken in devising and executing the tightness test.

AF-582.1 Inspection of Vessel Interior After Test for Tightness. Following the hydrostatic pressure test (see Article T-3), the interior of the vessel shall be inspected to determine if there is any seepage of the test fluid through the joints in the lining.

AF-582.2 Requirements When Seepage Is Detected. When the test fluid seeps behind the applied liner, there is danger that the fluid will remain in place until the vessel is put in service. In cases where the operating temperature of the vessel is above the boiling point of the test fluid, the vessel should be heated slowly for a sufficient time to drive out all test fluid from behind the applied liner without damage to the liner. This heating operation may be performed at the vessel manufacturing plant or at the plant where the vessel is being installed. After the test fluid is driven out, the lining should be repaired by welding. Repetition of the radiography, the heat treatment, or the hydrostatic test of the vessel after lining repairs is not required except when there is reason to suspect that the repair welds may have defects that penetrate into the base material, in which case an Inspector shall decide which one or more shall be repeated.

AF-590 STAMPING AND REPORTS

The provisions for stamping and reports in Part AS shall apply to vessels that are constructed of integral or weld metal overlay cladded base material and those having applied corrosion resistant linings, with the following supplements to the Manufacturer's Data Reports:

(a) include specification and type of lining material;

(b) include applicable paragraph under which the shell and heads were designed.

ARTICLE F-6
SPECIAL REQUIREMENTS FOR FERRITIC STEELS WITH TENSILE PROPERTIES ENHANCED BY QUENCHING AND TEMPERING

AF-600 GENERAL

The following rules are applicable to steels suitable for welded vessel parts, the tensile properties of which have been enhanced by quenching and tempering heat treatments listed in Table AF-630.1, and shall be used in conjunction with the general requirements for fabrication in Part AF when applicable and with the requirements of Parts AM and AD of this Division. The provisions of AM-202.1(d) shall also apply to materials whose tensile properties are enhanced by quenching and tempering heat treatment.

AF-601 Marking on Plates and Other Materials

Any steel stamping shall be done with "low stress" stamps, as commercially available. Steel stamping of all types may be omitted on material below $\frac{1}{2}$ in. (13 mm) in thickness. For the use of other markings in lieu of stamping, see AF-102.1.

AF-602 Requirements for Material Heat Treatment

All material shall be heat treated in accordance with the applicable material specification.

AF-605 Requirements for Heat Treating After Forming

(a) Pieces that are formed after quenching and tempering at a temperature lower than the final tempering temperature shall be heat treated in accordance with Table AF-630.1 when the extreme fiber elongation from forming exceeds 5% as determined by Eq. (1) or (2):

(1) for double curvature (for example, heads):

$$\%\ \text{extreme fiber elongation} = \frac{75t}{R_f}\left(1 - \frac{R_f}{R_o}\right) \qquad (1)$$

(2) for single curvature (for example, cylinders):

$$\%\ \text{extreme fiber elongation} = \frac{50t}{R_f}\left(1 - \frac{R_f}{R_o}\right) \qquad (2)$$

where

R_f = final centerline radius
R_o = original centerline radius (equals infinity for flat plate)
t = plate thickness

(b) Pieces formed at temperatures equal to or higher than the original tempering temperature shall be requenched and tempered in accordance with the applicable material specifications either before or after welding into the vessel.

AF-606 Minimum Thickness After Forming

The minimum thickness after forming of any section subject to pressure shall be $\frac{1}{4}$ in. (6 mm).

AF-610 WELDING REQUIREMENTS

AF-611 Qualification of Welding Procedures and Welders

The qualification of the welding procedure and the welders shall conform to the requirements of Section IX, and such qualification tests shall be performed on postweld heat treated specimens when a postweld heat treatment is used.

04 **AF-612 Additional Welding Requirements**

(a) Filler metal containing more than 0.06% vanadium shall not be used for weldments subject to postweld heat treatment.

(b) For welded vessels in which the welds are not subject to quenching and tempering, the deposited weld metal and the heat affected zone shall meet the impact test requirements of AM-204, except that the Charpy V-notch tests and requirements of Article T-2 shall apply.

(c) The following materials are exempt from production impact tests of the weld metal in accordance with AM-204 under the conditions given in (1)–(5) below:

Specification No.	UNS No.	P-No./Group No.
SA-353	K81340	11A/1
SA-522 Type I	K81340	11A/1
SA-553 Type I	K81340	11A/1
SA-553 Type II	K71340	11A/1
SA-645	K41583	11A/2

(1) One of the following high nickel alloy filler metals is used:

Specification No.	Classification	F-No.
SFA-5.11	ENiCrFe-2	43
SFA-5.11	ENiCrFe-3	43
SFA-5.11	ENiCrMo-3	43
SFA-5.11	ENiCrMo-6	43
SFA-5.14	ERNiCr-3	43
SFA-5.14	ERNiCrFe-6	43
SFA-5.14	ERNiCrMo-3	43
SFA-5.14	ERNiCrMo-4	44

(2) All required impact tests shall be performed as part of the procedure qualification tests as specified in AM-204.

(3) Production impact tests of the heat affected zone are performed in accordance with AM-204.

(4) The welding processes are limited to gas metal arc, shielded metal arc, and gas tungsten arc.

(5) The minimum allowable temperature of the vessel shall be not less than −320°F (−196°C).

(d) For SA-508 and SA-543 materials, the following, in addition to the variables in Section IX, QW-250, shall be considered as essential variables requiring requalification of the welding procedure.

(1) A change in filler metal SFA classification or to weld metal not covered by an SFA specification.

(2) An increase in the maximum interpass temperature or a decrease in the minimum specified preheat temperature. The specified range between the preheat and interpass temperatures shall not exceed 150°F (83°C).

(3) A change in the heat treatment (procedure qualification tests shall be subjected to heat treatment essentially equivalent to that encountered in fabrication of the vessel or vessel parts, including the maximum total aggregate time at temperature or temperatures and cooling rates).

(4) A change in the type of current (AC or DC), polarity, or a change in the specified range for amp, volt, or travel speed.

(5) A change in the thickness *T* of the welding procedure qualification test plate as follows:

(a) for welded joints which are quenched and tempered after welding, any increase in thickness [the minimum thickness qualified in all cases is $\frac{1}{4}$ in. (6 mm)];

(b) for welded joints which are not quenched and tempered after welding, any change as follows:

Thickness *T*	Change
Less than $\frac{5}{8}$ in. (16 mm)	Any decrease in thickness (the maximum thickness qualified is $2T$)
$\frac{5}{8}$ in. (16 mm) and over	Any departure from the range of $\frac{5}{8}$ in. (16 mm) to $2T$

(6) Consumables control, drying, storage, and exposure requirements shall be in accordance with the following.

(a) Due consideration shall be given to protection of electrodes and fluxes for all welding processes in order to minimize moisture absorption and surface contamination.

(b) Electrodes for shielded metal arc welding shall be low hydrogen type conforming to SFA-5.5. Electrodes shall be purchased or conditioned so as to have a coating moisture content not greater than 0.2% by weight. Once opened, electrode storage and handling must be controlled so as to minimize absorption of moisture from the ambient atmosphere. Practices used for controlling the moisture content shall be developed by the vessel Manufacturer or those recommended by the electrode manufacturer.

(7) Preheat shall be 100°F (38°C) minimum for material thickness up to and including $\frac{1}{2}$ in. (13 mm); 200°F (93°C) minimum for material above $\frac{1}{2}$ in. (13 mm) to and including $1\frac{1}{2}$ in. (38 mm); and 300°F (149°C) minimum above $1\frac{1}{2}$ in. (38 mm). Preheat temperature shall be maintained for a minimum of 2 hr after completion of the weld joint.

(e) For SA-517 and SA-592 materials, the requirements of (d)(1), (2), (3), (4), and (6), in addition to the variables in Section IX, QW-250, shall be considered as essential variables requiring requalification of the welding procedure.

(f) The PWHT as required by Table AF-630.1 may be waived for SA-517 and SA-592 materials with a nominal thickness over 0.58 in. to $1\frac{1}{4}$ in. (15 mm to 31 mm), inclusive, provided the following conditions are met:

(1) a minimum preheat of 200°F (93°C) and a maximum interpass of 400°F (204°C) are used;

(2) after completion of welding and without allowing the weldment to cool below the minimum preheat temperature, the temperature of the weldment is raised to a minimum of 400°F (204°C) and maintained at that temperature for at least 4 hr; and

(3) all welds are examined by nondestructive examination in accordance with the provisions of this Part.

AF-613 Preparation of Base Metal

Preparation of plate edges, welding bevels, and chamfers and similar operations involving the removal of metal shall be by machining, chipping, or grinding, by gas cutting or gouging, as provided in AF-613.1.

AF-613.1 Precautions Necessary When Using Gas Cutting or Gouging. When metal removal is accomplished by methods involving melting, such as gas cutting or arc air gouging, etc., it shall be done with due precautions to avoid cracking. Where the cut surfaces are not to be subsequently eliminated by fusion with weld deposits, they shall be removed by machining or grinding to a depth of at least $^1/_{16}$ in. (1.5 mm), followed by inspection by a magnetic particle or liquid penetrant method.

AF-614 Joint Alignment

AF-614.1 Longitudinal Joint Alignment. The longitudinal joint misalignment tolerances shall not exceed 20% of the nominal plate thickness, or $^3/_{32}$ in. (2.5 mm), whichever is less (instead of the values prescribed in AF-142.1).

AF-614.2 Circumferential Joint Alignment. The circumferential joint misalignment tolerances shall not exceed the following values (instead of the values prescribed in AF-142.1):

Plate Thickness	Tolerance
For plates up to and including $^{15}/_{16}$ in. (23 mm) in thickness	20% of nominal plate thickness
For plates over $^{15}/_{16}$ in. (23 mm) up to and including $1^1/_2$ in. (38 mm) in thickness	$^3/_{16}$ in. (5 mm)
For plates over $1^1/_2$ in. (38 mm) in thickness	$12^1/_2$% of nominal plate thickness but not more than $^1/_4$ in. (6 mm)

AF-615 Weld Finish

The requirements of AF-221 and AI-501 shall be met, except that the maximum weld reinforcement shall not exceed 10% of the plate thickness or $^1/_8$ in. (3 mm), whichever is less. The edge of the weld deposits shall merge smoothly into the base metal without undercuts or abrupt transitions; this requirement shall apply to fillet and groove welds as well as to butt welds.

AF-620 Permitted Types of Joints

For permitted types of joints, see AD-415.

AF-623 Attachment and Temporary Welds

AF-623.1 Material for Structural Attachments and Stiffening Rings. Except as permitted by AD-901, all permanent structural attachments and stiffening rings which are welded directly to pressure parts shall be made of material whose specified minimum yield strength is within ±20% of that of the material to which they are attached.

AF-623.2 Fabrication of Structural and Temporary Welds. Welds for pads, lifting lugs, and other nonpressure parts, as well as temporary lugs for alignment, shall be made by qualified welders in full compliance with a qualified welding procedure. The type of welds used shall conform to the requirements of AD-912; see AF-653 for examination requirements.

AF-623.3 Removal of Temporary Welds. Temporary welds shall be removed and the metal surface shall be restored to a smooth contour. The area shall be examined by a magnetic particle or liquid penetrant method for the detection and elimination of cracks or cracklike defects. If repair welding is required, it shall be in accordance with a qualified procedure, and the finished weld surface shall be examined as required in Article 9-1 or Article 9-2. Temporary welds and repair welds shall be considered the same as all other welds insofar as requirements for qualified operators and procedures and for heat treatment are concerned.

AF-630 POSTWELD HEAT TREATMENT

Vessels or parts of vessels constructed of quenched and tempered steels shall be postweld heat treated when required in Table AF-630.1, when welding ferritic materials greater than $^1/_8$ in. (3 mm) thick with the electron beam welding process, and when welding materials of all thicknesses using the inertia and continuous drive friction welding processes. When determining the thickness requiring postweld heat treatment in Table AF-630.1 for clad or weld deposit overlayed vessels or parts of vessels, the total thickness of the base material shall be employed.

TABLE AF-630.1
POSTWELD HEAT TREATMENT REQUIREMENTS FOR MATERIALS IN TABLE AQT-1

Spec. No.	Grade or Type	P-No. and Group No.	Nominal Thickness Requiring PWHT, in. (mm)	Postweld Heat Treatment Temp., °F	Postweld Heat Treatment Temp., °C	Holding Time hr/in. (hr/25 mm)	Holding Time min. hr
Plate Steels							
SA-353	9Ni	11A Gr. 1	Over 2 (50)	1,025–1,085	552–585	1	2
SA-517	Grade A	11B Gr. 1	Over 0.58 (15)	1,000–1,100	538–593	1	1/4
SA-517	Grade B	11B Gr. 4	Over 0.58 (15)	1,000–1,100	538–593	1	1/4
SA-517	Grade E	11B Gr. 2	Over 0.58 (15)	1,000–1,100	538–593	1	1/4
SA-517	Grade F	11B Gr. 3	Over 0.58 (15)	1,000–1,100	538–593	1	1/4
SA-517	Grade J	11B Gr. 6	Over 0.58 (15)	1,000–1,100	538–593	1	1/4
SA-517	Grade P	11B Gr. 8	Over 0.58 (15)	1,000–1,100	538–593	1	1/4
SA-533	Grades A, B, C & D, Cl. 2	3 Gr. 3	All	1,000–1,050	538–566	1/2	1/2
SA-533	Grades B & D, Cl. 3	11A Gr. 4	Over 0.58 (15)	1,000–1,050	538–566	1/2	1/2
SA-543	Types B & C, Cl. 1	11A Gr. 5	[Note (1)]	1,000–1,050	538–566	1	1
SA-543	Types B & C, Cl. 2	11A Gr. 5	[Note (1)]	1,000–1,050	538–566	1	1
SA-543	Types B & C, Cl. 3	11A Gr. 5	[Note (1)]	1,000–1,050	538–566	1	1
SA-553	Types I & II	11A Gr. 1	Over 2 (50)	1,025–1,085	552–585	1	2
SA-645	5Ni–1/4Mo	11A Gr. 2	Over 2 (50)	1,025–1,085	552–585	1	2
SA-724	Grades A & B	1 Gr. 4	None	NA	NA	NA	NA
SA-724	Grade C	1 Gr. 4	Over 1 1/2 (38)	1,050–1,150	566–621	1	1/2
Pipes and Tubes							
SA-333	Grade 8	11A Gr. 1	Over 2 (50)	1,025–1,085	552–585	1	2
SA-334	Grade 8	11A Gr. 1	Over 2 (50)	1,025–1,085	552–585	1	2
Forgings							
SA-372	Grade D	...	See SA-372 for heat treating requirements				
SA-372	Grade E, Cl. 70	...	See SA-372 for heat treating requirements				
SA-372	Grade F, Cl. 70	...	See SA-372 for heat treating requirements				
SA-372	Grade G, Cl. 70	...	See SA-372 for heat treating requirements				
SA-372	Grade H, Cl. 70	...	See SA-372 for heat treating requirements				
SA-372	Grade J, Cl. 70	...	See SA-372 for heat treating requirements				
SA-372	Grade J, Cl. 110	...	See SA-372 for heat treating requirements				
SA-508	Grade 4N, Cl. 1	11A Gr. 5	[Note (1)]	1,000–1,050	538–566	1	1
SA-508	Grade 4N, Cl. 2	11A Gr. 5	[Note (1)]	1,000–1,050	538–566	1	1
SA-522	Type 1	11A Gr. 1	Over 2 (50)	1,025–1,085	552–585	1	2
SA-592	Grade A	11B Gr. 1	Over 0.58 (15)	1,000–1,100	538–593	1	1/4
SA-592	Grade E	11B Gr. 2	Over 0.58 (15)	1,000–1,100	538–593	1	1/4
SA-592	Grade F	11B Gr. 3	Over 0.58 (15)	1,000–1,100	538–593	1	1/4

GENERAL NOTE: NA indicates not applicable.

NOTE:
(1) PWHT is neither required nor prohibited. Consideration should be given to the possibility of temper embrittlement. The cooling rate from PWHT, when used, shall not be slower than that obtained by cooling in still air.

AF-631 Requirements for Postweld Heat Treatment

Postweld heat treatment shall be performed in accordance with Article F-4, as modified by the requirements of Table AF-630.1. In no case shall the PWHT temperature exceed the tempering temperature. PWHT and tempering may be accomplished concurrently. The maximum cooling rate established in AF-415(e) need not apply. Where accelerated cooling from the tempering temperature is required by the material specification, the same minimum cooling rate shall apply to PWHT.

AF-631.1 Postweld Heat Treatment of Connections and Attachments. All welding of connections and attachments shall be postweld heat treated whenever required by Table AF-630.1 based on the greatest thickness of material at the point of attachment to the head or shell (see AF-402.1 and AF-402.2).

AF-635 Heat Treatment Procedure

AF-635.1 Heating Furnace. Furnaces for heating and for quenching and tempering shall be provided with suitable equipment for the automatic recording of temperatures. The metal temperature of the vessel or vessel part during the holding period shall be recorded and shall be controlled within ±25°F (±14°C).

AF-635.2 Liquid Quenching of Flat Plates or Parts. Liquid quenching of flat plates and individual parts shall be done as required by the applicable material specifications.

AF-635.3 Quenching of Shell Sections or Heads. Formed plates for shell sections and heads may be quenched by sprays or immersion.

AF-635.4 Quenching of Entire Vessels. Entire vessels, after completion of all welding operations, may be quenched by sprays or immersion.

AF-636 Design and Operation of Quenching Equipment

The design and operation of spray equipment and the size of tanks and provision for forced circulation shall be such as to produce a severity of quench in the quenched item sufficient to meet, in representative test specimens after tempering, the requirements of the material specifications.

AF-640 HEAT TREATMENT CERTIFICATION TESTS

AF-641 Heat Treatment Verification Tests

Tests shall be made to verify that the quenching and tempering heat treatments and subsequent thermal treatments, performed by the fabricator, have produced the required properties. The requirements of AF-642(b) and (c) are to be taken as minimum steps toward these objectives.

AF-642 Certification Test Procedure

(a) One or more test coupons representative of the material and the welding in each vessel or vessel component shall be heat treated with the vessel or vessel component.

(b) One or more test coupons from each lot of material in each vessel (see AF-642.2) shall be quenched with the vessel or vessel component. A *lot* is defined as material from the same melt, quenched or normalized simultaneously and whose thicknesses are within ±20% or $\frac{1}{2}$ in. (13 mm) of nominal thickness, whichever is smaller. The test coupons shall be so proportioned that tensile and impact tests may be taken from the same locations relative to thickness as are required by the applicable material specifications. Weld metal and heat affected zone impact test specimens shall be taken from locations relative to coupon thickness in accordance with AT-201. The gage length of tensile specimens and the middle third of the length of impact specimens must be located at a minimum distance of $1 \times t$ from the quenched edge and/or end of the test coupon, where t is the thickness of the material that the test coupon represents. If desired, the effect of this distance may be achieved by temporary attachment of suitable thermal buffers. The effectiveness of such buffers shall be demonstrated by tests.

(c) In cases where the test coupon is not attached to the part being treated, it shall be quenched from the same heat treatment charge and under the same conditions as the part which it represents (see AM-202.1). It shall be so proportioned that test specimens may be taken from the locations prescribed in (b) above.

AF-642.1 Tempering

(a) Attached Test Coupons. The test coupons shall remain attached to the vessel or vessel component during tempering, except that any thermal buffers may be removed after quenching. After the tempering operation and after removal from the component, the coupon shall be subjected to the same thermal treatment(s), if any, to which the vessel or vessel component will be later subjected. The holding time at temperature shall not be less than that applied to the vessel or vessel component (except that the total time at each temperature may be applied in one heating cycle) and the cooling rate shall be no faster.

(b) Separate Test Coupons. Test coupons that are quenched separately, as described in AF-642(c), shall be tempered similarly and simultaneously with the vessel or

component that they represent. The conditions for subjecting the test coupons to subsequent thermal treatment(s) shall be as described in AF-642(b).

AF-642.2 Number of Tests. For base materials, one tensile and one impact test shall be made on material from coupons representing each heat-treated lot of material in each vessel or vessel component. A *lot* is defined as material from the same melt quenched simultaneously and whose thicknesses are within ±20% or $\frac{1}{2}$ in. (13 mm) of nominal thickness, whichever is smaller.

(a) Coupons not containing welds shall meet the complete tensile requirements of the material specification and impact requirements of this Part.

(b) Coupons containing weld metal shall be tested across the weld and shall meet the ultimate tensile strength requirements of the material specifications; in addition, the minimum impact requirements shall be met by samples with notches in the weld metal. The form and dimension of the tensile test specimen shall conform to QW-462.1(a) or QW-462.1(d) of Section IX. Yield strength and elongation are not a requirement of this test. Charpy impact testing shall be in accordance with the requirements of AM-310.

AF-650 EXAMINATION REQUIREMENTS

AF-651 Type No. 1 Welded Joint

Complete radiographic examination in accordance with the requirements of Article I-5 is required for all welded joints of Type No. 1 made in or to quenched and tempered steel. The required radiographic examination shall be made after all corrosion resistant alloy cover weld has been deposited. In addition, all welds made by the electroslag welding process in ferritic materials shall be ultrasonically examined in accordance with the requirements of Article 9-3. This ultrasonic examination shall be done following the grain refining (austenitizing) heat treatment or postweld heat treatment. Ultrasonic examination for the final closure seam of a vessel may be substituted for radiography if construction does not permit interpretable radiography. See Note (3) to Table AF-241.1 for requirements. All welds made by the electron beam welding process and by the inertia and continuous drive friction welding processes shall also be ultrasonically examined for their entire length in accordance with the requirements of Article 9-3.

AF-652 Nozzle Attachment Welds

Nozzle attachment welds as provided for in Fig. AD-613.1 shall be radiographically examined in accordance with the requirements of Article I-5. Nozzle attachment welds in shells over 2 in. in thickness per Fig. AD-610.1, as permitted in AD-415, shall be examined by the ultrasonic method in accordance with Article 9-3 and radiographically examined in accordance with the requirements of Article I-5, except that for nozzles having an I.D. of 2 in. (50 mm) or less, radiography may be omitted. The required radiographic examination shall be made after all corrosion resistant alloy cover weld has been deposited. All welds made by the electron beam welding process and by the inertia and continuous drive friction welding processes shall also be ultrasonically examined for their entire length in accordance with the requirements of Article 9-3.

AF-653 Weld Examination

Except as permitted in AF-653.1, all welds, including welds for attaching nonpressure parts to quenched and tempered steel, shall be examined on all exposed surfaces, after pressure tests, by the magnetic particle method in accordance with the requirements of Article 9-1. A magnetization method shall be used which will avoid arc strikes. Cracks and cracklike defects are unacceptable and shall be repaired or removed. For nozzle attachments illustrated in sketches (a), (b), and (f) of Fig. AD-610.1, the exposed cross section of the vessel wall at the opening shall be included in the examination.

AF-653.1 Alternative Use of Liquid Penetrant Method. As an acceptable alternative to magnetic particle examination or when magnetic particle methods are not feasible because of the nonmagnetic character of the weld deposits, a liquid penetrant method meeting the requirements of Article 9-2 shall be used. For vessels constructed of SA-333 Grade 8, SA-334 Grade 8, SA-353, SA-522, SA-553 Types I and II, and SA-645 material, welds not examined radiographically shall be examined by the liquid penetrant method either before or after the pressure test. Cracks and cracklike defects are unacceptable and shall be repaired or removed.

AF-654 Corrosion Resistant Overlay Weld Metal

Corrosion resistant overlay weld metal shall be examined by a liquid penetrant method meeting the requirements of Article 9-2. Cracks and cracklike defects are unacceptable and shall be repaired or removed.

AF-660 INSPECTION AND TESTS

The provisions for inspection and testing in Parts AI and AT of this Division shall apply to vessels and vessel parts constructed of quenched and tempered steels.

AF-670 STAMPING AND REPORTS

The provisions for stamping and reports in Part AS shall apply to pressure vessels constructed in whole or in part of quenched and tempered steels, except that the use of nameplates is mandatory for shell thicknesses below $\frac{1}{2}$ in. (13 mm). Nameplates are preferred on vessels of quenched and tempered steels in thicknesses above $\frac{1}{2}$ in. (13 mm) instead of stamping. In addition to the required marking, the letters QT shall be applied below the symbol (see AF-601).

NOTE: As materials are added, detailed considerations for each material will be necessary for heat treatment, welding, and miscellaneous fabrication requirements.

ARTICLE F-7
SPECIAL REQUIREMENTS FOR FORGED FABRICATION

AF-700 GENERAL

The rules in the following paragraphs apply specifically to vessels, main sections of vessels and other vessel parts, and to liquid quenched and tempered, integrally forged vessels without welded joints, and shall be used to supplement the applicable requirements for fabrication given in Article F-1. For high alloy steel forged vessels, the applicable paragraphs of Part AM shall also apply.

AF-703 Ultrasonic Examination

(a) For vessels constructed of SA-372 Grade J, Class 110 material, the completed vessel after heat treatment shall be examined ultrasonically in accordance with AM-203. The reference specimen shall have the same nominal thickness, composition, and heat treatment as the vessel it represents. Angle beam examination shall be calibrated with a notch of a depth equal to 5% of the nominal section thickness, a length of approximately 1 in., and a width not greater than twice its depth.

(b) For vessels constructed of SA-723 Class 1, Grades 1, 2, and 3, and SA-723 Class 2, Grades 1, 2, and 3, materials, the completed vessel shall be examined in accordance with AM-203.2 regardless of thickness.

(c) A vessel is unacceptable if examination results show one or more discontinuities which produce indications exceeding in amplitude the indication from the calibrated notch. Round bottom surface indications such as pits, scores, and conditioned areas exceeding the amplitude of the calibrated notch shall be acceptable if the thickness below the indication is not less than the design wall thickness of the vessel, and its sides are faired to a ratio of not less than three to one.

AF-704 Toughness Requirements

(a) For vessels constructed of SA-372 Grade J, Class 110 material, transverse impact tests shall be made at the minimum allowable temperature in accordance with Article M-3, except that in no case shall the test temperature be higher than −20°F (−29°C); AM-311.4(b) and AM-312 are not applicable. Certification is required.

(b) For vessels constructed of SA-723 Class 1, Grades 1, 2, and 3, and SA-723 Class 2, Grades 1, 2, and 3, materials, the impact requirements of Table AM-211.1 shall be met when tested at 40°F (4°C) maximum.

AF-710 TOLERANCES ON CYLINDRICAL FORGINGS

AF-711 Localized Thin Areas

Forgings are permitted to have small areas thinner than required if the adjacent areas surrounding each has sufficient thickness to provide the necessary reinforcement according to the rules for reinforcement in Article D-5.

AF-712 Tolerances on Body Forgings

AF-712.1 Correction of Surface Irregularities to Meet Tolerances. Irregularities in the surface under consideration may be corrected by welding or other means to meet these tolerances. When welding is done, it shall meet the requirements of AF-740.

AF-712.2 Use of Out-of-Round Forgings for Lower Pressure. If out-of-roundness exceeds the limit in AF-130 and the condition cannot be corrected, the forging shall be rejected, except that if the out-of-roundness does not exceed 3%, the forging may be certified for a lower pressure in accordance with the following procedure:

$$P' = P\left[\frac{1.25}{\dfrac{S_b}{S_m} + 1}\right]$$

and in which

$$S_b = \frac{1.5PR_1t(D_1 - D_2)}{t^3 + 3\dfrac{P}{E}R_1R_a{}^2}$$

where

D_1, D_2 = respectively the inside diameters, maximum and minimum, as measured for the critical section, and for one additional section in each direction therefrom at a distance not exceeding $0.2D_2$. (The average of the three readings for D_1 and D_2 respectively shall be inserted in the formula.)

E = modulus of elasticity. For ferritic steels equals 29×10^6 psi (200×10^6 kPa); for austenitic steels equals 28×10^6 psi (193×10^6 kPa); to be corrected for metal service temperature (see Table TM-1 of Section II, Part D).

P = maximum allowable working pressure for forging meeting the requirements of AF-130

P' = reduced pressure

R_a = average radius to middle of shell wall at critical section
$= \frac{1}{4}(D_1 + D_2) + t/2$

R_1 = average inside radius at critical section
$= \frac{1}{4}(D_1 + D_2)$

S_b = bending stress at metal service temperature

S_m = design stress intensity value at metal service temperature

t = average (mean) thickness

NOTES:
(1) Use $P' = P$ when S_b is less than $0.25S_m$.
(2) In all measurements, correct for corrosion allowance if specified.

AF-720 METHODS OF FORMING FORGED HEADS

Heads shall be made as separate forgings (see AD-204), or by closing the extremities of a hollow forged body to such shape and dimensions as may be required to produce the final form desired.

AF-721 Tolerances on Head Forgings

Tolerances shall meet the requirements of AF-135.

AF-721.1 Correction of Surface Irregularities to Meet Tolerances. Irregularities may be corrected in accordance with AF-712.1.

AF-730 HEAT TREATMENT REQUIREMENTS

AF-730.1 Heat Treatment When Vessels Are Fabricated by Welding. Vessels fabricated by welding of forged parts requiring heat treatment shall be heat treated in accordance with the applicable material specification as follows:

(a) after all welding is completed; or

(b) prior to welding, followed by postweld heat treatment of the finished weld in accordance with AF-410.

AF-730.2 Heat Treatment When Material Is to Be Normalized or Annealed. After all forging is completed, each vessel or forged part fabricated without welding shall be heat treated in accordance with the applicable material specification. When irregularities are corrected by welding, subsequent heat treatment shall be in accordance with AF-753.2.

AF-730.3 Heat Treatment of Quenched and Tempered Ferritic Material. Vessels fabricated of SA-372 forging material to be liquid quenched and tempered shall be subjected to this heat treatment in accordance with the applicable material specifications after all forging and welding is completed, except for seal welding of threaded openings, which may be performed either before or after final heat treatment. 04

(a) Examination of Quenched and Tempered Vessels. After final heat treatment, such vessels shall be examined for the presence of cracks on the outside surface of the shell and heads and on the inside surface where practicable. This examination shall be made by a liquid penetrant method, in accordance with Article 9-2 when the material is nonmagnetic, and by either a liquid penetrant or a magnetic particle method when the material is magnetic, in accordance with Article 9-1.

(b) Check of Heat Treatment by Hardness Testing. After final heat treatment, liquid quenched and tempered forgings, except those made of austenitic steels, shall be subjected to Brinell hardness tests at 5 ft (1.5 m) intervals with a minimum of four readings at each of not less than three different locations representing approximately the center and each end of the heat treated forgings. The average of the individual Brinell hardness numbers at each location shall be not more than 10% below nor more than 25% above the number corresponding to the specified minimum tensile strength of the material, and the highest average hardness number shall not exceed the lowest average value on an individual vessel by more than 40.

NOTE: Other hardness testing methods may be used and converted to Brinell numbers by means of the table in ASTM E 140.

AF-730.4 Heat Treatment of Austenitic Material. In the case of austenitic steels, the heat treatment procedures followed shall be in accordance with AF-402.

AF-730.5 Nonheat-Treated Ferrous Material. Postweld heat treatment of vessels fabricated by welding of forged parts not requiring heat treatment shall meet with the requirements of AF-402.

AF-740 WELDING FOR FABRICATION

All welding used in connection with the fabrication of forged vessels or components shall comply with the applicable requirements of Article F-2, except as modified in AF-741.

AF-741 Restrictions on Ferrous Materials With Carbon Content Exceeding 0.35%

When the carbon content of the material exceeds 0.35% by ladle analysis, the vessel shall be fabricated without welding, except for repairs as limited in AF-752, for minor nonpressure attachments, for seal welding of threaded openings limited to fillet welds of not over $\frac{1}{4}$ in. (6 mm) throat dimension, and for adding reinforcement threaded, flanged, or studded openings. Such welding shall be allowed under the following conditions.

(a) The suitability of the electrode and procedure, including preheat and postheat, shall be established by making a groove weld specimen as shown in QW-461.2 and QW-461.3 of Section IX in material of the same analysis and of thickness in conformance with QW-451.1 and QW-451.2 of Section IX. The specimen before welding shall be in the same condition of heat treatment as the work it represents, and after welding the specimen shall be subjected to heat treatment equivalent to that contemplated for the work. Tension and bend specimens, as shown in QW-462.1, QW-462.2, and QW-462.3a of Section IX, shall be made. These tests shall meet the requirements of QW-150 and QW-160 of Section IX. The radius of the mandrel used in the guided bend test shall be as follows:

Specimen Thickness	Radius of Mandrel (B)[1]	Radius of Die (D)[1]
$\frac{3}{8}$ in. (10 mm)	$1\frac{1}{4}$ in. (31 mm)	$1\frac{11}{16}$ in. (42 mm)
t	$3\frac{1}{3}t$	$4\frac{1}{3}t + \frac{1}{16}$ in. (1.5 mm)

NOTE:
(1) Correspond to dimensions B and D for P-No. 11 material in QW-466.1 of Section IX and other dimensions to be in proportion.

(b) Welders shall be qualified for minor nonpressure attachments, seal welds, and for fillet welds specified by making and testing a specimen in accordance with QW-462.4(b) and QW-180 of Section IX. Welders shall be qualified for adding weld reinforcement for openings and for repair welding by making a test plate in accordance with QW-461, from which the bend tests outlined in QW-461.2, QW-452.1, and QW-452.2 of Section IX shall be made. The electrode used in making these tests shall be of the same classification number as that specified in the procedure. The material for these tests can be carbon steel plate or pipe, provided the test specimens are preheated, welded, and postweld heat treated in accordance with the procedure specification for the type of electrode involved.

(c) The finished welds shall be postweld heat treated or given a further heat treatment as required by the applicable material specification. The types of welding permitted in AF-741 shall be performed prior to final heat treatment except for seal welding of threaded openings, which may be performed either before or after final heat treatment.

(d) The finished welds shall be examined after postweld heat treatment by a liquid penetrant method when the material is nonmagnetic or by either a magnetic particle or a liquid penetrant method when the material is ferromagnetic in accordance with the requirements of Article 9-1 or 9-2, whichever is applicable.

AF-750 REPAIR OF DEFECTS IN MATERIAL

AF-751 Removal of Surface Defects

Surface imperfections such as chip marks, blemishes, or other irregularities may be removed by grinding or machining, and the surface exposed shall be blended smoothly into the adjacent surface when sufficient wall thickness permits thin areas in compliance with the requirements of AF-711.

AF-752 Repair of Defects by Welding

Thinning to remove defects may be repaired by welding only after approval by the Inspector. Defects shall be removed to sound metal as shown by acid etch or any other suitable method of examination. The welding shall meet the requirements of AF-753 and AF-754.

AF-753 Weld Repairs of Material Containing 0.35% Carbon or Less

Material having carbon content of 0.35% or less (by ladle analysis) may be repaired by welding when the requirements of this paragraph are met.

AF-753.1 Qualification of Welding Procedure and Welders. The welding procedure and welders shall be qualified in accordance with Section IX.

AF-753.2 Postweld Heat Treatment. Postweld heat treatment after welding shall be governed as follows.

(a) All welding shall be postweld heat treated, if AF-402 requires postweld heat treatment, for all thicknesses of material of the analysis being used.

(b) Fillet welds need not be postweld heat treated unless required by (a) above or unless the fillet welds exceed the limits given in AF-402, in which case they shall be heat treated in accordance with the requirements of AF-402.

(c) Repair welding shall be postweld heat treated when required by (a) above, or if it exceeds 6 sq in. (4 000 mm^2) at any spot, or if the maximum depth exceeds $\frac{1}{4}$ in. (6 mm).

AF-753.3 Examination of Weld Repairs. All weld repairs shall be examined by radiography, in accordance with the requirements of Article I-5, by a magnetic particle method, in accordance with the requirements of Article 9-1, or by a liquid penetrant method, in accordance with the requirements of Article 9-2. Repair welding shall be radiographed when the depth of weld repair exceeds $\frac{3}{8}$ in. (10 mm) or one-half the material thickness. The acceptability of the repair welds shall be determined by the acceptance standards set forth in the applicable paragraph.

AF-754 Weld Repairs of Material Containing More Than 0.35% Carbon

Material having carbon content over 0.35% (by ladle analysis) may be repaired by welding when the requirements of this paragraph are met.

AF-754.1 Qualification of Welding Procedure and Welders. The welding procedure and welders shall be qualified in accordance with Section IX and the additional requirements of AF-741(a) and (b).

AF-754.2 Postweld Heat Treatment. The finished repair welds shall be postweld heat treated or given a further heat treatment as required by the applicable material specification.

AF-754.3 Examination of Weld Repairs

(a) The examination of weld repairs in other than quenched and tempered materials shall meet the requirements of AF-753.3, except that radiography shall be required when the depth of weld repair exceeds $\frac{1}{4}$ in. (6 mm) or one-half the material thickness.

(b) Examination of welding repairs in material which is to be or has been liquid quenched and tempered shall meet the requirements of AF-753.3, except that radiography shall be required regardless of the depth of weld deposit.

AF-756 Repair of Weld Defects

The repair of welds in forgings having carbon content not exceeding 0.35% by ladle analysis shall follow the requirements of AF-250 through AF-254.

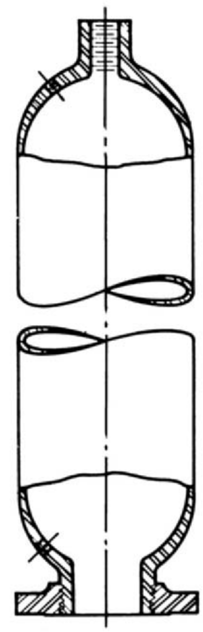


FIG. AF-762.1 STRAIGHT THREADED CENTER OPENINGS IN INTEGRALLY FORGED HEADS WITH NOZZLE EXTENSIONS

AF-760 THREADED CONNECTION OF PIPE AND NOZZLE NECKS TO VESSEL WALLS, INTERNALLY FORGED NECKS, AND THICKENED FORGED HEADS

AF-761 Requirements for Straight Threaded Openings

Straight threaded openings shall meet the rules governing openings and reinforcements in Article D-5, except as limited in AF-762. The length of thread shall be calculated for the opening design.

AF-762 Location and Maximum Size of Straight Threaded Openings

Straight threaded center openings in integrally forged heads with nozzle extensions shall not exceed the smaller of one-half the vessel diameter or 8 in. pipe size (NPS 8, DN 200) (see Fig. AF-762.1).

AF-763 Requirements for Tapered Threaded Openings

Tapered threaded openings shall meet the limitations and requirements of AD-640 and AD-641.

AF-764 Seal Welding of Threaded Openings

When piping or fittings are installed in threaded openings and seal welding is employed, the work shall be performed and examined at the vessel Manufacturer's plant and included in the certification. Seal welding shall comply with AF-740.

AF-770 INSPECTION, EXAMINATION, AND TESTING

The rules in the following paragraphs apply specifically to the inspection, examination, and testing of forged vessels and their component parts. These rules shall be used to supplement the applicable requirements and examination in Part AI and for tests given in Part AT.

(a) All forged vessels shall be examined as manufacture proceeds to assure freedom from loose scale, gouges, or grooves and cracks or seams. After fabrication has passed the machining stage, the vessel body shall be measured at suitable intervals along its length to get a record of variations in wall thickness, and the nozzles for connecting piping and other important details shall be checked for conformity to the design dimensions.

(b) Surfaces which are not to be machined shall be carefully examined for visible defects such as seams, laps, or folds. On surfaces to be machined, the examination shall be made after machining. Regions from which defective material has been removed shall be examined after removal and again after any necessary repair.

AF-771 Forged Parts

AF-771.1 Partial Data Reports Required. When welding is used in the fabrication of forged parts completed elsewhere, the manufacturer of the forged parts shall furnish a Partial Data Report, Form A-2.

AF-771.2 Identification and Certification. All parts forgings completed elsewhere shall be marked with the forging manufacturer's name and the forging identification, including material designation. Should identifying marks be obliterated in the fabrication process, and for small parts, other means of identification shall be used. The forging manufacturer shall furnish reports of chemical and mechanical properties of the material and certification that each forging conforms to all requirements of Part AM.

AF-771.3 Welded Repairs and Their Certification. Welded repairs to parts forgings need not be inspected by an Authorized Inspector at the plant of the forging manufacturer, but the forging manufacturer shall obtain the approval of the vessel Manufacturer and furnish a report of the extent and location of such repairs, together with certification that they were made in accordance with all other requirements of AF-754, as applicable. If desired, welding repairs of forgings made elsewhere may be made, examined, and tested at the shop of the pressure vessel Manufacturer.

AF-776 Check of Heat Treatment and Postweld Heat Treatment

The Inspector shall check the provisions made for heat treatment to assure him/herself that the heat treatment is carried out in accordance with the provisions of AF-730. He shall also assure him/herself that postweld heat treatment is done after repair welding when required under the rules of AF-753.2.

AF-777 Inspection of Test Specimens and Witnessing Tests

AF-777.1 Test Specimens. When test specimens are to be taken under the applicable material specifications, the Inspector at his option may witness the selection, identifying stamping, and testing of these specimens.

AF-777.2 Tests and Retests. Tests and retests shall be made in accordance with the requirements of the material specification.

AF-780 STAMPING AND REPORTS FOR FORGED VESSELS

AF-781 Stamping Requirements

The rules of Part AS shall apply to forged vessels as far as practicable. Vessels constructed of liquid quenched and tempered material, other than austenitic steels, shall be stamped on the thickened head, using low stress stamps as commercially available unless a nameplate is used.

AF-782 Information Required on Data Reports for Integrally Forged Vessels

Data reports for integrally forged vessels shall include the heat number or numbers of the metal in the ingot from which the vessel was forged and the test results obtained for the forging.

AF-790 PRESSURE RELIEF DEVICES

The provisions for pressure relief devices of Part AR shall apply without supplement.

ARTICLE F-8
SPECIAL FABRICATION REQUIREMENTS FOR LAYERED VESSELS

AF-800 GENERAL

The rules in the following paragraphs apply specifically to layered shells, layered heads, and layered transition sections and shall be used to supplement, or be used in lieu of, the applicable requirements given in Articles F-1 through F-6. Where requirements differ from those of Articles F-2, F-4, and F-6, they are specifically delineated.

AF-801 GENERAL FABRICATION REQUIREMENTS

Requirements shall be in accordance with Article F-1. For layered vessels, the minimum thickness permitted for layers is $^1/_8$ in. (3 mm).

AF-802 WELDING FABRICATION REQUIREMENTS

The welding fabrication shall be in accordance with Article F-2, except that the welding procedure qualification requirements are modified for layered construction as given in this Article. Also the specified requirements are modified for welded joints in AD-1110 and for nondestructive examination in AF-810.2.

AF-803 MATERIAL PROPERTIES ENHANCEMENT BY HEAT TREATMENT DURING FABRICATION

For helically wound interlocking strip vessels where the mechanical properties of the material are enhanced by heat treatment during the fabrication process, the mechanical test specimens as required by the material specification shall be taken from prolongations of the strip material after winding and after heat treatment. See Appendix 24, Requirements for Steel Bars of Special Section for Helically Wound Interlocking Strip Layered Pressure Vessels.

AF-805 WELDING QUALIFICATION AND RECORDS

Requirements for welding qualification and records shall be in accordance with AF-210, except that the layered test plate welding procedure qualification of Section IX in AF-210.1 and AF-210.4 shall be as modified in AF-805.1.

AF-805.1 Welding Procedure Qualification

(a) The minimum and maximum thicknesses qualified by procedure qualification test plates shall be as shown in Table QW-451 of Section IX, except that:

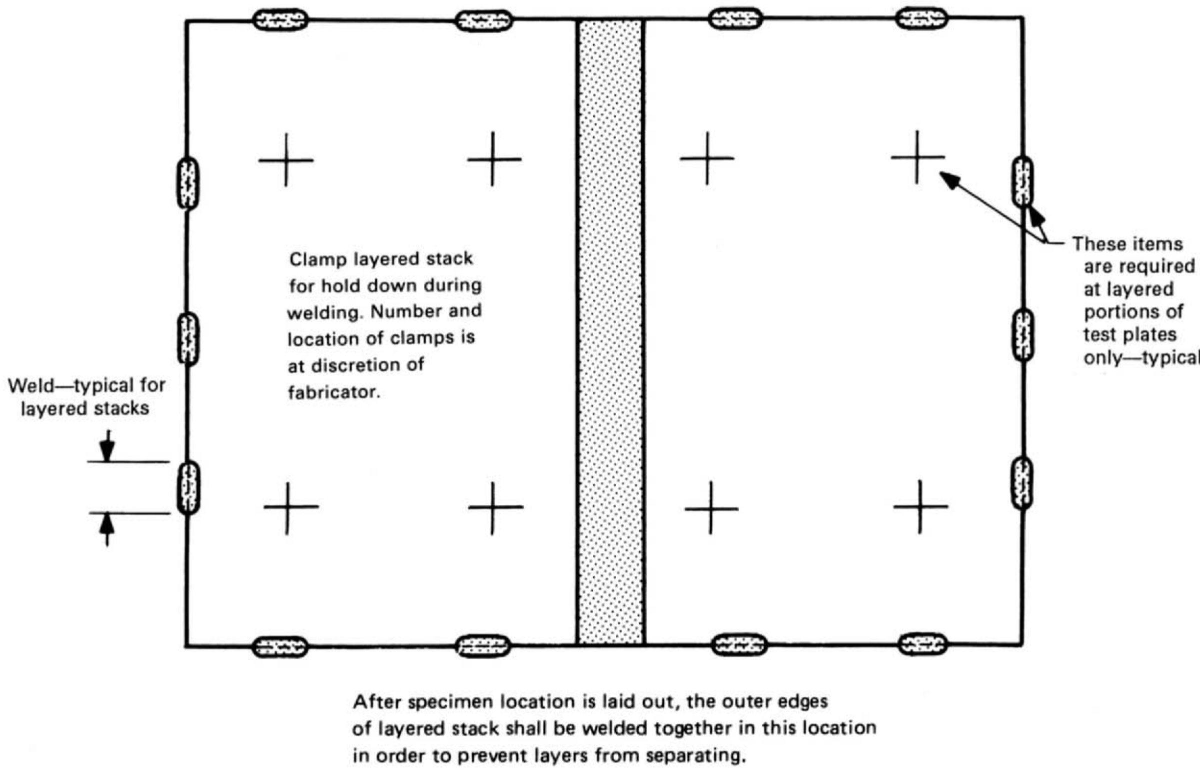
(1) for the longitudinal joints of the layer section of the shell, the qualification shall be based upon the thickness of the thickest individual layer exclusive of the inner shell or inner head;

(2) for circumferential joint procedure qualification, the thickness of the layered test plate need not exceed 3 in. (75 mm), shall consist of at least 2 layers, but shall not be less than 2 in. (50 mm) in thickness;

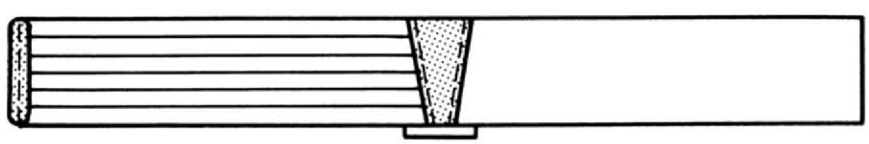
(3) for circumferential weld joints made individually for single layers and spaced at least one layer thickness apart, the procedure qualification for the longitudinal joint applies.

(b) The longitudinal weld joint of the inner shell or inner head and the longitudinal weld joint of the layer shell or layer head shall be qualified separately except if of the same P-Number material. The weld gap of the longitudinal layer weld joint shall be the minimum width used in the procedure qualification for layers $^7/_8$ in. (22 mm) and less in thickness.

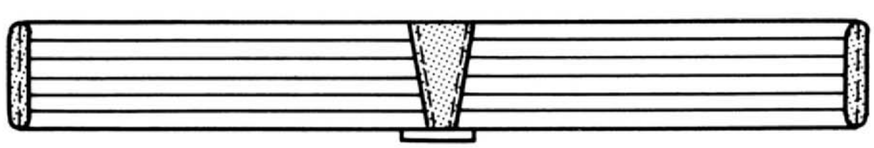
(c) The circumferential weld joint of the layer to layer shell or to layer head shall be qualified with a simulated layer test plate as shown in Fig. AF-805.1 (see also Fig. AF-805.4) for layer thicknesses $^7/_8$ in. (22 mm) and under. A special type of joint tensile specimen shall be made from the layer test coupon as shown in Fig. AF-805.2. (See also Fig. AF-805.4.) Face and root bend specimens shall be made of both the inner and outer weld to the



Plan View of Solid-to-Layered and Layered-to-Layered Test Plates



Layered-to-Solid Test Plate



Layered-to-Layered Test Plate

FIG. AF-805.1 SOLID-TO-LAYERED AND LAYERED-TO-LAYERED TEST PLATES

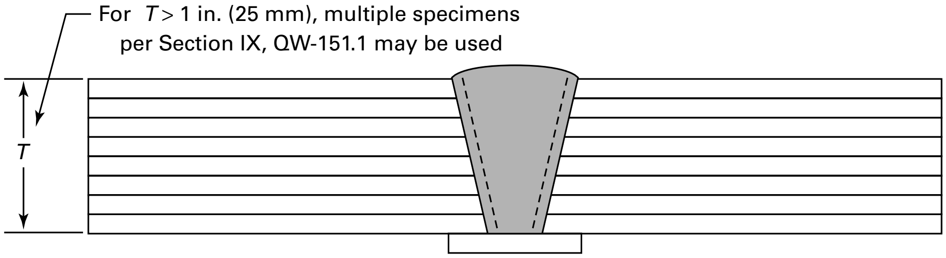


FIG. AF-805.2

thickness of the layer by cutting the weld to the layer thickness.

(d) The circumferential weld joint of the layer shell for layer thicknesses $^7/_8$ in. (22 mm) and under to the solid head, flange, or end closure shall be qualified with a simulated layer test coupon as shown in Fig. AF-805.1, wherein the one side of the test coupon is solid throughout its entire thickness. A special type of joint tensile specimen shall be made from the test coupon as shown in Fig. AF-805.3. (See also Fig. AF-805.4.) Face and root bend specimens shall be made of both the inner and outer weld to the thickness of the layer by slicing the weld and solid portion to the layer thickness.

AF-805.2 Welding Performance Qualification. Welding shall be performed only by welders and welding operators who have been qualified as given in Section IX. The minimum and maximum thicknesses qualified by any welder test plate shall be as shown in Table QW-452 of Section IX.

AF-810 SPECIFIC REQUIREMENTS FOR WELDED JOINTS

The rules of the following paragraphs shall be used in lieu of AF-220 and AF-240.

AF-810.1 Welding of Joints. AD-1110 establishes the types of joints permitted, according to location, in layered vessels and their components. AD-1115 and AD-1116 establish rules for attaching nozzles and other pressure connections by welding. Likewise AD-1125 gives rules for attaching nonpressure parts and stiffeners. The requirements are summarized in Table AF-810.1.

AF-810.2 Type No. 1 Butt Joints. Type No. 1 butt joints are those produced by double welding or by other means which produce the same quality of deposited weld metal on both inside and outside weld surfaces. Welds using backing strips which remain in place do not qualify as Type No. 1 butt joints.

AF-810.3 Weld Penetration and Reinforcement. Type No. 1 butt joints shall have complete joint penetration and full fusion and shall be free from undercuts, overlaps, or abrupt ridges or valleys.[1] To assure that the weld grooves are completely filled so that the surface of the weld metal at any point does not fall below the surface of the adjoining plate, weld metal may be built up as reinforcement on both sides of the plate. The thickness of the reinforcement on each side of the plate shall not exceed the limits specified in AI-501(a).

AF-810.4 Type No. 2 Butt Joints. Type No. 2 butt joints are single-welded butt joints having backing strips which remain in place. See AD-412.1 for stress concentration factors to be applied to Type No. 2 joints when a fatigue analysis is required. This stress concentration factor need not be applied to butt joints welded to the previous layer surface.

AF-810.5 Penetration and Reinforcement. When Type No. 2 butt joints are used, particular care shall be taken in aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joints for their full length. However, for assuring complete filling of the weld grooves, weld reinforcement need be supplied only on the side opposite the backing strip. Weld reinforcement need not be provided on welds which are subsequently ground flush.

AF-810.6 Backing Strips. Backing strips shall be continuous and any splices shall be butt welded. Circumferential single-welded butt joints with one plate offset to form a backing strip are prohibited.

AF-810.7 Fillet Welded Joints. Fillet welded joints, permitted by the rules of this Division, are those of

[1] If the reinforcement is built up so as to form a ridge with a valley or depression in the weld at the edge next to the plate, the result is a notch that causes concentration of stress and reduces the strength of the joint.

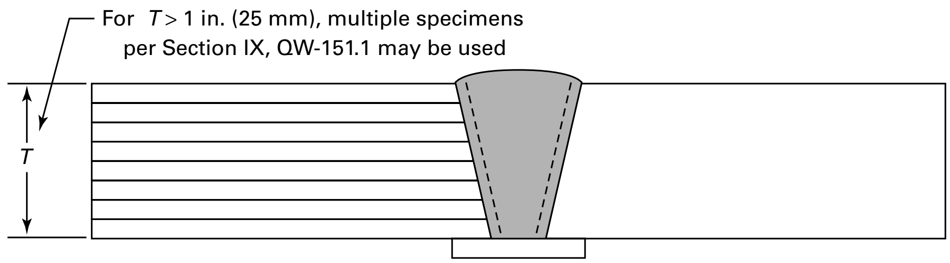
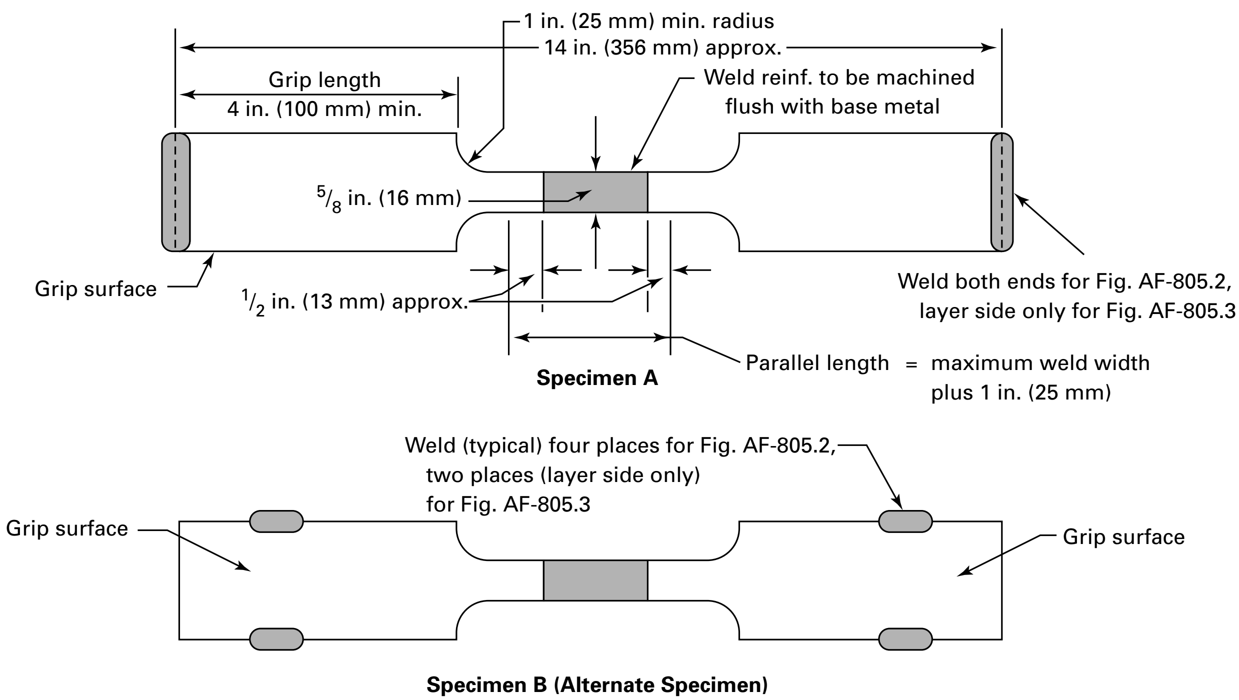


FIG. AF-805.3



GENERAL NOTE: Specimens A and B are plan views of Figs. AF-805.2 and AF-805.3, and are identical except for locations of grip surfaces and welds. All grip surfaces are to be machined flat.

FIG. AF-805.4

approximately triangular cross section, joining two surfaces at approximately right angles to each other and having a throat dimension at least 70% of the smaller thickness of the parts being joined.

AF-810.8 Quality Requirements. The surface of fillet welds shall be free from coarse ripples or grooves, undercuts, overlaps, and abrupt ridges or valleys, and shall merge smoothly with the surfaces joined.

AF-810.9 Welds Attaching Nonpressure Parts and Stiffeners. The rules governing the types of welds which may be used to join supports, lugs, brackets, stiffeners, and other attachments to the vessel wall are set forth in Articles D-9 and D-11 (AD-1125). See AD-911 for rules governing welds for attachment to pressure parts of materials listed in Column 1, Table AF-241.1. See AD-912 for rules governing welds for attachment to pressure parts of all other materials.

AF-810.10 Surface Weld Metal Buildup. Construction in which deposits of weld metal are applied to the surface of base metal for the purpose of:

(a) restoring the thickness of the base metal for strength consideration; or

(b) modifying the configuration of weld joints in order to provide the tapered transition requirements of AD-420

or AF-142.3 in solid wall sections shall be performed in accordance with the requirements of AF-229 and AF-229.2. For use of layers as transitions, see AD-1110 and Figs. AD-1117.1, AD-1117.2, and AD-1117.5.

(c) a butt welding procedure qualification in accordance with the provisions of Section IX must be performed for the thickness of weld metal deposited, prior to production welding.

AF-810.20 Nondestructive Examination of Welded Joints. The rules of the following paragraphs apply specifically to the nondestructive examination of pressure vessels and vessel parts that are fabricated using layered construction.

(a) Inner Shells and Inner Heads. Category A and B joints in the inner shells of layered shell sections and in the inner heads of layered heads before application of the layers shall be examined throughout their entire length by radiography and meet the requirements of Article I-5.

04 *(b) Layers — Welded Joints*

(1) Category A joints in layers $\frac{1}{8}$ in. through $\frac{5}{16}$ in. (3 mm through 8 mm) in thickness welded to the previous surface shall be examined for 100% of their length in accordance with Article 9-1 by the magnetic particle method using direct current.

(2) Category A joints in layers over $\frac{5}{16}$ in. through $\frac{5}{8}$ in. (8 mm through 16 mm) in thickness welded to the previous surface shall be examined for 100% of their length in accordance with Article 9-1 by the magnetic particle method using direct current. In addition, these joints shall be examined for 10% of their length at random in accordance with Article 9-3 ultrasonic method, except that for the bottom 10% of the weld thickness the distance amplitude correction curve or reference level may be raised by 6 dB. The random spot examination shall be performed as specified in AF-810.21.

(3) Category A joints in layers over $\frac{5}{8}$ in. through $\frac{7}{8}$ in. (16 mm through 22 mm) in thickness welded to the previous layer shall be examined for 100% of their length in accordance with Article 9-3 ultrasonic method, except that for the bottom 10% of the weld thickness the distance amplitude correction curve or reference level may be raised by 6 dB.

(4) Category A joints in layers not welded to the previous surface shall be examined before assembly for 100% of their length by radiography and meet the requirements of Article I-5.

(5) Welds in spirally wound strip construction with a winding (spiral angle) of 75 deg or less measured from the vessel axial centerline shall be classified as Category A joints and examined accordingly.

(c) Layers — Step Welded Girth Joints

(1) Category B joints in layers $\frac{1}{8}$ in. through $\frac{5}{16}$ in. (3 mm through 8 mm) in thickness shall be examined for 10% of their length in accordance with Article 9-1 by the magnetic particle method using direct current. The random spot examination shall be performed as specified in AF-810.21.

(2) Category B joints in layers over $\frac{5}{16}$ in. through $\frac{5}{8}$ in. (8 mm through 16 mm) in thickness shall be examined for 100% of their length in accordance with Article 9-1 by the magnetic particle method using direct current.

(3) Category B joints in layers over $\frac{5}{8}$ in. through $\frac{7}{8}$ in. (16 mm through 22 mm) in thickness shall be examined for 100% of their length in accordance with Article 9-1 by the magnetic particle method using direct current. In addition these joints shall be examined for 10% of their length in accordance with Article 9-3 ultrasonic method, except that for the bottom 10% of the weld thickness the distance amplitude correction curve or reference level may be raised by 6 dB. The random spot examination shall be performed as specified in AF-810.21.

(4) Category B joints in layers over $\frac{7}{8}$ in. (22 mm) in thickness shall be examined for 100% of their length in accordance with Article 9-3 ultrasonic examination, except that for the bottom 10% of the weld thickness the distance amplitude correction curve or reference level may be raised by 6 dB.

(d) Butt Joints. Full thickness welding of solid section to layered sections. Category A, B, and D joints attaching a solid section to a layered section of any of the layered thicknesses given in AF-810.20(b) shall be examined by radiography for their entire length in accordance with AF-810.20(a).

It is recognized that layer wash[2] or acceptable gaps (see AF-815) may show as indications difficult to distinguish from slag on the radiographic film. Acceptance shall be based on reference to the weld geometry as shown in Fig. AF-810.1. As an alternative, an angle radiographic technique, as shown in Fig. AF-810.2, may be used to locate individual gaps in order to determine the acceptability of the indication. Category A and B joints attaching a layered section to a layered section need not be radiographed after being fully welded when the Category A hemispherical head and Category B welded joints of the inner shell or inner head made after application of the layers have been radiographed in accordance with AF-810.20(a).

The inner shell or inner head thicknesses need not be radiographed in thicknesses over $\frac{7}{8}$ in. (22 mm) if the completed joint is radiographed. Weld joints in the inner

[2] *Layer wash* is defined as the indications resulting from slight weld penetration at the layer interfaces.

shell or inner head welded after application of the layers of the inner shell or inner head weld joints shall be radiographed throughout their entire length and meet the requirements of AF-810.20(a).

(e) Flat Head and Tubesheet Weld Joints. Category C joints attaching layered shell, or layered heads to flat heads and tubesheets as shown in Fig. AD-1117.3 shall be examined to the same requirements as specified in AF-810.20(c) for Category B joints.

(f) Nozzle and Communicating Chambers Weld Joints. Category D weld joints in layered shells or layered heads not requiring radiographic examination shall be examined by the magnetic particle method in accordance with Article 9-1. The partial penetration weld joining liner type nozzle, as shown in Fig. AD-1118.1 sketches (i), (j), (k), and (l), to layer vessel shells or layer heads shall be examined by magnetic particle or liquid penetrant. Acceptance standards shall meet the requirements of Article 9-1 or Article 9-2, respectively, for magnetic particle and liquid penetrant examination.

(g) Welds Attaching Nonpressure Parts and Stiffeners

(1) All welds attaching supports, lugs, brackets, stiffeners, and other nonpressure attachments to pressure parts (see Article D-9) shall be examined on all exposed surfaces by the magnetic particle or the liquid penetrant method in accordance with the requirements of Article 9-1 or 9-2, whichever is applicable.

(2) The examination required in AF-227.1(a) shall be made after postweld heat treatment, if performed for attachment to materials covered by Column 2 of Table AF-241.1.

(h) Transition Welds

(1) All weld metal buildup in solid wall sections or fillet welds in layered transitions shall be examined over the full surface of the deposit by either a magnetic particle method in accordance with Article 9-1 or by a liquid penetrant method in accordance with Article 9-2.

(2) When such surface weld metal buildup is used in welded joints which require radiographic examination, the weld metal buildup shall be included in the examination.

(i) Table AF-810.1 Examination Requirements. In addition to summarizing the types of joints permitted, Table AF-810.1 gives the concomitant examination requirements as set forth above. Unless specifically exempted, all welds shall be examined as required by these paragraphs and Table AF-810.1.

AF-810.21 Random Spot Examination and Repair of Weld. The random ultrasonic examination of AF-810.20(b)(2) and (c)(3), and random magnetic particle examination of AF-810.20(c)(1), shall be performed as follows.

(a) The location of the random spot shall be chosen by the Inspector, except that when the Inspector has been duly notified in advance and cannot be present or otherwise make the selection, the fabricator may exercise his own judgment in selecting the random spot or spots. The minimum length of a spot shall be 6 in. (150 mm).

(b) When any random spot examination discloses welding which does not comply with the minimum quality requirements of AF-810.20(b)(2), (c)(1), and (c)(3), two additional spots of equal length shall be examined in the same weld unit at locations away from the original spot. The locations of these additional spots shall be determined by the Inspector or fabricator as provided for in the original spot examination.

(c) If either of the two additional spots examined shows welding which does not comply with the minimum quality requirements of AF-810.20(b)(2), (c)(1), and (c)(3), the entire unit of weld represented shall be rejected. The entire rejected weld shall be removed and the joint shall be rewelded or, at the fabricator's option, the entire unit of weld represented shall be completely examined and defective welding only need be corrected.

(d) Repair welding shall be performed using a qualified procedure and in a manner acceptable to the Inspector. The rewelded joint or the weld repaired areas shall be random spot examined at one location in accordance with the foregoing requirements of AF-810.20(b)(2), (c)(1), and (c)(3).

AF-811 WELDED JOINT EFFICIENCY

When the nondestructive examination outlined in AF-810.20 has been complied with, the weld joint efficiency for design purposes shall be 100%.

AF-815 CONTACT BETWEEN LAYERS

(a) Category A weld joints shall be ground to ensure contact between the weld area and the succeeding layer, before application of the layer.

(b) Category A weld joints of layered shell sections shall be in an offset pattern so that the centers of the welded longitudinal joints of adjacent layers are separated circumferentially by a distance of at least five times the layer thickness.

(c) Category A weld joints in layered heads may be in an offset pattern; if offset, the joints of adjacent layers shall be separated by a distance of at least five times the layer thickness.

(d) After weld preparation and before welding circumferential seams, the height of the radial gaps between any two adjacent layers shall be measured at the ends of the

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TABLE AF-810.1
PERMITTED TYPES OF WELDS AND REQUIRED EXAMINATION OF LAYERED CONSTRUCTION

Joint Category or Type Connection		Materials[1] Materials P-No. 1 Gr. 1, 2, and 3; P-No. 8 Gr. 1 and 2; P-No. 9A Gr. 1; SA-387 Grade 12 Only of P-No. 4 Gr. 1; P-No. 3 Gr. 3 Except SA-302; and Materials in Table AQT-1				
		Joint Design			Fabrication & Examination[2]	
		Type Weld	Applic. Paras.	Applic. Figs.	Applic. Paras.	Exam. Method
Category A	Inner Shell and Inner Head of Layered Sections	No. 1 B	AD-1110(a)(1)	. . .	AF-810.20(a)	RT
	Layers Over $^7/_8$ in. (22 mm) Thick	No. 1 B	AD-1110(b)(1)	. . .	AF-810.20(b)	RT
	Layers $^7/_8$ in. (22 mm) Thick or Less	No. 1 or 2 B	AD-1110(b)(2) and (b)(3)	. . .	AF-810.20(b)	UT and/or MT
	Hemi-Heads to Layered Shell Junction	No. 1 B	AD-1110(d) and (h)	AD-1117.2(a), (b-3), and AD-1117.5(a-1)	AF-810.20(d)	RT
Category B		No. 1 or 2 B	AD-1110(a)(2), (c)(2), and (c)(4)	AD-1117.1(a), (c), (d), (e), and (f); AD-1117.2(d-1), (e), and (f); AD-1117.6(a) or (e)	AF-810.20(d)	RT
		No. 1 or 2 B	AD-1110(c)(3)	AD-1117.1(b); AD-1117.2(d-2); AD-1117.5(b-1)	AF-810.20(e)	MT or UT
Category C		No. 1 or 2 B	AD-1110(f) and (g)	AD-1117.3(a), (b), (c), (d), and (e); AD-1117.4(a), (b), (c), and (d)	AF-810.20(e) and AF-810.20(d)	RT
		No. 1 or 2 B	AD-1110(f) and (g)	AD-1117.3(f)	AF-810.20(d) and AF-810.20(e)	MT or UT
Category D		B	AD-1110(k)	AD-1118.1(e), (f), (g), (h)	AF-810.20(f)	RT
		FP	AD-1110(k)	AD-1118.1(a), (b), (c-1), (c-2), (d)	AF-810.20(f)	RT or MT
		PP	AD-1110(k)	AD-1118.1(i), (j), (k), (l)	AF-810.20(f)	MT or PT

(continued)

TABLE AF-810.1
PERMITTED TYPES OF WELDS AND REQUIRED EXAMINATION OF LAYERED CONSTRUCTION (CONT'D)

Joint Category or Type Connection	Materials[1] Materials P-No. 1 Gr. 1, 2, and 3; P-No. 8 Gr. 1 and 2; P-No. 9A Gr. 1; SA-387 Grade 12 Only of P-No. 4 Gr. 1; P-No. 3 Gr. 3 Except SA-302; and Materials in Table AQT-1				
	Joint Design			Fabrication & Examination[2]	
	Type Weld	Applic. Paras.	Applic. Figs.	Applic. Paras.	Exam. Method
Attachments	B FP FP&FW PP&FW FW	AD-1125	. . .	AF-810.20(g)	MT or PT
Transition Welds	FW	. . .	AD-1117.1, AD-1117.2, AD-1117.4, and AD-1117.5	AF-810.20(h)(1)	MT or PT
	Weld buildup	. . .	AD-1117.2(e) and (f)	AF-810.20(h)(2)	RT

NOMENCLATURE:
Type of Joint:
B = butt weld: Type No. 1 — see AF-810.2; Type No. 2 — see AF-810.4
FP = full penetration weld except butt weld
PP = partial penetration weld — see AD-1116(a)
FW = fillet weld

Method of Examination:
RT = complete radiography
MT = magnetic particle
PT = liquid penetrant
UT = ultrasonic

NOTES:
(1) Inner shells and inner heads are covered for all materials in Table AF-241.1.
(2) AF-653 is applicable to all vessels constructed with materials in Table AQT-1.

layered shell section or layered head section at right angles to the vessel axis, and also the length of the relevant radial gap in inches shall be measured [neglecting radial gaps of less than 0.010 in. (0.25 mm) as nonrelevant]. An approximation of the area of the gap shall be calculated as indicated in Fig. AF-815.

The gap area A_g shall not exceed the thickness of a layer expressed in square inches. The maximum length of any gap shall not exceed the inside diameter of the vessel. Where more than one gap exists between any two adjacent layers, the sum of the gap lengths shall not exceed the inside diameter of the vessel. The maximum height of any gap shall not exceed $^3/_{16}$ in. (5 mm). It is recognized that there may be vessels of dimensions wherein it would be desirable to calculate a maximum permissible gap area, and also when cyclical service conditions require it. This procedure is provided in AF-815.1.

(e) In the case of layered spheres or layered heads, if the gaps cannot be measured as required in AF-815(d), measurement of gap heights shall be taken through vent holes in each layer course to assure that the height of layer gaps between any two layers does not exceed the gap permitted in (d) above. The spacing of the vent holes shall be such that gap lengths can be determined. In the event an excessive gap height is measured through a vent hole, additional vent holes shall be drilled as required to determine the gap length. There shall be at least one vent hole per layer segment.

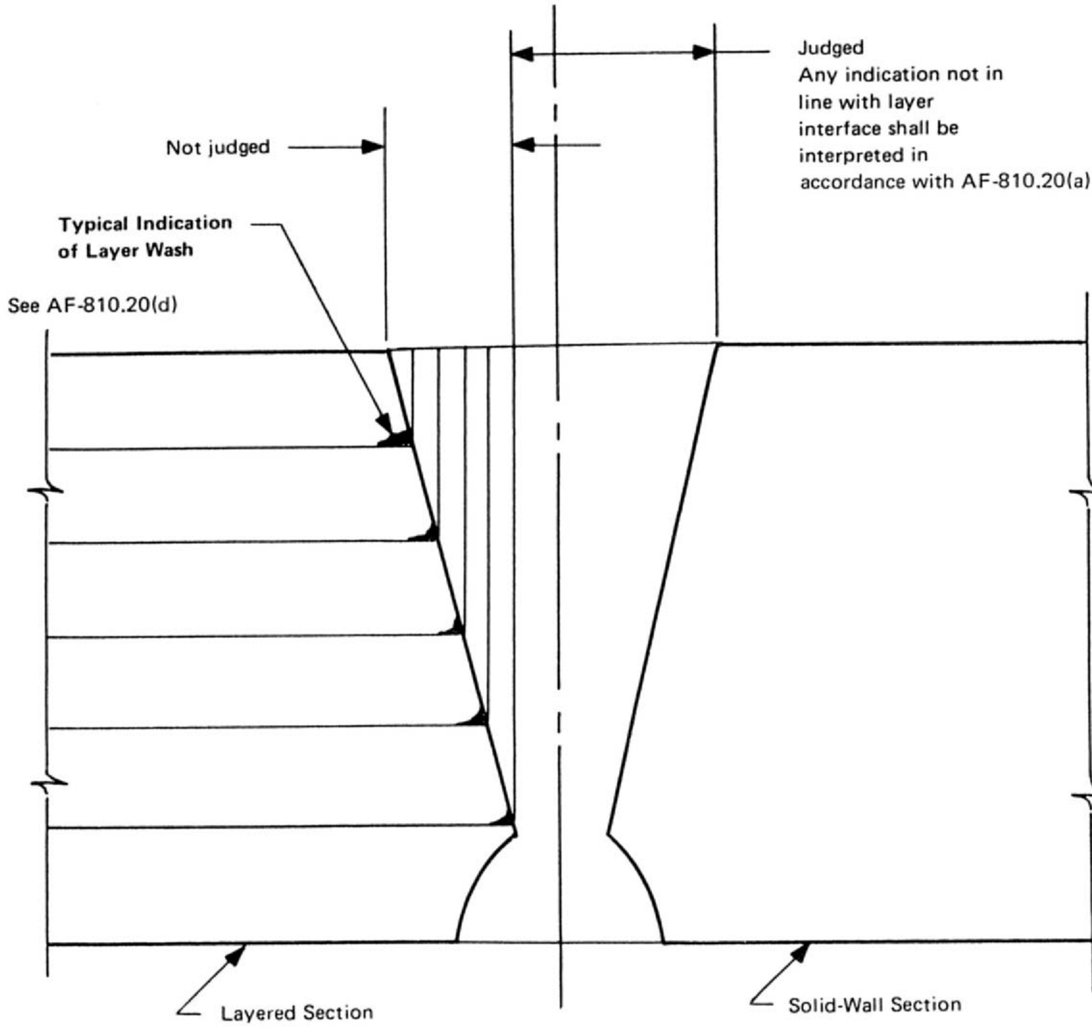

FIG. AF-810.1

(f) The requirements in (a) through (e) above do not apply to helically wound interlocking strip construction; see AF-816.

AF-815.1 Alternative to Measuring Contact Between Layers During Construction. As an alternative to AF-815, the following measurements shall be taken at the time of the hydrostatic test to check on the contact between successive layers, and the effect of gaps which may or may not be present between layers.

(a) The circumference shall be measured at the midpoint between adjacent circumferential joints, or between a circumferential joint and any nozzle in a shell course. Measurements shall be taken at zero pressure and, following application of hydrostatic test pressure, at the design pressure. The difference in measurements shall be averaged for each course in the vessel and the results recorded as average middle circumferential expansion e_m in inches (millimeters).

(b) The theoretical circumferential expansion of a solid vessel of the same dimensions and materials as the layered vessel shall be calculated from the following formula:

$$e_{th} = \frac{1.7\,\pi P(2R - t_s)^2(2R + t_s)}{8ERt_s}$$

where

e_{th} = theoretical circumferential expansion
P = internal design pressure
R = mean radius
= outside radius − $t_s/2$
t_s = wall thickness

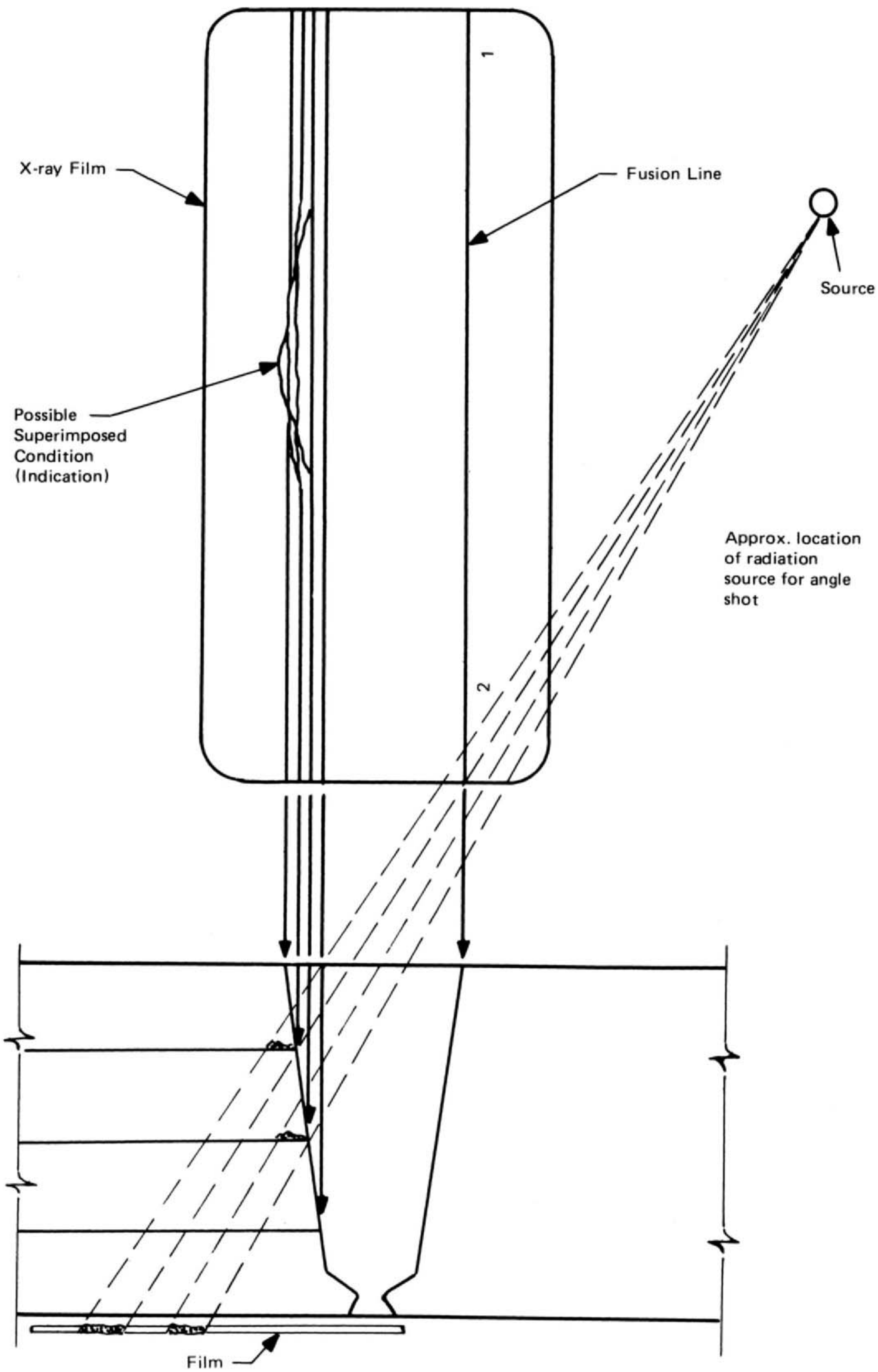
X-ray Film
Fusion Line
1
2
Source
Possible Superimposed Condition (Indication)
Approx. location of radiation source for angle shot
Film

FIG. AF-810.2

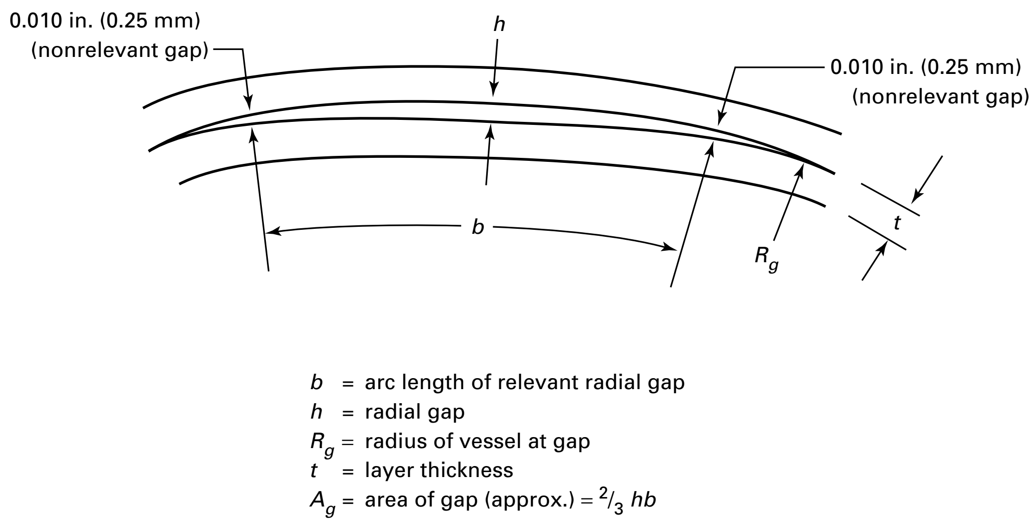

FIG. AF-815

E = modulus of elasticity [use 30 × 10^6 psi (207 × 10^6 kPa) for carbon steel]

(c) Acceptance criteria for circumferential expansion at the design pressure shall be as follows: e_m shall not be less than $0.5e_{th}$.

AF-815.2 Rules for Calculating Maximum Permissible Gaps. The maximum number and size of gaps permitted in any cross section of a layered vessel shall be limited by (a), (b), and (c) below.

(a) Maximum gap between any two layers shall not exceed the value of h given by the following equation:

$$h = 0.55 \left[N - 0.5 - \frac{P}{S_m} \right] \frac{R_g S_m}{E}$$

where

h = gap between any two layers

N = 3, for an indefinite number of cycles, or

$= \dfrac{2}{K_c} \dfrac{S_a}{S_m}$ for low cycle service

$$K_c = \sqrt{\frac{4S_a}{3S_m} + 0.25} - 0.5$$

S_a = stress amplitude from design fatigue curve, Fig. 5-110.1

S_m = allowable stress at design temperature

P = internal design pressure

R_g = outside radius of layer above which the gap is located

E = modulus of elasticity

(b) Maximum permissible number of gaps and their corresponding arc lengths at any cross section of a layered vessel shall be calculated as follows.

(1) Measure each gap and its corresponding length throughout the cross section.

(2) Calculate the value of F for each of the gaps using the following equation:

$$F = 0.109 \left(\frac{b \times h}{R_g^2} \right)$$

where

F = gap value (dimensionless)

b = length of gap

h = gap between any two layers

R_g = as defined in (a) above

(c) The total sum of the calculated F values shall not exceed the quantity

$$F_T = \frac{1 - \nu^2}{E} \left(NS_m - \frac{2PR_2^2}{R_2^2 - R_1^2} \right)$$

where

ν = Poisson's ratio

R_2 = outside radius of vessel

R_1 = inside radius of vessel

E, N, S_m, P = as defined in (a) above

AF-816 RULES FOR DETERMINING MAXIMUM PERMISSIBLE ELONGATION FOR HELICALLY WOUND INTERLOCKING STRIP VESSELS

Two hydrostatic tests shall be performed. The requirements for determining the maximum permissible elongation are as follows.

(a) During the first test, the longitudinal expansion shall be measured at design pressure, at test pressure, and again after the test pressure is reduced to design pressure. The difference in the measured lengths at design pressure shall not exceed 0.1% of the original length at design pressure.

(b) During the second test, the length of the vessel shall be measured at the test pressure and after the pressure has been completely released. The longitudinal contraction ϵ_L shall not exceed the tangential contraction ϵ_T of a solid wall vessel of the same dimensions, where

$$\epsilon_L = \frac{L_1 - L}{L}$$

$$\epsilon_T = \frac{1.7P}{E\,(y^2 - 1)}$$

and where

ϵ_L = longitudinal contraction
ϵ_T = tangential contraction
L_1 = measured length of vessel at second test pressure
L = final length of vessel at atmospheric pressure after the second test
P = test pressure
E = modulus of elasticity
y = diameter ratio (O.D./I.D.)

AF-817 VENT HOLES

Vent holes shall be provided to detect leakage of the inner shell and to prevent buildup of pressure within the layers as follows.

(a) In each shell course or head segment, a layer may be made up of one or more plates. Each layer plate shall have at least two vent holes 1/4 in. (6 mm) minimum diameter. Holes may be drilled radially through the multiple layers or may be staggered in individual layer plates.

(b) For continuous coil wrapped layers, each layered section shall have at least four vent holes 1/4 in. (6 mm) minimum diameter. Two of these vent holes shall be located near each end of the section and spaced approximately 180 deg apart.

(c) Vent holes are not required in helically wound interlocking strip construction.

(d) The minimum requirement for spirally wound strip layered construction shall be 1/4 in. (6 mm) minimum diameter vent holes drilled near both edges of the strip. They shall be spaced for the full length of the strip and shall be located a distance of approximately $\pi R/\tan\,\theta$ from each other (where R is the mean radius of the shell and θ is the acute angle of spiral wrap measured from the longitudinal centerline, degrees).

If a strip weld covers a vent hole, partially or totally, an additional vent hole shall be drilled on each side of the obstructed hole.

In addition to the above, holes may be drilled radially through the multiple layers.

(e) Vent holes shall not be obstructed. If a monitoring system is used, it shall be designed to prevent buildup of pressure within the layers.

AF-820 HEAT TREATMENT OF WELDMENTS

(a) When required, pressure parts shall be postweld heat treated in accordance with Article F-4 and Article F-6; however, completed layered vessels or layered vessel sections need not be postweld heat treated provided the requirements of (b) below are met.

(b) Unless required by AF-402, completed layered vessels or layered vessel sections need not be postweld heat treated when welded joints connect a layered section to a layered section, or a layered section to a solid wall, provided all of the following conditions are met.

(1) The thickness referred to in AF-402.3 and AF-630 is the thickness of one layer. Should more than one thickness of layer be used, the thickness of the thickest layer shall govern.

(2) The finished joint preparation of a solid section or solid nozzle which is required to be postweld heat treated under the provisions of AF-402.2 or AF-630 shall be provided with a buttered[3] layer of at least 1/8 in. (3 mm) thick welding material not requiring postweld heat treatment. Solid sections of P-No. 1 materials need not have this buttered layer. Postweld heat treatment of the buttered solid section shall then be performed prior to attaching to the layered sections. Postweld heat treatment following attachment to the layered section is not required unless the layered section is required to be postweld heat treated.

(3) Multipass welding technique is used and the weld layer thickness is limited to 3/8 in. (10 mm) maximum. When materials listed in Table AQT-1 are used, the last pass shall be given a temper bead technique[4] treatment, except for 5%, 8%, and 9% nickel steels.

(c) The postweld heat treating rules in AF-820 shall apply to all weld repairs.

(d) These heat requirements for layered vessels that are to contain lethal substances, AG-301.1(c), apply only to the inner shell and inner head.

[3] *Buttered* means built-up overlay welding.

[4] Temper bead welding technique is done when the final beads of welding are made over-flush, deposited only on previous beads of welding for tempering purposes without making contact with the base metal, and then removing these final beads.

Part AR
PRESSURE RELIEF DEVICES

ARTICLE R-1
GENERAL REQUIREMENTS

AR-100 PROTECTION AGAINST OVERPRESSURE[1]

(a) All pressure vessels within the scope of this Division shall be provided with protection against overpressure in accordance with this Article.

(b) Heat exchangers and similar vessels shall be protected against overpressure in case of an internal failure.

(c) Vessels that are to operate completely filled with liquid shall be equipped with pressure relief devices designed for liquid service unless otherwise protected against overpressure.

(d) The protective devices required in (a) need not be installed directly on a pressure vessel when the source of pressure is external to the vessel and is under such positive control that the pressure in the vessel cannot exceed the design pressure at the operating temperature except as permitted in AR-150.

(e) Vessels connected together by a system of adequate piping not containing valves which can isolate any vessel may be considered as one unit in figuring the required relieving capacity of pressure relieving safety devices to be furnished.

(f) Pressure relieving devices shall be constructed, located, and installed so that they are readily accessible for inspection and repair and so that they cannot be readily rendered inoperative (see Appendix A), and should be selected on the basis of their intended service.

[1] Safety devices need not be provided by the vessel Manufacturer, but overpressure protection shall be provided prior to placing the vessel in service.

AR-110 TYPE OF OVERPRESSURE PROTECTION

Pressure relief valves,[2] nonreclosing pressure relief devices,[3] or flow paths or vents, open directly or indirectly to the atmosphere, may be used as protective devices. Nonreclosing pressure relief devices may be used either alone or, if applicable, in combination with safety or safety relief valves on vessels.

NOTE: Use of nonreclosing devices of some types may be advisable on vessels containing substances that may render a safety or safety relief valve inoperative, where a loss of valuable material by leakage should be avoided, or where contamination of the atmosphere by leakage of noxious fluids must be avoided. The use of rupture disk devices may also be advisable when very rapid rates of pressure rise may be encountered.

AR-120 PRESSURE RELIEF VALVES[4]

(a) Safety, safety relief, and relief valves shall be of the direct spring loaded type.

[2] A *pressure relief valve* is a pressure relief device which is designed to reclose and prevent the further flow of fluid after normal conditions have been restored.

[3] A *nonreclosing pressure relief device* is a pressure relief device designed to remain open after operation.

[4] A *safety valve* is a pressure relief valve actuated by inlet static pressure and characterized by rapid opening or pop action. A *relief valve* is a pressure relief valve actuated by inlet static pressure which opens in proportion to the increase in pressure over the opening pressure. A *safety relief valve* is a pressure relief valve characterized by rapid opening or pop action, or by opening in proportion to the increase in pressure over the opening pressure, depending on application. A *pilot operated pressure relief valve* is a pressure relief valve in which the major relieving device is combined with and is controlled by a self-actuated auxiliary pressure relief valve.

(b) Pilot operated pressure relief valves may be used, provided that the pilot is self-actuated and the main valve will open automatically at not over the set pressure and will discharge its full rated capacity if some essential part of the pilot should fail.

(c) The spring in a safety valve or safety relief valve shall not be set for any pressure more than 5% above or below that for which the valve is marked, unless the setting is within the spring design range established by the valve Manufacturer or is determined to be acceptable to the Manufacturer. The initial adjustment shall be performed by the Manufacturer, his authorized representative, or an Assembler, and a valve data tag shall be provided that identifies the set pressure capacity and date. The valve shall be sealed with a seal identifying the Manufacturer, his authorized representative, or the Assembler performing the adjustment.

(d) The set pressure tolerances, plus or minus, of pressure relief valves shall not exceed 2 psi (15 kPa) for pressures up to and including 70 psi (485 kPa) and 3% for pressures above 70 psi (485 kPa).

(e) Safety and safety relief valves for steam service shall meet the requirements of AR-511.

AR-130 NONRECLOSING PRESSURE RELIEF DEVICES

AR-131 Rupture Disk Devices[5]

AR-131.1 Burst Pressure. Every rupture disk shall have a stamped burst pressure established by the rules of AR-131.1 within a manufacturing design range[6] at a specified disk temperature,[7] and shall be marked with a lot number. The burst pressure tolerance at the specified disk temperature shall not exceed ±2 psi (±15 kPa) for stamped burst pressure up to and including 40 psi (275 kPa) and ±5% for stamped burst pressure above 40 psi (275 kPa).

The stamped bursting pressure within the manufacturing design range at the coincident disk temperature shall be derived by one of the following methods. All the tests of disks for a given lot shall be made in a holder of the same form and dimensions as that with which the disk is to be used.

(a) At least two sample rupture disks from each lot of rupture disks, made from the same materials and of the same size as those to be used, shall be burst to verify that the stamped bursting pressure falls within the manufacturing design range at the coincident disk temperature. At least one disk shall be burst at room temperature. The stamped rating at the specified disk temperature shall be the average of the bursts at coincident disk temperature.

(b) At least four sample rupture disks, but not less than 5%, from each lot of rupture disks, made from the same material and of the same size as those to be used, shall be burst at four different temperatures, distributed over the applicable temperature range for which the disks will be used. This data shall be used to establish a curve of bursting pressure versus temperature for the lot of disks. The stamped rating at the coincident disk temperature shall be interpolated from this curve.

(c) For prebulged, solid metal disks or graphite disks only, a curve of percentage ratio at temperatures other than ambient may be established as in (b) above, using one size of disk for each lot of material. At least four bursts at four different temperatures shall be used to establish the above curve over the applicable temperature range. At least two disks from each lot of disks made from this lot of material and of the same size as those to be used shall be burst at ambient temperature to establish the room temperature rating of the lot of disks.

The percent change of bursting pressure taken from the above curve shall be used to establish the stamped rating at the coincident disk temperature for the lot of disks.

AR-131.2 Capacity Rating

(a) The calculated capacity rating of a rupture disk device shall not exceed a value based on the applicable theoretical formula (see AR-500) for the various media multiplied by:

$$K = \text{coefficient} = 0.62$$

The area A (square inches) in the theoretical formula shall be the minimum net area existing after disk burst.[8]

[5] A *rupture disk device* is a nonreclosing pressure relief device actuated by inlet static pressure and designed to function by the bursting of a pressure containing disk. A *rupture disk* is the pressure containing and pressure sensitive element of a rupture disk device. A *rupture disk holder* is the structure which encloses and clamps the rupture disk in position. Rupture disks may be designed in several configurations, such as plain flat, prebulged, or reverse buckling, and may be made of either ductile or brittle material; rupture disk material is not required to conform to an ASME specification. The material of the rupture disk holder shall be listed in Section II and this Division.

[6] The *manufacturing design range* is a range of pressure within which the average burst pressure of test disks must fall to be acceptable for a particular requirement as agreed upon between the rupture disk manufacturer and the user or his agent. The disk will be marked with the average burst pressure of all test disks.

[7] The specified disk temperature supplied to the rupture disk manufacturer shall be the temperature of the disk when the disk is expected to burst.

[8] The *minimum net flow area* is defined as the calculated net area after complete burst of the disk with appropriate allowance for any structural members which may reduce the net flow area through the rupture disk device. The net flow area for sizing purposes shall not exceed the nominal pipe size area of the rupture disk device.

(b) In lieu of the method of capacity rating given in (a) above, a manufacturer may have the capacity of a given rupture disk device design determined for the K_D coefficient in general accordance with the procedures of AR-500, as applicable.

AR-131.3 Sole Relief Device. Application of rupture disk devices to liquid service should be carefully evaluated to assure that the design of the rupture disk device and the dynamic energy of the system on which it is installed will result in sufficient opening of the rupture disk.

A rupture disk device may be used as the sole pressure relieving device on a vessel.

NOTE: When rupture disk devices are used, it is recommended that the design pressure of the vessel be sufficiently above the intended operating pressure to provide sufficient margin between operating pressure and rupture disk bursting pressure to prevent premature failure of the rupture disk due to fatigue or creep.

AR-131.4 Installed Upstream of Pressure Relief Valve. A rupture disk device may be installed between a pressure relief valve[9] and the vessel provided:

(a) the combination of the spring loaded safety or safety relief valve and the rupture disk device is ample in capacity to meet the requirements of AR-150;

(b) the stamped capacity of a spring loaded safety or safety relief valve (nozzle type) when installed with a rupture disk device between the inlet of the valve and the vessel shall be multiplied by a factor of 0.80 of the rated relieving capacity of the valve alone, or alternatively, the capacity of such a combination shall be established in accordance with (c);

(c) the capacity of the combination of the rupture disk device and the spring loaded safety or safety relief valve may be established in accordance with the appropriate paragraphs of AR-560;

(d) the space between a rupture disk device and a safety or safety relief valve shall be provided with a pressure gage, a try cock, free vent, or suitable telltale indicator. This arrangement permits detection of disk rupture or leakage.[10]

(e) the opening (see footnote 8) provided through the rupture disk, after burst, is sufficient to permit a flow equal to the capacity of the valve [see (b) and (c) above], and there is no chance of interference with proper functioning of the valve; but in no case shall this area be less than 80% of the area of the inlet of the valve unless the capacity and functioning of the specific combination of rupture disk and valve have been established by test in accordance with AR-560.

AR-131.5 Installed Downstream of a Spring Loaded Safety Relief Valve. A rupture disk device may be installed on the outlet side[11] of a spring loaded safety relief valve which is opened by direct action of the pressure in the vessel, provided:

(a) the valve is so designed that it will not fail to open at its proper pressure setting regardless of any back pressure that can accumulate between the valve disk and the rupture disk. The space between the valve disk and the rupture disk shall be vented or drained to prevent accumulation of pressure due to small amount of leakage from the valve.[12]

(b) the valve is ample in capacity to meet the requirements of AR-150(a), (b), and (c);

(c) the stamped bursting pressure of the rupture disk at the coincident temperature plus any pressure in the outlet piping shall not exceed the design pressure of the outlet portion of the safety or safety relief valve and any pipe or fitting between the valve and the rupture disk device. However, in no case shall the stamped bursting pressure of the rupture disk at the coincident disk temperature plus any pressure in the outlet piping exceed the maximum allowable working pressure of the vessel or the set pressure of the safety or safety relief valve.

(d) the opening provided through the rupture disk device after breakage is sufficient to permit a flow equal to the rated capacity of the attached safety or safety relief valve without exceeding the allowable overpressure;

(e) any piping beyond the rupture disk cannot be obstructed by the rupture disk or fragment;

(f) the contents of the vessel are clean fluids, free from gumming or clogging matter, so that accumulation in the space between the valve inlet and the rupture disk (or in any other outlet that may be provided) will not clog the outlet;

(g) the bonnet of the safety relief valve shall be vented to prevent accumulation of pressure.

[9] Use of a rupture disk device in combination with a pressure relief valve should be carefully evaluated to insure that the media being handled and the valve operational characteristics will result in opening action of the valve coincident with the bursting of the rupture disk.

[10] Users are warned that a rupture disk will not burst at its design pressure if back pressure builds up in the space between the disk and the safety or safety relief valve, which will occur should leakage develop in the rupture disk due to corrosion or other cause.

[11] This use of a rupture disk device in series with the safety or safety relief valve is permitted to minimize the loss by leakage through the valve of valuable or of noxious or otherwise hazardous materials, and where a rupture disk alone or disk located on the inlet side of the valve is impracticable, or to prevent corrosive gases from a common discharge line reaching the valve internals.

[12] Users are warned that an ordinary spring loaded safety relief valve will not open at its set pressure if back pressure builds up in the space between the valve and rupture disk. A specially designed valve is required, such as a diaphragm valve or a valve equipped with a bellows above the disk.

AR-132 Breaking Pin Device[13]

(a) Breaking pin devices shall not be used as single devices but only in combination between the safety or safety relief valve and the vessel.

(b) The space between a breaking pin device and a safety or safety relief valve shall be provided with a pressure gage, a try cock, a free vent, or suitable telltale indicator. This arrangement permits detection of breaking pin device operation or leakage.

(c) Each breaking pin device shall have a rated pressure and temperature at which the pin will break. The breaking pin shall be identified by a lot number and shall be guaranteed by the manufacturer to break when the rated pressure, within the following tolerances, is applied to the device.

Rated Pressure, psi (kPa)		
Minimum	Maximum	Tolerance, Plus or Minus, psi (kPa)
30 (200)	150 (1 000)	5 (35)
151 (1 040)	275 (1 900)	10 (70)
276 (1 900)	375 (2 600)	15 (100)

(d) The rated pressure of the breaking pin plus the tolerance in pounds per square inch shall not exceed 105% of the maximum allowable working pressure of the vessel to which it is applied.

(e) The rated pressure at the coincident operating temperature[14] shall be verified by breaking two or more sample breaking pins from each lot of the same material and the same size as those to be used. The lot size shall not exceed 25. The test shall be made in a device of the same form and pressure dimensions as that in which the breaking pin is to be used.

AR-133 Spring Loaded Nonreclosing Pressure Relief Devices

(a) A spring loaded nonreclosing pressure relief device, pressure actuated by means which permit the spring loaded portion of the device to open at the specified set pressure and remain open until manually reset, may be used provided the design of the spring loaded nonreclosing device is such that if the actuating means fail, the device will achieve full opening at or below its set pressure. Such a device may not be used in combination with any other pressure relief device. The tolerance on opening point shall not exceed ±5%.

(b) The calculated capacity rating of a spring loaded nonreclosing pressure relief device shall not exceed a value based on the applicable theoretical formula (see AR-500) for the various media, multiplied by:

$$K = \text{coefficient} = 0.62$$

The area A (square inches) in the theoretical formula shall be the flow area through the minimum opening of the nonreclosing pressure relief device.

(c) In lieu of the method of capacity rating given in (b) above, a manufacturer may have the capacity of a spring loaded nonreclosing pressure relief device design certified in general accordance with the procedures of AR-500, as applicable.

AR-140 SET PRESSURES

AR-141 For a Single Relief Device

A single pressure relieving device shall be set to operate[15] at a pressure (see AR-145 for tolerances) not exceeding the design pressure of the vessel at the operating temperature, except as permitted in AR-142.

AR-142 For Multiple Relief Devices

(a) If the required discharging capacity is supplied by more than one device, only one need be set to operate at a pressure not exceeding the design pressure of the vessel. The additional device or devices may be set at a higher pressure but not to exceed 105% of the design pressure of the vessel, except as provided in (b).

(b) When supplemental relieving devices are provided for protection against excessive pressure due to exposure to fire or other unexpected sources of external heat, such devices shall be set to operate at a pressure not in excess of 110% of the design pressure of the vessel [see AR-150(c)].

AR-143 Pressure Effects to Be Included in Setting

The pressure at which any device is set shall include the effects of static head and back pressure.

AR-144 Pressure Gage Range

If a pressure indicating gage is provided to determine the vessel pressure at or near the set pressure of the relief

[13] A *breaking pin device* is a nonreclosing pressure relief device actuated by inlet static pressure and designed to function by the breakage of a load-carrying section of a pin which supports a pressure containing member. A *breaking pin* is the load-carrying element of a breaking pin device. A *breaking pin housing* is the structure which encloses the breaking pin mechanism. The material of the housing shall be listed in Section II and this Division.

[14] The specified temperature supplied to the breaking pin manufacturer should be the temperature of the breaking pin when an emergency condition exists and the pin is expected to break.

[15] *Set to operate* means the set pressure of a pressure relief valve or a spring loaded nonreclosing device, the bursting pressure of a rupture disk device, or the breaking pressure of a breaking pin device.

device, one should be selected that is graduated with an upper limit that is neither less than 1.25 times the set pressure of the relief device nor more than twice the design pressure of the vessel. Additional gages may be installed if desired.

AR-145 Set Pressure Tolerances

Set pressure tolerances, as stated in AR-120 and AR-130, are sufficiently restrictive so that the nominal set-to-operate pressure of the overpressure protection device may equal the design pressure of the vessel.

AR-150 PERMISSIBLE OVERPRESSURES

The aggregate capacity of the pressure relieving devices, open flow paths, or vents shall be sufficient to prevent overpressure in excess of those specified in (a), (b), and (c) when the pressure relieving devices are discharging.

(a) The permissible overpressure for all pressure vessels constructed according to this Division shall be limited to not more than 10% or 3 psi (20 kPa), whichever is greater, above the design pressure of the vessel, except as provided in (b) and (c). See AR-140 for pressure settings.

(b) The permissible overpressure for vessels provided with multiple pressure relieving devices in accordance with AR-142(a) shall be limited to 16% or 4 psi (30 kPa), whichever is greater, above the design pressure.

(c) The permissible overpressure shall be limited to 21% of the design pressure when the pressure relief devices are discharging for conditions such as exposure to fire or other unexpected sources of external heat.

(d) The same pressure relieving devices may be used to satisfy the capacity requirements of (a) and (c) or (b) and (c), provided the pressure setting requirements of AR-140 are met.

AR-160 PRORATION OF STAMPED CAPACITY

(a) To prorate the relieving capacity of any relieving pressure greater than 1.10p, as permitted under AR-140 and AR-150, a multiplier may be applied to the official relieving capacity of a pressure relieving device as follows:

(U.S. Customary Units)

$$\frac{P + 14.7}{1.10p + 14.7}$$

(SI Units)

$$\frac{P + 101}{1.10p + 101}$$

where

P = relieving pressure
p = set pressure

For steam pressures above 1,500 psig (10 MPa), the above multiplier is not applicable. For steam valves with relieving pressures greater than 1,500 psig (10 MPa) and less than or equal to 3,200 psig (22 MPa), the capacity at relieving pressures greater than 1.10p shall be determined using the equation for steam and the correction factor for high pressure steam in AR-523 with the permitted absolute relieving pressure and the coefficient K for that valve design.

(b) The official rated capacity of a pressure relieving safety device shall be that which is stamped on the device and guaranteed by the manufacturer.

AR-161 Conversion of Capacity for a Different Fluid

The rated pressure relieving capacity of a pressure relief valve for other than steam or air shall be determined by the method of conversion given in Appendix 10.

ARTICLE R-2
MATERIAL AND DESIGN REQUIREMENTS

AR-200 MINIMUM REQUIREMENTS FOR PRESSURE RELIEF VALVES

(a) The design shall incorporate guiding arrangements necessary to insure consistent operation and tightness.

(b) The spring shall be designed so that the full lift spring compression shall be no greater than 80% of the nominal solid deflection. The permanent set of the spring (defined as the difference between the free height and height measured 10 min after the spring has been compressed solid three additional times after presetting at room temperature) shall not exceed 0.5% of the free height.

(c) Each pressure relief valve on air, water over 140°F (60°C), or steam service shall have a substantial lifting device which when activated will release the seating force on the disk when the valve is subjected to a pressure of at least 75% of the set pressure of the valve. Pilot operated pressure relief valves used on these services shall be provided with either a lifting device as described above or means for connecting and applying pressure to the pilot adequate to verify that the moving parts critical to proper operation are free to move.

(d) The seat of a safety valve shall be fastened to the body of the valve in such a way that there is no possibility of the seat lifting.

(e) In the design of the body of the valve, consideration shall be given to minimizing the effects of deposits.

(f) Valves having screwed inlet or outlet connections shall be provided with wrenching surfaces to allow for normal installation without damaging operating parts.

(g) Means shall be provided in the design of all valves for use under this Division for sealing all initial adjustments which can be made without disassembly of the valve. Seals shall be installed by the Manufacturer or Assembler at the time of initial adjustment. Seals shall be installed in a manner to prevent changing the adjustment without breaking the seal. For valves larger than NPS $\frac{1}{2}$ (DN 15), the seal shall serve as a means of identifying the Manufacturer or Assembler making the initial adjustment.

(h) For pressure relief valves of the diaphragm type, the space above the diaphragm shall be vented to prevent a buildup of pressure above the diaphragm. Pressure relief valves of the diaphragm type shall be designed so that failure or deterioration of the diaphragm material will not impair the ability of the valve to relieve at the rated capacity.

AR-210 MATERIAL SELECTIONS

(a) Cast iron seats and disks are not permitted.

(b) Adjacent sliding surfaces such as guides and disks or disk holders shall both be of corrosion resistant material. Springs of corrosion resistant material or having a corrosion resistant coating are required. The seats and disks of pressure relief valves shall be of suitable material to resist corrosion by the fluid to be contained.

NOTE: The degree of corrosion resistance, appropriate to the intended service, shall be a matter of agreement between the Manufacturer and the purchaser.

(c) Materials used in bodies and bonnets or yokes shall be listed in Section II and this Division. Materials used in nozzles, disks, and other parts contained within the external structure of the safety or safety relief valves shall be one of the following categories:

(1) listed in Section II;

(2) listed in ASTM Specifications;

(3) controlled by the Manufacturer of the pressure relief valve by a specification insuring control of chemical and physical properties and quality at least equivalent to ASTM standards.

AR-211 MINIMUM SIZE OF SAFETY RELIEF VALVES

Any safety relief valve used for liquid service shall be at least NPS $\frac{1}{2}$ (DN 15).

AR-213 DRAIN REQUIREMENTS

(a) If the design of a safety or safety relief valve is such that liquid can collect on the discharge side of the disk, except as permitted in (b) below, the valve shall be equipped with a drain at the lowest point where liquid can collect.

(b) Pressure relief valves which cannot be equipped with a drain as required in (a) above because of design or application may be used provided:

(1) the pressure relief valves are used only on gas service where there is neither liquid discharged from the valve nor liquid formed by condensation on the discharge side of the valve; and

(2) the pressure relief valves are provided with a cover or discharge piping per AR-610(c) to prevent liquid or other contaminants from entering the discharge side of the valve; and

(3) the pressure relief valve is marked "FOR GAS SERVICE ONLY" in addition to the requirements of AR-400.

AR-214 WELDING AND OTHER REQUIREMENTS

All welding, brazing, heat treatment, and nondestructive examination used in the construction of bodies, bonnets, and yokes shall be performed in accordance with the applicable requirements of this Division.

AR-220 INSPECTION OF MANUFACTURING AND/OR ASSEMBLY OF PRESSURE RELIEF VALVES

(a) A Manufacturer or Assembler shall demonstrate to the satisfaction of a representative from an ASME designated organization that his manufacturing, production, and testing facilities and quality control procedures will insure close agreement between the performance of random production samples and the performance of those valves submitted for capacity certification.

(b) Manufacturing, assembly, inspection, and test operations including capacity are subject to inspection at any time by a representative from an ASME designated organization.

(c) A Manufacturer or Assembler may be granted permission to apply the UV Code symbol to production pressure relief valves capacity certified in accordance with AR-500 provided the following tests are successfully completed. This permission shall expire on the fifth anniversary of the date it is initially granted. The permission may be extended for 5 year periods if the following tests are successfully repeated within the 6 month period before expiration.

(1) Two sample production pressure relief valves of a size and capacity within the capability of an ASME accepted laboratory shall be selected by a representative from an ASME designated organization.

(2) Operational and capacity tests shall be conducted in the presence of a representative from an ASME designated organization at an ASME accepted laboratory. The valve Manufacturer shall be notified of the time of the test and may have representatives present to witness the test. Valves having an adjustable blowdown construction shall be adjusted by the Manufacturer or Assembler following successful testing for operation but prior to flow testing so that the blowdown does not exceed 7% of the set pressure or 3 psi (20 kPa), whichever is greater. This adjustment may be made on the flow test facility.

(3) Should any valve fail to relieve at or above its certified capacity, or should it fail to meet performance requirements of this Division, the test shall be repeated at the rate of two replacement valves, selected in accordance with AR-220(c)(1), for each valve that failed.

(4) Failure of any of the replacement valves to meet the capacity or the performance requirements of this Division shall be cause for revocation within 60 days of the authorization to use the Code symbol on that particular type of valve. During this period, the Manufacturer or Assembler shall demonstrate the cause of such deficiency and the action taken to guard against future occurrence, and the requirements of AR-220(c) above shall apply.

(d) Use of the Code symbol stamp by an Assembler indicates the use of original, unmodified parts in strict accordance with the instructions of the Manufacturer of the valve.

(e) In addition to the requirements of AR-401, the nameplate marking shall include the name of the Manufacturer and the Assembler. The Code symbol stamp shall be that of the Assembler.

NOTE: Within the requirements of AR-220 and AR-230, a *Manufacturer* is defined as a person or organization who is completely responsible for design, material selection, capacity certification, and manufacture of all component parts, assembly, testing, sealing, and shipping of pressure relief valves certified under this Section of the Code.

An *Assembler* is defined as a person or organization who purchases or receives from a Manufacturer the necessary component parts or valves and assembles, adjusts, tests, seals, and ships pressure relief valves certified under this Division, at a geographical location other than and using facilities other than those used by the Manufacturer. An Assembler may be organizationally independent of a Manufacturer or may be wholly or partly owned by a Manufacturer.

AR-230 PRODUCTION TESTING BY MANUFACTURERS AND ASSEMBLERS

(a) Each pressure relief valve to which the Code symbol is to be applied shall be subjected to the following tests by the Manufacturer or Assembler. A Manufacturer or Assembler shall have a documented program for application, calibration, and maintenance of gages and instruments used during the tests.

(b) The primary pressure parts of each valve exceeding NPS 1 inlet size (DN 25) or 300 psi (2 MPa) set pressure, where the materials used are either cast or welded, shall be tested at a pressure of at least 1.5 times the design pressure of the parts. These tests shall be conducted after all machining operations on the parts have been completed. There shall be no visible sign of leakage.

(c) The secondary pressure zone of each closed bonnet valve exceeding NPS 1 (DN 25) inlet size when such valves are designed for discharge to a closed system shall be tested with air or other gas at a pressure of at least 30 psi (200 kPa). There shall be no visible sign of leakage.

(d) Each valve shall be tested to demonstrate popping or set pressure. Valves marked for steam service or having special internal parts for steam service shall be tested with steam, except that valves beyond the capability of the production steam test facility either because of size or set pressure may be tested on air. Necessary corrections for differentials in popping pressure between steam and air shall be established by the Manufacturer and applied to the popping point on air. Valves marked for gas or vapor may be tested with air. Valves marked for liquid service shall be tested with water or other suitable liquid. When a valve is adjusted to correct for service conditions of superimposed back pressure, temperature, or the differential pressure between steam and air, the actual test pressure (cold differential test pressure) shall be marked on the valve per AR-401. Test fixtures and test drums where applicable shall be of adequate size and capability to insure that valve action is consistent with the stamped set pressure within tolerances required by AR-120(d).

(e) After completion of the tests required by (d) above, a seat tightness test shall be conducted. Unless otherwise designated by a Manufacturer's published valve specification, the seat tightness test and acceptance criteria shall be in accordance with API Standard 527.

(f) Testing time on steam valves shall be sufficient, depending on size and design, to insure that test results are repeatable and representative of field performance.

AR-240 DESIGN REQUIREMENTS

At the time of the submission of valves for capacity certification, or testing in accordance with AR-220, the ASME designated organization has the authority for conformity with the requirements of AR-200(a) and (b) and to reject or require modification of designs which do not conform, prior to capacity testing.

ARTICLE R-4
MARKING AND STAMPING

AR-400 MARKING

AR-401 Safety, Safety Relief, Liquid Relief, and Pilot Operated Valves

Each safety, safety relief, liquid relief, and main valve of a pilot operated pressure relief valve NPS $\frac{1}{2}$ (DN 15) and larger shall be plainly marked by the Manufacturer or Assembler with the required data in such a way that the marking will not be obliterated in service. The marking shall be placed on the valve or on a nameplate securely fastened to the valve. The Code UV symbol shall be stamped on the valve or nameplate, but the other required data may be stamped, etched, impressed, or cast on the valve or nameplate. The marking shall include the following:

(a) the name or an acceptable abbreviation of the Manufacturer and Assembler;

(b) Manufacturer's design or type number;

(c) NPS size (the nominal pipe size of the valve inlet);

(d) set pressure, psi (kPa), and, if applicable per AR-230(d), cold differential test pressure, psi (kPa);

(e) certified capacity (as applicable):

(1) lb/hr saturated steam at an overpressure of 10% or 3 psi (20 kPa), whichever is greater for valves certified on steam complying with AR-511;

(2) gal/min water at 70°F (21°C) at an overpressure of 10% or 3 psi (20 kPa), whichever is greater for valves certified on water;

(3) SCFM [standard cubic feet per minute, 60°F (20°C) and 14.7 psia (101 kPa)] air at an overpressure of 10% or 3 psi (20 kPa), whichever is greater;

(4) in addition to one of the fluids specified above, the Manufacturer may indicate the capacity in other fluids (see Appendix 10);

(f) year built, or alternatively, a coding may be marked on the valve such that the valve Manufacturer or Assembler can identify the year the valve was assembled and tested;

(g) ASME symbol as shown in Fig. AR-401.1. The pilot of a pilot operated pressure relief valve shall be plainly marked by the Manufacturer or Assembler, showing the name of the Manufacturer, the Manufacturer's design or type number, the set pressure in psi, and the year built or, alternatively, a coding that the Manufacturer can use to identify the year built.

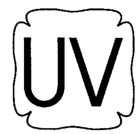

FIG. AR-401.1 OFFICIAL SYMBOL FOR STAMP TO DENOTE THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS' STANDARD

On valves smaller than NPS $\frac{1}{2}$ (DN 15), the markings may be made on a metal tag attached by wire, adhesive, or other means suitable for the service conditions.

AR-401.1 Safety and Safety Relief Valves Certified for Steam Discharging Capacity. Safety and safety relief valves certified for a steam discharging capacity under the provisions of Section I, and bearing the official Code symbol stamp of that Section for safety valves, may be used on pressure vessels. The rated capacity in terms of other fluids shall be determined by the method of conversion given in Appendix 10 (see AR-550).

AR-401.2 Units of Measurement. The units of measurement shall be in accordance with AG-151.

AR-402 Pressure Relief Valves in Combination With Rupture Disk Devices

Pressure relief valves in combination with rupture disk devices shall be marked with the capacity as established in accordance with AR-131.4(b) (using 0.80 factor) or the combination capacity factor established by test in accordance with AR-561 or AR-562, in addition to the marking of AR-401 and AR-405. The marking may be placed on the valve or rupture disk device or on a plate or plates securely fastened on the valve or rupture disk device. The marking shall include the following:

(a) name of Manufacturer of valve;

(b) design or type number of valve;

(c) name of manufacturer of rupture disk device;

(d) design or type number of rupture disk device;

(e) capacity or combination capacity factor;

(f) name of organization responsible for this marking. This shall be either the vessel user, vessel Manufacturer, rupture disk manufacturer, or pressure relief valve Manufacturer.

AR-403 Pressure Relief Valves in Combination With Breaking Pin Devices

Pressure relief valves in combination with breaking pin devices shall be marked in accordance with AR-401. In addition, the rated pressure shall be marked on the breaking pin and the breaking pin housing.

AR-404 Rupture Disk Devices

Every rupture disk shall be plainly marked by the manufacturer in such a way that the marking will not be obliterated in service. The rupture disk marking may be placed on the flange of the disk or on a metal tab permanently attached thereto. The marking shall include the following:

(a) the name or identifying trademark of the manufacturer;

(b) manufacturer's design or type number;

(c) lot number;

(d) disk material;

(e) size;

(f) stamped bursting pressure;

(g) coincident disk temperature;

(h) capacity of saturated steam or air [60°F (15°C) and 14.7 psia (101 kPa absolute)].

NOTE: In addition, the manufacturer may indicate the capacity in other fluids (see Appendix 10).

Items (a), (b), and (e) shall also be marked on the rupture disk holder.

AR-405 Spring Loaded Nonreclosing Pressure Relief Devices

Spring loaded nonreclosing pressure relief devices shall be marked in accordance with AR-401, except that the Code symbol stamp is to be applied only when the capacity has been established and certified in accordance with AR-500 and all other requirements of AR-410 have been met.

AR-410 USE OF CODE SYMBOL STAMP

Each pressure relief device[1] to which the Code symbol (see Fig. AR-401.1) will be applied shall have been fabricated or assembled by a Manufacturer or Assembler holding a valid Certificate of Authorization (see Article S-2) and capacity certified in accordance with the requirements of this Division. A Certified Individual (CI) shall provide oversight to ensure that each use of the Code symbol is in accordance with the requirements of this Division. In addition, each use of the Code symbol is to be documented on Certificate of Conformance Form A-4.

(a) Requirements for the Certified Individual. The CI shall:

(1) be an employee of the Manufacturer or Assembler

(2) be qualified and certified by the Manufacturer or Assembler. Qualifications shall include, as a minimum:

(a) knowledge of the requirements of this Division for the application of the appropriate Code symbol

(b) knowledge of the Manufacturer's or Assembler's quality program

(c) training commensurate with the scope, complexity, or special nature of the activities to which oversight is to be provided

(3) have a record, maintained and certified by the Manufacturer or Assembler, containing objective evidence of the qualifications of the CI and the training program provided

(b) Duties of the Certified Individual. The CI shall:

(1) verify that each item to which the Code symbol is applied meets all applicable requirements of this Division and has a current capacity certification for the UV symbol

(2) for the UV symbol, review documentation for each lot of items to be stamped, to verify, for the lot, that requirements of this Division have been completed

(3) sign Certificate of Conformance Form A-4 prior to release of control of the item

(c) Certificate of Conformance Form A-4

(1) The Certificate of Conformance shall be filled out by the Manufacturer or Assembler and signed by the Certified Individual. Multiple duplicate pressure relief devices may be recorded in a single entry, provided the devices are identical and produced in the same lot.

(2) The Manufacturer's or Assembler's written Quality Control System shall include requirements for completion of Certificate of Conformance forms and retention by the Manufacturer or Assembler for a minimum of 5 years.

[1] Vacuum relief valves are not covered by Code symbol stamp requirements.

ARTICLE R-5
CERTIFICATION OF CAPACITY OF SAFETY AND SAFETY RELIEF VALVES

AR-500 CERTIFICATION OF CAPACITY BEFORE APPLYING SYMBOL

(a) Before the symbol is applied to any pressure relief valve, the valve Manufacturer shall have the capacity of his valves certified as prescribed in this Article.

(b) When changes are made in the design of a pressure relief valve in such a manner as to affect the flow path, lift, or performance characteristics of the valve, new tests in accordance with this Division shall be performed.

AR-510 FLUID MEDIA AND TEST PRESSURES

AR-511 Fluid Media for Capacity Certification Tests

(a) Capacity certification tests for pressure relief valves for compressible fluids shall be conducted on saturated steam, air, or natural gas. When dry saturated steam is used, the limits for test purposes shall be 98% minimum quality and 20°F (11°C) maximum superheat. Correction from within these limits may be made to the dry saturated condition. Valves for steam service may be rated as above, but at least one valve of each series shall be tested on steam to demonstrate the steam capacity and performance.

(b) Capacity certification tests for pressure relief valves for incompressible fluids shall be conducted on water at a temperature between 40°F (5°C) and 125°F (50°C).

AR-512 Maximum Test Pressure

Capacity certification tests shall be conducted at a pressure which does not exceed the pressure for which the pressure relief valve is set to operate by more than 10% or 3 psi (20 kPa), whichever is greater. Minimum pressure for capacity certification tests shall be at least 3 psi (20 kPa) above set pressure. The reseating pressure shall be noted and recorded. Pressure relief valves for compressible fluids having an adjustable blowdown construction shall be adjusted prior to testing so that the blowdown does not exceed 5% of the set pressure or 3 psi (20 kPa), whichever is greater. The blowdown of pressure relief valves for incompressible fluids and pressure relief valves for compressible fluids having nonadjustable blowdown shall be noted and recorded.

AR-513 Tests of Pilot Operated Valves

Capacity certification of pilot operated pressure relief valves may be based on tests without the pilot valves installed, provided, prior to capacity tests, it has been demonstrated by test to the satisfaction of the authorized observer that the pilot valve will cause the main valve to fully open at a pressure which does not exceed the set pressure by more than 10% or 3 psi (20 kPa), whichever is greater, and that the pilot valve in combination with the main valve will meet all the requirements of this Division.

AR-520 PROCEDURES FOR CAPACITY CERTIFICATION TESTS

AR-521 Three Valve Method

A capacity certification test is required on a set of three valves for each combination of size, design, and pressure setting. The stamped capacity rating for each combination of design, size, and test pressure shall not exceed 90% of the average capacity of the three valves tested. The capacity for each set of three valves shall fall within a range of ±5% of the average capacity. Failure to meet this requirement shall be cause to refuse certification of that particular safety valve design.

AR-522 Slope Method

If a Manufacturer wishes to apply the Code symbol to a design of pressure relief valves, four valves of each combination of pipe size and orifice size shall be tested. These four valves shall be set at pressures which cover the approximate range of pressures for which the valve will be used or covering the range available at the certified test facility which shall conduct the tests. The capacities based on these four tests shall be as follows.

(a) For compressible fluids, the slope W/P of the actual measured capacity versus the flow pressure for each test point shall be calculated and averaged:

(U.S. Customary Units)

$$\text{Slope} = \frac{W}{P} = \frac{\text{measured capacity}}{\text{absolute flow pressure, psia}}$$

(SI Units)

$$\text{Slope} = \frac{W}{P} = \frac{\text{measured capacity}}{\text{absolute flow pressure, kPa (absolute)}}$$

All values derived from the testing must fall within ±5% of the average value:

$$\text{Minimum slope} = 0.95 \times \text{average slope}$$

$$\text{Maximum slope} = 1.05 \times \text{average slope}$$

If the values derived from the testing do not fall between the minimum and maximum slope values, the authorized observer shall require that additional valves be tested at the rate of two for each valve beyond the maximum and minimum values, with a limit of four additional valves.

The relieving capacity to be stamped on the valve shall not exceed 90% of the average slope times the absolute accumulation pressure:

$$\text{Rated slope} = 0.90 \times \text{average slope}$$

Stamped capacity ≤ rated slope (set pressure × 1.10 + 14.7)
or (set pressure + 3 psi + 14.7)
[set pressure + 20 kPa + 101],
whichever is greater

(b) For incompressible fluids, the capacities shall be plotted on log–log paper against the differential (inlet minus discharge pressure) test pressure and a straight line drawn through these four points. If the four points do not establish a straight line, two additional valves shall be tested for each unsatisfactory point, with a limit of two unsatisfactory points. Any point that departs from the straight line by more than 5% should be considered an unsatisfactory point. The relieving capacity shall be determined from this line. The certified capacity shall not exceed 90% of the capacity taken from the line.

AR-523 Coefficient of Discharge Method

Instead of individual capacity certification, as provided in AR-521 and AR-522, a coefficient of discharge K may be established for a specific pressure relief valve design according to the procedure in (a) and (b).

(a) For each design, the pressure relief valve Manufacturer shall submit for test at least three valves for each of three different sizes (a total of nine valves), together with detailed drawings showing the valve construction. Each valve of a given size shall be set at a different pressure.

(b) Tests shall be made on each pressure relief valve to determine its capacity lift, popping and blowdown pressures, and actual capacity in terms of the fluid used in the test. A coefficient K_D shall be established for each test run as follows: 04

$$K_D = \frac{\text{actual flow}}{\text{theoretical flow}} = \text{coefficient of discharge}$$

where actual flow is determined quantitatively by test and theoretical flow is calculated by the appropriate formula which follows:

For tests with dry saturated steam,

$$W_T = 51.5AP$$

NOTE: For dry saturated steam pressures over 1,500 psig (10 MPa) and up to 3,200 psig (22 MPa), the value of W_T calculated by the above equation shall be corrected by being multiplied by the following factor, which shall only be used if it is 1.0 or greater:

For U.S. customary units,

$$\frac{0.1906P - 1{,}000}{0.2292P - 1{,}061}$$

For SI units,

$$\frac{27.6P - 1\,000}{33.2P - 1\,061}$$

For tests with air,

$$W_T = 356AP\sqrt{M/T}$$

For tests with natural gas,

$$W_T = CAP\sqrt{M/ZT}$$

For tests with water,

$$W_T = 2407A\sqrt{(P - P_d)\,w}$$

where

A = actual discharge area through the valve at developed lift

C = constant for gas or vapor based on the ratio of specific heats (see Fig. 10-100.1) $k = c_p/c_v$

M = molecular weight

P = (set pressure × 1.10) plus atmospheric pressure

P_d = pressure at discharge from valve
T = absolute temperature at inlet, °F + 460 (°C + 273.15)
W_T = theoretical flow
Z = compressibility factor corresponding to P and T
w = specific weight of water at valve inlet conditions

The average of the coefficients K_D of the nine tests required shall be multiplied by 0.90, and this product shall be taken as the coefficient K of that design. The coefficient of the design shall not be greater than 0.878 (the product of 0.9 × 0.975).

NOTE: All experimentally determined coefficients K_D shall fall within a range of ±5% of the average K_D found. Failure to meet this requirement shall be cause to refuse certification of that particular valve design.

To convert lb/hr water to gal/min water, multiply the capacity in lb/hr by 1/500.

(c) The official relieving capacity of all sizes and pressures of a given design, for which K has been established under the provisions of (b), that are manufactured subsequently shall not exceed the value calculated by the appropriate formula in (b) multiplied by the coefficient K (see Appendix 10).

(d) The coefficient shall not be applied to valves whose β ratio (ratio of valve throat to inlet diameter) lies outside the range of 0.15 to 0.75, unless tests have demonstrated that the individual coefficient of discharge K_D for valves at the extreme ends of a larger range is within ±5% of the average coefficient K. For designs where the lift is used to determine the flow area, all valves shall have the same nominal lift to seat diameter ratio (L/D).

AR-524 Rating of Nozzle Type Valves

Rating of nozzle type valves, i.e., coefficient K_D greater than 0.90 and nozzle construction, for saturated water shall be according to 10-101 in Appendix 10.

AR-530 WHERE AND BY WHOM CAPACITY TESTS SHALL BE CONDUCTED

Tests shall be conducted at a place where the testing facilities, methods, procedures, and person supervising the tests (authorized observer) meet the applicable requirements of ASME PTC 25. The tests shall be made under the supervision of and certified by an authorized observer. The testing facilities, methods, procedures, and qualifications of the authorized observer shall be subject to the acceptance of the Boiler and Pressure Vessel Committee on recommendation of a representative from an ASME designated organization. Acceptance of the testing facility is subject to review within each 5 year period.

AR-540 TEST DATA REPORT

Capacity test data reports for each valve model, type, and size signed by the Manufacturer and the authorized observer witnessing the tests shall be submitted to the ASME designated organization for review and acceptance.[1] Where changes are made in the design, capacity certification tests shall be repeated.

AR-550 WAIVER OF FURTHER TESTS OF VALVES TESTED PER SECTION I

For absolute pressures up to 1,500 psia (10 MPa), it is permissible to rate safety valves under PG-69.2 of Section I with capacity ratings at 103% flow, for use on pressure vessels, without further test. In such instances, the capacity rating of the valve may be increased to allow for the flow pressure permitted in AR-512, namely 110%, by a multiplier as follows:

(U.S. Customary Units)

$$\frac{1.10p + 14.7}{1.03p + 14.7}$$

(SI Units)

$$\frac{1.10p + 101}{1.03p + 101}$$

where

p = set pressure

Such valves shall be marked in accordance with AR-401. This multiplier shall not be used as a divisor to transform test ratings from a higher to a lower flow. For steam pressures above 1,500 psig (10 MPa), the above multiplier is not applicable. For steam valves with relieving pressures between 1,500 psig (10 MPa) and 3,200 psig (22 MPa), the capacity shall be determined by using the equation for steam and the correction factor for high pressure steam in AR-523 with the permitted absolute relieving pressure ($1.10p + 14.7$ for U.S. customary units; $1.10p + 101$ for SI units) and the coefficient K for that valve design.

[1] Valve capacities are published in "Pressure Relief Device Certifications." This publication may be obtained from the National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Ave., Columbus, Ohio 43229.

AR-560 CERTIFICATION OF CAPACITY OF SAFETY AND SAFETY RELIEF VALVES IN COMBINATION WITH NONRECLOSING PRESSURE RELIEF DEVICES

AR-561 Capacity of Safety or Safety Relief Valves in Combination With a Rupture Disk Device at the Inlet

(a) For each combination of safety or safety relief valve design and rupture disk device design, the safety valve Manufacturer or the rupture disk device manufacturer may have the capacity of the combination certified as prescribed in (c) and (d).

(b) Capacity certification test shall be conducted on saturated steam, air, or natural gas. When saturated steam is used, corrections for moisture content of the steam shall be made.

(c) The valve Manufacturer or the rupture disk device manufacturer may submit for tests the smallest rupture disk device size with the equivalent size of safety or safety relief valve that is intended to be used as a combination device. The safety or safety relief valve to be tested shall have the largest orifice used in the particular inlet size.

(d) Tests may be performed in accordance with the following subparagraphs. The rupture disk device and safety or safety relief valve combination to be tested shall be arranged to duplicate the combination assembly design.

(1) The test shall embody the minimum burst pressure of the rupture disk device design which is to be used in combination with safety or safety relief valve design. The stamped bursting pressure shall be between 90–100% of the stamped set pressure of the valve.

(2) The test procedure to be used shall be as follows. The safety or safety relief valve (one valve) shall be tested for capacity as an individual valve, without the rupture disk device, at a pressure 10% above the valve set pressure. The rupture disk device shall then be installed ahead of the safety or safety relief valve and the disk burst to operate the valve. The capacity test shall be performed on the combination at 10% above the valve set pressure duplicating the individual safety or safety relief valve capacity test.

(3) Tests shall be repeated with two additional rupture disks of the same nominal rating, for a total of three rupture disks to be tested with the single valve. The results of the test capacity shall fall within a range of 10% of the average capacity of the three tests. Failure to meet this requirement shall be cause to require retest for determination of cause of the discrepancies.

(4) From the results of the tests, a combination capacity factor shall be determined. The *combination capacity factor* is the ratio of the average capacity determined by the combination tests to the capacity determined on the individual valve.

The combination capacity factor shall be used as a multiplier to make appropriate changes in the ASME rated relieving capacity of the safety or safety relief valve in all sizes of the design. The value of the combination capacity factor shall not be greater than one. The combination capacity factor shall apply only to combinations of the same design of safety or safety relief valve and the same design of rupture disk device as those tested.

(5) The test laboratory shall submit the test results to the ASME designated organization for acceptance of the combination capacity factor.

AR-562 Optional Testing of Rupture Disk Devices and Safety or Safety Relief Valves

(a) If desired, a valve Manufacturer or a rupture disk manufacturer may conduct tests in the same manner as outlined in AR-561(d)(3) and (d)(4) using the next two larger sizes of the design of rupture disk device and safety or safety relief valve to determine a combination capacity factor applicable to larger sizes. If a greater combination capacity factor is established and can be certified, it may be used for all larger sizes of the combination, but shall not be greater than one.

(b) If desired, additional tests may be conducted at higher pressure in accordance with AR-561(d)(3) and AR-561(d)(4) to establish a maximum combination capacity factor to be used at all pressures higher than the highest tested, but it shall not be greater than one.

AR-570 CAPACITY OF BREAKING PIN DEVICES IN COMBINATION WITH SAFETY RELIEF VALVES

(a) Breaking pin devices in combination with safety relief valves shall be capacity tested in compliance with AR-522 or AR-523 as a combination.

(b) Capacity certification and Code symbol stamping shall be based on the capacity established in accordance with these paragraphs.

ARTICLE R-6
PROVISIONS IN VESSELS FOR INSTALLATION OF PRESSURE RELIEVING DEVICES

AR-600 NUMBER, SIZE, AND LOCATION OF CONNECTIONS

AR-601 Connections for Vapor Pressure Relief Devices

Pressure relief devices designed for vapor application shall be connected to the vessel in the vapor space above any contained liquid or to piping connected to the vapor space in the vessel which is to be protected. Piping connecting the vapor space of one vessel to the vapor space of another vessel may serve as this connection when the provisions of AR-100(e) are used.

AR-602 Connections for Liquid Pressure Relief Devices

Pressure relief devices for liquid service application shall be connected below the normal liquid level. Any pressure relief device used for liquid service shall be at least NPS $\frac{1}{2}$ (DN 15).

AR-610 SIZE OF OPENINGS AND NOZZLES

(a) The opening through all pipe and fittings between a pressure vessel and its pressure relieving device shall have at least the area of the pressure relieving device inlet, and the flow characteristics of this upstream system shall be such that the pressure drop will not reduce the relieving capacity below that required or adversely affect the proper operation of the pressure relieving device. The opening in the vessel wall shall be designed to provide direct and unobstructed flow between the vessel and its pressure relieving device.

(b) When two or more required pressure relieving devices are placed on one connection, the inlet internal cross-sectional area of this connection shall be at least equal to the combined inlet areas of the safety devices connected to it, and the flow characteristics of the upstream system shall satisfy the requirements of (a) above. (See Appendix A.)

(c) Discharge lines from pressure relieving safety devices shall be designed to facilitate drainage or shall be fitted with drains to prevent liquid from accumulating on the discharge side of the safety device, and such lines shall lead to a safe place of discharge. The size of the discharge lines shall be such that any pressure that may exist or develop will not reduce the relieving capacity of the relieving devices below that required to properly protect the vessel or adversely affect the proper operation of the pressure relieving devices. (See Appendix A.)

AR-615 INTERVENING STOP VALVES

There shall be no intervening stop valves between the vessel and its protective device or devices or between the protective devices and the point of discharge, except:

(a) when these stop valves are so constructed or positively controlled that the closing of the maximum number of block valves possible at one time will not reduce the pressure relieving capacity provided by the unaffected relieving devices below the required relieving capacity; or

(b) under the conditions set forth in Appendix A.

AR-620 LOCATION OF OPENINGS AND CONNECTIONS

Openings and connections for pressure relieving purposes shall be so located that the nature of the vessel contents will not hinder flow through such openings and connections.

Part AI
INSPECTION AND RADIOGRAPHY

ARTICLE I-1
GENERAL RULES FOR INSPECTION

AI-100 GENERAL REQUIREMENTS

(a) The inspection and examination of pressure vessels with the Code symbol shall conform to the general requirements for inspection and examination in this Article and, in addition, to the specific requirements for inspection and examination given in the applicable paragraphs.

(b) General Requirements for Layered Vessels. The provisions of inspection of Articles I-1 through I-4 shall apply. The provisions of Article I-5 on Radiographic Examination shall apply, except that consideration shall be given to indications that may be present on the film as a result of permissible layer gaps [see AF-810.20(d)].

AI-101 MANUFACTURER'S RESPONSIBILITY

(a) The Manufacturer who completes any vessel to be marked with the Code symbol has the responsibility of complying with all the requirements of this Division and, through proper certification, of ensuring that any work done by others also complies with all requirements of this Division [AG-302.1(b)].

(b) The Manufacturer has the responsibility of assuring that the quality control, the detailed examinations, and the tests required by this Division are performed at the stages of construction to permit them to be meaningful (see 18-115). The Manufacturer shall provide to the Inspector, at the appropriate time (see 18-115), the information necessary to enable him/her to perform his/her specified duties. (See AI-120 and 18-123.) The Manufacturer shall provide documentation, records, Inspector access, and perform the other actions as required by this Division. Some, but not all, of these responsibilities, which are defined in the applicable rules, are summarized as follows:

(1) the Certificate of Authorization from the ASME Boiler and Pressure Vessel Committee authorizing the Manufacturer to fabricate the class of vessel being constructed (see Article S-2);

(2) the drawings and design calculations for the vessel or part (see Article G-3);

(3) the mill test report or material certification for all material used in the fabrication of the vessel or part (see AM-101) and sample test coupons (see AT-110) when required;

(4) any Partial Data Reports when required by AM-105 and AS-310;

(5) access for the Inspectors in accordance with AI-120 and 18-123;

(6) examination of all materials before fabrication to make certain they have the required thickness in accordance with the design specification (see AF-105), for detection of unacceptable defects (see AF-112 and AF-770), to make certain the materials are permitted by this Division (see AM-100), and that the identification traceable to the mill test report or material certification has been maintained (see AF-102 and AF-771);

(7) documentation of impact tests when such tests are required (see AM-204, AM-310, AF-704, and AT-200);

(8) concurrence of the Inspector prior to any repairs when required by AF-104, AF-752, and 18-116;

(9) examination of head and shell sections to confirm they have been properly formed to the specified shapes within permissible tolerances (see AF-130 and AF-710);

(10) qualification of the welding procedures before they are used in fabrication (see AF-210 and AT-200);

(11) qualification of all welders and welding operators before using welders in production work (see AF-210);

(12) examination of all parts prior to joining to make certain they have been properly fitted for welding and that the surfaces to be joined have been cleaned and the alignment tolerances are maintained (see AF-140);

(13) examination of parts as fabrication progresses for material identification (see AF-102), that surface defects are not evident, and that dimensional geometries are maintained;

(14) provision of controls to assure that all required heat treatments are performed (see AF-400, AF-550, AF-605, AF-630, AF-640, and AF-730);

(15) provision of records of nondestructive examinations performed on the vessel or vessel parts. This shall include retaining the radiographic film (see Article I-5).

(16) making the required hydrostatic or pneumatic test and having the required inspection performed during such test (see Article T-3 and Article T-4);

(17) applying the required stamping and/or nameplate to the vessel and making certain it is applied to the proper vessel (see Article S-1);

(18) preparing the required Manufacturer's Data Report Form and having it certified by the Inspector (see Article S-1);

(19) maintenance of records (see AS-320).

AI-102 INSPECTOR'S DUTY

(a) The Inspector of vessels to be marked with the Code symbol has the duty of making all required inspections and such other inspections as he/she considers are necessary in order to be satisfied that all requirements have been met (see AG-303).

(b) Some, but not all, of the required inspections and verifications, which are defined in the applicable rules, are summarized as follows:

(1) verifying that the Manufacturer has a valid Certificate of Authorization and is working according to a Quality Control System (see AG-304);

(2) verifying that the applicable Design Report, user's Design Specification, drawings, and related documents are available (see AG-303);

(3) verifying that materials used in the construction of the vessel comply with the requirements of Articles M-1 through Articles M-5 (see Article I-2);

(4) verifying that all welding procedures have been qualified (see AF-210 and AI-300);

(5) verifying that all welders and welding operators have been qualified (see AF-210 and AI-301);

(6) verifying that the heat treatments, including PWHT, have been performed [see AI-101(b)(14) and AF-776];

(7) verifying that material imperfections repaired by welding are acceptably repaired and reexamined (see AF-104 and AF-752);

(8) verifying that the required nondestructive examinations, impact tests, and other tests have been performed and that the results are acceptable (see AI-310);

(9) making a visual inspection of the vessel to confirm that the material numbers have been properly transferred (see AF-102 and AF-771);

(10) performing internal and external inspections and witnessing the hydrostatic or pneumatic tests (see AI-220, Article T-3, and Article T-4);

(11) verifying that the required marking is provided, including stamping required in AS-131, and that the nameplate has been permanently attached to the proper vessel or vessel chamber (see Article S-1);

(12) signing the Certificate of Inspection on the Manufacturer's Data Report when the vessel, to the best of his knowledge and belief, is complete and in compliance with all the provisions of this Division (see Article S-3);

(13) verifying that the Manufacturer has maintained proper records (see AS-320).

AI-110 THE INSPECTOR

(a) All references to *Inspectors* throughout this Division mean the Authorized Inspector as defined in this paragraph. All inspections required by this Division of Section VIII shall be:

(1) by an Inspector regularly employed by an ASME accredited Authorized Inspection Agency,[1] i.e., the inspection organization of a state or municipality of the

[1] Whenever *Authorized Inspection Agency* or *AIA* is used in this Code, it shall mean an Authorized Inspection Agency accredited by ASME in accordance with the requirements in the latest edition of ASME QAI-1, Qualifications for Authorized Inspection.

United States, a Canadian province, or an insurance company authorized to write boiler and pressure vessel insurance, except that

(2) inspections may be by the regularly employed user's Inspector in the case of a user–Manufacturer that manufactures pressure vessels exclusively for its own use and not for resale.

Except as permitted in (2) above, the Inspector shall not be in the employ of the Manufacturer. All Inspectors shall have been qualified by a written examination under the rules of any state of the United States or province of Canada which has adopted the Code.

(b) In addition to the duties specified, the Inspector has the duty to monitor the Manufacturer's Quality Control System as required in Appendix 18.

AI-120 ACCESS FOR INSPECTOR

The Manufacturer of the vessel or part thereof shall arrange for the Inspector to have free access to such parts of all plants as are concerned with the supply or manufacture of materials for the vessel, when so requested. The Inspector shall be permitted free access, at all times while work on the vessel is being performed, to all parts of the Manufacturer's shop that concern the construction of the vessel and to the site of field erected vessels during the period of assembly and testing of the vessel. The Manufacturer shall keep the Inspector informed of the progress of the work and shall notify him/her reasonably in advance when the vessel or materials will be ready for any required tests or inspections.

ARTICLE I-2
INSPECTION OF MATERIALS

AI-200 COMPLIANCE OF MATERIALS WITH REQUIREMENTS

The Inspector shall assure him/herself that all materials used comply in all respects with the requirements of this Division. The Manufacturer shall submit to the Inspector certification of materials compliance (see AM-101). He/she shall examine certified test reports or certificates of compliance for the materials used, except as otherwise provided for in the material specification or in this Division.

AI-201 Examination of Materials

See AF-112.1.

AI-210 MARKING ON MATERIALS

The Inspector shall inspect materials used in the construction to see that they bear the identification required by the applicable material specification, except as otherwise provided in AM-105.1 and AM-105.2. Should the identifying marks be obliterated or the material be divided into two or more parts, the marks shall be properly transferred by the Manufacturer as provided in AF-102.1.

AI-220 DIMENSIONAL CHECK OF COMPONENT PARTS

The Inspector shall satisfy him/herself that:

(a) head and shell sections conform to the prescribed shape and meet the thickness requirements after forming;

(b) nozzles, manhole frames, reinforcement around openings, and other appurtenances to be attached to the inside or outside of the vessel fit properly to the curvature of the vessel surface (see Fig. AD-912.1);

(c) the dimensional requirements have been met. This shall include making such dimensional measurements as he/she considers necessary.

AI-220.1 Use of Templates. If required by the Inspector, the Manufacturer of the vessel shall furnish accurately formed templates for his/her use (see AF-130).

AI-230 CHECK OF HEAT TREATMENT PRACTICE

The Inspector shall satisfy him/herself that the Manufacturer has conducted all heat treatment operations required by this Division. Certificates furnished by the Manufacturer may be accepted as evidence that the heat treatment operations were correctly carried out.

ARTICLE I-3
INSPECTION OF WELDING

AI-300 CHECK OF WELDING PROCEDURE SPECIFICATIONS

It is the duty of the Inspector to assure him/herself that the welding procedures employed in construction have been qualified under the provisions of Section IX and as specified in this Division. The Manufacturer shall submit evidence to the Inspector that those requirements have been met. When there is a specific reason to question a welding procedure, the Inspector may require requalification as a requirement for the procedure to be used on work subject to his/her inspection.

AI-301 Check of Welder and Welding Operator Performance Qualification

It is the duty of the Inspector to assure him/herself that all welding is done by welders or welding operators qualified under the provisions of Section IX. The Manufacturer shall make available to the Inspector a certified copy of the record of performance qualification tests of each welder and welding operator as evidence that these requirements have been met. When there is a specific reason to question the ability of a welder or welding operator to make welds that meet the requirements of the Welding Procedure Specification, the Inspector may require requalification as a requirement for the welder or welding operator to continue welding on work subject to his/her inspection.

AI-310 CHECK OF NONDESTRUCTIVE EXAMINATION METHODS

It is the duty of the Inspector to assure him/herself that the nondestructive examination methods of Article I-5 and Appendix 9 which are used follow the techniques specified therein, that the examinations are performed by operators who are certified by the Manufacturer as being qualified in the techniques of the methods employed and in the interpretation and evaluation of the results, and that the Manufacturer has met the requirements of the rules. If there is a specific reason to question an operator's qualifications, the Inspector has the right to require proof of the operator's ability to perform and interpret the examinations specified. The Inspector may witness nondestructive examinations at his/her discretion.

AI-311 Certification of Competence of Nondestructive Test Operator

The Manufacturer shall certify that each operator meets the following requirements.

(a) He/she has vision, with correction if necessary, to enable him to read a Jaeger Type No. 2 Standard Chart, at a distance of not less than 12 in. (300 mm), and is capable of distinguishing and differentiating contrast between colors used. These requirements shall be checked annually.

(b) He/she is competent in the techniques of the particular nondestructive examination method for which he is certified, including making the examination and interpreting and evaluating the results, except that, where the examination method consists of more than one operation, he/she may be certified as being qualified only for one or more of these operations.

ARTICLE I-4
FINAL INSPECTION

AI-400 REQUIRED PRESSURE TESTS

After all required heat treatments have been performed, the completed vessel shall be subjected either to the hydrostatic test prescribed in Article T-3 or to the pneumatic test prescribed in Article T-4.

AI-410 INSPECTOR'S DUTY

The Inspector shall witness the hydrostatic test prescribed in Article T-3 or the pneumatic test prescribed in Article T-4.

ARTICLE I-5
RADIOGRAPHIC EXAMINATION

AI-500 TECHNIQUE FOR RADIOGRAPHIC EXAMINATION OF WELDED JOINTS

AI-501 Welded Joints to Be Radiographed

All welded joints to be radiographed shall be examined in accordance with Article 2 of Section V, except as specified below.

(a) The reinforcement on each side of all butt welded joints shall not exceed the limits specified in AF-221.3. (For Type No. 2 butt joints, see AF-222.1.)

(b) A complete set of radiographs and records, as described in T-291 and T-292 of Article 2 of Section V, for each vessel or vessel part shall be retained by the Manufacturer until the Manufacturer's Data Report has been signed by the Inspector.

(c) The Manufacturer shall certify that personnel performing and evaluating radiographic examinations required by this Division have been qualified and certified in accordance with their employer's written practice. SNT-TC-1A[1] shall be used as a guideline for employers to establish their written practice for qualification and certification of their personnel. Alternatively, the ASNT Central Certification Program (ACCP) or CP-189[1] may be used to fulfill the examination and demonstration requirements of SNT-TC-1A and the employer's written practice. Provisions for training, experience, qualification, and certification of NDE personnel shall be described in the Manufacturer's Quality Control System (see Appendix 18).

(d) A written radiographic examination procedure is not required. Demonstration of density and penetrameter image requirements on production or technique radiographs shall be considered satisfactory evidence of compliance with Article 2 of Section V.

(e) The requirements of T-285 of Article 2 of Section V are to be used only as a guide. Final acceptance of radiographs shall be based on the ability to see the prescribed penetrameter image and the specified hole or the designated wire of a wire penetrameter.

AI-510 ACCEPTANCE STANDARDS FOR RADIOGRAPHS OF WELDS

AI-511 Unacceptable Defects and Repair Requirements

Sections of weld that are shown by radiography to have any of the following types of defects are unacceptable unless the defects are removed, the weld is repaired in accordance with the requirements of AF-252, and the repaired weld is reexamined in accordance with the requirements of AF-253:

(a) any type of crack or zone of incomplete fusion or penetration;

(b) any elongated inclusion, such as slag, which has a length greater than:

$\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm)
$\frac{1}{3}\,t$ for t from $\frac{3}{4}$ in. (19 mm) to $2\frac{1}{4}$ in. (56 mm)
$\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (56 mm)

where

t = thickness of the weld excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t.

(c) any group of inclusions in line that has an aggregate length greater than t in a length of $12t$, except when the distance between the successive imperfections exceeds $6L$, where L is the length of the longest imperfection in the group;

(d) rounded indications in excess of that specified by the acceptance of the porosity of the standards given in Appendix 8.

AI-511.1 Treatment of Imperfections Believed Nonrelevant. Any indication of an imperfection which

[1] SNT-TC-1A, ACCP, and CP-189 are published by American Society for Nondestructive Testing, Inc., 1711 Arlingate Lane, P.O. Box 28518, Columbus, OH 43228-0518.

is believed to be nonrelevant shall be regarded as a defect unless, on reevaluation, it is shown by reexamination by the same method or by the use of other nondestructive conditioning that no unacceptable imperfection is present.

AI-512 Examination of Areas From Which Defects Have Been Removed

After a defect is thought to have been removed and prior to making weld repairs, the area shall be examined by suitable methods to ensure that the defect has been eliminated.

AI-513 Reexamination of Repaired Areas

After repairs have been made, the repaired area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners, and reexamined by radiography and all other methods of examination that were originally required for the affected area, except that, when the depth of the repair is less than the radiographic sensitivity required, reradiography may be omitted.

Part AT
TESTING

ARTICLE T-1
TESTING REQUIREMENTS

AT-100 GENERAL REQUIREMENTS

The tests to be made relative to vessels covered by this Division shall be performed in accordance with the rules in this Part AT.

AT-110 REQUIREMENTS FOR SAMPLE TEST COUPONS

AT-111 Heat Treatment

Heat treatment as used in this Section shall include all thermal treatments of the material during fabrication at 900°F (480°C) and above.

AT-112 Provision of Sample Test Coupons

When material is subjected to heat treatment during fabrication, the test specimens required by the applicable specification shall be obtained from sample coupons which have been heat treated in the same manner as the material, including such heat treatments as were applied by the material producer before shipment. The required tests may be performed by the material producer or the fabricator (see AM-202).

AT-113 Heat Treating of Sample Test Coupons

The material used in the vessel shall be represented by test specimens which have been subjected to the same manner of heat treatment, including postweld heat treatment. The kind and number of tests and test results shall be as required by the material specification. The vessel Manufacturer shall specify the temperature, time, and cooling rates to which the material will be subject during fabrication. Material from which the specimens are prepared shall be heated at the specified temperature within the tolerances established by the Manufacturer for use in actual fabrication. The total time at temperature shall be at least 80% of the total time at temperature during actual heat treatment of the product and may be performed in a single cycle. Simulation of postweld heat treatment may be applied to the test specimen blanks.

AT-114 Operations Not Considered as Heat Treatment

Heat treatment of material is not intended to include such local heating as flame or arc cutting, preheating, welding, or heating below the critical range of tubing and pipe for bending or sizing.

AT-115 Exemptions From Requirement of Sample Test Coupons

AT-115.1 For Standard Pressure Parts. An exception to the requirements of AT-112 and AT-113 shall apply to standard items such as described in AM-105. These may be subjected to postweld heat treatment with the vessel or vessel part without the same treatment being required of the test specimens. This exception shall not apply to specially designed cast or wrought fittings.

AT-115.2 For P-No. 1 Materials When Postweld Heat Treated Only. Materials conforming to one of the specifications listed in P-No. 1, Groups 1 and 2 of QW/QB-422 of Section IX are exempt from the requirements of AT-112 and AT-113 when the heat treatment during fabrication consists only of postweld heat treatment below the lower transformation temperature of the steel.

AT-115.3 For Materials When PWHT to Table AF-402.2. Materials listed in QW/QB-422 as P-No. 1, Group 3 and P-No. 3, Groups 1 and 2 that are certified in accordance with AT-112 and AT-113 from test specimens subjected to the PWHT requirements of Table AF-402.1 need not be recertified if subjected to the alternative PWHT conditions permitted in Table AF-402.2.

AT-115.4 Re-Austenitized Materials. All thermal treatments which precede a thermal treatment that fully austenitizes the material need not be accounted for by the specimen heat treatments, provided the austenitizing temperature is at least as high as any of the preceding thermal treatments.

ARTICLE T-2
IMPACT TESTING OF WELDS AND VESSEL TEST PLATES OF FERROUS MATERIALS

AT-200 IMPACT TESTS

(a) For steel vessels of welded construction, the impact toughness of welds and heat affected zones of procedure qualification test plates and vessel test plates (production impact test plates) shall be determined as required in this Article.

(b) All test plates shall be subjected to heat treatment, including cooling rates and aggregate time at temperature or temperatures as established by the Manufacturer for use in actual manufacture. Heat treatment requirements of Article F-4, Article T-1, and AM-201 shall apply to test plates, except that the provisions of AT-115.3 are not applicable to test plates for welds joining P-No. 3, Groups 1 and 2 materials. For P-No. 1, Groups 1, 2, and 3 materials, impact testing of the welds and heat affected zones of the weld procedure qualification and production test plates need not be repeated if the impact properties were determined after PWHT of the test plates at the temperatures and times specified in Table AF-402.1 and the production welds are PWHT at the temperatures and times permitted in Table AF-402.2.

AT-201 Location, Orientation, Temperature, and Values of Weld Impact Tests

All weld impact tests shall comply with the following requirements.

(a) Each set of weld metal impact specimens shall be taken across the weld with the notch in the weld metal. Each specimen shall be oriented so that the notch is normal to the surface of the material, and one face of the specimen shall be within $^1/_{16}$ in. (1.5 mm) of the surface of the material. When procedure tests are made on material over $1^1/_2$ in. (38 mm) in thickness, two sets of impact specimens shall be taken from the weld with one set located near [within $^1/_{16}$ in. (1.5 mm)] the surface of one side of the material and one set taken as near as practical midway between the surface and the center of thickness of the opposite side as described above. See QW-200.4(a) of Section IX.

(b) Each set of heat affected zone impact specimens shall be taken across the weld and of sufficient length to locate, after etching, the notch in the affected zone. The notch shall be cut approximately normal to the material surface in such a manner as to include as much heat affected zone material as possible in the resulting fracture.

(c) For welds made by a solid-state welding process, such as for electric resistance welded (ERW) pipe, the weld impact tests shall consist only of one set of three specimens taken across the weld with the notch at the weld centerline. Each specimen shall be oriented so that the notch is normal to the surface of the material and one face of the specimen shall be within $^1/_{16}$ in. (1.5 mm) of the surface of the material.

(d) The test temperature for welds and heat affected zones shall not be higher than for the base materials.

(e) Impact values shall be at least as high as those required for the base materials (see AM-211).

AT-202 Impact Tests for Welding Procedures

(a) Welding procedure impact tests shall be made on welds and heat affected zones when base materials are required to be impact tested, except as exempted by AM-213(c) and AM-218.2.

(b) If impact tests are required for the deposited weld, but the base material is exempted from impact tests (as in AM-213), welding procedure test plates shall be made. The test plate material shall be material of the same P-Number and Group Number used in the vessel. One set of impact specimens shall be taken with the notch approximately centered in the weld metal and perpendicular to the surface; the heat affected zone need not be impact tested.

(c) When the welding procedure employed for production welding is used for fillet welds only, it shall be

qualified by a groove weld qualification test. The qualification test plate or pipe material shall meet the requirements of AM-204 and AM-211 when impact testing is a requirement. This welding procedure test qualification is in addition to the requirements of Section IX, QW-202.2 for P-No. 11 materials.

AT-202.1 Variables for Impact Tested Procedures. The supplementary essential variables specified in Section IX, QW-250, for impact testing are required.

AT-202.2 Thickness Qualified When Lower Critical Temperature Is Exceeded. For test plates or pipe receiving a postweld heat treatment in which the lower critical temperature is exceeded, the maximum thickness qualified is the thickness of the test plate or pipe.

AT-202.3 Test Plate Material for Carbon and Low Alloy Steels. For Table ACS-1 materials, the test plate material shall satisfy all of the following requirements relative to the material to be used in production:

(a) be of the same P-Number and Group Number;

(b) be in the same heat treated condition; and

(c) meet the minimum notch toughness requirements of AM-211 for the thickest material of the range of base material qualified by the procedure (see Fig. AM-211).

AT-203 Impact Tests of Vessel Test Plates

(a) When the base material is required to be impact tested, impact tests of welds and heat affected zones shall be made for Category A and B joints in accordance with AT-201 for each qualified welding procedure used on each vessel. The test plate shall be from one of the heats of steel used for the vessel or group of vessels and shall be welded as an extension to the end of a production Category A joint where practicable, or welded as close to the start of production welding as practicable, utilizing equipment, welding materials, and procedures which are to be used on the production joint.

(b) For Category B joints that are welded using a different welding procedure than used on Category A joints, a test plate shall be welded under the production welding conditions used for the vessel, using the same type of equipment and at the same location and using the same procedures as used for the joint, and it shall be welded concurrently with the production welds or as close to the start of production welding as practicable.

AT-203.1 Number of Vessel Impact Test Plates Required

(a) For each vessel, one test plate shall be made for each welding procedure used for joints of Categories A and B, unless the vessel is one of several as defined in (b) below.

In addition, for Category A and B joints, the following requirements shall apply.

(1) If automatic or semiautomatic welding is performed, a test plate shall be made in each position employed in the vessel welding.

(2) If manual welding is also employed, a test plate shall be made in the flat position only, except if welding is to be performed in other positions a test plate need be made in the vertical position only (where the major portions of the layers of welds are deposited in the vertical upward direction). The vertically welded test plate will qualify the manual welding in all positions.

(3) The vessel test plate shall qualify the impact requirements for vessel materials thickness in accordance with QW-451.1 and QW-451.2 (including Notes) of Section IX, except that, if the thickness is less than $\frac{5}{8}$ in. (16 mm), the thickness of the test material is the minimum thickness qualified.

(b) For several vessels or parts of vessels, welded within any 3 month period at one location, the plate thickness of which does not vary by more than $\frac{1}{4}$ in. (6 mm) or 25%, whichever is greater, and of the same specification and grade of material, a test plate shall be made for each 400 ft (122 m) of joints welded by the same procedure.

AT-203.2 Rejection. If the vessel test plate fails to meet the impact requirements, the welds represented by the test plate shall be unacceptable. Reheat treatment and retesting, or retesting only, are permitted.

ARTICLE T-3
HYDROSTATIC TESTS

AT-300 HYDROSTATIC TESTS BASED ON VESSEL DESIGN PRESSURE

Except as otherwise permitted in AT-330 and AT-400, completed vessels designed for internal pressure shall be subjected to a hydrostatic test pressure which, at every point in the vessel, is not less than 1.25 times the design pressure (see AD-121.1) to be marked on the vessel, multiplied by the lowest ratio (for the materials of which the vessel is constructed) of the stress intensity value S_m for the test temperature of the vessel to the stress intensity value S_m for the design temperature (see Table AD-150.1).

AT-301 Hydrostatic Tests Based on Calculated Pressure

A hydrostatic test based on a calculated pressure may be used by agreement between the user and the Manufacturer. The hydrostatic test pressure at the top of the vessel shall be the minimum of the test pressure calculated by multiplying the basis for calculated test pressure for each pressure element by $1\frac{1}{4}$ and reducing this value by the hydrostatic head on that element. The basis for this calculated test pressure is the highest permissible internal pressure, as determined by the design formulas, for each element of the vessel using nominal thicknesses, including corrosion allowance, and the allowable stress intensity values given in Subpart 1 of Section II, Part D for the temperature of the test. When this pressure is used, it shall be as set forth in the Design Report.

AT-302 Upper Limit of Hydrostatic Test Pressure

The requirements of AT-300 represent the minimum standard hydrostatic test pressure required by this Division, except as permitted in AT-330. The requirements of AT-301 represent a special test condition based on calculations. Any intermediate value of pressure may be used. The upper limits of hydrostatic test pressure are established in AD-151 and AD-151.1. If the hydrostatic test pressure is allowed to exceed, either intentionally or accidentally, the value determined as prescribed in AT-301 to the degree that the vessel is subject to visual permanent distortion, the Inspector shall reserve the right to reject the vessel. (See AT-330.)

AT-310 HYDROSTATIC TESTS OF COMBINATION UNITS

Combination units shall be tested by one of the following methods.

AT-310.1 Pressure Chambers Designed to Operate Independently. Pressure chambers of combination units that have been designed to operate independently shall be hydrostatically tested as separate vessels; that is, each chamber shall be tested without pressure in the adjacent chamber.

AT-310.2 Common Elements Designed for a Maximum Differential Pressure. When pressure chambers of combination units have their common elements designed for the maximum differential pressure that can possibly occur during startup, operation, and shutdown, and the differential pressure is less than the higher pressure in the adjacent chambers, the common elements shall be subjected to a hydrostatic test pressure of at least $1\frac{1}{4}$ times the differential pressure to be marked on the unit, corrected for temperature as in AM-300.

AT-310.3 Adjacent Chambers. Following the test of the common elements, as required by AT-310.2, and their inspection, the adjacent chambers shall be hydrostatically tested simultaneously (see AT-300 and AT-301). Care must be taken to limit the differential pressure between the chambers to the pressure used when testing the common elements.

AT-310.4 Special Stamping and Data Report Requirements for Combination Units. The vessel stamping and the Manufacturer's Data Report must describe the common elements and their limiting differential pressure (see AS-101, AS-300, and AS-301).

AT-320 VESSELS DESIGNED FOR VACUUM

Vessels designed for a vacuum or partial vacuum only and chambers of multichamber vessels designed for a vacuum or partial vacuum only shall be subjected to an internal hydrostatic test or, when a hydrostatic test is not practicable, to a pneumatic test in accordance with the provisions of Article T-4. Either type of test shall be made at a pressure not less than $1\frac{1}{4}$ times the difference between normal atmospheric pressure and the minimum design internal absolute pressure.

AT-330 ENAMELED VESSELS

The test pressure for enameled vessels shall be at least equal to but need not exceed the design pressure to be marked on the vessel.

AT-340 PAINTED/COATED/LINED VESSELS

Vessels, except for those in lethal service as defined in AG-301(c), may be painted or otherwise coated either internally or externally, and may be lined internally, prior to the pressure test. However, the user is cautioned that such painting/coating/lining may mask leaks that would otherwise have been detected during the pressure test.

AT-350 HYDROSTATIC TESTING PROCEDURE

AT-351 Provision of Vents at High Points

Vents shall be provided at all high points of the vessel in the position in which it is to be tested to purge possible air pockets while the vessel is being filled.

AT-352 Fluid Media and Temperatures for Hydrostatic Tests

Any liquid, nonhazardous at any temperature, may be used for the hydrostatic test if below its boiling point. Combustible liquids having a flash point less than 110°F (45°C), such as petroleum distillates, may be used only for near atmospheric temperature tests. It is recommended that the metal temperature during hydrostatic test be maintained at least 30°F (17°C) above the minimum design metal temperature, but need not exceed 120°F (50°C), to minimize the risk of brittle fracture. The test pressure shall not be applied until the vessel and the pressurizing medium are at about the same temperature. If the test temperature exceeds 120°F (50°C), it is recommended that examination of the vessel required by AT-355 be delayed until the temperature is reduced to 120°F (50°C).

AT-353 Check of Test Equipment Before Applying Pressure

Before applying pressure, the test equipment shall be inspected to see that it is tight and that all low-pressure filling lines and other appurtenances that should not be subjected to the test pressure have been disconnected or isolated by valves or other suitable means.

AT-355 Examination for Leakage After Application of Pressure

Following the application of the hydrostatic test pressure, examination for leakage shall be made of all joints and connections and of all regions of high stress such as head knuckles, regions around openings, and thickness transition sections. This examination shall be made at a pressure equal to the greater of the design pressure or three-fourths of the test pressure and shall be witnessed by the Inspector. Any leaks that are present shall be corrected in accordance with the rules, after which the vessel shall be retested in accordance with these requirements.

ARTICLE T-4
PNEUMATIC TESTS

AT-400 WHEN PNEUMATIC TESTS MAY BE USED[1]

The pneumatic test[2] prescribed herein may be used in lieu of the hydrostatic test prescribed in Article T-3 only if the circumstances in AT-400.1 or AT-400.2 apply.

AT-400.1 For Vessels That Cannot Be Safely Filled With Water. Pneumatic testing may be used for vessels that are so designed and/or supported that they cannot safely be filled with water. The test of such vessels may be made with the vessel partially filled with water, if desired.

AT-400.2 For Vessels in Which Traces of Testing Liquid Cannot Be Tolerated. Pneumatic testing may be used for vessels, not readily dried, that are to be used in services where traces of the testing liquid cannot be tolerated and the parts of which have, where possible, been previously tested by hydrostatic pressure to the pressure required in Article T-3.

AT-410 REQUIRED PNEUMATIC TEST PRESSURE

Except for enameled vessels, for which the pneumatic test pressure shall be at least equal to but need not exceed the design pressure to be marked on the vessel, the pneumatic test pressure shall be not less than 1.15 times the design pressure to be stamped on the vessel, multiplied by the lowest ratio (for the materials of which the vessel is constructed) of the stress intensity value S_m for the test temperature of the vessel to the stress intensity value S_m for the design temperature.

AT-411 Upper Limit of Pneumatic Test Pressure

The requirements of AT-410 represent the minimum standard pneumatic test pressure required by this Division. The upper limits of pneumatic test pressure are established in AD-151 and AD-151.2.

AT-420 PNEUMATIC TESTING PROCEDURE

AT-421 Check of Test Equipment

The test equipment shall be examined before pressure is applied to ensure that it is tight and that all appurtenances that should not be subjected to the test pressure have been disconnected or isolated by valves or other suitable means.

AT-422 Temperature of Vessel and Testing Medium

The metal temperature during pneumatic test shall be maintained at least 30°F (17°C) above the minimum design metal temperature, but need not exceed 120°F (50°C), to minimize the risk of brittle fracture. The test pressure shall not be applied until the vessel and the pressuring medium are at about the same temperature. If the test temperature exceeds 120°F (50°C), it is recommended that examination of the vessel required by AT-423 be delayed until the temperature is reduced to 120°F (50°C).

AT-423 Rate of Applying Test Pressure and Examination

The pressure in the vessel shall gradually be increased to not more than one-half of the test pressure, after which the test pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached. The pressure shall then be reduced to a value equal to the greater of the design pressure or three-fourths of the test pressure and held for a sufficient time to permit examination of the vessel in accordance with AT-355.

[1] In some cases it is desirable to test vessels when partly filled with liquids. For such vessels a combined hydrostatic and pneumatic test may be used as an alternative to the pneumatic test of this paragraph.

[2] Air or gas is hazardous when used as a testing medium. It is, therefore, recommended that special precautions be taken when air or gas is used for test purposes.

ARTICLE T-5
PRESSURE TEST GAGES

AT-500 REQUIREMENTS FOR PRESSURE TEST GAGES

AT-501 Type and Number of Gages

Pressure test gages used in testing vessels shall be indicating pressure gages and shall be connected directly to the vessel. If the indicating gage is not readily visible to the operator controlling the pressure applied, an additional indicating gage shall be provided where it will be visible to the operator throughout the duration of the test. It is recommended that a recording gage be used in addition to the indicating gages.

AT-502 Pressure Range of Test Gages

Dial indicating pressure gages used in testing shall be graduated over a range of about double the intended maximum test pressure, but in no case shall the range be less than $1\frac{1}{2}$ nor more than 4 times that pressure. Digital reading pressure gages having a wider range of pressure may be used, provided the readings give the same or greater degree of accuracy as obtained with dial pressure gages.

AT-510 CALIBRATION OF TEST GAGES

All gages shall be calibrated against a standard deadweight tester or a calibrated master gage at least every 6 months or at any time there is reason to believe that they are in error.

Part AS
MARKING, STAMPING, REPORTS, AND RECORDS

ARTICLE S-1
CONTENTS AND METHOD OF STAMPING

AS-100 REQUIRED MARKING FOR VESSELS

Each pressure vessel to which the Code symbol is applied shall be marked with the following:

(a) the official Code symbol, as shown in Fig. AS-100.1;

(b) name of the Manufacturer of the pressure vessel, preceded by "certified by";

(c) design pressure,[1,2] psi (kPa), at coincident temperature, °F (°C);

(d) minimum design metal temperature;

(e) Manufacturer's serial number;

(f) year built.

AS-100.1 Units of Measurement. The units of measurement shall be in accordance with AG-151.

FIG. AS-100.1 OFFICIAL SYMBOL FOR STAMP TO DENOTE THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS' STANDARD

AS-101 Methods of Marking Vessels With Two or More Independent Chambers

Either of the following arrangements may be used in marking vessels having two or more independent pressure chambers designed for the same or different operating conditions. Each detachable chamber shall be marked so as to identify it positively with the combined unit.

AS-101.1 If Markings Are Grouped in One Location. The markings may be grouped in one location on the vessel, provided they are arranged so as to indicate clearly the data applicable to each chamber, including the maximum differential pressure for the common elements, when this pressure is less than the higher pressure in the adjacent chambers.

AS-101.2 If Each Independent Chamber Is Marked. The complete required marking may be applied to each independent pressure chamber, provided additional marking, such as stock space, jacket, tubes, or channel box, is used to indicate clearly to which chamber the data apply.

AS-110 APPLICATION OF STAMP

(a) The Manufacturer who completes the fabrication of the vessel shall have a valid Certificate of Authorization for the use of the Code symbol. The Code symbol shall be applied by the Manufacturer only with the acceptance

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[1] When a vessel is expected to operate at more than one pressure and temperature condition, other values of coincident pressure and design temperature may be added (see Table AD-120.1).

[2] Not required on parts for which the parts manufacturer does not prepare a Manufacturer's Design Report.

of the Inspector. Such application of the Code symbol, together with final certification in accordance with the rules of this Division, shall confirm that all applicable Code requirements have been fulfilled.

(b) Except as provided in (c) below, the Code symbol shall be applied after the hydrostatic test or pneumatic test.

(c) The Code symbol may be preapplied to a nameplate. The nameplate may be attached to the vessel after the final fabrication and examination sequence but before the hydrostatic test or pneumatic test, provided the procedure for sequence of stamping is described in the Manufacturer's accepted Quality Control System.

AS-120 PART MARKING

Parts of pressure vessels for which Partial Data Reports are required in AS-310 shall be marked by the parts manufacturer with the following:

(a) the official Code symbol shown in Fig. AS-100.1 above the word "Part";

(b) name of the Manufacturer of the pressure vessel, preceded by the words "certified by";

(c) Manufacturer's serial number;

(d) design pressure,[3] psi (kPa), at coincident temperature, °F (°C).

This requirement does not apply to such items as handhole covers, manhole covers, and accessories.

AS-130 NAMEPLATE

(a) The marking required in AS-100 shall be applied to a separate nameplate permanently attached to the vessel. The nameplate shall be located within 30 in. (750 mm) of the vessel and shall be attached by suitable means. Removal shall require the willful destruction of the nameplate or its attachment system.

(1) Nameplates may be attached by either welding, brazing, or soldering.

(2) Nameplates may be attached by tamper-resistant mechanical fasteners of suitable metal construction.

(3) Nameplates may be attached with pressure-sensitive acrylic adhesive systems, provided that, in addition to the requirements of this paragraph, those of Appendix 23 are met.

[3] Not to be included on parts for which the parts manufacturer does not prepare a Manufacturer's Design Report.

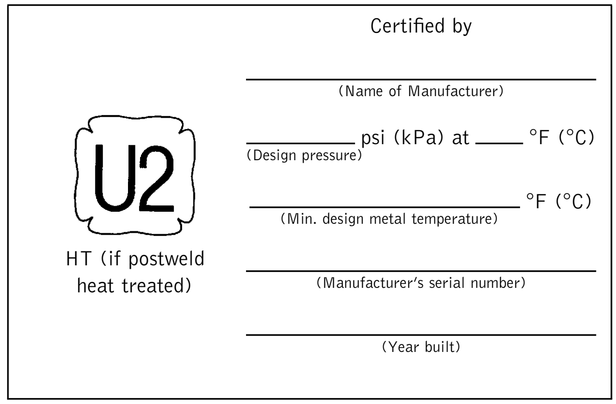


FIG. AS-131.1 FORM OF STAMPING

The marking shall not be stamped directly on the vessel, except that steel stamping shall be permitted on the head section of vessels over $1/2$ in. (13 mm) thick having $1/4$ in. (6 mm) greater thickness than the design requirements for the head; such stamping shall be done with "low stress" stamps as commercially available (see AF-102.1).

(b) An additional nameplate may be installed on the skirt, supports, jacket, or other permanent attachment to a vessel. All data on the additional plate, including the Code symbol, shall be cast, etched, or stamped and this marking need not be witnessed by the Inspector. The additional nameplate shall be marked "duplicate."

AS-131 Stamping of Nameplate

The Code symbol and the Manufacturer's serial number shall be stamped on the nameplate, but the other required data may be stamped, etched, cast, or impressed thereon. The data shall be in characters not less than $5/32$ in. (4 mm) high. The arrangement shall be substantially as shown in Fig. AS-131.1.

AS-132 Attachment of Nameplate

If the nameplate is marked before it is affixed to the vessel, the Manufacturer shall ensure that the nameplate with the correct marking has been applied to the vessel to which it applies and the Inspector shall satisfy himself that this has been done. The nameplate shall be permanently attached by a method which will not affect the integrity of the vessel (see AF-102.1 and AF-670).

ARTICLE S-2
OBTAINING AND USING CODE STAMPS

AS-200 CODE STAMPS BEARING OFFICIAL SYMBOL

A Certificate of Authorization to use the Code U2 or UV symbols shown in Fig. AS-100.1 and Fig. AR-401.1 will be granted by the Society pursuant to the provisions of the following paragraphs. Stamps for applying the Code symbol shall be obtained from the Society.

AS-201 Application for Authorization

Any organization desiring a Certificate of Authorization shall apply to the Boiler and Pressure Vessel Committee of the Society, on forms issued by the Society,[1] specifying the stamp desired and the scope of Code activities to be performed. When an organization intends to build Code items in plants in more than one geographical area, either separate applications for each plant or a single application listing the addresses of all such plants may be submitted. Each application shall identify the Authorized Inspection Agency providing Code inspection at each plant. A separate Certificate of Authorization will be prepared and a separate fee charged by the Society for each plant.

Each applicant must agree that each Certificate of Authorization and each Code symbol stamp are at all times the property of the Society, that they will be used according to the rules and regulations of this Division of the Code, and that they will be promptly returned to the Society upon demand, or when the applicant discontinues the Code activities covered by his certificate, or when the Certificate of Authorization has expired and no new certificate has been issued. The holder of a Code symbol stamp shall not allow any other organization to use it.

AS-202 Issuance of Authorization

Authorization to use Code symbol stamps may be granted or withheld by the Society in its absolute discretion. If authorization is granted, and the proper administrative fee paid, a Certificate of Authorization evidencing permission to use any such symbol, expiring on the triennial anniversary date thereafter, will be forwarded to the applicant. Each such certificate will identify the Code symbol to be used, and the type of shop and/or field operations for which authorization is granted (see Appendix L). The certificate will be signed by the Chairman of the Boiler and Pressure Vessel Committee and the Director of Accreditation. Six months prior to the date of expiration of any such certificate, the applicant must apply for a renewal of such authorization and the issuance of a new certificate. The Society reserves the absolute right to cancel or refuse to renew such authorization, returning, pro rata, fees paid for the unexpired term.

The Boiler and Pressure Vessel Committee may at any time make such regulations concerning the issuance and use of Code symbol stamps as it deems appropriate, and all such regulations shall become binding upon the holders of any valid Certificates of Authorization.

AS-203 Inspection Agreement

As a condition of obtaining and maintaining a Certificate of Authorization to use the U2 Code symbol stamp, the Manufacturer must have in force at all times an inspection contract or agreement with an Authorized Inspection Agency as defined in AI-110 to provide inspection services. This inspection agreement is a written agreement between the Manufacturer and the inspection agency which specifies the terms and conditions under which the inspection services are to be furnished and which states the mutual responsibilities of the Manufacturer and the Authorized Inspectors. A certificate holder shall notify the Society whenever his/her agreement with an Authorized Inspection Agency is cancelled or changed to another Authorized Inspection Agency.

Neither Manufacturers nor Assemblers of pressure relief valves are required to have an inspection agreement with an Authorized Inspection Agency.

AS-204 Quality Control System

Any Manufacturer or Assembler holding or applying for a Certificate of Authorization to use the U2 or UV

[1] The application forms and related information and instructions may be obtained by writing to the Secretary, ASME Boiler and Pressure Vessel Committee, Three Park Avenue, New York, NY 10016-5990.

stamp shall have, and demonstrate, a Quality Control System to establish that all Code requirements, including material, design, fabrication, examination (by the Manufacturer), inspection for vessel and vessel parts (by the Authorized Inspector), pressure testing, and certification, will be met. The Quality Control Systems of UV stamp holders shall include the duties of a Certified Individual, as required by this Division (see AR-410).

AS-205 Evaluation for Authorization and Reauthorization

Before issuance or renewal of a Certificate of Authorization for use of the U2 stamp, the Manufacturer's facilities and organization are subject to a joint review by a representative of his/her inspection agency and an individual certified as an ASME Designee who is selected by the concerned legal jurisdiction. A written description or checklist of the Quality Control System which identifies what documents and what procedures the Manufacturer will use to produce a Code item shall be available for review.

A written report to the Society shall be made jointly by the ASME Designee and the inspection agency employed by the Manufacturer to do his Code inspection. This report is then reviewed by the Subcommittee on Boiler and Pressure Vessel Accreditation, which will either issue a Certificate of Authorization or notify the applicant of deficiencies revealed by the review. In such a case, the applicant will be given an opportunity to explain or correct these deficiencies.

Certificates of Authorization will be endorsed to indicate the scope of activity authorized. Authorization may include field operations if the review team determines that these operations are adequately described in the Quality Control Manual, and this determination is accepted by the Society.

Before issuance or renewal of a Certificate of Authorization for use of the UV stamp, the valve Manufacturer's or Assembler's facilities and organization are subject to a review by a representative from an ASME designated organization. A written description or checklist of the Quality Control System, which identifies the documents and procedures the Manufacturer or Assembler will use to produce Code pressure relief valves, shall be available for review. The representative from an ASME designated organization shall make a written report to the Society, where the Subcommittee on Boiler and Pressure Vessel Accreditation will act on it as described above.

The purpose of the review is to evaluate the applicant's Quality Control System and its implementation. The applicant shall demonstrate sufficient administrative and fabrication functions of the system to show that he has the knowledge and ability to produce the Code items covered by his/her Quality Control System. Fabrication functions may be demonstrated using current work, a mock-up, or a combination of the two.

The Manufacturer may at any time make changes in the Quality Control System concerning the methods of achieving results, subject to acceptance by the Authorized Inspector. For Manufacturers and Assemblers of UV stamped pressure relief valves, such acceptance shall be by the ASME designated organization.

For those areas where there is no jurisdiction or where a jurisdiction does not choose to select an ASME Designee to review a vessel or vessel parts Manufacturer's facility, that function shall be performed by an ASME Designee selected by ASME. Where the jurisdiction is the Manufacturer's inspection agency, the joint review and joint report shall be made by the jurisdiction and ASME Designee.

AS-206 Code Construction Before Receipt of Certificate of Authorization

When used to demonstrate his Quality Control System, a Manufacturer may start fabricating Code items before receipt of a Certificate of Authorization to use a Code symbol stamp under the following conditions.

(a) The fabrication is done with the participation of the Authorized Inspector and is subject to his acceptance.

(b) The activity is in conformance with the applicant's Quality Control System.

(c) The item is stamped with the appropriate Code symbol and certified once the applicant receives his/her Certificate of Authorization from the Society.

ARTICLE S-3
REPORT FORMS AND MAINTENANCE OF RECORDS

AS-300 MANUFACTURER'S DATA REPORTS

A Data Report shall be filled out (Form A-1) by the Manufacturer and the Inspector for each pressure vessel to be marked with the Code symbol. For sample Report Forms and guidance in preparing Data Reports, see Appendix I.

AS-300.1 Units of Measurement. The units of measurement shall be in accordance with AG-151.

AS-301 Distribution and Filing of Reports

(a) The Manufacturer shall:

(1) furnish a copy of the Manufacturer's Data Report to the user and, upon request, to the Inspector;

(2) submit a copy of the Manufacturer's Data Report to the appropriate enforcement authority in the jurisdiction in which the vessel is to be installed where required by law;

(3) keep a copy of the Manufacturer's Data Report on file in a safe repository for at least 10 years or for the intended life of the vessel, whichever is greater.

(b) In lieu of (2) and (3) above, the vessel may be registered and the Data Reports filed with the National Board of Boilers and Pressure Vessel Inspectors, 1055 Crupper Ave., Columbus, Ohio 43229.

AS-310 PARTIAL DATA REPORTS

The parts manufacturer shall indicate under "Remarks" whether or not he has performed any or all of the design functions. For guidance in preparing Partial Data Reports, see Appendix I.

(a) Data Reports for pressure vessel parts requiring inspection under this Division, which are furnished by other than the location of the Manufacturer responsible for the completed vessel, shall be executed by the parts manufacturer and his Inspector in accordance with the requirements of this Division and shall be forwarded, in duplicate, to the Manufacturer of the finished vessel (see AG-302). These Partial Data Reports, together with his own inspection, shall be the final Inspector's authority to approve and witness the application of a Code symbol to the vessel (see AS-110). When Form A-2 is used, it shall be attached to the associated Form A-1 by the Manufacturer of the finished vessel.

Manufacturers with multiple locations, each with its own Certificate of Authorization, may transfer pressure vessel parts from one of their locations to another without Partial Data Reports, provided the Quality Control System describes the method of identification, transfer, and receipt of the parts.

(b) Data Reports for those parts of a pressure vessel which are furnished by a parts manufacturer to the user of an existing Code vessel, as replacement or repair parts, shall be executed on Form A-2 by the parts manufacturer and his Inspector in accordance with the requirements of this Division. A copy of the parts manufacturer's Partial Data Report shall be furnished to the user or his designated agent and a copy shall be maintained in accordance with AS-320.

AS-320 MAINTENANCE OF RECORDS

In addition to the requirements of AS-301, the Manufacturer shall maintain other records as follows.

(a) Contents of File. The Manufacturer of the vessel or part shall maintain the complete file for all material certification and/or Partial Data Reports, examination, testing, heat treatment and manufacturing procedures, specifications, and drawings used. All records shall be fully identified by pertinent material or item identification numbers. The record shall include all data on repaired material, items, and assemblies.

(b) Maintenance and Access to Reports. Records specified above shall be filed and maintained in a manner which will allow access by the Inspector to specific information contained therein within a period not in excess of 24 hr at any time during the period of vessel

manufacture. The Manufacturer shall take such steps as may be required to provide suitable protection of all records from deterioration or damage.

(c) Duration of Files. The vessel Manufacturer shall maintain these records for at least 5 years after vessel completion. After that time, the Manufacturer may either continue to maintain the records or, after offering them to the user and receiving a rejection, the records may be destroyed.

ARTICLE S-4
SPECIAL REQUIREMENTS FOR LAYERED VESSELS

AS-400 GENERAL

The rules for stamping and reports of layered pressure vessels shall meet the requirements given in Articles S-1 through S-3, with the following supplemental requirements.

AS-410 STAMPING

The stamping below the Code symbol prescribed in AS-100 shall be the letters WL to designate layered construction.

AS-420 MANUFACTURER'S DATA REPORTS

A Data Report shall be filled out on Form A-1 (a sample Report Form is given at the end of this Division) by the Manufacturer and verified by the Inspector for each pressure vessel to be marked with the Code symbol.

A description of the layered shell and/or layered heads shall be given on the Data Report, describing the number of layers, their thickness or thicknesses, and type of construction. See I-200 and Table I-220 for the use of Form A-3, Manufacturer's Data Report Supplementary Sheet. An example of the use of Form A-3 illustrating the minimum required data for layered construction is given in Fig. I-221.

Mandatory Appendices

MANDATORY APPENDIX 1
BASIS FOR ESTABLISHING DESIGN STRESS INTENSITY VALUES

See Mandatory Appendix 2 of Section II, Part D.

MANDATORY APPENDIX 2
CHARTS FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE

See Subpart 3 of Section II, Part D.

MANDATORY APPENDIX 3
RULES FOR BOLTED FLANGE CONNECTIONS[1]

ARTICLE 3-1
GENERAL REQUIREMENTS

3-100 SCOPE

(a) The rules in Appendix 3 apply specifically to the design of bolted flange connections for pressure vessels and are to be used in conjunction with the applicable requirements in Parts AM, AD, and AF of this Division. Article 3-5 provides discussions on design considerations for bolted flange connections.

(b) These rules provide only for hydrostatic end loads and gasket seating. See 3-380 for flanges subject to external pressure. Proper allowance shall be made if connections are subject to external loads other than external pressure.

(c) When analysis by Appendices 4, 5, and 6 is required, only 3-320, 3-321, and 3-322 of this Appendix are applicable.

3-101 Elements Involved in Flange Design

The design of a flange involves the selection of the gasket (material, type, and dimensions), flange facing, bolting, hub proportions, flange width, and flange thickness. [See Note to 3-323(a).] Flange dimensions shall be such that the stress intensities in the flange, calculated in accordance with 3-340, do not exceed the allowable flange stress intensities specified in 3-350. All calculations shall be based on dimensions of the flange in the corroded condition.

3-102 Conditions for Which Design Calculations Shall Be Made

In the design of a bolted flange connection, complete calculations shall be made for two separate and independent sets of conditions, which are defined below.

3-102.1 Operating Conditions. The conditions required to resist the hydrostatic end force of the design pressure, tending to part the joint, and to maintain on the gasket or joint contact surface sufficient compression to assure a tight joint, all at the design temperature. The minimum load is a function of the design pressure, the gasket material, and the effective gasket or contact area to be kept tight under pressure, per Eq. (1) in 3-323(a), and determines one of the two requirements for the amount of the bolting A_{m1}. This load is also used for the design of the flange, per Eq. (3) in 3-325.

3-102.2 Gasket Seating. The conditions existing when the gasket or joint contact surface is seated by applying an initial load with the bolts when assembling the joint, at atmospheric temperature and pressure. The minimum initial load considered to be adequate for proper seating is a function of the gasket material and of the effective gasket or contact area to be seated, as calculated by Eq. (2) in 3-323(b), and determines the other of the two requirements for the amount of bolting A_{m2}. In designing the flange, the initial load must be modified in accordance with Eq. (4) in 3-325; this takes account of the operating conditions, when these govern the amount of bolting required A_m, as well as the amount of bolting actually provided A_b.

3-103 Bolted Flange Connections to External Piping

It is recommended that bolted flange connections conforming to the standards[2] listed in AD-711 be used for

[1] These rules are the same as those in Section VIII, Division 1, Appendix 2, except that certain types of flanges are prohibited.

[2] The ratings in these standards are based on the hub diameter given or on the minimum specified thickness of flanged fittings of integral construction. Flanges fabricated from rings may be used in place of the hub flanges in these standards provided that their strength, calculated by the rules in this Appendix, is not less than that calculated for the corresponding size of hub flange.

connections to external piping. These standards may be used for other bolted flange connections within the limits of size in the standards and the pressure– temperature ratings in AD-711.

3-104 Bolted Flange Connections to Conform to This Appendix

Except as otherwise provided in 3-103, bolted flange connections for pressure vessels shall satisfy the requirements in this Appendix.

ARTICLE 3-2
MATERIALS FOR BOLTED FLANGE CONNECTIONS

3-200 MATERIAL REQUIREMENTS

Materials used in the construction of bolted flange connections shall comply with the requirements given in Part AM.

3-201 Heat Treatment of Flanges

Flanges made from ferritic steel and designed in accordance with this Appendix shall be given a normalizing or full-annealing heat treatment when the thickness of the flange section exceeds 3 in. (75 mm).

3-202 Weldability of Flange Materials

Material on which welding is to be performed shall be proved of good weldable quality. Satisfactory qualification of the welding procedure under Section IX is considered as proof. Welding shall not be performed on steel that has a carbon content greater than 0.35%.

3-202.1 Postweld Heat Treatment Requirements. All welding on flange connections shall comply with the requirements for postweld heat treatment given in Part AF of this Division, AF-402.

3-203 Fabricated Hubbed Flanges

Fabricated hubbed flanges shall be in accordance with the following.

(a) Hubbed flanges may be machined from a hot rolled or forged billet. The axis of the finished flange shall be parallel to the long axis of the original billet. (This is not intended to imply that the axis of the finished flange and the original billet must be concentric.)

(b) Hubbed flanges, except as permitted in (a) above, shall not be machined from plate or bar stock material unless the material has been formed into a ring, and further provided that:

(1) in a ring formed from plate, the original plate surfaces are parallel to the axis of the finished flange. (This is not intended to imply that the original plate surface be present in the finished flange.)

(2) the joints in the ring are welded butt joints that conform to the requirements of this Division. Thickness to be used to determine the necessity of postweld heat treatment shall be the lesser of:

$$t \text{ or } \frac{A - B}{2}$$

where these symbols are as defined in 3-301.1.

(c) The back of the flange and the outer surface of the hub are examined by either the magnetic particle method as per Article 9-1 or the liquid penetrant method as per Article 9-2.

3-204 Bolting Materials

Bolts, studs, nuts, and washers shall comply with the requirements in Article M-5 of this Division.

3-204.1 Minimum Size of Bolts and Studs. It is recommended that use of bolts and studs having a nominal diameter of less than $\frac{1}{2}$ in. (13 mm) be avoided. If bolts or studs smaller than $\frac{1}{2}$ in. (13 mm) are used, ferrous bolting material shall be of alloy steel. Precautions shall be taken to avoid overstressing small diameter bolts.

ARTICLE 3-3
FLANGES WITH RING TYPE GASKETS

3-300 FLANGES WITH GASKETS WHOLLY INSIDE THE BOLT HOLES

The rules in this Article apply specifically to flanges with gaskets that are entirely within the circle enclosed by the bolt holes and with no contact outside this circle. These rules are not to be used for the determination of the thickness of supported or unsupported tubesheets integral with a bolting flange.

3-301 Flanges Subject to Internal Pressure

The flange design methods outlined in this Article, exclusive of 3-360, 3-370, and 3-380, are applicable to circular flanges under internal pressure. Modifications of these methods are outlined in 3-360 and 3-370 for the design of split and noncircular flanges.

3-301.1 Nomenclature Used in Formulas. The symbols defined below are used in the formulas for the design of flanges (see also Fig. 3-310.1).

A = outside diameter of flange or, where slotted holes extend to the outside of the flange, the diameter to the bottom of the slots

A_b = actual total cross-sectional area of bolts at root of thread or section of least diameter under stress

A_m = total required cross-sectional area of bolts, taken as the greater of A_{m1} and A_{m2}

A_{m1} = total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for the operating conditions

= W_{m1}/S_b

A_{m2} = total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for gasket seating

= W_{m2}/S_a

B = inside diameter of flange. When B is less than $20g_1$, it will be optional for the designer to substitute B_1 for B in the formula for longitudinal hub stress S_H [see Eq. (6)].

B_1 = $B + g_1$ for loose type hub flanges and also for integral type flanges when f is less than 1

= $B + g_o$ for integral type flanges when F is equal to or greater than 1

b = effective gasket or joint contact surface seating width [see Note to 3-323(a)]

b_o = basic gasket seating width (from Table 3-320.2)

C = bolt circle diameter

c = basic dimension used for the minimum sizing of welds, equal to t_n or t_x, whichever is less

d = factor as follows:

= $\frac{U}{V} h_o g_o^2$ for integral type flanges

= $\frac{U}{V_L} h_o g_o^2$ for loose type flanges

e = factor as follows:

= $\frac{F}{h_o}$ for integral type flanges

= $\frac{F_L}{h_o}$ for loose type flanges

F = factor for integral type flanges (from Fig. 3-340.2)

F_L = factor for loose type flanges (from Fig. 3-340.4)

f = hub stress correction factor for integral flanges from Fig. 3-340.6 (when greater than 1, this is the ratio of the stress in the small end of hub to the stress in the large end). For values below limit of figure, use $f = 1$.

G = diameter at location of gasket load reaction. Except as noted in sketch (a) of Fig. 3-310.1, G is defined as follows (see Table 3-320.2):

When $b_o \leq 1/4$ in. (6 mm), G = mean diameter of gasket contact face.

When $b_o > 1/4$ in. (6 mm), G = outside diameter of gasket contact face less $2b$.

g_o = thickness of hub at small end

g_1 = thickness of hub at back of flange

H = total hydrostatic end force

= $0.785\ G^2P$

H_D = hydrostatic end force on area inside of flange

= $0.785\ B^2P$

H_G = gasket load (difference between flange design bolt load and total hydrostatic end force)

= $W - H$

H_p = total joint contact surface compression load

$= 2b \times 3.14\ GmP$

H_T = difference between total hydrostatic end force and the hydrostatic end force on area inside of flange

$= H - H_D$

h = hub length

h_D = radial distance from the bolt circle to the circle on which H_D acts, as prescribed in 3-330

h_G = radial distance from gasket load reaction to the bolt circle

$= \dfrac{C - G}{2}$

h_o = factor

$= \sqrt{Bg_o}$

h_T = radial distance from the bolt circle to the circle on which H_T acts, as prescribed in 3-330

K = ratio of outside diameter of flange to inside diameter of flange

$= A/B$

L = factor

$= \dfrac{te + 1}{T} + \dfrac{t^3}{d}$

M_D = component of moment due to H_D

$= H_D h_D$

M_G = component of moment due to H_G

$= H_G h_G$

M_o = total moment acting upon the flange, for the operating conditions or gasket seating, as may apply (see 3-330)

M_T = component of moment due to H_T

$= H_T h_T$

m = gasket factor, obtained from Table 3-320.1 [see Note to 3-323(a)]

N = width used to determine the basic gasket seating width b_o, based upon the possible contact width of the gasket (see Table 3-320.2)

P = internal design pressure. For flanges subject to external pressure, see 3-380.

R = radial distance from bolt circle to point of intersection of hub and back of flange. For integral and hub flanges,

$= \dfrac{C - B}{2} - g_1$

S_a = allowable bolt stress value at atmospheric temperature (given in Table 3 of Section II, Part D)

S_b = allowable bolt stress value at design temperature (given in Table 3 of Section II, Part D)

S_f = maximum allowable stress value for material of flange at design temperature (operating condition) or atmospheric temperature (gasket seating), as may apply (given in Tables 1A and 1B of Section II, Part D)

S_n = maximum allowable stress value for material of nozzle, neck, vessel, or pipe wall, at design temperature (operating condition) or atmospheric temperature (gasket seating), as may apply (given in Tables 1A and 1B of Section II, Part D)

S_H = calculated longitudinal stress in hub (see 3-350)

S_R = calculated radial stress in flange (see 3-350)

S_T = calculated tangential stress in flange (see 3-350)

T = factor involving K (from Fig. 3-340.1)

t = flange thickness

t_n = nominal thickness of shell or nozzle wall to which flange or lap is attached

t_x = two times the thickness g_o when the design is calculated as an integral flange, or two times the thickness of the shell or nozzle wall required for internal pressure, when the design is calculated as a loose flange, but not less than $\frac{1}{4}$ in. (6 mm)

U = factor involving K (from Fig. 3-340.1)

V = factor for integral type flanges (from Fig. 3-340.3)

V_L = factor for loose type flanges (from Fig. 3-340.5)

W = flange design bolt load, for the operating conditions or gasket seating, as may apply (see 3-325)

W_{m1} = minimum required bolt load for the operating conditions (see 3-321). For flange pairs used to contain a tubesheet for a floating head for a U-tube type of heat exchanger, or for any other similar design, W_{m1} shall be the larger of the values as individually calculated for each flange, and that value shall be used for both flanges.

W_{m2} = minimum required bolt load for gasket seating (see 3-321)

w = width used to determine the basic gasket seating width b_o, based upon the contact width between the flange facing and the gasket (see Table 3-320.2)

Y = factor involving K (from Fig. 3-340.1)

y = gasket or joint contact surface unit seating load [see Note to 3-323(a)]

Z = factor involving K (from Fig. 3-340.1)

3-310 CIRCULAR FLANGE TYPES

For purposes of computation, there are two types of circular flanges.

3-310.1 Loose Type Flanges. This type covers those designs in which the flange has no direct connection to the nozzle neck, vessel, or pipe wall, and designs where the method of attachment is not considered to give the mechanical strength equivalent of integral attachment. See Fig. 3-310.1 sketches (a), (b), (b-1), and (b-2) for typical loose type flanges and the location of the loads and moments. Welds and other details of construction shall satisfy the dimensional requirements given in Fig. 3-310.1 sketches (a), (b), (b-1), and (b-2).

3-310.2 Integral Type Flanges. This type covers designs where the flange is cast or forged integrally with the nozzle neck, vessel, or pipe wall, butt welded thereto, or attached by other forms of arc or gas welding of such a nature that the flange and nozzle neck, vessel, or pipe wall are considered to be the equivalent of an integral structure. In welded construction, the nozzle neck, vessel, or pipe wall is considered to act as a hub. See Fig. 3-310.1 sketches (c), (d), (e), (f), (g), and (h) for typical integral type flanges and the location of the loads and moments. Welds and other details of construction shall satisfy the dimensional requirements given in Fig. 3-310.1 sketches (c), (d), (e), (f), (g), and (h).

3-320 BOLT LOADS

3-321 General Requirements

(a) In the design of a bolted flange connection, calculations shall be made for each of the two design conditions of operating and gasket seating, and the more severe shall control.

(b) In the design of flange pairs used to contain a tubesheet of a heat exchanger or any similar design where the flanges and/or gaskets may not be the same, loads must be determined for the most severe condition of operating and/or gasket seating loads applied to each side at the same time. This most severe condition may be gasket seating on one flange with operating on the other, gasket seating on each flange at the same time, or operating on each flange at the same time. Although no specific rules are given for the design of flange pairs, after the loads for the most severe conditions are determined, calculations shall be made for each flange following the rules of this Article.

3-322 Design Conditions

(a) Operating Conditions. The conditions required to resist the hydrostatic end force of the design pressure tending to part the joint, and to maintain on the gasket or joint contact surface sufficient compression to assure a tight joint, all at the design temperature. The minimum load is a function of the design pressure, the gasket material, and the effective gasket or contact area to be kept tight under pressure, per Eq. (1) in 3-323(a), and determines one of the two requirements for the amount of bolting A_{m1}. This load is also used for the design of the flange, per Eq. (3) in 3-325.

(b) Gasket Seating. The conditions existing when the gasket or joint contact surface is seated by applying an initial load with the bolts when assembling the joint, at atmospheric temperature and pressure. The minimum initial load considered to be adequate for proper seating is a function of the gasket material, and the effective gasket or contact area to be seated, per Eq. (2) in 3-323(b), and determines the other of the two requirements for the amount of bolting A_{m2}. For the design of the flange, this load is modified per Eq. (4) in 3-325 to take account of the operating conditions when these govern the amount of bolting required A_m, as well as the amount of bolting actually provided A_b.

3-323 Required Bolt Loads

The flange bolt loads used in calculating the required cross-sectional area of bolts shall be determined as given below.

(a) The required bolt load for the operating conditions W_{m1} shall be sufficient to resist the hydrostatic end force H exerted by the maximum allowable working pressure on the area bounded by the diameter of gasket reaction and, in addition, to maintain on the gasket or joint contact surface a compression load H_p, which experience has shown to be sufficient to assure a tight joint. This compression load is expressed as a multiple m of the internal pressure. Its value is a function of the gasket material and construction (see Note below). This required bolt load for the operating conditions W_{m1} is determined in accordance with Eq. (1):

$$W_{m1} = H + H_p = 0.785G^2P + (2b \times 3.14GmP) \quad (1)$$

NOTE: Tables 3-320.1 and 3-320.2 give a list of many commonly used gasket materials and contact facings, with suggested values of m, b, and y that have proved satisfactory in actual service. These values are suggested only and are not mandatory. Values that are too low may result in leakage at the joint without affecting the safety of the design. The primary proof that the values are adequate is the hydrostatic test.

(b) Before a tight joint can be obtained, it is necessary to seat the gasket or joint contact surface properly by applying a minimum initial load (under atmospheric temperature conditions without the presence of internal pressure), which is a function of the gasket material and the effective gasket area to be seated. The minimum initial bolt load required for this purpose W_{m2} shall be determined in accordance with Eq. (2):

$$W_{m2} = 3.14bGy \quad (2)$$

The need for providing sufficient bolt load to seat the gasket or joint contact surfaces in accordance with Eq. (2) will prevail on many low-pressure designs, with facings and materials that require a high seating load and

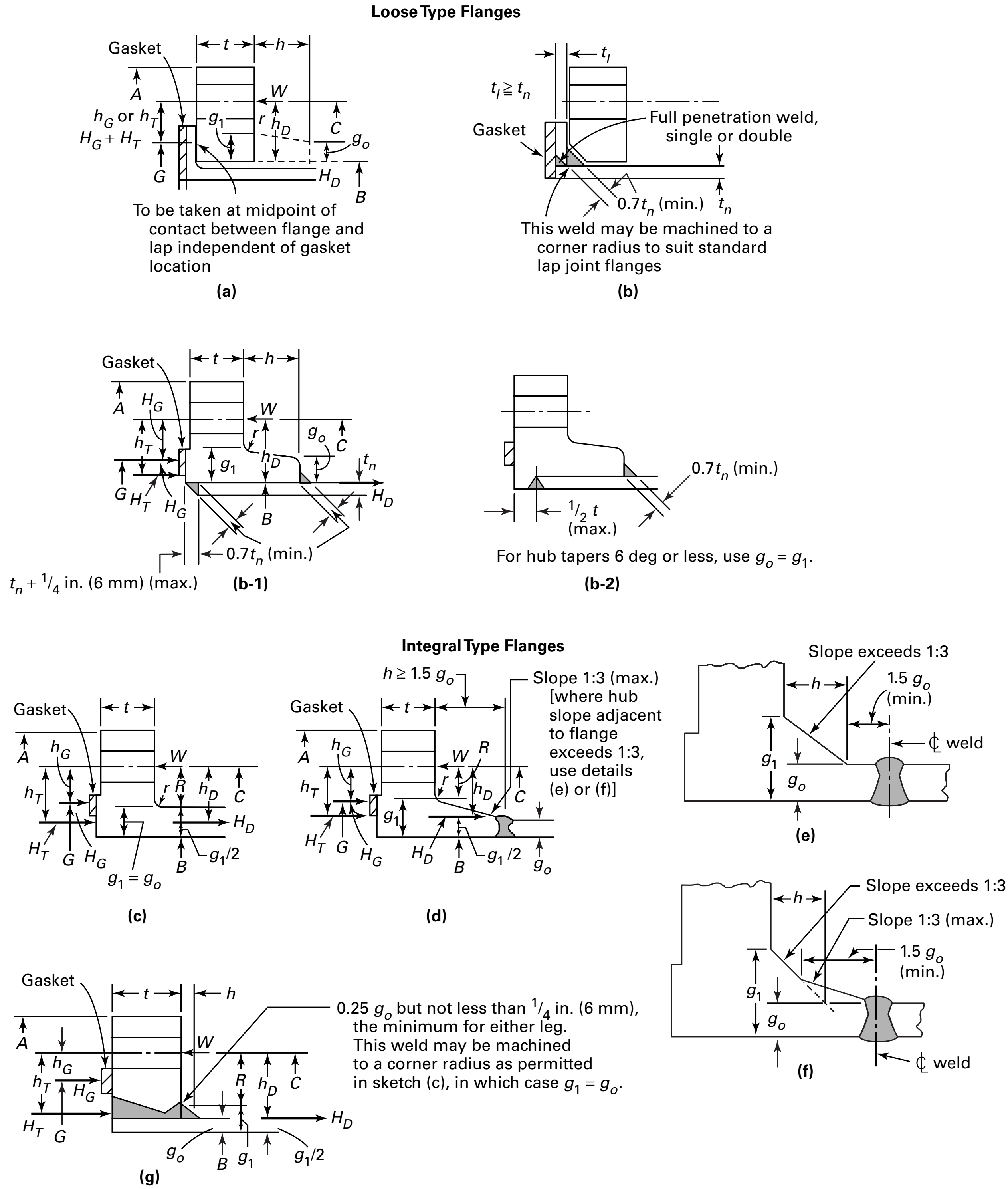
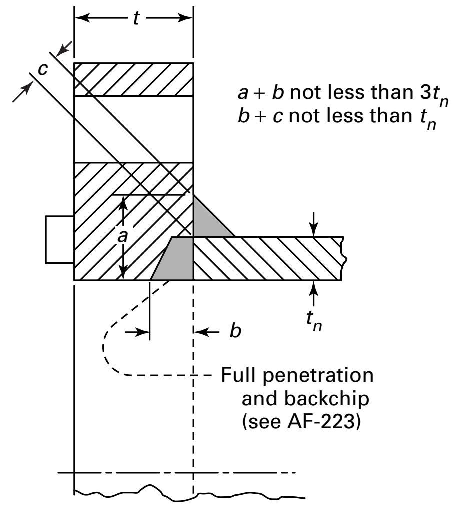
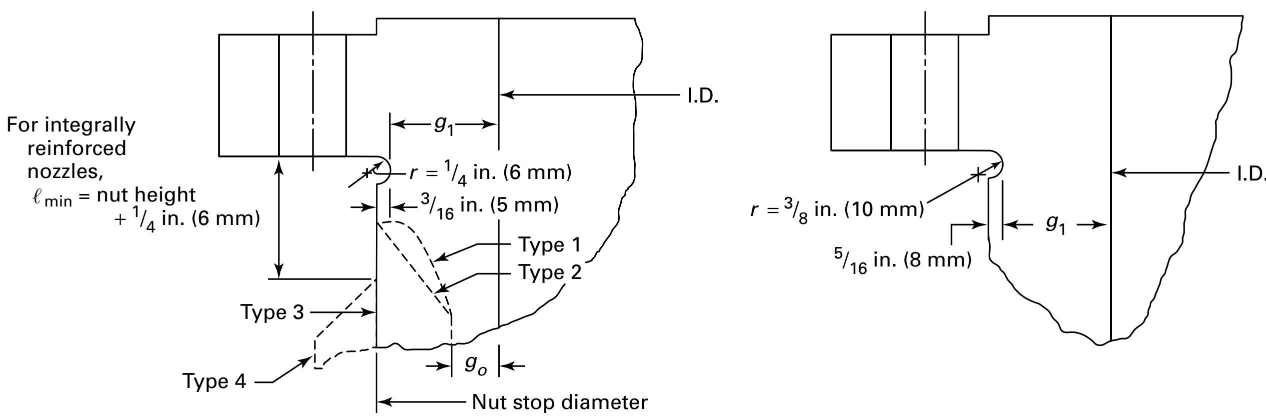


FIG. 3-310.1 TYPES OF FLANGES



(h) [Note (1)]

Flanges With Nut Stops



(i-1)
Flanged Nozzles 18 in. (450 mm) and Smaller Nominal Size
[Note (2)]

(i-2)
Flanged Nozzles
Over 18 in. (450 mm) Nominal Size
[Note (3)]

GENERAL NOTES:

(a) Hub type flanges are illustrated in sketches (a), (b-1), (b-2), (d), (e), and (f).

(b) For loose and integral type flanges, fillet radius r to be at least $0.25g_1$ but not less than $^3/_{16}$ in. (5 mm). Facing thicknesses or groove depths greater than $^1/_{16}$ in. (1.5 mm) shall be in excess of the required minimum flange thickness t ; those $\leq ^1/_{16}$ in. (1.5 mm) may be included.

NOTES:

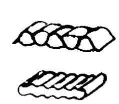
(1) Loading and dimensions not shown are the same as in sketch (g) for integral type.

(2) For Types 1 and 2, g_o is the thickness of the hub at the small end. For Types 3 and 4, $g_o = g_1$.

(3) All other details as shown in sketch (i-1).

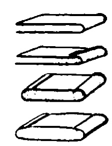
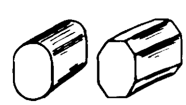
FIG. 3-310.1 TYPES OF FLANGES (CONT'D)

TABLE 3-320.1
GASKET MATERIALS AND CONTACT FACINGS
Gasket Factors *m* for Operating Conditions and Minimum Design Seating Stress *y*

Gasket Material	Gasket Factor *m*	Min. Design Seating Stress *y*, psi	Min. Design Seating Stress *y*, MPa	Sketches	Facing Sketch and Column in Table 3-320.2
Self-energizing types (O rings, metallic, elastomer, other gasket types considered as self-sealing)	0	0	0	. . .	. . .
Elastomers without fabric or high percent of asbestos fiber:					
Below 75A Shore durometer	0.50	0	0		(1a),(1b),(1c),(1d), (4),(5); Column II
75A or higher Shore durometer	1.00	200	1.5		
Asbestos with suitable binder for operating conditions:					
$\frac{1}{8}$ in. (3 mm) thick	2.00	1,600	11		
$\frac{1}{16}$ in. (1.5 mm) thick	2.75	3,700	26		(1a),(1b),(1c),(1d), (4),(5); Column II
$\frac{1}{32}$ in. (0.8 mm) thick	3.50	6,500	45		
Elastomers with cotton fabric insertion	1.25	400	3		(1a),(1b),(1c),(1d), (4),(5); Column II
Elastomers with asbestos fabric insertion (with or without wire reinforcement):					
3-ply	2.25	2,200	15		
2-ply	2.50	2,900	20		(1a),(1b),(1c),(1d), (4),(5); Column II
1-ply	2.75	3,700	26		
Vegetable fiber	1.75	1,100	7.5		(1a),(1b),(1c),(1d), (4),(5); Column II
Spiral-wound metal, asbestos filled:					
Carbon	2.50	10,000	69		(1a),(1b); Column II
Stainless or Monel	3.00	10,000	69		
Corrugated metal, asbestos inserted, or corrugated metal, jacketed asbestos filled:					
Soft aluminum	2.50	2,900	20		(1a),(1b); Column II
Soft copper or brass	2.75	3,700	26		
Iron or soft steel	3.00	4,500	31		
Monel or 4–6% chrome	3.25	5,500	38		
Stainless steels	3.50	6,500	45		

(continued)

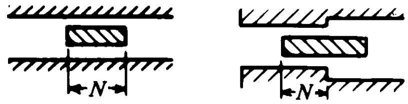
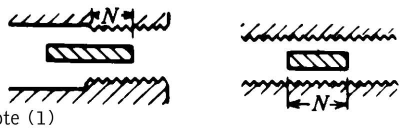
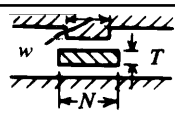
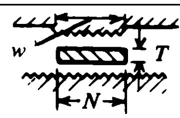
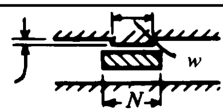
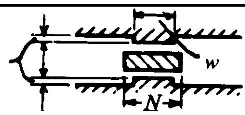
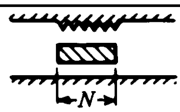
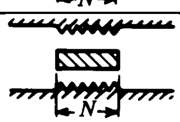
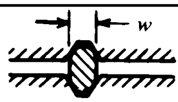
TABLE 3-320.1
GASKET MATERIALS AND CONTACT FACINGS (CONT'D)
Gasket Factors *m* for Operating Conditions and Minimum Design Seating Stress *y*

Gasket Material	Gasket Factor *m*	Min. Design Seating Stress *y*, psi	Min. Design Seating Stress *y*, MPa	Sketches	Facing Sketch and Column in Table 3-320.2
Corrugated metal:					
Soft aluminum	2.75	3,700	26		(1a),(1b),(1c),(1d); Column II
Soft copper or brass	3.00	4,500	31		
Iron or soft steel	3.25	5,500	38		
Monel or 4–6% chrome	3.50	6,500	45		
Stainless steels	3.75	7,600	52		
Flat metal, jacketed asbestos filled:					
Soft aluminum	3.25	5,500	38		(1a),(1b),(1c),[1] (1d),[1](2)[1]; Column II
Soft copper or brass	3.50	6,500	45		
Iron or soft steel	3.75	7,600	52		
Monel	3.50	8,000	55		
4–6% chrome	3.75	9,000	62		
Stainless steels	3.75	9,000	62		
Grooved metal:					
Soft aluminum	3.25	5,500	38		(1a),(1b),(1c),(1d), (2),(3); Column II
Soft copper or brass	3.50	6,500	45		
Iron or soft steel	3.75	7,600	52		
Monel or 4–6% chrome	3.75	9,000	62		
Stainless steels	4.25	10,100	70		
Solid flat metal:					
Soft aluminum	4.00	8,800	61		(1a),(1b),(1c),(1d), (2),(3),(4),(5); Column I
Soft copper or brass	4.75	13,000	90		
Iron or soft steel	5.50	18,000	124		
Monel or 4–6% chrome	6.00	21,800	150		
Stainless steels	6.50	26,000	180		
Ring joint:					
Iron or soft steel	5.50	18,000	124		(6), Column I
Monel or 4–6% chrome	6.00	21,800	150		
Stainless steels	6.50	26,000	180		

GENERAL NOTE: This Table gives a list of many commonly used gasket materials and contact facings with suggested design values of *m* and *y* that have generally proved satisfactory in actual service when using effective gasket seating width *b* given in Table 3-320.2. The design values and other details given in this Table are suggested only and are not mandatory.

NOTE:
(1) The surface of a gasket having a lap should not be against the nubbin.

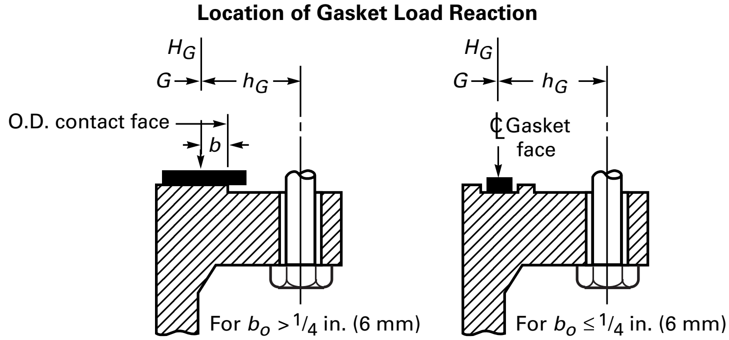
TABLE 3-320.2
EFFECTIVE GASKET WIDTH

Facing Sketch (Exaggerated)	Basic Gasket Seating Width b_o	
	Column I	Column II
(1a) 	$\frac{N}{2}$	$\frac{N}{2}$
(1b)  See Note (1)		
(1c)  $w \leq N$	$\frac{w+T}{2}; \frac{w+N}{4}$ max.	$\frac{w+T}{2}; \frac{w+N}{4}$ max.
(1d)  See Note (1) $w \leq N$		
(2) $^1/_{64}$ in. (0.4 mm) nubbin  $w \leq N/2$	$\frac{w+N}{4}$	$\frac{w+3N}{8}$
(3) $^1/_{64}$ in. (0.4 mm) nubbin  $w \leq N/2$	$\frac{N}{4}$	$\frac{3N}{8}$
(4)  See Note (1)	$\frac{3N}{8}$	$\frac{7N}{16}$
(5)  See Note (1)	$\frac{N}{4}$	$\frac{3N}{8}$
(6) 	$\frac{w}{8}$	. . .

Effective Gasket Seating Width b

$b = b_o$ when $b_o \leq \frac{1}{4}$ in. (6 mm); $b = 0.5\sqrt{b_o}$ $(2.5\sqrt{b_o})$ when $b_o > \frac{1}{4}$ in. (6 mm)

Location of Gasket Load Reaction



Notes follow on next page.

TABLE 3-320.2 (CONT'D)

GENERAL NOTE: The gasket factors listed only apply to flanged joints in which the gasket is contained entirely within the inner edges of the bolt holes.

NOTE:
(1) Where serrations do not exceed $\frac{1}{64}$ in. (0.4 mm) depth and $\frac{1}{32}$ in. (0.8 mm) width spacing, sketches (1b) and (1d) shall be used.

TABLE 3-330.1
MOMENT ARMS FOR FLANGE LOADS UNDER OPERATING CONDITIONS

Flange Type	h_D	h_T	h_G
Integral type flanges [see Fig. 3-310.1, sketches (c), (d), (e), (f), (g), and (h)]	$R + 0.5g_1$	$\frac{R + g_1 + h_G}{2}$	$\frac{C - G}{2}$
Loose type, except lap-joint, flanges [see Fig. 3-310.1, sketches (b-1) and (b-2)]	$\frac{C - B}{2}$	$\frac{h_D + h_G}{2}$	$\frac{C - G}{2}$
Lap-joint flanges [see Fig. 3-310.1, sketches (a) and (b)]	$\frac{C - B}{2}$	$\frac{C - G}{2}$	$\frac{C - G}{2}$

where the bolt load computed by Eq. (1) for the operating conditions is insufficient to seat the joint. Accordingly, it is necessary to furnish bolting and to pretighten the bolts to provide a bolt load sufficient to satisfy both of these requirements, each one being individually investigated. When Eq. (2) governs, flange proportions will be a function of the bolting instead of internal pressure.

3-324 Total Required and Actual Bolt Areas, A_m and A_b

The total cross-sectional area of bolts A_m required for both the operating conditions and gasket seating is the greater of the values for A_{m1} and A_{m2}, where $A_{m1} = W_{m1}/S_b$ and $A_{m2} = W_{m2}/S_a$. A selection of size and number bolts to be used shall be such that the actual total cross-sectional area of bolts A_b will not be less than A_m.

3-325 Flange Design Bolt Load W

The bolt loads used in the design of the flange shall be the values obtained from Eqs. (3) and (4). For operating conditions:

$$W = W_{m1} \tag{3}$$

For gasket seating:

$$W = \frac{(A_m + A_b)S_a}{2} \tag{4}$$

S_a in Eq. (4) shall be not less than that tabulated in Table 3 of Section II, Part D.

In addition to the minimum requirements for safety, Eq. (4) provides a margin against abuse of the flange from overbolting. Since margin against such abuse is needed primarily for the initial bolting-up operation which is done at atmospheric temperature and before application of internal pressure, the flange design is required to satisfy this loading only under such conditions (see Note).

NOTE: Where additional safety against abuse is desired, or where it is necessary that the flange be suitable to withstand the full available bolt load $A_b \times S_a$, the flange may be designed on the basis of this latter quantity.

3-330 FLANGE MOMENTS

In the calculation of flange stresses, the moment of a load acting on the flange is the product of the load and its moment arm. The moment arm is determined by the relative position of the bolt circle with respect to that of the load producing the moment (see Fig. 3-310.1). No consideration shall be given to any possible reduction in moment arm due to cupping of the flanges or due to inward shifting of the line of action of the bolts as a result thereof.

(a) For the operating conditions, the total flange moment M_o is the sum of the three individual moments M_D, M_T, and M_G, as defined in 3-301.1 and based on the flange design bolt load of Eq. (3) with moment arms as given in Table 3-330.1.

(b) For gasket seating, the total flange moment M_o is based on the flange design bolt load of Eq. (4), which is opposed only by the gasket load, in which case

$$M_o = W\frac{(C - G)}{2} \tag{5}$$

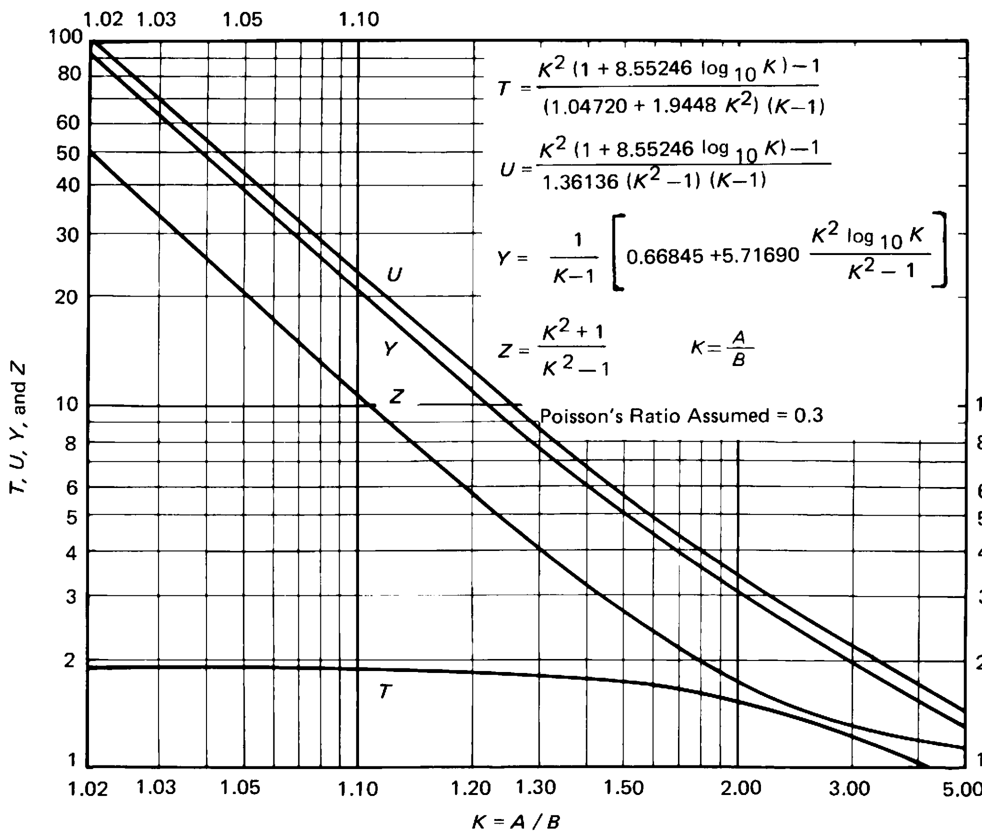


FIG. 3-340.1 VALUES OF *T, U, Y,* AND *Z* (Terms Involving *K*; *K=A/B*)

3-340 CALCULATION OF FLANGE STRESSES

The stresses in the flange shall be determined for both the operating conditions and gasket seating, whichever controls, in accordance with the following equations.

(a) For integral type flanges [see Fig. 3-310.1 sketches (c), (d), (e), (f), (g), and (h)] and loose type flanges with hubs [see Fig. 3-310.1 sketches (a), (b-1), and (b-2)]:

Longitudinal hub stress

$$S_H = \frac{fM_o}{Lg_1^2 B} \quad (6)$$

Radial flange stress

$$S_R = \frac{(1.33te + 1)M_o}{Lt^2 B} \quad (7)$$

Tangential flange stress

$$S_T = \frac{YM_o}{t^2 B} - ZS_R \quad (8)$$

(b) For loose type flanges without hubs and loose type flanges with hubs which the designer chooses to calculate without considering the hub [see Fig. 3-310.1 sketches (a), (b), (b-1), and (b-2)]:

$$S_T = \frac{YM_o}{t^2 B} \quad (9)$$

$$S_R = 0$$

$$S_H = 0$$

3-350 ALLOWABLE FLANGE DESIGN STRESSES

The flange stresses calculated by the formulas in 3-340 shall not exceed the following values:

(a)(1) the longitudinal hub stress S_H shall not be greater than the smaller of $1.5S_f$ or $1.5S_n$ where the neck material constitutes the hub of the flange [see Fig. 3-310.1 sketches (g) and (h)];

(2) the longitudinal hub stress S_H shall not be greater than the smaller of $1.5S_f$ or $2.5S_n$ where integral type flanges with a hub are welded to the neck, pipe, or vessel wall [see Fig. 3-310.1 sketches (d), (e), and (f)];

(b) the radial flange stress S_R shall not be greater than S_f;

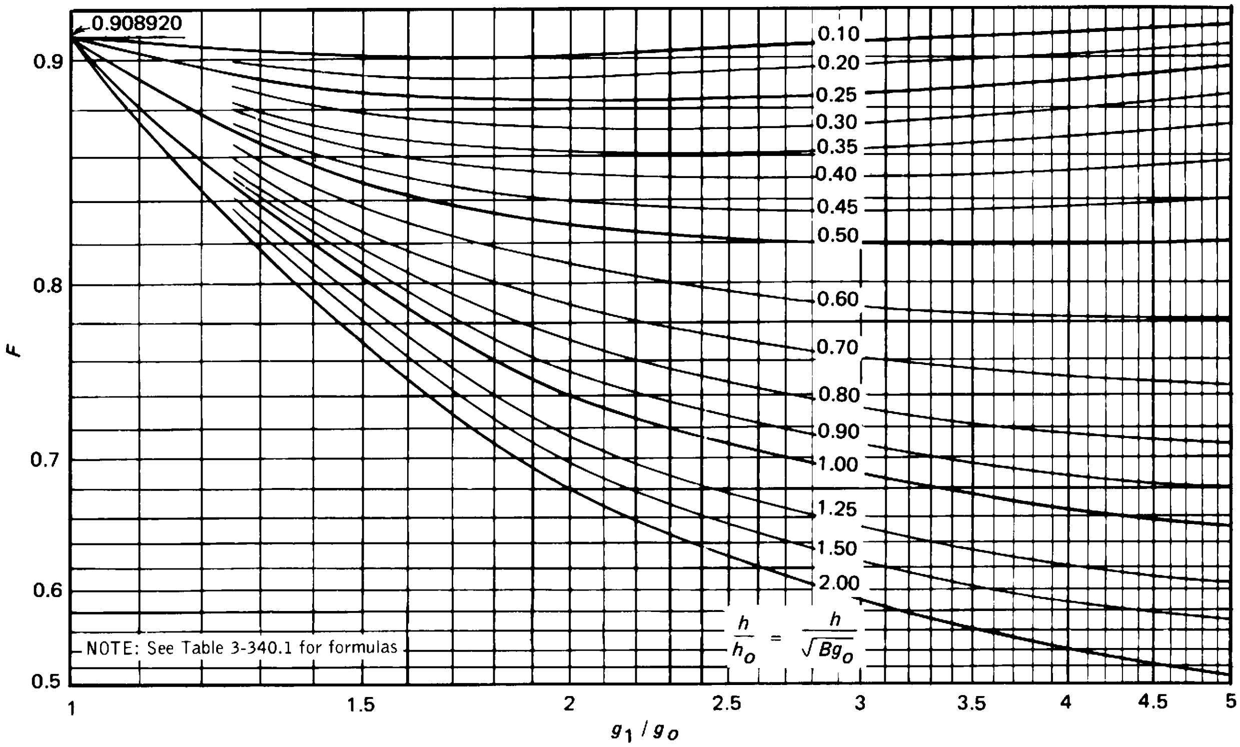


FIG. 3-340.2 VALUES OF F (Integral Flange Factors)

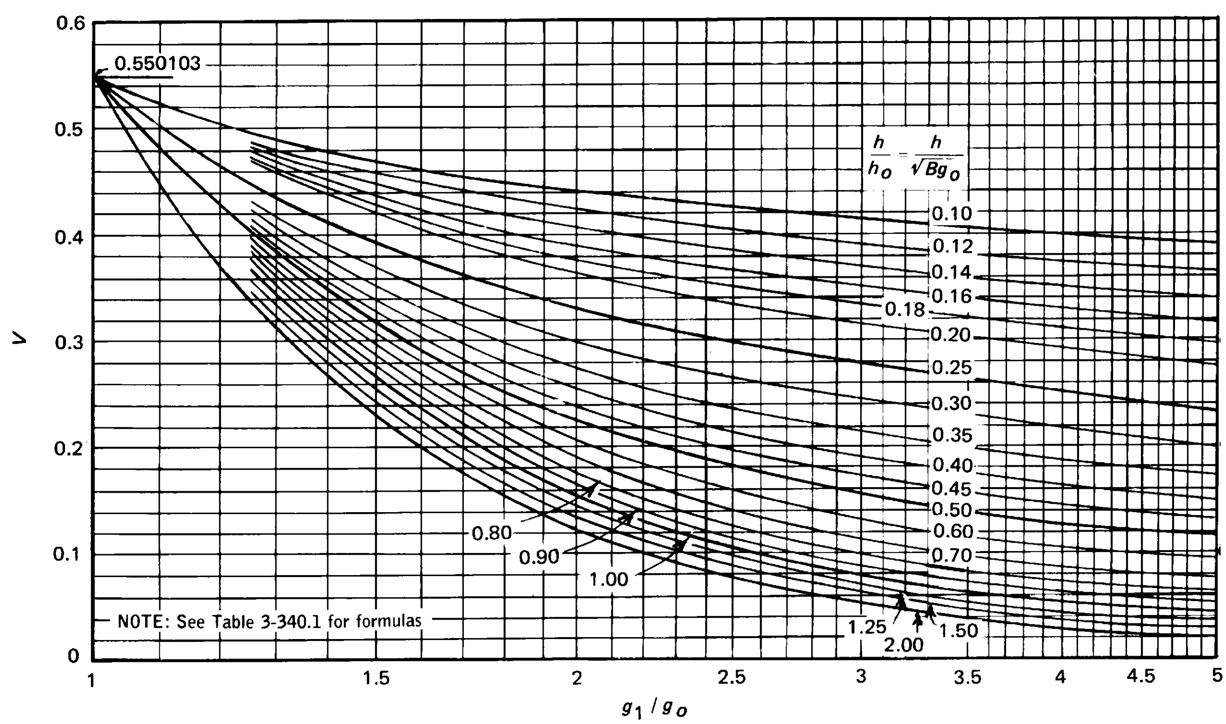


FIG. 3-340.3 VALUES OF V (Integral Flange Factors)

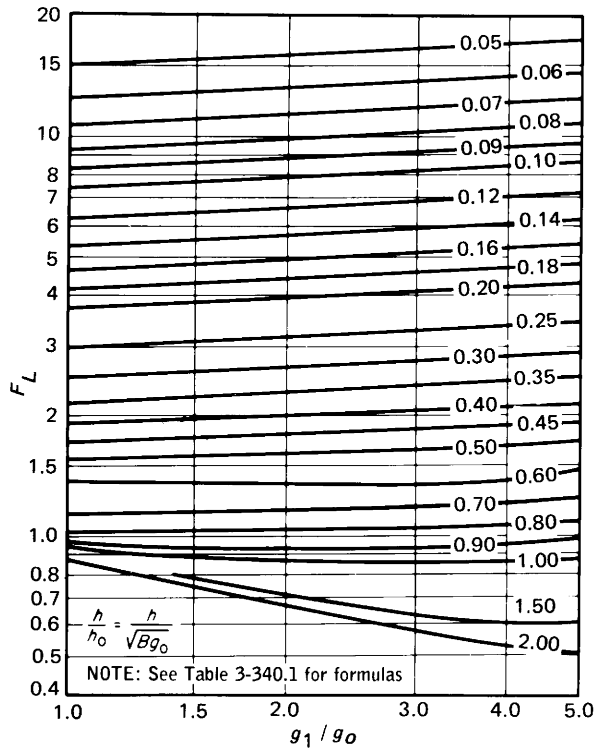


FIG. 3-340.4 VALUES OF F_L
(Loose Hub Flange Factors)

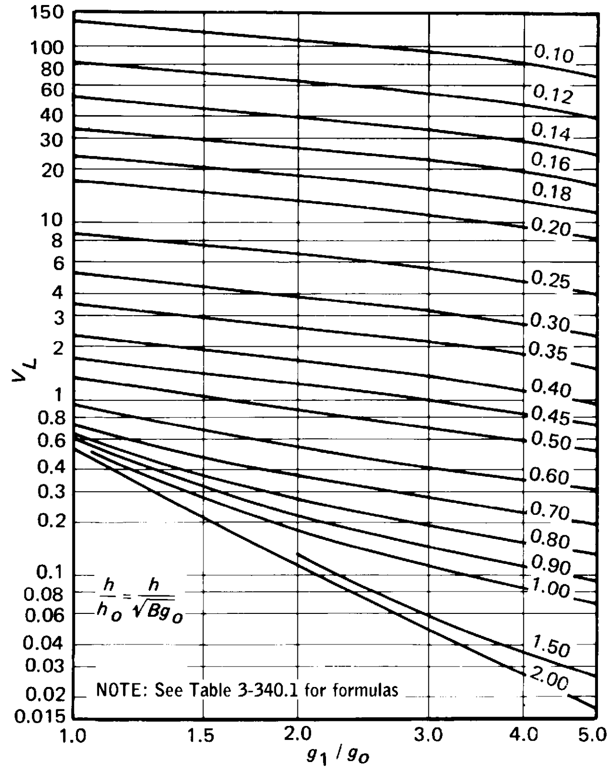


FIG. 3-340.5 VALUES OF V_L
(Loose Hub Flange Factors)

(c) the tangential flange stress S_T shall not be greater than S_f;

(d) also

$$\frac{S_H + S_R}{2} \text{ not greater than } S_f$$

and

$$\frac{S_H + S_T}{2} \text{ not greater than } S_f$$

(e) in the case of loose type flanges with laps, as shown in Fig. 3-310.1 sketches (a) and (b), where the gasket is so located that the lap is subjected to shear, the shearing stress shall not exceed 0.8 times S_n for the material of the lap, as defined in 3-301.1. In the case of welded flanges, shown in Fig. 3-310.1 sketch (g), where the nozzle neck, vessel, or pipe wall extends near to the flange face and may form the gasket contact face, the shearing stress carried by the welds shall not exceed 0.8 times S_n. The shearing stress shall be calculated on the basis of W_{m1} or W_{m2}, as defined in 3-301.1, whichever is greater. Similar cases where flange parts are subjected to shearing stress shall be governed by the same requirements.

3-360 SPLIT LOOSE FLANGES[1]

Loose flanges, split across a diameter and designed under these rules, may be used under the following provisions.

(a) When the flange consists of a single split flange or flange ring, it shall be designed as if it were a solid flange (without splits), using 200% of the total moment M_o as defined in 3-330.

(b) When the flange consists of two split rings, each ring shall be designed as if it were a solid flange (without splits), using 75% of the total moment M_o as defined in 3-330. The pair of rings shall be assembled so that the splits in one ring shall be 90 deg from the splits in the other ring.

(c) The splits should preferably be midway between bolt holes.

[1] Loose flanges of the type shown in Fig. 3-310.1(a) are of the split design when it is necessary to install them after a heat treatment of a stainless steel vessel or when for any reason it is desired to have them completely moveable from the nozzle or vessel.

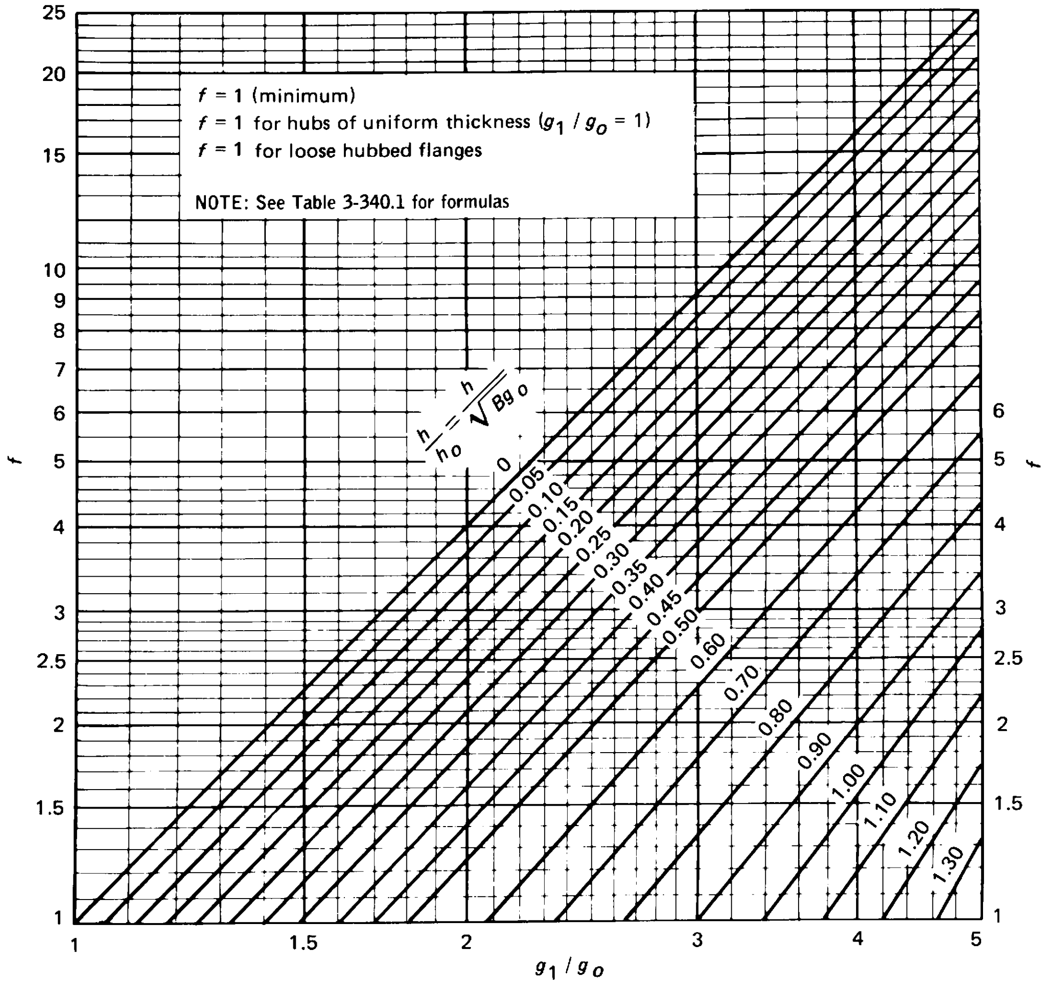


FIG. 3-340.6 VALUES OF f (Hub Stress Correction Factors)

3-370 NONCIRCULAR SHAPED FLANGES WITH CIRCULAR BORE

The outside diameter A for a noncircular flange with a circular bore shall be taken as the diameter of the largest circle, concentric with the bore, inscribed entirely within the outside edges of the flange. Bolt loads and moments, as well as stresses, are then calculated as for circular flanges, using a bolt circle drawn through the centers of the outermost bolt holes.

3-380 FLANGES SUBJECT TO EXTERNAL PRESSURE

(a) The design of flanges for external pressure only (see AT-320)[2] shall be based on the equations given in 3-340 for internal pressure except that for operating conditions:

$$M_o = H_D (h_D - h_G) + H_T(h_T - h_G) \qquad (10)$$

and for gasket seating:

$$M_o = Wh_G \qquad (11)$$

In the above equations

$$W = \frac{A_{m2} + A_b}{2} S_a \qquad (11a)$$

$$H_D = 0.785B^2 P_e \qquad (11b)$$

$$H_T = H - H_D \qquad (11c)$$

$$H = 0.785G^2 P_e \qquad (11d)$$

where

P_e = external design pressure

See 3-301.1 for definitions of other symbols.

[2] When internal pressure occurs only during the required pressure test, the design may be based on external pressure, and auxiliary devices such as clamps may be used during the application of the required test pressure.

TABLE 3-340.1
FLANGE FACTORS IN FORMULA FORM

Integral Flange

Factor F per Fig. 3-340.2 is then solved by

$$F = -\frac{E_6}{\left(\frac{C}{2.73}\right)^{1/4} \frac{(1+A)^3}{C}}$$

Factor V per Fig. 3-340.3 is then solved by

$$V = \frac{E_4}{\left(\frac{2.73}{C}\right)^{1/4} (1+A)^3}$$

Factor f per Fig. 3-340.6 is then solved by

$$f = C_{36}/(1+A)$$

NOTE: The values used in the above equations are solved using Eqs. (1) through (45), below, based on the values g_1, g_o, h, and h_o as defined by 3-301.1. When $g_1 = g_o$, $F = 0.908920$, $V = 0.550103$, and $f = 1$; thus, Eqs. (1) through (45) need not be solved.

Loose Hub Flange

Factor F_L per Fig. 3-340.4 is solved by

$$F_L = \frac{C_{18}\left(\frac{1}{2}+\frac{A}{6}\right) + C_{21}\left(\frac{1}{4}+\frac{11A}{84}\right) + C_{24}\left(\frac{1}{70}+\frac{A}{105}\right) - \left(\frac{1}{40}+\frac{A}{72}\right)}{\left(\frac{C}{2.73}\right)^{1/4} \frac{(1+A)^3}{C}}$$

Factor V_L per Fig. 3-340.5 is solved by

$$V_L = \frac{\frac{1}{4} - \frac{C_{24}}{5} - \frac{3C_{21}}{2} - C_{18}}{\left(\frac{2.73}{C}\right)^{1/4} (1+A)^3}$$

Factor f per Fig. 3-340.6 is set equal to 1.

$$f = 1$$

NOTE: The values used in the above equations are solved using Eqs. (1) through (5), (7), (9), (10), (12), (14), (16), (18), (20), (23), and (26), below, based on the values of g_1, g_o, h, and h_o as defined by 3-301.1.

Equations

(1) $A = (g_1/g_o) - 1$

(2) $C = 43.68(h/h_o)^4$

(3) $C_1 = 1/3 + A/12$

(4) $C_2 = 5/42 + 17A/336$

(5) $C_3 = 1/210 + A/360$

(6) $C_4 = 11/360 + 59A/5{,}040 + (1 + 3A)/C$

TABLE 3-340.1
FLANGE FACTORS IN FORMULA FORM (CONT'D)

(7) $C_5 = 1/90 + 5A/1{,}008 - (1 + A)^3/C$

(8) $C_6 = 1/120 + 17A/5{,}040 + 1/C$

(9) $C_7 = 215/2{,}772 + 51A/1{,}232 + (60/7 + 225A/14 + 75A^2/7 + 5A^3/2)/C$

(10) $C_8 = 31/6{,}930 + 128A/45{,}045 + (6/7 + 15A/7 + 12A^2/7 + 5A^3/11)/C$

(11) $C_9 = 533/30{,}240 + 653A/73{,}920 + (1/2 + 33A/14 + 39A^2/28 + 25A^3/84)/C$

(12) $C_{10} = 29/3{,}780 + 3A/704 - (1/2 + 33A/14 + 81A^2/28 + 13A^3/12)/C$

(13) $C_{11} = 31/6{,}048 + 1{,}763A/665{,}280 + (1/2 + 6A/7 + 15A^2/28 + 5A^3/42)/C$

(14) $C_{12} = 1/2{,}925 + 71A/300{,}300 + (8/35 + 18A/35 + 156A^2/385 + 6A^3/55)/C$

(15) $C_{13} = 761/831{,}600 + 937A/1{,}663{,}200 + (1/35 + 6A/35 + 11A^2/70 + 3A^3/70)/C$

(16) $C_{14} = 197/415{,}800 + 103A/332{,}640 - (1/35 + 6A/35 + 17A^2/70 + A^3/10)/C$

(17) $C_{15} = 233/831{,}600 + 97A/554{,}400 + (1/35 + 3A/35 + A^2/14 + 2A^3/105)/C$

(18) $C_{16} = C_1C_7C_{12} + C_2C_8C_3 + C_3C_8C_2 - (C_3^2C_7 + C_8^2C_1 + C_2^2C_{12})$

(19) $C_{17} = [C_4C_7C_{12} + C_2C_8C_{13} + C_3C_8C_9 - (C_{13}C_7C_3 + C_8^2C_4 + C_{12}C_2C_9)]/C_{16}$

(20) $C_{18} = [C_5C_7C_{12} + C_2C_8C_{14} + C_3C_8C_{10} - (C_{14}C_7C_3 + C_8^2C_5 + C_{12}C_2C_{10})]/C_{16}$

(21) $C_{19} = [C_6C_7C_{12} + C_2C_8C_{15} + C_3C_8C_{11} - (C_{15}C_7C_3 + C_8^2C_6 + C_{12}C_2C_{11})]/C_{16}$

(22) $C_{20} = [C_1C_9C_{12} + C_4C_8C_3 + C_3C_{13}C_2 - (C_3^2C_9 + C_{13}C_8C_1 + C_{12}C_4C_2)]/C_{16}$

(23) $C_{21} = [C_1C_{10}C_{12} + C_5C_8C_3 + C_3C_{14}C_2 - (C_3^2C_{10} + C_{14}C_8C_1 + C_{12}C_5C_2)]/C_{16}$

(24) $C_{22} = [C_1C_{11}C_{12} + C_6C_8C_3 + C_3C_{15}C_2 - (C_3^2C_{11} + C_{15}C_8C_1 + C_{12}C_6C_2)]/C_{16}$

(25) $C_{23} = [C_1C_7C_{13} + C_2C_9C_3 + C_4C_8C_2 - (C_3C_7C_4 + C_8C_9C_1 + C_2^2C_{13})]/C_{16}$

(26) $C_{24} = [C_1C_7C_{14} + C_2C_{10}C_3 + C_5C_8C_2 - (C_3C_7C_5 + C_8C_{10}C_1 + C_2^2C_{14})]/C_{16}$

(27) $C_{25} = [C_1C_7C_{15} + C_2C_{11}C_3 + C_6C_8C_2 - (C_3C_7C_6 + C_8C_{11}C_1 + C_2^2C_{15})]/C_{16}$

(28) $C_{26} = -(C/4)^{1/4}$

(29) $C_{27} = C_{20} - C_{17} - 5/12 + C_{17}C_{26}$

(30) $C_{28} = C_{22} - C_{19} - 1/12 + C_{19}C_{26}$

(31) $C_{29} = -(C/4)^{1/2}$

(32) $C_{30} = -(C/4)^{3/4}$

TABLE 3-340.1
FLANGE FACTORS IN FORMULA FORM (CONT'D)

(33) $C_{31} = 3A/2 - C_{17}C_{30}$	(34) $C_{32} = 1/2 - C_{19}C_{30}$
(35) $C_{33} = 0.5C_{26}C_{32} + C_{28}C_{31}C_{29} - (0.5C_{30}C_{28} + C_{32}C_{27}C_{29})$	(36) $C_{34} = 1/12 + C_{18} - C_{21} - C_{18}C_{26}$
(37) $C_{35} = -C_{18}(C/4)^{3/4}$	(38) $C_{36} = (C_{28}C_{35}C_{29} - C_{32}C_{34}C_{29})/C_{33}$
(39) $C_{37} = [0.5C_{26}C_{35} + C_{34}C_{31}C_{29} - (0.5C_{30}C_{34} + C_{35}C_{27}C_{29})]/C_{33}$	(40) $E_1 = C_{17}C_{36} + C_{18} + C_{19}C_{37}$
(41) $E_2 = C_{20}C_{36} + C_{21} + C_{22}C_{37}$	(42) $E_3 = C_{23}C_{36} + C_{24} + C_{25}C_{37}$
(43) $E_4 = 1/4 + C_{37}/12 + C_{36}/4 - E_3/5 - 3E_2/2 - E_1$	(44) $E_5 = E_1(1/2 + A/6) + E_2(1/4 + 11A/84) + E_3(1/70 + A/105)$
(45) $E_6 = E_5 - C_{36}(7/120 + A/36 + 3A/C) - 1/40 - A/72 - C_{37}(1/60 + A/120 + 1/C)$	

S_a in Eq. (11a) shall be not less than that tabulated in Table 3 of Section II, Part D.

(b) When flanges are subject at different times during operation to external or internal pressure, the design shall satisfy the external pressure design requirements given in (a) above and the internal pressure design requirements given elsewhere in this Appendix.

NOTE: The combined force of external pressure and bolt loading may plastically deform certain gaskets, resulting in loss of gasket contact pressure when the connection is depressurized.

To maintain a tight joint when the unit is repressurized, consideration should be given to gasket and facing details so that excessive deformation of the gasket will not occur. Joints subject to pressure reversals, such as in heat exchanger floating heads, are in this type of service.

3-390 FLANGES WITH NUT STOPS

When flanges are designed per this Appendix, or are fabricated to the dimensions of ASME B16.5 or other acceptable standards (see AD-711), except that the dimension R is decreased to provide a nut stop, the fillet radius relief shall be as shown in Fig. 3-310.1 sketches (i-1) and (i-2), except that:

(a) for flanges designed to this Appendix, the dimension G_1 must be the lesser of $2t$ (t from AD-201) or $4r$, but in no case less than $\frac{1}{2}$ in. (13 mm), where r is the radius of the undercut;

(b) for ASME B16.5 or other standard flanges, the dimension of the hub g_o shall be increased as necessary to provide a nut stop.

ARTICLE 3-4
FLANGES WITH OTHER THAN RING TYPE GASKETS

3-400

The rules in Article 3-3 shall not be construed to prohibit the use of other types of bolted flanged connections, such as flanges using full-face gaskets, or other means of fixing or clamping the flange at the bolt circle to provide effective restraint against flange deflection. Such designs may be used provided they are designed in accordance with good engineering practice and the method of design is acceptable to the Inspector.

ARTICLE 3-5
DESIGN CONSIDERATIONS FOR BOLTED FLANGE CONNECTIONS

3-500

(a) The primary purpose of the rules for bolted flange connections in Articles 3-1 to 3-4 is to insure safety, but there are certain other practical matters to be taken into consideration in order to obtain a serviceable design. One of the most important of these is the proportioning of the bolting, i.e., determining the number and size of the bolts.

(b) In the great majority of designs the practice that has been used in the past should be adequate, viz., to follow the design rules in Articles 3-1 to 3-4 and tighten the bolts sufficiently to withstand the test pressure without leakage. The considerations presented in the following discussion will be important only when some unusual feature exists, such as a very large diameter, a high design pressure, a high temperature, severe temperature gradients, an unusual gasket arrangement, etc.

(c) The maximum allowable stress values for bolting given in Table 3 of Section II, Part D are design values to be used in determining the minimum amount of bolting required under the rules. However, a distinction must be kept carefully in mind between the design value and the bolt stress that might actually exist or that might be needed for conditions other than the design pressure. The initial tightening of the bolts is a prestressing operation, and the amount of bolt stress developed must be within proper limits to insure, on the one hand, that it is adequate to provide against all conditions that tend to produce a leaking joint and, on the other hand, that it is not so excessive that yielding of the bolts and/or flanges can produce relaxation that also can result in leakage.

(d) The first important consideration is the need for the joint to be tight in the hydrostatic test. An initial bolt stress of some magnitude greater than the design value therefore must be provided. If it is not, further bolt strain develops during the test, which tends to part the joint and thereby to decompress the gasket enough to allow leakage. The test pressure is usually $1\frac{1}{4}$ times the design pressure, and on this basis it may be thought that 25% extra bolt stress above the design value will be sufficient. However, this is an over-simplification because, on the one hand, the safety factor against leakage under test conditions in general need not be as great as under operating conditions. On the other hand, if a stress–strain analysis of the joint is made, it may indicate that an initial bolt stress still higher than $1\frac{1}{4}$ times the design value is needed. Such an analysis is one that considers the changes in bolt elongation, flange deflection, and gasket load that take place with the application of internal pressure, starting from the prestressed condition. In any event, it is evident that an initial bolt stress higher than the design value may and, in some cases, must be developed in the tightening operation, and it is the intent of this Code that such a practice is permissible, provided it includes necessary and appropriate provision to insure against excessive flange distortion and gross crushing of the gasket.

(e) It is possible for the bolt stress to decrease after initial tightening, because of slow creep or relaxation of the gasket, particularly in the case of the "softer" gasket materials. This may be the cause of leakage in the hydrostatic test, in which case it may suffice merely to retighten the bolts. A decrease in bolt stress can also occur in service at elevated temperatures, as a result of creep in the bolt and/or flange or gasket material, with consequent relaxation. When this results in leakage under service conditions, it is common practice to retighten the bolts, and sometimes a single such operation or perhaps several repeated at long intervals is sufficient to correct the condition. To avoid chronic difficulties of this nature, however, it is advisable when designing a joint for high temperature service to give attention to the relaxation properties of the materials involved, especially for temperatures where creep is the controlling factor in design.

(f) In the other direction, excessive initial bolt stress can present a problem in the form of yielding in the bolting itself and may occur in the tightening operation to the extent of damage or even breakage. This is especially likely with bolts of small diameter and with bolt materials having a relatively low yield strength. The yield strength of mild carbon steel, annealed austenitic stainless steel,

and certain of the nonferrous bolting materials can easily be exceeded with ordinary wrench effort in the smaller bolt sizes. Even if no damage is evident, any additional load generated when internal pressure is applied can produce further yielding with possible leakage. Such yielding can also occur when there is very little margin between initial bolt stress and yield strength.

(g) An increase in bolt stress, above any that may be due to internal pressure, might occur in service during startup or other transient conditions, or perhaps even under normal operation. This can happen when there is an appreciable differential in temperature between the flanges and the bolts or when the bolt material has a different coefficient of thermal expansion than the flange material. Any increase in bolt load due to this thermal effect, superposed on the load already existing, can cause yielding of the bolt material, whereas any pronounced decrease due to such effects can result in such a loss of bolt load as to be a direct cause of leakage. In either case, retightening of the bolts may be necessary, but it must not be forgotten that the effects of repeated retightening can be cumulative and may ultimately make the joint unserviceable.

(h) In addition to the difficulties created by yielding of the bolts as described above, the possibility of similar difficulties arising from yielding of the flange or gasket material, under like circumstances or from other causes, should also be considered.

(i) Excessive bolt stress, whatever the reason, may cause the flange to yield even though the bolts may not yield. Any resulting excessive deflection of the flange, accompanied by permanent set, can produce a leaking joint when other effects are superposed. It can also damage the flange by making it more difficult to effect a tight joint thereafter. For example, irregular permanent distortion of the flange due to uneven bolt load around the circumference of the joint can warp the flange face and its gasket contact surface out of a true plane.

(j) The gasket, too, can be overloaded, even without excessive bolt stress. The full initial bolt load is imposed entirely on the gasket, unless the gasket has a stop ring or the flange face detail is arranged to provide the equivalent. Without such means of controlling the compression of the gasket, consideration must be given to the selection of gasket type, size, and material that will prevent gross crushing of the gasket.

(k) From the foregoing, it is apparent that the bolt stress can vary over a considerable range above the design stress value. The design stress values for bolting in Table 3 of Section II, Part D have been set at a conservative value to provide a factor against yielding. At elevated temperatures, the design stress values are governed by the creep rate and stress rupture strength. Any higher bolt stress existing before creep occurs in operation will have already served its purpose of seating the gasket and holding the hydrostatic test pressure, all at atmospheric temperature, and is not needed at the design pressure and temperature.

(l) Theoretically, the margin against flange yielding is not as great. The design values for flange materials may be as high as two-thirds of the yield strength. However, the highest stress in a flange is usually the bending stress in the hub or shell and is more or less localized. It is too conservative to assume that local yielding is followed immediately by overall yielding of the entire flange. Even if a "plastic hinge" should develop, the ring portion of the flange takes up the portion of the load the hub and shell refuse to carry. Yielding is far more significant if it occurs first in the ring, but the limitation in the rules on the combined hub and ring stresses provides a safeguard. In this connection, it should be noted that a dual set of allowable stresses is given for some of the materials in the tables in Section II, Part D and that the lower values should be used in order to avoid yielding in the flanges.

(m) Another very important item in bolting design is the question of whether the necessary bolt stress is actually realized and what special means of tightening, if any, must be employed. Most joints are tightened manually by ordinary wrenching and it is advantageous to have designs that require no more than this. Some pitfalls must be avoided, however. The probable bolt stress developed manually, when using standard wrenches, is:

(U.S. Customary Units)

$$S = \frac{45,000}{\sqrt{d}}$$

(SI Units)

$$S = \frac{1\ 600}{\sqrt{d}}$$

where S is the bolt stress and d is the nominal diameter of the bolt. It can be seen that smaller bolts will have excessive stress unless judgment is exercised in pulling up on them. On the other hand, it will be impossible to develop the desired stress in very large bolts by ordinary hand wrenching. Impact wrenches may prove serviceable but, if not, resort may be had to such methods as preheating the bolt or using hydraulically powered bolt tensioners. With some of these methods, control of the bolt stress is possible by means inherent in the procedure, especially if effective thread lubricants are employed, but in all cases the bolt stress can be regulated within reasonable tolerances by measuring the bolt elongation with suitable extensometer equipment. Ordinarily, simple wrenching without verification of the actual bolt stress meets all practical needs, and measured control of the stress is employed only when there is some special or important reason for doing so.

MANDATORY APPENDIX 4
DESIGN BASED ON STRESS ANALYSIS

ARTICLE 4-1

4-100 GENERAL REQUIREMENTS

(a) When a fatigue evaluation is not required (see AD-160), a vessel or a vessel part may be designed using the stress analysis methods given in this Appendix. When a fatigue evaluation is required, this Appendix should be used together with Appendix 5, Design Based on Fatigue Analysis.

(b) Use of the analytical methods contained in the Articles of this Appendix which follow Article 4-1 is an acceptable way of obtaining solutions to problems for which these procedures are applicable. Other techniques, analytical or experimental (see Appendix 6), may be used provided they are either more accurate or more conservative than those contained herein.

4-110 DESIGN ACCEPTABILITY

The requirements for the acceptability of a design are:

(a) the design shall be such that the stresses shall not exceed the limits described in 4-130;

(b) for configurations where compressive stresses occur, in addition to the requirement in (a), the critical buckling stress shall be taken into account (for the case of external pressure, see AD-330);

(c) for layered vessels subjected to external pressure, in addition to the requirements of (a) and (b), the rules specified in AD-300 shall apply.

4-111 Basis for Determining Stresses

The equivalent stress at any point in a vessel is the value of stress deduced from the stress condition at the point by means of a theory of failure for comparison with the mechanical properties of the material obtained in tests under uniaxial load. The theory of failure used in the rules of this Appendix for combining stresses is the maximum shear stress theory. The maximum shear stress at a point is equal to one-half the difference between the algebraically largest and the algebraically smallest of the three principal stresses at the point.

4-112 Terms Relating to Stress Analysis

Terms used in this Appendix relating to stress analysis are defined below.

(a) Stress Intensity. The *equivalent intensity of combined stress,* or in short, the *stress intensity,* is defined as twice the maximum shear stress. In other words, the stress intensity is the difference between the algebraically largest principal stress and the algebraically smallest principal stress at a given point. Tension stresses are considered positive and compression stresses are considered negative.

(b) Gross Structural Discontinuity. A source of stress or strain intensification which affects a relatively large portion of a structure and has a significant effect on the overall stress or strain pattern or on the structure as a whole.

Examples of gross structural discontinuities are head-to-shell and flange-to-shell junctions, nozzles, and junctions between shells of different diameters or thicknesses.

(c) Local Structural Discontinuity. A source of stress or strain intensification which affects a relatively small volume of material and does not have a significant effect on the overall stress or strain pattern or on the structure as a whole.

Examples are small fillet radii, small attachments, and partial penetration welds.

(d) Normal Stress. The component of stress normal to the plane of reference. (This is also referred to as direct stress.)

Usually the distribution of normal stress is not uniform through the thickness of a part, so this stress is considered to be made up in turn of two components, one of which is uniformly distributed and equal to the average value of stress across the thickness of the section under consideration, and the other of which varies with the location across the thickness.

(e) Shear Stress. The component of stress tangent to the plane of reference.

(f) Membrane Stress. The component of normal stress which is uniformly distributed and equal to the average value of stress across the thickness of the section under consideration.

(g) Primary Stress. A normal stress or a shear stress developed by the imposed loading which is necessary to satisfy the simple laws of equilibrium of external and internal forces and moments.

The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses which considerably exceed the yield strength will result in failure or at least in gross distortion. A thermal stress is not classified as a primary stress. Primary membrane stress is divided into *general* and *local* categories. A general primary membrane stress is one which is so distributed in the structure that no redistribution of load occurs as a result of yielding.

Examples of primary stress are:

(1) general membrane stress in a circular cylindrical or a spherical shell due to internal pressure or to distributed live loads;

(2) bending stress in the central portion of a flat head due to pressure.

(h) Secondary Stress. A normal stress or a shear stress developed by the constraint of adjacent parts or by self-constraint of a structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions which cause the stress to occur and failure from one application of the stress is not to be expected.

Examples of secondary stress are:

(1) general thermal stress [see (l)(1) below];

(2) bending stress at a gross structural discontinuity.

(i) Local Primary Membrane Stress. Cases arise in which a membrane stress produced by pressure or other mechanical loading and associated with a discontinuity would, if not limited, produce excessive distortion in the transfer of load to other portions of the structure. Conservatism requires that such a stress be classified as a local primary membrane stress even though it has some characteristics of a secondary stress. A stressed region may be considered as local if the distance over which the membrane stress intensity exceeds $1.1kS_m$ (see Table AD-150.1 for values of k) does not extend in the meridional direction more than $1.0\sqrt{Rt}$, where R is the minimum midsurface radius of curvature normal to the surface from the axis of rotation and t is the minimum thickness in the region considered. Regions of local primary membrane stress intensity which exceed $1.1kS_m$ shall not be closer in the meridional direction than $2.5\sqrt{Rt}$, where R is defined as $(R_1 + R_2)/2$ and t is defined as $(t_1 + t_2)/2$, where t_1 and t_2 are the minimum thicknesses at each of the regions considered, and R_1 and R_2 are the midsurface radii of curvature normal to the surface from the axis of rotation at these regions where the membrane stress intensity exceeds $1.1kS_m$. Discrete regions of local primary membrane stress intensity, such as those resulting from concentrated loads acting on brackets, where the membrane stress intensity exceeds $1.1kS_m$ shall be spaced so that there is no overlapping of the areas in which the membrane stress intensity exceeds $1.1kS_m$.

An example of a local primary membrane stress is the membrane stress in a shell produced by external load and moment at a permanent support or at a nozzle connection.

(j) Peak Stress. The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture. A stress which is not highly localized falls into this category if it is of a type which cannot cause noticeable distortion. Examples of peak stress are:

(1) the thermal stress in the austenitic steel cladding of a carbon steel vessel;

(2) the thermal stress in the wall of a vessel or pipe caused by a rapid change in temperature of the contained fluid;

(3) the stress at a local structural discontinuity.

(k) Load Stress. The stress resulting from the application of a load, such as internal pressure or the effects of gravity, as distinguished from thermal stress.

(l) Thermal Stress. A self-balancing stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally should under a change in temperature.

For the purpose of establishing allowable stresses, two types of thermal stress are recognized, depending on the volume or area in which distortion takes place, as follows:

(1) general thermal stress which is associated with distortion of the structure in which it occurs. If a stress of this type, neglecting stress concentrations, exceeds twice the yield strength of the material, the elastic analysis may be invalid and successive thermal cycles may produce incremental distortion. Therefore this type is classified as secondary stress in Table 4-120.1 and Fig. 4-130.1.

Examples of general thermal stress are:

(a) stress produced by an axial temperature distribution in a cylindrical shell;

(b) stress produced by the temperature difference between a nozzle and the shell to which it is attached;

(c) the equivalent linear stress[1] produced by the radial temperature distribution in a cylindrical shell.

[1] *Equivalent linear stress* is defined as the linear stress distribution which has the same net bending moment as the actual stress distribution.

(2) local thermal stress which is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses shall be considered only from the fatigue standpoint and are therefore classified as local stresses in Table 4-120.1 and Fig. 4-130.1. In evaluating local thermal stresses the procedures of 4-136.1(b) shall be used.

Examples of local thermal stresses are:

(a) the stress in a small hot spot in a vessel wall;

(b) the difference between the actual stress and the equivalent linear stress resulting from a radial temperature distribution in a cylindrical shell;

(c) the thermal stress in a cladding material which has a coefficient of expansion different from that of the base metal.

(m) Operational Cycle. An operational cycle is defined as the initiation and establishment of new conditions followed by a return to the conditions that prevailed at the beginning of the cycle. Three types of operational cycles are considered:

(1) startup–shutdown cycle, defined as any cycle which has atmospheric temperature and/or pressure as one of its extremes and normal operating conditions as its other extreme;

(2) the initiation of and recovery from any emergency or upset condition that must be considered in the design;

(3) normal operating cycle, defined as any cycle between startup and shutdown which is required for the vessel to perform its intended purpose.

(n) Stress Cycle. A stress cycle is a condition in which the alternating stress difference (5-101) goes from an initial value through an algebraic maximum value and an algebraic minimum value and then returns to the initial value. A single operational cycle may result in one or more stress cycles.

(o) Fatigue Strength Reduction Factor. A stress intensification factor which accounts for the effect of a local structural discontinuity (stress concentration) on the fatigue strength. Values for some specific cases, based on experiment, are given elsewhere in this Division. In the absence of experimental data, the theoretical stress concentration factor may be used.

(p) Deformation. Deformation of a component part is an alteration of its shape or size.

(q) Inelasticity. Inelasticity is a general characteristic of material behavior in which the material does not return to its original (undeformed) shape and size after removal of all applied loads. Plasticity and creep are special cases of inelasticity.

(1) Plasticity. Plasticity is the special case of inelasticity in which the material undergoes time-independent nonrecoverable deformation.

(2) Plastic Analysis. Plastic analysis is that method which computes the structural behavior under given loads considering the plasticity characteristics of the materials including strain hardening and the stress redistribution occurring in the structure. (Strain rate effects may also be significant where impact or other dynamic loads are involved.)

(3) Plastic Instability Load. The plastic instability load for members under predominantly tensile or compressive loading is defined as that load at which unbounded plastic deformation can occur without an increase in load. At the plastic tensile instability load the true stress in the material increases faster than strain hardening can accommodate.

(4) Strain Limiting Load. When a limit is placed upon a strain, the load associated with the strain limit is called the strain limiting load.

(5) Limit Analysis. Limit analysis is a special case of plastic analysis in which the material is assumed to be ideally plastic (nonstrain-hardening). In limit analysis the equilibrium and flow characteristics at the limit state are used to calculate the collapse load. Two bounding methods are used in limit analysis, the lower bound approach which is associated with a statically admissible stress field and the upper bound approach which is associated with a kinematically admissible velocity field. For beams and frames the term *mechanism* is commonly used in lieu of *kinematically admissible velocity field.*

(6) Limit Analysis — Collapse Load. The methods of limit analysis are used to compute the maximum load a structure made of ideally plastic material can carry. The deformations of an ideally plastic structure increase without bound at this load, which is termed collapse load.

(7) Plastic Hinge. A plastic hinge is an idealized concept used in limit analysis. In a beam or a frame, a plastic hinge is formed at the point where the moment, shear, and axial force lie on the yield interaction surface. In plates and shells a plastic hinge is formed where the generalized stresses lie on the yield surface.

(8) Creep. Creep is the special case of inelasticity that relates to the stress induced time-dependent deformation under load. Small time-dependent deformations may occur after the removal of all applied loads.

(9) Ratcheting. Ratcheting is a progressive incremental inelastic deformation or strain which can occur in a component that is subjected to variations of mechanical stress, thermal stress, or both (thermal stress ratcheting is partly or wholly caused by thermal stress).

(10) Shakedown. Shakedown of a structure occurs if, after a few cycles of load application, ratcheting ceases. The subsequent structural response is elastic, or elastic–plastic, and progressive incremental inelastic deformation

is absent. Elastic shakedown is the case in which the subsequent response is elastic.

(11) Free End Displacement. Free end displacement consists of the relative motions that would occur between an attachment and connected structure or equipment if the two members were separated. Examples of such motions are those that would occur because of relative thermal expansion of piping, equipment, and equipment supports, or because of rotations imposed upon the equipment by sources other than the piping.

(12) Expansion Stresses. Expansion stresses are those stresses resulting from restraint of free end displacement of the piping system.

4-120 DERIVATION OF STRESS INTENSITIES

One requirement for the acceptability of a design [see 4-110(a)] is that the calculated stress intensities shall not exceed specified allowable limits. These limits differ depending on the stress category (primary, secondary, etc.) from which the stress intensity is derived. This paragraph describes two procedures: the development of the component stresses for each stress category [subparagraphs (a), (b), and (c)] and the derivation of the stress intensities for the primary stress categories [subparagraphs (d) and (e)].

The primary plus secondary stress category (see 4-134) requires the calculation of a stress intensity range for comparison to its limit. The derivation of the primary plus secondary stress intensity range is presented in 5-110.3.

(a) At the point on the vessel which is being investigated, choose an orthogonal set of coordinates such as tangential, longitudinal, and radial, and designate them by the subscripts *t, l,* and *r*. The stress components in these directions are then designated σ_t, σ_r, and σ_l for normal stresses, and τ_{tl}, τ_{lr}, and τ_{rt} for shearing stresses.

(b) Calculate the stress components for each type of loading to which the part will be subjected and assign each set of stress values to one or a group of the categories below:[2]

(1) general primary membrane stress P_m [see 4-112(f) and (g)];

(2) local primary membrane stress P_L [see 4-112(i)];

(3) primary bending stress P_b [see 4-112(g)];

(4) secondary stress[3] Q [see 4-112(h)];

(5) peak stress F [see 4-112(j)].

(c) Group the stress components in accordance with 4-120(b). Figure 4-130.1 is to provide assistance in assigning the stress values to the appropriate category. At any rectangular box calculate the algebraic sum of the σ_t's which result from the different types of loadings and which have entered the box, and similarly for the other five stress components. The result is a set of six stress components in each box.

(d) For the derivation of the stress intensities for the primary stress categories [see 4-120(b)(1), (2), and (3)], translate the stress components in the *t, l,* and *r* directions into principal stresses, σ_1, σ_2, and σ_3. (In many pressure vessel calculations, the *t, l,* and *r* directions may be so chosen that the shearing stress components are zero, and σ_1, σ_2, and σ_3 are identical to σ_t, σ_l, and σ_r.)

(e) Calculate the stress differences S_{12}, S_{23}, and S_{31} from the relations:

$$S_{12} = \sigma_1 - \sigma_2$$

$$S_{23} = \sigma_2 - \sigma_3$$

$$S_{31} = \sigma_3 - \sigma_1$$

The stress intensity S is the largest absolute value of S_{12}, S_{23}, and S_{31}.

NOTE: Membrane stress intensity is derived from the stress components averaged across the thickness of the section. The averaging shall be performed at the component level, in (b) or (c) above.

(f) The stress intensity calculated as in (e) from the stress components in any rectangle in Fig. 4-130.1 shall not exceed the allowable values of 4-130 which are shown in the circle adjacent to the rectangle in Fig. 4-130.1.

4-130 BASIC STRESS INTENSITY LIMITS

The five basic stress intensity limits which are to be satisfied are given below (see Fig. 4-130.1).

4-131 General Primary Membrane Stress Intensity (Derived From P_m in Fig. 4-130.1)

The stress intensity, derived from the average value across the thickness of a section, of the general primary stresses [see 4-112(g)] produced by design internal pressure and other specified mechanical loads but excluding all secondary and peak stresses. The allowable value of this stress intensity is kS_m, as given in Tables 2A and 2B of Section II, Part D.

4-132 Local Membrane Stress Intensity (Derived From P_L in Fig. 4-130.1)

The stress intensity, derived from the average value across the thickness of a section, of the local primary

[2] See Table 4-120.1 and Note (1) of Fig. 4-130.1.

[3] Subdivision of secondary stresses into membrane and bending components is not required because the same stress limits apply to both components.

TABLE 4-120.1
CLASSIFICATION OF STRESSES FOR SOME TYPICAL CASES

Vessel Component	Location	Origin of Stress	Type of Stress	Classification
Cylindrical or spherical shell	Shell plate remote from discontinuities	Internal pressure	General membrane Gradient through plate thickness	P_m Q
		Axial thermal gradient	Membrane Bending	Q Q
	Junction with head or flange	Internal pressure	Membrane Bending	P_L Q
Any shell or head	Any section across entire vessel	External load or moment, or internal pressure	General membrane averaged across full section. Stress component perpendicular to cross section	P_m
		External load or moment	Bending across full section. Stress component perpendicular to cross section	P_m
	Near nozzle or other opening	External load moment, or internal pressure	Local membrane Bending Peak (fillet or corner)	P_L Q F
	Any location	Temp. diff. between shell and head	Membrane Bending	Q Q
Dished head or conical head	Crown	Internal pressure	Membrane Bending	P_m P_b
	Knuckle or junction to shell	Internal pressure	Membrane Bending	P_L [Note (1)] Q
Flat head	Center region	Internal pressure	Membrane Bending	P_m P_b
	Junction to shell	Internal pressure	Membrane Bending	P_L Q [Note (2)]
Perforated head or shell	Typical ligament in a uniform pattern	Pressure	Membrane (avg. thru cross section) Bending (avg. thru width of ligament, but gradient thru plate) Peak	P_m P_b F
	Isolated or atypical ligament	Pressure	Membrane Bending Peak	Q F F

(continued)

TABLE 4-120.1
CLASSIFICATION OF STRESSES FOR SOME TYPICAL CASES (CONT'D)

Vessel Component	Location	Origin of Stress	Type of Stress	Classification
Nozzle	Cross section perpendicular to nozzle axis	Internal pressure or external load or moment	General membrane (avg. across full section). Stress component perpendicular to section	P_m; see 4-138
		External load or moment	Bending across nozzle section	P_m; see 4-138
	Nozzle wall	Internal pressure	General membrane Local membrane Bending Peak	P_m; see 4-138 P_L Q F
		Differential expansion	Membrane Bending Peak	Q Q F
Cladding	Any	Differential expansion	Membrane Bending	F F
Any	Any	Radial temperature distribution [Note (3)]	Equivalent linear stress [Note (4)] Nonlinear portion of stress distribution	Q F
Any	Any	Any	Stress concentration (notch effect)	F

NOTES:
(1) Consideration must also be given to the possibility of wrinkling and excessive deformation in vessels with large diameter-to-thickness ratio.
(2) If the bending moment at edge is required to maintain the bending stress in the center region within acceptable limits, the edge bending is classified as P_b; otherwise, it is classified as Q.
(3) Consider possibility of thermal stress ratchet.
(4) Equivalent linear stress is defined as the linear stress distribution which has the same net bending moment as the actual stress distribution.

stresses [4-112(i)] produced by design pressure and specified mechanical loads but excluding all thermal and peak stresses. The allowable value of this stress intensity is $1.5kS_m$, as given in Fig. 4-130.1.

4-133 Primary Membrane (General or Local) Plus Primary Bending Stress Intensity (Derived From $P_L + P_b$ in Fig. 4-130.1)

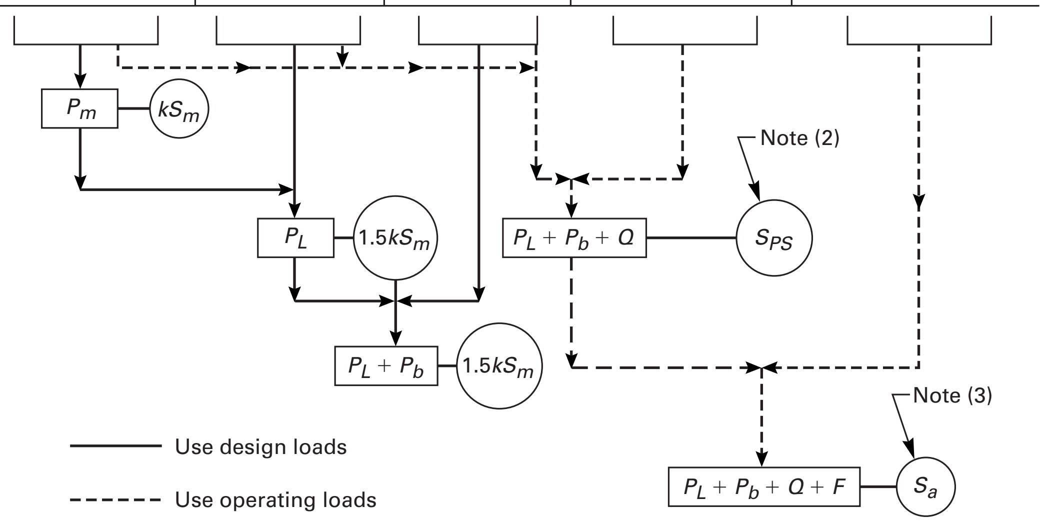
The stress intensity, derived from the highest value across the thickness of a section, of the general or local primary membrane stresses plus primary bending stresses produced by design pressure and other specified mechanical loads but excluding all secondary and peak stresses. The allowable value of this stress intensity is $1.5kS_m$, as given in Fig. 4-130.1.

4-134 Primary Plus Secondary Stress Intensity (Derived From $P_L + P_b + Q$ in Fig. 4-130.1)

(a) The stress intensity, derived from the highest value at any point across the thickness of a section, of the combination of general or local primary membrane stresses plus primary bending stresses plus secondary stresses, produced by specified operating pressure and other specified mechanical loads and by general thermal effects. The effects of gross structural discontinuities but not of local structural discontinuities (stress concentrations) shall be included. The maximum range of this stress intensity is limited to S_{PS}, as defined in (b) below, except as permitted by 4-136.7.

Stress Category	Primary			Secondary Membrane Plus Bending	Peak
	General Membrane	Local Membrane	Bending		
Description (for examples, see Table 4-120.1)	Average primary stress across solid section. Excludes discontinuities and concentrations. Produced only by mechanical loads.	Average stress across any solid section. Considers discontinuities but not concentrations. Produced only by mechanical loads.	Component of primary stress proportional to distance from centroid of solid section. Excludes discontinuities and concentrations. Produced only by mechanical loads.	Self-equilibrating stress necessary to satisfy continuity of structure. Occurs at structural discontinuities. Can be caused by mechanical load or by differential thermal expansion. Excludes local stress concentrations.	(1) Increment added to primary or secondary stress by a concentration (notch) (2) Certain thermal stresses which may cause fatigue but not distortion of vessel shape
Symbol [Note (1)]	P_m	P_L	P_b	Q	F

Combination of stress components and allowable limits of stress intensities



GENERAL NOTES:

(a) The stresses in Category Q are those parts of the total stress that are produced by thermal gradients, structural discontinuities, etc., and do not include primary stresses which may also exist at the same point. It should be noted, however, that a detailed stress analysis typically gives the combination of primary and secondary stresses directly and, when appropriate, this calculated value represents the total of P_m (or P_L) + P_b + Q and not Q alone. Similarly, if the stress in Category F is produced by a stress concentration, the quantity F is the additional stress produced by the notch, over and above the nominal stress. For example, if a plate has a nominal stress intensity S and has a notch with a stress concentration factor K, then $P_m = S$, $P_b = 0$, $Q = 0$, $F = P_m(K - 1)$, and the peak stress intensity equals $P_m + P_m(K - 1) = KP_m$.

(b) The k factors are given in Table AD-150.1.

NOTES:

(1) The symbols P_m, P_L, P_b, Q, and F do not represent single quantities, but rather sets of six quantities representing the six stress components σ_t, σ_l, σ_r, τ_{tl}, τ_{lr}, and τ_{rt}.

(2) Values for S_{PS} are defined in 4-134. This limit applies to the range of stress intensity (see 5-110.3).

(3) S_a is obtained from the fatigue curves, Figs. 5-110.1, 5-110.2, and 5-110.3. The allowable stress intensity for the full range of fluctuation is $2S_a$ (see 5-110.3).

FIG. 4-130.1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY

(b) The term S_{PS} is used for allowable primary-plus-secondary stress intensity range. The value of S_{PS} is the larger of (1) and (2) below:

(1) three times the average of the tabulated S_m values of the material for the highest and lowest temperatures during the operational cycle;

(2) two times the average tabulated yield strength values of the material for the highest and lowest temperatures during the operational cycle, except (1) above shall be used if the room temperature ratio of minimum specified yield strength to ultimate strength exceeds 0.70.

(c) The procedure for calculating stress intensity range is provided in 5-110.3. In the determination of the maximum primary-plus-secondary stress intensity range, it may be necessary to consider the superposition of cycles of various origins that produce a total range greater than the range of any of the individual cycles. The value of S_{PS} may vary with the specific cycle, or combination of cycles, being considered, since temperature extremes may be different in each case. Therefore, care must be exercised to ensure that the applicable values of S_{PS} for each cycle, and combination of cycles, is not exceeded except as permitted by 4-136.7.

4-135 Peak Stress Intensity [Derived From $P_L + P_b + Q + F$ in Fig. 4-130.1. See Note (3) of Fig. 4-130.1.]

The stress intensity, derived from the highest value at any point across the thickness of a section, of the combination of all primary, secondary, and peak stresses produced by specified operating pressures and other mechanical loads and by general and local thermal effects and including the effects of gross and local structural discontinuities. The allowable value of this stress intensity is dependent on the range of the stress difference from which it is derived and on the number of times it is to be applied. The stress intensity is to be compared with the allowable value obtained by the methods of analysis for cyclic operation described in 5-100 through the use of the fatigue curves. See Figs. 5-110.1, 5-110.2.1, 5-110.2.2, 5-110.2.3, 5-110.3, and 5-110.4.

4-136 Applications of Plastic Analysis

(a) Certain of the allowable stresses permitted in these design criteria are such that the maximum stress calculated on an elastic basis may exceed the yield strength of the material. The limit on primary plus secondary stress intensity of S_{PS} (see 4-134) has been placed at a level which assures shakedown to elastic action after a few repetitions of the stress cycle except in regions containing significant local structural discontinuities or local thermal stresses. These last two factors are considered only in the performance of a fatigue evaluation.

(b) The limits on local membrane stress intensity (see 4-132) and primary membrane plus primary bending stress intensity of $1.5S_m$ (see 4-133) have been placed at a level which conservatively assures the prevention of collapse as determined by the principles of limit analysis. The following paragraphs provide guidance in the application of plastic analysis and some relaxation of the basic stress limits which are allowed if plastic analysis is used.

4-136.1 Value of Poisson's Ratio

(a) In evaluating stresses for comparison with any stress limits other than fatigue allowables, stresses shall be calculated on an elastic basis using the elastic value of Poisson's ratio.

(b) In evaluating stresses for comparison with fatigue allowables, the elastic equations shall be used, except that the numerical value substituted for Poisson's ratio shall be determined from the expression:

$$\nu = 0.5 - 0.2\left(\frac{S_y}{S_a}\right), \text{ but not less than } 0.3$$

where

S_a = the value obtained from the applicable design fatigue curve for the specified number of cycles of the condition being considered

S_y = the yield strength of the material at the mean value of the temperature of the cycle

4-136.2 Plastic Analysis. The limits on local membrane stress intensity (see 4-132), primary plus secondary stress intensity (see 4-134), thermal stress ratchet in shell (see 5-130), and progressive distortion of nonintegral connections (see 5-140) need not be satisfied at a specific location if at that location the following procedures are used.

(a) In evaluating stresses for comparison with the stress limits of 4-131, 4-133 (general primary membrane plus primary bending stress intensity only), 4-140, AD-132.1, 4-137, and 4-110(b), the stresses are calculated on an elastic basis.

(b) In lieu of satisfying the specific requirements of 4-132, 4-134, AD-132.2, and 5-140 at a specific location, the structural action is calculated on a plastic basis and the design shall be considered to be acceptable if shakedown occurs, as opposed to continuing deformation, and if the deformations which occur prior to shakedown do not exceed specified limits.

(c) In evaluating stresses for comparison with fatigue allowables, the numerically maximum principal total

strain range which occurs after shakedown shall be multiplied by one-half of the Young's modulus of the material at the mean value of the temperature of the cycle.

4-136.3 Limit Analysis. The limits on general membrane stress intensity (4-131), local membrane stress intensity (4-132), and primary membrane plus primary bending stress intensity (4-133) need not be satisfied at a specific location if it can be shown by limit analysis that the specified loadings do not exceed two- thirds of the lower bound collapse load. The yield strength to be used in these calculations is $1.5S_m$. The use of $1.5S_m$ for the yield strength of those materials of Tables 1A and 1B of Section II, Part D to which AM-600(c) is applicable may result in small permanent strains during the first few cycles of loading. If these strains are not acceptable, the yield strength to be used shall be reduced according to the strain limiting factors of Table Y-2 of Section II, Part D. When two-thirds of the lower bound collapse load is used, the effects of plastic strain concentrations in localized areas of the structure such as the points where hinges form must be considered. The effects of these concentrations of strain on fatigue behavior, ratcheting behavior, or buckling behavior of the structure must be considered in the design. The design shall satisfy the minimum wall thickness requirements as defined in AD-100(c).

4-136.4 Experimental Analysis. The limits of general primary membrane stress intensity (4-131), local membrane stress intensity (4-132), and primary membrane plus primary bending stress intensity (4-133) need not be satisfied at a specific location if it can be shown that the specified loadings do not exceed two-thirds of the test collapse load determined by the application of 6-153, Criterion of Collapse Load (Appendix 6), in which case the effects of plastic strain concentrations in localized areas of the structure such as the points where hinges form must be considered. The effects of these concentrations of strain on the fatigue behavior, ratcheting behavior, or buckling behavior of the structure must be considered in the design. The design shall satisfy the minimum wall thickness requirements as defined in AD-100(c).

4-136.5 Plastic Analysis. Plastic analysis is a method of structural analysis by which the structural behavior under given loads is computed by considering the actual material stress–strain relationship and stress redistribution, and it may include either strain hardening, change in geometry, or both.

The limits of general membrane stress intensity (4-131), local membrane stress intensity (4-132), and primary membrane plus primary bending stress intensity (4-133) need not be satisfied at a specific location if it can be shown that the specified loadings do not exceed two-thirds of the plastic analysis collapse load determined by application of 6-153, Criterion of Collapse Load (Appendix 6), to a load deflection or load strain relationship obtained by plastic analysis. When this rule is used, the effects of plastic strain concentrations in localized areas of the structure such as the points where hinges form must be considered. The effects of the concentrations of strain on the fatigue behavior, ratcheting behavior, or buckling of the structure must be considered in the design. The design shall satisfy the minimum wall thickness requirements as defined in AD-100(c).

4-136.6 Shakedown Analysis. The limits on thermal stress ratchet in shell (5-130) and progressive distortion of nonintegral connections (5-140) need not be satisfied at a specific location, if, at the location, the procedures of (a) through (c) below are used.

(a) In evaluating stresses for comparison with the remaining stress limits in 4-130, the stresses shall be calculated on an elastic basis.

(b) In lieu of satisfying the specific requirements of 4-132, 4-134, 5-130, and 5-140 at a specific location, the structural action shall be calculated on a plastic basis and the design shall be considered to be acceptable if shakedown occurs (as opposed to continuing deformation). However, this shakedown requirement need not be satisfied for materials having a specified minimum yield strength to specified minimum ultimate strength ratio less than or equal to 0.70, provided the maximum accumulated local strain at any point, as a result of cyclic operation to which plastic analysis is applied, does not exceed 5.0%. In all cases, the deformations that occur shall not exceed specified limits.

(c) In evaluating stresses for comparison with fatigue allowables, the numerically maximum principal total strain range shall be multiplied by one-half the modulus of elasticity of the material (see Section II, Part D, Subpart 2, Tables TM-1 through TM-5) at the mean value of the temperature of the cycle.

4-136.7 Simplified Elastic–Plastic Analysis. The S_{PS} stress intensity limit on the range of primary plus secondary stress intensity (see 4-134) may be exceeded provided that:

(a) the range of primary plus secondary membrane plus bending stress intensity, excluding thermal bending stresses, shall be less than S_{PS};

(b) the value of S_a used for entering the design fatigue curve is multiplied by the factor K_e, where

$$K_e = 1.0 \text{ for } S_n \leq S_{PS}$$

$$= 1.0 + \frac{(1-n)}{n(m-1)}\left(\frac{S_n}{S_{PS}} - 1\right)$$

$$\text{for } S_{PS} < S_n < mS_{PS}$$

$$= 1/n \text{ for } S_n \geq mS_{PS}$$

S_n = range of primary plus secondary stress intensity

The values of the material parameters m and n are given for the various classes of Code materials in the following table.

	m	n	T_{max}, °F	T_{max}, °C
Low alloy steel	2.0	0.2	700	370
Martensitic stainless steel	2.0	0.2	700	370
Carbon steel	3.0	0.2	700	370
Austenitic stainless steel	1.7	0.3	800	425
Nickel–chromium–iron	1.7	0.3	800	425
Nickel–copper	1.7	0.3	800	425

(c) the rest of the fatigue evaluation stays the same as required in Appendix 5, except that the procedure of 4-136.1 need not be used;

(d) the component meets the thermal ratcheting requirement of 5-130;

(e) the temperature does not exceed those listed in the above table for the various classes of Code materials;

(f) the material shall have a specified minimum yield strength to specified minimum tensile strength ratio of less than 0.80.

4-137 Triaxial Stresses

The algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) shall not exceed four times the tabulated value of S_m.

4-138 Nozzle Piping Transition

(a) The classification of stresses in this paragraph is applicable to the nozzle neck. The evaluation of stresses at other locations shall be according to 4-130.

(b) Within the limits of reinforcement given by AD-540.2 whether or not nozzle reinforcement is provided, the P_m classification is applicable to stress intensities resulting from pressure induced general membrane stresses as well as stresses, other than discontinuity stresses, due to external loads and moments including those attributable to restrained free end displacements of the attached pipe. Also, within the limits of reinforcement, a P_L classification shall be applied to local primary membrane stress intensities derived from discontinuity effects plus primary bending stress intensities due to combined pressure and external loads and moments including those attributable to restrained free end displacements of the attached pipe; and a $P_L + P_b + Q$ classification shall apply to primary plus secondary stress intensities resulting from a combination of pressure, temperature, and external loads and moments, including those due to restrained free end displacements of the attached pipe.

(c) Beyond the limits of reinforcement, a P_m classification is applicable to stress intensities resulting from pressure induced general membrane stresses as well as the average stress across the nozzle thickness due to externally applied nozzle axial, shear, and torsional loads other than those attributable to restrained free end displacement of the attached pipe. Also, outside the limits of reinforcement, a $P_L + P_b$ classification is applicable to the stress intensities which result from adding those stresses classified as P_m to those due to externally applied bending moments except those attributable to restrained free end displacement of the pipe. Further, beyond the limits of reinforcement, a $P_L + P_b + Q$ classification is applicable to stress intensities resulting from all pressure, temperature, and external loads and moments, including those attributable to restrained free end displacements of the attached pipe.

(d) Beyond the limits of reinforcement, the S_{PS} limit on the range of primary plus secondary stress intensity may be exceeded as provided in 4-136.7, except that in the evaluation of 4-136.7(a) stresses from restrained free end displacements of the attached pipe may also be excluded. The range of membrane plus bending stress intensity attributable solely to the restrained free end displacements of the attached piping shall be $\leq S_{PS}$.

4-140 BOLTING

(a) The number and cross-sectional area of bolts required to resist internal pressure shall be determined in accordance with the procedures of Appendix 3. The allowable bolt design stresses, as used in the formulas of Appendix 3, shall be the values given in Table 4 of Section II, Part D for bolting materials. When sealing is effected by a seal weld instead of a gasket, the gasket factor m and the minimum design seating stress y may be taken as zero.

(b) When gaskets are used for preservice testing only, the design is satisfactory if the above requirements are satisfied for $m = y = 0$ and the requirements of 4-141 are satisfied when the appropriate m and y are used for the test gasket.

4-141 Allowable Maximum Service Stresses in Bolts

It is recognized that actual service stresses in bolts such as those produced by the combination of preload, pressure, and differential thermal expansion may be higher than the values given in Table 4 of Section II, Part D. The maximum of such service stress, averaged across the bolt cross section and neglecting stress concentrations, shall not exceed two times the stress values of Table 4 of Section II, Part D. Except as restricted by 5-120(b)(2), the maximum value of such service stress at the periphery of the bolt cross section (resulting from direct tension plus bending and neglecting stress concentrations) shall not exceed three times the stress values of Table 4 of Section II, Part D. Stress intensity, rather than maximum stress, shall be limited to this value when the bolts are tightened by methods other than heaters, stretchers, or other means which minimize residual torsion.

ARTICLE 4-2
ANALYSIS OF CYLINDRICAL SHELLS

4-210 SIGN CONVENTION AND NOMENCLATURE

The symbols and sign convention adopted in this Article for the analysis of cylindrical shells are defined as follows:

(1) $D = Et^3/12\,(1 - \nu^2)$, lb-in. (N-mm)

(2) E = modulus of elasticity

(3) L = length of cylinder, subscript to denote evaluation of a quantity at end of cylinder removed from reference end

(4) M = longitudinal bending moment per unit length of circumference, in.-lb/in. (N-mm/mm)

(5) o = subscript to denote evaluation of a quantity at reference end of cylinder, $x = 0$

(6) p = internal pressure

(7) Q = radial shearing forces per unit length of circumference, lb/in. (N/mm)

(8) R = inside radius

(9) S = stress intensity

(10) t = thickness of cylinder

(11) w = radial displacement of cylinder wall, in. (mm)

(12) x = axial distance measured from the reference end of cylinder

(13) Y = ratio of outside radius to inside radius

(14) Z = ratio of outside radius to an intermediate radius

(15) $\beta = [3(1 - \nu^2)/(R + t/2)^2 t^2]^{1/4}$, in.$^{-1}$ (mm^{-1})

(16) θ = rotation of cylinder wall, rad $= dw/dx$

(17) ν = Poisson's ratio

(18) σ_t = tangential (circumferential) stress component

(19) σ_l = longitudinal (meridional) stress component

(20) σ_r = radial stress component

(21) $F_{11}(\beta x) = (\cosh \beta x \sin \beta x - \sinh \beta x \cos \beta x)/2$

(22) $F_{12}(\beta x) = \sinh \beta x \sin \beta x$

(23) $F_{13}(\beta x) = (\cosh \beta x \sin \beta x + \sinh \beta x \cos \beta x)/2$

(24) $F_{14}(\beta x) = \cosh \beta x \cos \beta x$

(25) $f_1(\beta x) = e^{-\beta x} \cos \beta x$

(26) $f_2(\beta x) = e^{-\beta x} (\cos \beta x - \sin \beta x)$

(27) $f_3(\beta x) = e^{-\beta x} (\cos \beta x + \sin \beta x)$

(28) $f_4(\beta x) = e^{-\beta x} \sin \beta x$

(29) $B_{11} = B_{11}(\beta L) = (\sinh 2\beta L - \sin 2\beta L)/2(\sinh^2 \beta L - \sin^2 \beta L)$

(30) $B_{12} = B_{12}(\beta L) = (\cosh 2\beta L - \cos 2\beta L)/2(\sinh^2 \beta L - \sin^2 \beta L)$

(31) $B_{22} = B_{22}(\beta L) = (\sinh 2\beta L + \sin 2\beta L)/(\sinh^2 \beta L - \sin^2 \beta L)$

(32) $G_{11} = G_{11}(\beta L) = -(\cosh \beta L \sin \beta L - \sinh \beta L \cos \beta L)/(\sinh^2 \beta L - \sin^2 \beta L)$

(33) $G_{12} = G_{12}(\beta L) = -2 \sinh \beta L \sin \beta L/(\sinh^2 \beta L - \sin^2 \beta L)$

(34) $G_{22} = G_{22}(\beta L) = -2(\cosh \beta L \sin \beta L + \sinh \beta L \cos \beta L)/(\sinh^2 \beta L - \sin^2 \beta L)$

The sign convention arbitrarily chosen for the analysis of cylindrical shells in this Article is as indicated in Fig. 4-210.1. Positive directions assumed for pertinent quantities are indicated.

4-220 PRINCIPAL STRESSES AND STRESS INTENSITIES DUE TO INTERNAL PRESSURE

The formulas for principal stresses and stress intensities presented in this paragraph include the loading effects

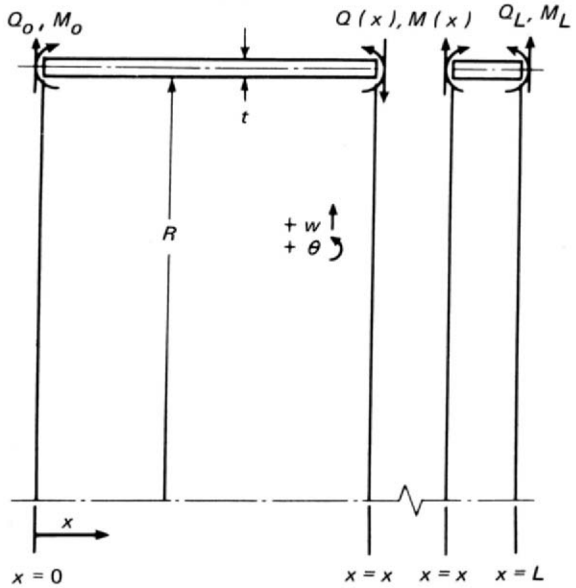


FIG. 4-210.1

of internal pressure only and exclude the effects of all structural discontinuities.

4-221 Principal Stresses

The principal stresses developed at any point in the wall of a cylindrical shell due to internal pressure are given by the formulas:

$$\sigma_1 = \sigma_t = p(1 + Z^2)/(Y^2 - 1) \qquad (1)$$

$$\sigma_2 = \sigma_l = p/(Y^2 - 1) \qquad (2)$$

$$\sigma_3 = \sigma_r = p(1 - Z^2)/(Y^2 - 1) \qquad (3)$$

4-222 Stress Intensities

(a) The general primary membrane stress intensity developed across the thickness of a cylindrical shell due to internal pressure is given by the formula:

$$S = \frac{pR}{t} + \frac{p}{2} \qquad (1)$$

(b) The maximum value of the primary plus secondary stress intensity developed at any point across the thickness of a cylindrical shell due to internal pressure occurs at the inside surface and is given by the equation:

$$S = 2pY^2/(Y^2 - 1) \qquad (2)$$

(c) Note that in evaluating the general primary membrane stress intensity, the average value of the radial stress has been taken as $(-p/2)$. This has been done to obtain a result consistent with burst pressure analyses. On the other hand, the radial stress value used in (b) is $(-p)$, the value at the inner surface since the purpose of that quantity is to control local behavior.

4-230 BENDING ANALYSIS FOR UNIFORMLY DISTRIBUTED EDGE LOADS

The formulas in this paragraph describe the behavior of a cylindrical shell when subjected to the action of bending moments *M,* in.-lb/in. (N-mm/mm) of circumference, and radial shearing forces *Q*, lb/in. (N/mm) of circumference, uniformly distributed at the edges and acting at the mean radius of the shell. The behavior of the shell due to all other loadings must be evaluated independently and combined by superposition.

4-231 Displacements, Bending Moments, and Shearing Forces in Terms of Conditions at Reference Edge, $x = 0$

(a) The radial displacement $w(x)$, the angular displacement or rotation $\theta(x)$, the bending moments $M(x)$, and the radial shearing forces $Q(x)$ at any axial location of the cylinder are given by the following equations in terms of w_o, θ_o, M_o, and Q_o:

$$\begin{aligned} w(x) &= (Q_o/2\beta^3 D)F_{11}(\beta x) \\ &\quad + (M_o/2\beta^2 D)F_{12}(\beta x) \\ &\quad + (\theta_o/\beta)F_{13}(\beta x) + w_o F_{14}(\beta x) \end{aligned} \qquad (1)$$

$$\begin{aligned} \theta(x)/\beta &= (Q_o/2\beta^3 D)F_{12}(\beta x) \\ &\quad + 2(M_o/2\beta^2 D)F_{13}(\beta x) \\ &\quad + (\theta_o/\beta)F_{14}(\beta x) - 2w_o F_{11}(\beta x) \end{aligned} \qquad (2)$$

$$\begin{aligned} M(x)/2\beta^2 D &= (Q_o/2\beta^3 D)F_{13}(\beta x) \\ &\quad + (M_o/2\beta^2 D)F_{14}(\beta x) \\ &\quad - (\theta_o/\beta)F_{11}(\beta x) - w_o F_{12}(\beta x) \end{aligned} \qquad (3)$$

$$\begin{aligned} Q(x)/2\beta^3 D &= (Q_o/2\beta^3 D)F_{14}(\beta x) \\ &\quad - 2(M_o/2\beta^2 D)F_{11}(\beta x) \\ &\quad - (\theta_o/\beta)F_{12}(\beta x) - 2w_o F_{13}(\beta x) \end{aligned} \qquad (4)$$

(b) In the case of cylinders of sufficient length, the equations in (a) above reduce to those given below. These equations may be used for cylinders characterized by lengths not less than $3/\beta$. The combined effects of loadings at the two edges may be evaluated by applying the

equations to the loadings at each edge, separately, and superposing the results.

$$w(x) = (Q_o/2\beta^3 D)f_1(\beta x) + (M_o/2\beta^2 D)f_2(\beta x) \quad (1)$$

$$\theta(x)/\beta = -(Q_o/2\beta^3 D)f_3(\beta x) - 2(M_o/2\beta^2 D)f_1(\beta x) \quad (2)$$

$$M(x)/2\beta^2 D = (Q_o/2\beta^3 D)f_4(\beta x) + (M_o/2\beta^2 D)f_3(\beta x) \quad (3)$$

$$Q(x)/2\beta^3 D = (Q_o/2\beta^3 D)f_2(\beta x) - 2(M_o/2\beta^2 D)f_4(\beta x) \quad (4)$$

4-232 Edge Displacements and Rotations in Terms of Edge Loads

(a) The radial displacements w_o and w_L and rotations θ_o and $-\theta_L$ developed at the edges of a cylindrical shell sustaining the action of edge loads Q_o, M_o, Q_L, and M_L are given by the following formulas:

$$w_o = (B_{11}/2\beta^3 D)Q_o + (B_{12}/2\beta^2 D)M_o + (G_{11}/2\beta^3 D)Q_L + (G_{12}/2\beta^2 D)M_L \quad (1)$$

$$-\theta_o = (B_{12}/2\beta^2 D)Q_o + (B_{22}/2\beta D)M_o + (G_{12}/2\beta^2 D)Q_L + (G_{22}/2\beta D)M_L \quad (2)$$

$$w_L = (G_{11}/2\beta^3 D)Q_o + (G_{12}/2\beta^2 D)M_o + (B_{11}/2\beta^3 D)Q_L + (B_{12}/2\beta^2 D)M_L \quad (3)$$

$$\theta_L = (G_{12}/2\beta^2 D)Q_o + (G_{22}/2\beta D)M_o + (B_{12}/2\beta^2 D)Q_L + (B_{22}/2\beta D)M_L \quad (4)$$

(b) The influence functions, B's and G's, appearing in the formulas, (a) above, rapidly approach limiting values as the length L of the cylinder increases. The limiting values are:

$$B_{11} = B_{12} = 1$$

$$B_{22} = 2$$

$$G_{11} = G_{12} = G_{22} = 0$$

(1) Thus for cylindrical shells of sufficient length, the loading conditions prescribed at one edge do not influence the displacements at the other edge.

(2) In the case of cylindrical shells characterized by lengths not less than $3/\beta$, the influence functions, B's and G's, are sufficiently close to the limiting values that the limiting values may be used in the formulas, (a) above, without significant error.

(c) In the case of sufficiently short cylinders, the influence functions, B's and G's, appearing in the formulas, (a) above, are, to a first approximation, given by the following expressions:

$$B_{11} = 2/\beta L$$

$$B_{12} = 3/(\beta L)^2$$

$$B_{22} = 6/(\beta L)^3$$

$$G_{11} = -1/\beta L$$

$$G_{12} = -3/(\beta L)^2$$

$$G_{22} = -6/(\beta L)^3$$

Introducing these expressions for the influence functions, B's and G's, into the formulas, (a) above, yields expressions identical to those obtained by the application of ring theory. Accordingly, the resultant expressions are subject to all of the limitations inherent in the ring theory, including the limitations due to the assumption that the entire cross-sectional area of the ring, $t \times L$, rotates about its centroid without distortion. Nevertheless, in the analysis of very short cylindrical shells characterized by lengths not greater than $0.5/\beta$, the expressions may be used without introducing significant error.

4-233 Principal Stresses Due to Bending

The principal stresses developed at the surfaces of a cylindrical shell at any axial location x due to uniformly distributed edge loads (see Fig. 4-210.1) are given by the formulas:

$$\sigma_1 = \sigma_t(x) = Ew(x)/(R + t/2) \pm 6\nu M(x)/t^2 \quad (1)$$

$$\sigma_2 = \sigma_l(x) = \pm 6M(x)/t^2 \quad (2)$$

$$\sigma_3 = \sigma_r = 0 \quad (3)$$

In these formulas where terms are preceded by a double sign ±, the upper sign refers to the inside surface of the cylinder and the lower sign refers to the outside surface.

4-240 LAYERED CYLINDRICAL SHELL FORMULAS

The formulas developed for solid wall cylindrical shells as expressed in this Article may be applied to layered cylindrical shells provided that the shell is constructed to prevent slip between the layers in the area of discontinuity.

4-241 Layered Vessel Shells

Solid wall equivalence for layered shells will be assured by ascertaining that the in-plane shear force on each layer is adequately supported by the weld joint. To satisfy the requirements of 4-240, consideration must be given to the construction details in the zones of load application. In order to assure solid-wall equivalence for layered shells as described above, all shell sections subjected to radial forces and/or longitudinal bending moments due to discontinuities or externally applied loads, must have all layers adequately bonded together to resist any longitudinal shearing forces resulting from the radial forces and/or longitudinal bending moments acting on the sections. For example, the use of girth weld to bond layers together is shown in Fig. 4-241.1, where the symbols used are defined as follows:

F = externally applied radial force, lb (N)

F_1 = externally applied radial force per unit length of circumference, lb/in. (N/mm)

M = externally applied bending moment, in.-lb (N-mm)

M_o = longitudinal bending moment per unit length of circumference existing at the weld junction of layered shells (due to discontinuity or external loads), in.-lb/in. (N-mm/mm)

M_1 = externally applied longitudinal bending moment per unit length of circumference, in.-lb/in. (N-mm/mm)

W = required width of attachment weld at the mid-point of the weld depth

= $1.88\ M_o/tS_m$ (minimum)

t = as defined in 4-210

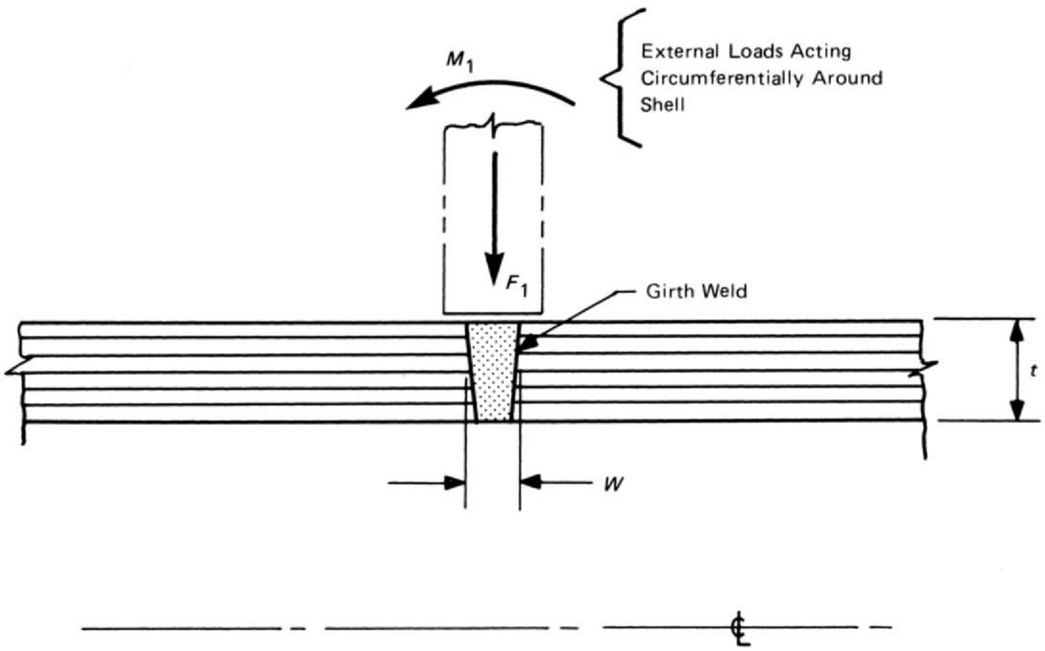


FIG. 4-241.1 AN EXAMPLE OF GIRTH WELD USED TO TIE LAYERS FOR SOLID WALL EQUIVALENCE

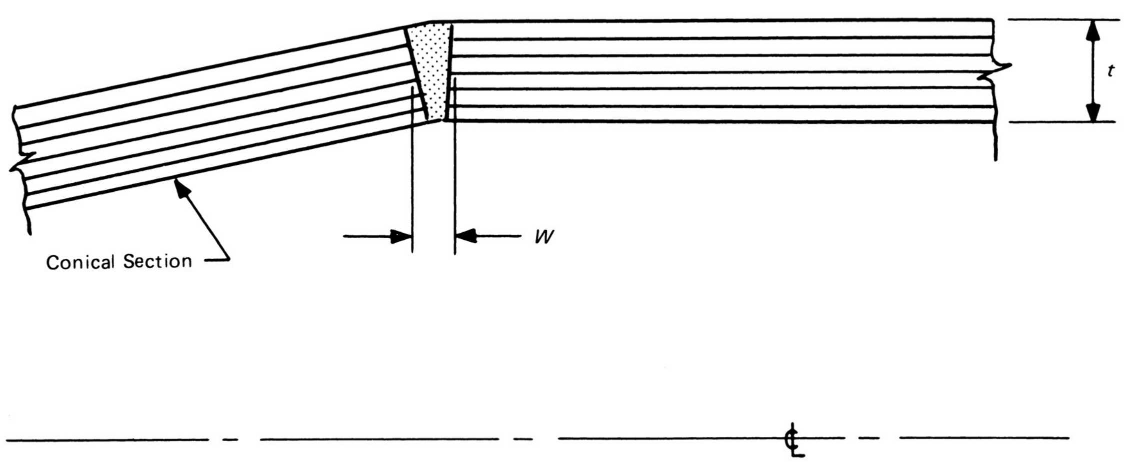


FIG. 4-241.2 AN EXAMPLE OF CIRCUMFERENTIAL BUTT WELD ATTACHMENT BETWEEN LAYERED SECTIONS IN ZONE OF DISCONTINUITY

ARTICLE 4-3
ANALYSIS OF SPHERICAL SHELLS

4-300 SCOPE

(a) In this Article, formulas are given for stresses and deformations in spherical shells subjected to internal or external pressure.

(b) Formulas are also given for bending analysis of partial spherical shells under the action of uniformly distributed edge forces and moments.

4-310 NOMENCLATURE AND SIGN CONVENTION

The symbols and sign convention adopted in this Article are defined as follows:

(1) p = pressure, internal or external
(2) M = meridional bending moment per unit length of circumference, in.-lb/in. (N-mm/mm)
(3) H = force per unit length of circumference, perpendicular to centerline of sphere, lb/in. (N/mm)
(4) N = membrane force, lb/in. (N/mm)
(5) Q = radial shearing force per unit of circumference, lb/in. (N/mm)
(6) S = stress intensity
(7) R_m = radius of midsurface of spherical shell
(8) R = inside radius
(9) t = thickness of spherical shell
(10) E = modulus of elasticity
(11) ν = Poisson's ratio
(12) D = flexural rigidity, in.-lb (N-mm) $= Et^3/12(1 - \nu^2)$
(13) $\beta = [3(1 - \nu^2)/R_m{}^2t^2]^{1/4}$, in.$^{-1}$ (mm^{-1})
(14) ϕ = meridional angle measured from centerline of sphere, rad
(15) ϕ_o = meridional angle of reference edge where loading is applied, rad
(16) ϕ_L = meridional angle of second edge, rad
(17) α = meridional angle measured from the reference edge, rad
(18) x = length of arc for angle α, measured from reference edge of hemisphere $= R_m\alpha$
(19) $\lambda = \beta R_m$
(20) Y = ratio of outside radius to inside radius
(21) Z = ratio of outside radius to an intermediate radius
(22) U = ratio of inside radius to an intermediate radius
(23) w = radial displacement of midsurface
(24) δ = lateral displacement of midsurface, perpendicular to centerline of spherical shell
(25) θ = rotation of midsurface, rad
(26) o = subscript to denote a quantity at reference edge of sphere
(27) l = subscript to denote meridional direction
(28) t = as a subscript used to denote circumferential direction

(29) $$K_1 = 1 - \frac{1 - 2\nu}{2\lambda}\cot(\phi_o - \alpha)$$

(30) $$K_2 = 1 - \frac{1 + 2\nu}{2\lambda}\cot(\phi_o - \alpha)$$

(31) $$k_1 = 1 - \frac{1 - 2\nu}{2\lambda}\cot\phi_o$$

(32) $$k_2 = 1 - \frac{1 + 2\nu}{2\lambda}\cot\phi_o$$

(33) $$A_o = \sqrt{1 + k_1{}^2}$$

(34) $$B(\text{at } \alpha) = [(1 + \nu^2)(K_1 + K_2) - 2K_2]$$

(35) $$C(\text{at } \alpha) = \sqrt{\sin\phi_o/\sin(\phi_o - \alpha)}$$

(36) $$F(\text{at } \alpha) = \sqrt{\sin(\phi_o)\sin(\phi_o - \alpha)}$$

(37) $\gamma_o = \tan^{-1}(-k_1)$, rad
(38) σ_r = radial stress component
(39) σ_t = tangential (circumferential) stress component
(40) σ_l = longitudinal (meridional) stress component

The sign convention is listed below and shown in Fig. 4-310.1 by the positive directions of the pertinent quantities.

(p) pressure, positive radially outward

(δ) lateral displacement, perpendicular to ℄ of sphere, positive outward

(θ) rotation, positive when accompanied by an increase in the radius or curvature, as caused by a positive moment

(M), (M_o) moment, positive when causing tension on the inside surface

(H), (H_o) force perpendicular to ℄, positive outward

(N_t), (N_l) membrane force, positive when causing tension

4-320 PRINCIPAL STRESSES AND STRESS INTENSITIES RESULTING FROM INTERNAL OR EXTERNAL PRESSURE

In this paragraph formulas are given for principal stresses and stress intensities resulting from uniformly distributed internal or external pressure in complete or partial spherical shells. The effects of discontinuities in geometry and loading are not included and should be evaluated independently. The stresses resulting from all effects must be combined by superposition.

4-321 Principal Stresses Resulting From Internal Pressure

The principal stresses at any point in the wall of a spherical shell are given by the following formulas:

$$\sigma_1 = \sigma_l = p(Z^3 + 2)/2(Y^3 - 1) \quad (1)$$

$$\sigma_2 = \sigma_t = p(Z^3 + 2)/2(Y^3 - 1) \quad (2)$$

$$\sigma_3 = \sigma_r = p(1 - Z^3)/(Y^3 - 1) \quad (3)$$

4-322 Stress Intensities Resulting From Internal Pressure

(a) The average primary stress intensity in a spherical shell resulting from internal pressure is given by the formula:

$$S_{avg} = 0.75p(Y^3 + 1)/(Y^3 - 1)$$

(b) The maximum value of the stress intensity in a spherical shell resulting from internal pressure occurs at the inside surface and is given by the formula:

$$S_{max} = 1.5pY^3/(Y^3 - 1)$$

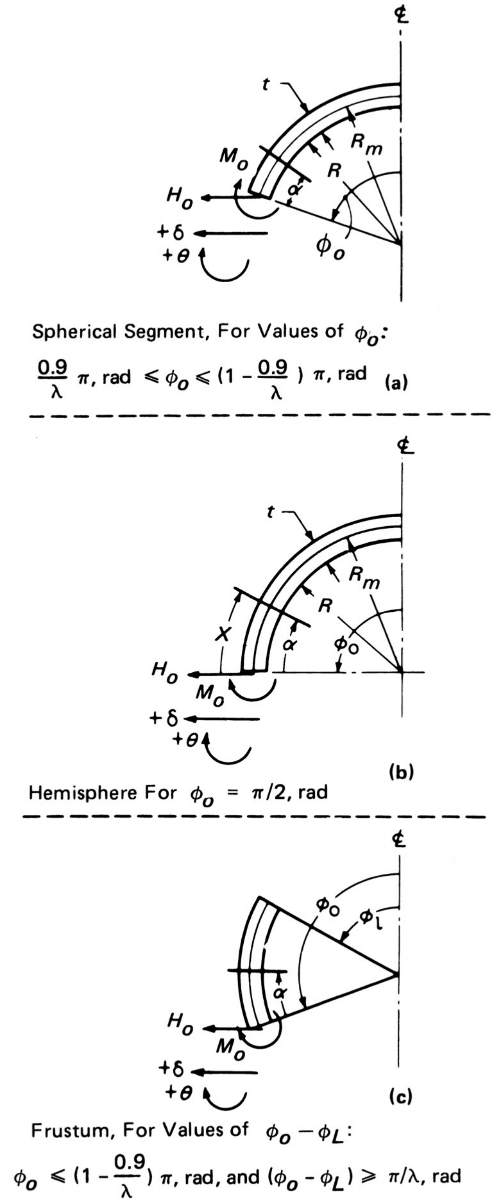


FIG. 4-310.1

4-323 Principal Stresses Resulting From External Pressure

The principal stresses at any point in the wall of a spherical shell resulting from external pressure are given by the following formulas:

$$\sigma_1 = \sigma_l = -pY^3(U^3 + 2)/2(Y^3 - 1) \quad (1)$$

$$\sigma_2 = \sigma_t = -pY^3(U^3 + 2)/2(Y^3 - 1) \quad (2)$$

$$\sigma_3 = \sigma_r = pY^3(U^3 - 1)/(Y^3 - 1) \quad (3)$$

4-324 Stress Intensities Resulting From External Pressure

(a) The average primary stress intensity in a spherical shell resulting from external pressure is given by the formula:

$$S_{avg} = 0.75p(Y^3 + 1)/(Y^3 - 1)$$

(b) The maximum value of the stress intensity in a spherical shell resulting from external pressure occurs at the inside surface and is given by the formula:

$$S_{max} = 1.5p(Y^3)/(Y^3 - 1)$$

NOTE: The formulas in 4-323 and 4-324 may be used only if the applied external pressure is less than the critical pressure which would cause instability of the spherical shell. The value of the critical pressure must be evaluated in accordance with the rules given in Article D-3.

4-330 BENDING ANALYSIS FOR UNIFORMLY DISTRIBUTED EDGE LOADS

(a) The formulas in this paragraph describe the behavior of partial spherical shells of the types shown in Fig. 4-310.1, when subjected to the action of meridional bending moment M_o [in.-lb/in. (N-mm/mm) of circumference] and forces H_o [in.-lb/in. (N/mm) of circumference], uniformly distributed at the reference edge and acting at the mean radius of the shell. The effects of all other loading must be evaluated independently and combined by superposition.

(b) The formulas listed in this paragraph become less accurate and should be used with caution when R_m/t is less than 10 and/or the opening angle limitations shown in Fig. 4-310.1 are exceeded.

4-331 Displacement, Rotation, Moment, and Membrane Force in Terms of Loading Conditions at Reference Edge

The displacement δ, the rotation θ, the bending moments M_l, M_t, and the membrane forces N_l, N_t at any location of sphere are given in terms of the edge loads M_o and H_o by the following formulas:

$$\delta = M_o \left\{ \frac{2\lambda^2}{Etk_1} F(\text{at } \alpha) e^{-\lambda\alpha} [\cos(\lambda\alpha) - K_2 \sin(\lambda\alpha)] \right\} + H_o \left\{ \frac{R_m\lambda}{Etk_1} A_o \sin\phi_o F(\text{at } \alpha) e^{-\lambda\alpha} \times [\cos(\lambda\alpha + \gamma_o) - K_2 \sin(\lambda\alpha + \gamma_o)] \right\} \quad (1)$$

$$\theta = M_o \left\{ \frac{4\lambda^3}{R_m Etk_1} C(\text{at } \alpha) e^{-\lambda\alpha} \cos(\lambda\alpha) \right\} + H_o \left\{ \frac{2\lambda^2}{Etk_1} A_o \sin\phi_o C(\text{at } \alpha) e^{-\lambda\alpha} \times \cos(\lambda\alpha + \gamma_o) \right\} \quad (2)$$

$$M_l = M_o \left\{ \frac{1}{k_1} C(\text{at } \alpha) e^{-\lambda\alpha} [K_1 \cos(\lambda\alpha) + \sin(\lambda\alpha)] \right\} + H_o \left\{ \frac{R_m}{2\lambda k_1} A_o \sin\phi_o C(\text{at } \alpha) e^{-\lambda\alpha} \times [K_1 \cos(\lambda\alpha + \gamma_o) + \sin(\lambda\alpha + \gamma_o)] \right\} \quad (3)$$

$$M_t = M_o \left\{ \frac{C(\alpha)}{2\nu k_1} e^{-\lambda\alpha} [B(\text{at } \alpha) \cos(\lambda\alpha) + 2\nu^2 \sin(\lambda\alpha)] \right\} + H_o \left\{ \frac{R_m}{4\nu\lambda k_1} A_o \sin\phi_o C(\text{at } \alpha) e^{-\lambda\alpha} \times [B(\alpha) \cos(\lambda\alpha + \gamma_o) + 2\nu^2 \sin(\lambda\alpha + \gamma_o)] \right\} \quad (4)$$

$$N_l = -M_o \left\{ \frac{2\lambda}{R_m k_1} C(\text{at } \alpha) e^{-\lambda\alpha} \sin(\lambda\alpha) \cot(\phi_o - \alpha) \right\} - H_o \left\{ \frac{1}{k_1} A_o \cot(\phi_o - \alpha) \sin\phi_o C(\text{at } \alpha) e^{-\lambda\alpha} \times \sin(\lambda\alpha + \gamma_o) \right\} \quad (5)$$

$$N_t = M_o \left\{ \frac{2\lambda^2}{R_m k_1} C(\text{at } \alpha) e^{-\lambda\alpha} \times \left[\cos(\lambda\alpha) - \left(\frac{K_1 + K_2}{2} \right) \sin(\lambda\alpha) \right] \right\} + H_o \left\{ \frac{\lambda}{k_1} A_o \sin\phi_o C(\text{at } \alpha) e^{-\lambda\alpha} \times \left[\cos(\lambda\alpha + \gamma_o) - \left(\frac{K_1 + K_2}{2} \right) \sin(\lambda\alpha + \gamma_o) \right] \right\} \quad (6)$$

4-332 Displacement and Rotation of Reference Edge in Terms of Loading Conditions at Reference Edge

(a) At the reference edge $\alpha = 0$, and $\phi = \phi_o$. The formulas for the displacement and rotation (4-331) simplify to those given below:

$$\delta_o = M_o \frac{2\lambda^2 \sin \phi_o}{Etk_1} + H_o \frac{R_m\lambda \sin^2 \phi_o}{Et}\left(\frac{1}{k_1} + k_2\right) \quad (1)$$

$$\theta_o = M_o \frac{4\lambda^3}{R_mEtk_1} + H_o \frac{2\lambda^2 \sin \phi_o}{Etk_1} \quad (2)$$

(b) In the case where the shell under consideration is a full hemisphere, the formulas given in (1) and (2) above reduce to those given below:

$$\delta_o = M_o \frac{2\lambda^2}{Et} + H_o \frac{2R_m\lambda}{Et} \quad (1)$$

$$\theta_o = M_o \frac{4\lambda^3}{R_mEt} + H_o \frac{2\lambda^2}{Et} \quad (2)$$

4-333 Principal Stresses in Spherical Shells Resulting From Edge Loads

The principal stresses at the inside and outside surfaces of a spherical shell at any location, resulting from edge loads M_o and H_o, are given by the following formulas:

$$\sigma_1 = \sigma_l(\text{at } \alpha) = \frac{N_l}{t} \pm \frac{6M_l}{t^2} \quad (1)$$

$$\sigma_2 = \sigma_t(\text{at } \alpha) = \frac{N_t}{t} \pm \frac{6M_t}{t^2} \quad (2)$$

$$\sigma_3 = \sigma_r(\text{at } \alpha) = 0 \quad (3)$$

In these formulas where terms are preceded by a double sign ±, the upper sign refers to the inside surface of the shell and the lower sign refers to the outside surface.

4-340 ALTERNATIVE BENDING ANALYSIS OF A HEMISPHERICAL SHELL SUBJECTED TO UNIFORMLY DISTRIBUTED EDGE LOADS

If a less exacting but more expedient analysis of hemispherical shells is required, formulas derived for cylindrical shells may be used in a modified form. The formulas listed in this paragraph describe the behavior of a hemispherical shell as approximated by a cylindrical shell of the same radius and thickness when subjected to the action of uniformly distributed edge loads M_o and H_o at $\alpha = 0$, $x = 0$, and $\phi_o = 90$ deg $= \pi/2$ rad.

4-341 Displacement Rotation, Moment, and Shear Forces in Terms of Loading Conditions at Edge

$$\delta_o = H_o/2\beta^3D + M_o/2\beta^2D \quad (1)$$

$$\theta_o = H_o/2\beta^2D + M_o/\beta D \quad (2)$$

$$\delta(x) = \frac{H_o \sin^2 \phi}{2\beta^3D} f_1(\beta x) + \frac{M_o \sin \phi}{2\beta^2D} f_2(\beta x) \quad (3)$$

$$\theta(x) = \frac{H_o \sin \phi}{2\beta^2D} f_3(\beta x) + \frac{M_o}{\beta D} f_1(\beta x) \quad (4)$$

$$M(x) = \frac{H_o \sin \phi}{\beta} f_4(\beta x) + M_o f_3(\beta x) \quad (5)$$

$$Q(x) = H_o \sin \phi\, f_2(\beta x) - 2\beta M_o f_4(\beta x) \quad (6)$$

where f_1, f_2, f_3, and f_4 are defined in Article 4-2, Analysis of Cylindrical Shells, and

$$x = \alpha R_m = (\pi/2 - \phi)R_m$$

4-342 Principal Stresses in a Hemispherical Shell Due to Edge Loads

The principal stresses in a hemispherical shell, due to edge loads M_o and H_o at the inside and outside surfaces of a hemispherical shell at any meridional location, are given by the formulas:

$$\sigma_1 = \sigma_l(\text{at } x) = \pm 6M(\text{at } x)/t^2 \quad (1)$$

$$\sigma_2 = \sigma_t(\text{at } x) = E\delta(\text{at } x)/R_m \pm \nu 6M(\text{at } x)/t^2 \quad (2)$$

$$\sigma_3 = \sigma_r(\text{at } x) = 0 \quad (3)$$

In these formulas where terms are preceded by a double sign ±, the upper sign refers to the inside surface of the hemisphere and the lower sign refers to the outside surface.

4-350 LAYERED SPHERICAL SHELL AND HEAD FORMULAS

The formulas developed for solid wall spherical shells or heads as expressed in this Article may be applied to layered spherical shells or heads provided that the shell or head is constructed to prevent slip between the layers in the area of discontinuity.

4-351 Layered Spherical Shells and Heads

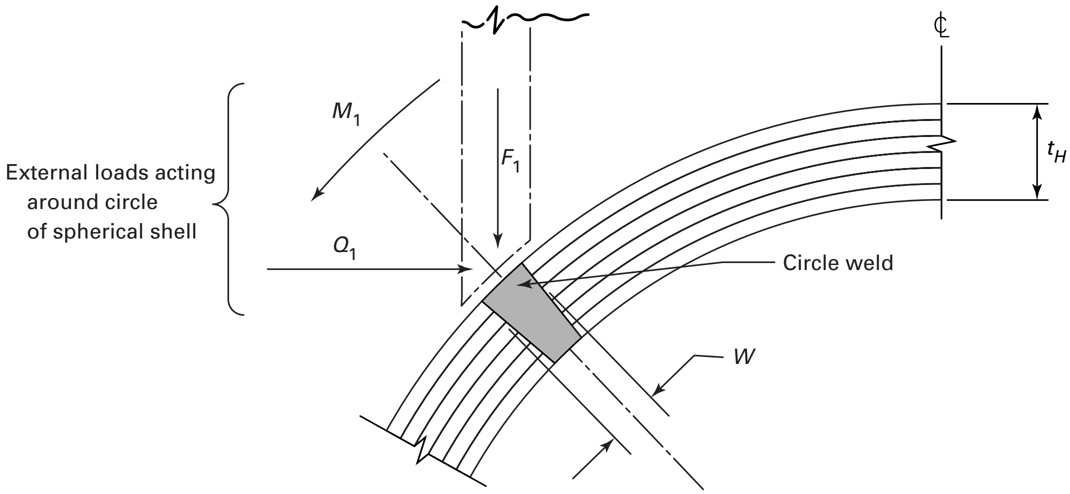
Solid wall equivalence for spherical shells and heads will be assured by ascertaining that the in-plane shear force on each layer is adequately supported by the weld joint. To satisfy the requirements of 4-350, consideration must be given to the construction details in the zones of load application. In order to assure solid wall equivalence for layered spherical shells or heads as described above, all spherical shells or heads subjected to radial forces and/or longitudinal bending moments due to discontinuities or externally applied loads, must have all layers adequately bonded together to resist any longitudinal shearing forces resulting from the radial forces and/or longitudinal bending moments acting on the sections. For example, the use of the girth weld to bond layers together is shown in Fig. 4-351.1, where the symbols used are defined as follows:

W = required width of attachment weld at the midpoint of the weld depth
= $1.88\ M_o/tS_m$ (min.)

M_o = longitudinal bending moment per unit length of circumference existing at the weld junction of layered spherical shells or heads (due to discontinuity or external loads), in.-lb/in. (N-mm/mm)

M_1 = externally applied bending moment per unit length of circumference, in.-lb/in. (N-mm/mm)

M = externally applied bending moment, in.-lb (N-mm)



F_1, Q_1 = externally applied forces per unit length of circumference, lb/in. (N/mm)
F = externally applied force, lb (N)
t = as defined in 4-210

FIG. 4-351.1 AN EXAMPLE OF CIRCLE WELD USED TO TIE LAYERS FOR SOLID WALL EQUIVALENCE

ARTICLE 4-4
DESIGN CRITERIA AND FORMULAS FOR TORISPHERICAL AND ELLIPSOIDAL HEADS

4-400 SCOPE

The equations defining the curves in Fig. AD-204.1 are summarized in this Article. The analysis is for pressure on the concave portion of the head and does not include effects of thermal gradients and loadings other than pressure.

4-410 NOMENCLATURE

The nomenclature in this Article is defined as follows:

D = inside diameter of a head skirt or inside length of the major axis of an ellipsoidal head
L = inside crown radius of torispherical head
P = internal design pressure
S = membrane stress intensity limit from the tables of design stress intensity values of Subpart 1 of Section II, Part D multiplied by the stress intensity factor in Table AD-150.1
r = inside knuckle radius of torispherical head
t = minimum required thickness of head

4-420 METHOD USED TO DETERMINE DESIGN PRESSURE

The maximum internal pressure capacity or required thickness of a torispherical and ellipsoidal pressure vessel head is determined from the controlling criteria of primary membrane stress, elastic–plastic collapse load, buckling collapse, and fatigue. For thick heads, where $P/S > 0.08$ (approximately $t/L = 0.04$ to 0.05), primary membrane stress dominates. For thin heads, where $t/L < 0.002$, buckling collapse is the limiting condition. For the intermediate thickness heads, where $t/L > 0.002$ up to t/L where $P/S < 0.08$ (approximately $t/L = 0.04$ to 0.05), elastic–plastic collapse pressure and fatigue due to pressurization cycles are the determining conditions. At the present time, only design of thick heads and heads of intermediate thickness are considered in this Article.

4-430 INTERMEDIATE THICKNESS HEADS

4-431 Mathematical Expressions for Curves, Fig. AD-204.1

The formula for computing A for the given set of parameters r/D and P/S is as follows:

$$A = a_1 + a_2 x + a_3 x^2 + (b_1 + b_2 x + b_3 x^2)y + (c_1 + c_2 x + c_3 x^2)y^2 \quad (1)$$

where

$$x = r/D$$

Constants a_1 through c_3 are given in 4-432 for natural logarithms and in 4-433 for common base logarithms.

4-432 Natural Logarithms

$$y = \ln (P/S)$$

$$t/L = e^A$$

and

$$a_1 = -1.26176643$$

$$a_2 = -4.5524592$$

$$a_3 = 28.933179$$

$$b_1 = 0.66298796$$

$$b_2 = -2.2470836$$

$$b_3 = 15.682985$$

$$c_1 = 0.26878909 \times 10^{-4}$$

$$c_2 = -0.42262179$$

$$c_3 = 1.8878333$$

4-433 Common Base Logarithms

$$y = \log (P/S)$$

$$t/L = 10^A$$

and

$$a_1 = -0.5479782$$

$$a_2 = -1.9771079$$

$$a_3 = 12.565520$$

$$b_1 = 0.66298796$$

$$b_2 = -2.2470836$$

$$b_3 = 15.682985$$

$$c_1 = 0.61890975 \times 10^{-4}$$

$$c_2 = -0.97312263$$

$$c_3 = 4.3468967$$

4-434 Sample Problem

Consider a torispherical head having the following parameters:

L = 84 in.
D = 90 in.
r = 5.5 in.
P = 200 psi

Material SA-515 Grade 70, $S = 23{,}300$ psi

With these data and using the formula of 4-431 and common base logarithms and constants of 4-433:

$$P/S = 0.00858369$$

$$r/D = 0.06111111 = x$$

$$y = \log (P/S) = -2.066325925$$

$$y^2 = 4.269702828$$

$$A = -2.013430932$$

Solving Eq. (1) of 4-431:

$$t/L = 10^A = 0.009695474$$

$$t = 0.814 \text{ in.}$$

Direct reading of Fig. AD-204.1 gives

$$t/L = 0.0097$$

$$t = 0.814 \text{ in.}$$

4-440 THICK HEADS

For thick heads, the allowable pressure is governed by the Lamé formula as follows:

$$P/S = \ln \left(\frac{D + 2t}{D} \right)$$

(ln is the natural log) from which

$$t = \frac{D}{2} (e^{P/S} - 1)$$

4-441 Sample Problem

Consider a torispherical head having the following parameters:

L = 90 in.
D = 100 in.
r = 20 in.
P = 2,008 psi

Material: SA 515 Grade 70 at 100°F, $S = 23.3$ ksi

Then $P/S = 2{,}008/23{,}300 = 0.08618$ which is above the range of Fig. AD-204.1. Therefore, establish t from the formula:

$$t = \frac{D}{2} (e^{P/S} - 1)$$

$$= 4.50 \text{ in.}$$

ARTICLE 4-5
ANALYSIS OF FLAT CIRCULAR HEADS

4-500 SCOPE

(a) In this Article, formulas are given for stresses and displacements in flat circular plates used as heads for pressure vessels.

(b) Formulas are also given for stresses and displacements in these heads due to forces and edge moments uniformly distributed along the outer edge and uniformly distributed over a circle on one face. The radius of this circle is intended to match the mean radius of an adjoining element such as a cylinder, cone, or spherical segment.

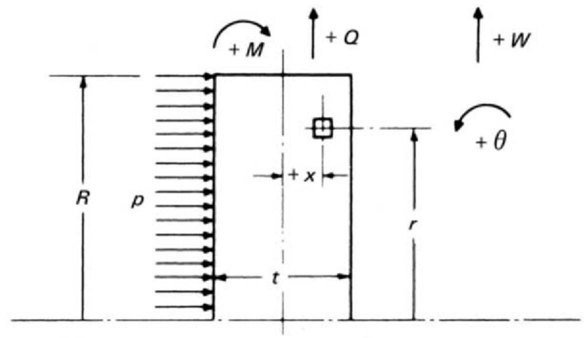


FIG. 4-510.1

4-510 NOMENCLATURE AND SIGN CONVENTION

The symbols and sign conventions adopted in this Article are defined as follows:

(1) p = pressure
(2) M = radial bending moment, in.-lb/in. (N-mm/mm) of circumference
(3) Q = radial force, lb/in. (N/mm) of circumference
(4) σ_r = radial stress
(5) σ_l = longitudinal stress
(6) σ_t = tangential (circumferential) stress
(7) w = radial displacement
(8) θ = rotation, rad
(9) R = outside radius of plate
(10) r = radial distance from center of plate
(11) x = longitudinal distance from midplane of plate
(12) t = thickness of plate
(13) t_s = thickness of connecting shell at the head junction
(14) E = elastic modulus
(15) ν = Poisson's ratio
(16) F = geometry constant, given in Table 4-540.1

Tensile stresses are positive. The positive directions of the coordinates, radial forces, moments, and displacements are shown in Fig. 4-510.1. The pressure is assumed to act on the surface where $x = -t/2$.

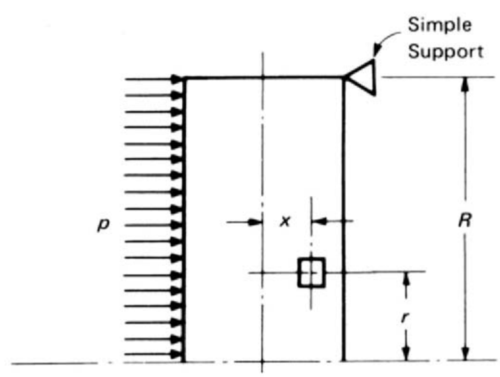


FIG. 4-521.1

4-520 PRESSURE AND EDGE LOADS ON CIRCULAR FLAT PLATES

In the following paragraphs formulas are given for the principal stresses and deformations of flat plates under axisymmetric loading conditions.

4-521 Pressure Loads on Simply Supported Flat Plates

The principal stresses and deformations for a flat plate, simply supported at its periphery and loaded in the manner shown in Fig. 4-521.1, are given for a radial location

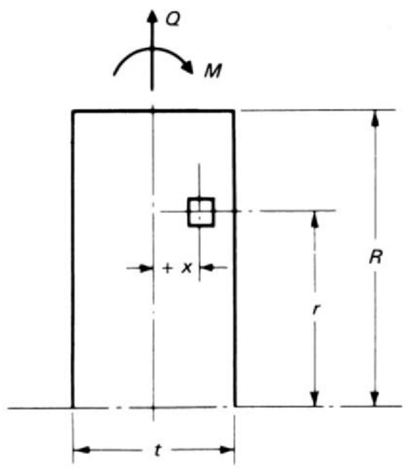


FIG. 4-522.1

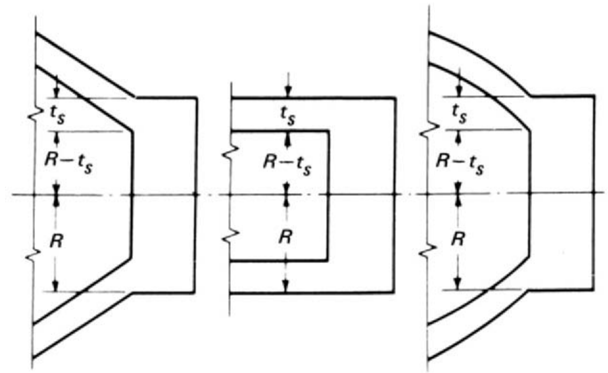


FIG. 4-530.1

r at any point x in the cross section by the following formulas.

Radial bending stress

$$\sigma_r = p\,\frac{3(x)}{4t^3}\,[(3+\nu)(R^2-r^2)] \qquad (1)$$

Tangential bending stress

$$\sigma_t = p\,\frac{3(x)}{4t^3}\,[(3+\nu)R^2-(1+3\nu)r^2] \qquad (2)$$

Longitudinal stress

$$\sigma_l = \frac{p}{t}\left(x-\frac{t}{2}\right) \qquad (3)$$

Rotation of the midplane

$$\theta = -p\,\frac{3(1-\nu)}{4t^3E}\,[r^3(1+\nu)-rR^2(3+\nu)] \qquad (4)$$

Rotation of the midplane at the outer edge

$$\theta = +p\,\frac{3(1-\nu)}{2E}\left(\frac{R}{t}\right)^3 \qquad (5)$$

Radial displacement

$$w = +(x)\theta \qquad (6)$$

4-522 Edge Loads on Flat Plates

The principal stresses and deformations of a flat plate subjected to uniformly distributed edge loads, as shown in Fig. 4-522.1, are given for radial location r at any point x in the cross section by the following formulas.

Radial and tangential stresses

$$\sigma_r = \sigma_t = \frac{Q}{t} - \frac{12(x)}{t^3}M \qquad (1)$$

Rotation of the midplane

$$\theta = \frac{-12(1-\nu)(r)}{Et^3}M \qquad (2)$$

Radial displacement

$$w = \frac{(1-\nu)(r)}{Et}Q + (x)\theta \qquad (3)$$

4-530 FLAT PLATE PRESSURE VESSEL HEADS

Flat plates used as pressure vessel heads are attached to a vessel shell in the manner shown by the typical examples in Fig. 4-530.1.

Since the support conditions at the edge of the plate depend upon the flexibility of the adjoining shell, the stress distribution in the plate is influenced by the shell thickness and geometry. The structure formed by the head and the shell may be analyzed according to the principles of discontinuity analysis described in Article 4-7. In the following paragraph formulas are given for the quantities necessary to perform a discontinuity analysis.

4-531 Displacements and Principal Stresses in a Flat Head

The head is assumed to be separated from the adjoining shell element and under the action of the pressure load.

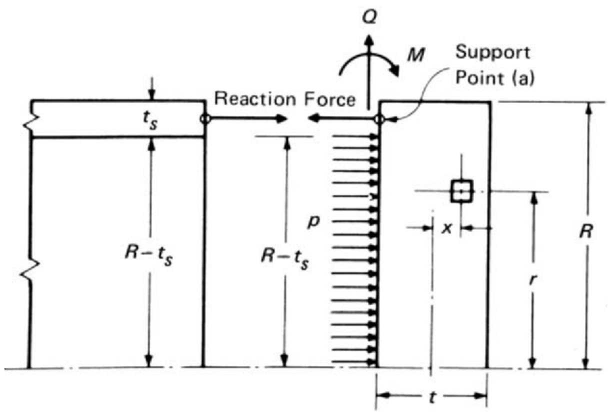


FIG. 4-531.1

Figure 4-531.1 illustrates this condition. The effects of the adjacent shell are represented by the pressure reaction force, the discontinuity force Q, and the discontinuity moment M. These act at the assumed junction point (a). The pressure acts on the left-hand face over a circular area defined by the inside radius of the adjacent shell. The support point lies on this same face at the midradius of the adjacent shell. The formulas in this paragraph are given in terms of the head dimensions R and t and multiplying factors F_1 to F_4. These factors reflect the extent of the pressure area and the location of the junction point. The numerical values for F_1 to F_4 are given in Table 4-540.1. These are functions of the ratio of the shell thickness t_s to the head radius R.

4-531.1 Displacements of a Flat Head

(a) For a plate simply supported at a point (a), the rotational displacement θ_p and the radial displacement w_p of point (a) due to pressure p acting over the area defined by the radius $(R - t_s)$ are given by the following formulas:

$$\theta_p = + \frac{F_1}{E(t/R)^3} p \qquad (1)$$

$$w_p = - \frac{t}{2} \theta_p \qquad (2)$$

(b) The rotational displacements θ and the radial displacement w of point (a) due to a uniformly distributed radial force Q and moment M acting at point (a) are given by the following formulas:

$$\theta = \frac{-F_3}{ER(t/R)^2} Q + \frac{-2F_3}{ER^2(t/R)^3} M \qquad (1)$$

$$w = \frac{2F_3}{3E(t/R)} Q + \frac{F_3}{ER(t/R)^2} M \qquad (2)$$

4-531.2 Principal Stresses in a Flat Head. When the values of the discontinuity force Q and the moment M have been determined by a discontinuity analysis, the principal stresses in a flat plate can be calculated as follows:

(a) For a plate simply supported at point (a), the radial stress σ_r for a radial location r less than $(R - t_s)$ at any point x due to pressure p acting over the area defined by the radius $(R - t_s)$ is given by the following formula:

$$\sigma_r = \frac{xp}{t(t/R)^2} \left[F_2 - \frac{3(3 + \nu)r^2}{4R^2} \right] \qquad (1)$$

(b) For these same conditions, the tangential stress σ_t and the axial stress σ_l are given by the following formulas:

$$\sigma_t = \frac{xp}{t(t/R)^2} \left[F_2 - \frac{3(1 + 3\nu)r^2}{4R^2} \right] \qquad (2)$$

$$\sigma_l = \left(x - \frac{t}{2} \right) \frac{p}{t} \qquad (3)$$

(c) The radial stress σ_r and the tangential stress σ_t for any radial location at any point x in the cross section, due to uniformly distributed radial force Q and a uniformly distributed moment M acting at point (a), are given by the formula:

$$\sigma_r = \sigma_t = \frac{F_4}{t} \left[1 - \frac{6(x)}{t} \right] Q - \frac{12F_4(x)}{t^3} M \qquad (1)$$

4-540 GEOMETRY CONSTANTS

The geometry constants F_1 through F_4 are functions of Poisson's ratio and t_s/R. These are:

$$F_1 = \frac{3(1 - \nu)(2 - f^2)(1 - f)^2[8 - f(4 - f)(1 - \nu)]}{16(2 - f)}$$

$$F_2 = {}^3\!/_8 (1 - f)^2 \left\{ (1 - \nu)(2 - f^2) + 4(1 + \nu) \left[1 + 2 \left(\ln \frac{2 - f}{2 - 2f} \right) \right] \right\}$$

$$F_3 = {}^3\!/_8 (1 - \nu)(2 - f)[8 - f(4 - f)(1 - \nu)]$$

$$F_4 = {}^1\!/_8 [8 - f(4 - f)(1 - \nu)]$$

In these expressions

$$f = t_s/R$$

Table 4-540.1 lists these functions for various values of t_s/R. These tabular values have been computed using 0.3 for Poisson's ratio.

4-550 STRESS INTENSITIES IN A FLAT PLATE

The principal stresses due to pressure *p*, discontinuity force *Q*, discontinuity moment *M*, and other coincident loadings should be combined algebraically and the stress differences determined according to the procedures of 4-120. The calculated stress intensity values should not exceed the allowable values given in 4-130.

TABLE 4-540.1

t_s/R	F_1	F_2	F_3	F_4
0.00	1.0500	2.4750	4.2000	1.0000
0.02	1.0113	2.4149	4.1290	0.9930
0.04	0.9730	2.3547	4.0589	0.9861
0.06	0.9350	2.2943	3.9897	0.9793
0.08	0.8975	2.2339	3.9214	0.9726
0.10	0.8604	2.1734	3.8538	0.9659
0.12	0.8238	2.1129	3.7872	0.9593
0.14	0.7878	2.0524	3.7213	0.9527
0.16	0.7523	1.9920	3.6563	0.9462
0.18	0.7174	1.9316	3.5920	0.9398
0.20	0.6831	1.8713	3.5286	0.9335

ARTICLE 4-6
STRESSES IN OPENINGS
FOR FATIGUE EVALUATION

4-600 GENERAL

For the purpose of determining peak stresses around the opening, three acceptable methods are listed in (a), (b), and (c) below.

(a) Analytical Method. This method uses suitable analytical techniques such as finite element computer analyses, which provide detailed stress distributions around openings. In addition to peak stresses due to pressure, the effects of other loadings shall be included. The total peak stress at any given point shall be determined by combining stresses due to pressure, thermal, and external loadings in accordance with the rules of Part AD.

(b) Experimental Stress Analysis. This is based on data from experiments (4-620).

(c) Stress Index Method. This uses various formulas based on data obtained from an extensive series of tests covering a range of variations of applicable dimensional ratios and configurations (4-610). This method covers only single, isolated openings. Stress indices may also be determined by theoretical or experimental stress analysis. Such analysis shall be included in the Design Report.

4-610 STRESS INDEX METHOD

4-611 Stress Index

The term stress index, as used herein, is defined as the numerical ratio of the stress components σ_t, σ_n, and σ_r under consideration to the computed membrane hoop stress in the unpenetrated and unreinforced vessel material. When the thickness of the vessel wall is increased over that required to the extent provided hereinafter, the values of r_1 and r_2 in Fig. 4-613.1 shall be referred to the thickened section.

The symbols for the stress components are shown in Fig. 4-611.1 and are defined as follows:

σ = the stress intensity (combined stress) at the point under consideration

σ_t = the stress component in the plane of the section under consideration and parallel to the boundary of the section

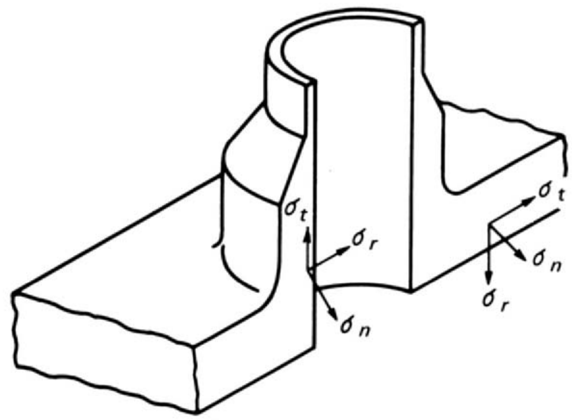


FIG. 4-611.1 DIRECTION OF STRESS COMPONENTS

σ_n = the stress component normal to the plane of the section (ordinarily the circumferential stress around the hole in the shell)

σ_r = the stress component normal to the boundary of the section

t = nominal wall thickness of shell or formed head

R = inside radius of the shell or formed head

D = inside diameter of shell

d = inside diameter of nozzle

4-612 Stress Indices for Nozzles

When the conditions of 4-613 are satisfied, the following stress indices may be used for nozzles designed in accordance with the applicable rules of Article D-5. These stress indices deal only with the maximum stresses, at certain general locations, due to internal pressure. In the evaluation of stress in or adjacent to vessel openings and connections, it is often necessary to consider the effect of stresses due to external loadings or thermal stresses. In such cases, the total stress at a given point may be determined by superposition. In the case of combined stresses due to internal pressure and nozzle loading, the maximum stresses for a given location should be considered as acting at the same point and added algebraically unless positive evidence is available to the contrary.

(a) Nozzles in Spherical Shells and Spherical Portions of Formed Heads

Stress	Inside Corner	Outside Corner
σ_n	2.0	2.0
σ_t	− 0.2	2.0
σ_r	$-2t/R$	0
σ	2.2	2.0

(b) Nozzles in Cylindrical Shells

	Longitudinal Plane		Transverse Plane	
Stress	Inside Corner	Outside Corner	Inside Corner	Outside Corner
σ_n	3.1	1.2	1.0	2.1
σ_t	− 0.2	1.0	− 0.2	2.6
σ_r	$-t/R$	0	$-t/R$	0
σ	3.3	1.2	1.2	2.6

4-613 Limitations of Indices of 4-612

The indices of 4-612 apply if:

(a) the opening is for a circular nozzle whose axis is normal to the vessel wall. If the axis of the nozzle makes an angle ϕ with the normal to the vessel wall, an estimate of the σ_n index on the inside may be obtained from the following formula, provided $d/D \leq 0.15$.

For hillside connections in spheres or cylinders

$$K_2 = K_1(1 + 2\sin^2\phi) \tag{1}$$

For lateral connections in cylinders

$$K_2 = K_1\left[1 + (\tan\phi)^{4/3}\right] \tag{2}$$

where

K_1 = the σ_n inside stress index of 4-612 for a radial connection

K_2 = the estimated σ_n inside stress index for the nonradial connection

(b) the arc distance measured between the centerlines of adjacent nozzles along the inside surface of the shell is not less than three times the sum of their inside radii for openings in a head or along the longitudinal axis of a shell and is not less than two times the sum of their radii for openings along the circumference of a cylindrical shell [see AD-501(a)(3) when two nozzles are not on a longitudinal or circumferential line];

(c) the following dimensional limitations are met:

Ratio	Cylinder	Sphere
$\dfrac{\text{Inside shell diameter}}{\text{Shell thickness}} = \dfrac{D}{t}$	10 to 100	10 to 100
$\dfrac{\text{Inside nozzle diameter}}{\text{Inside shell diameter}} = \dfrac{d}{D}$	0.50 max.	0.50 max.
$d/\sqrt{Dt}$	. . .	0.80 max.
$d/\sqrt{Dt_n r_2/t}$	1.50 max.	. . .

In the case of cylindrical shells, the total nozzle reinforcement area on the transverse plane of the connections including any outside of the reinforcement limits shall not exceed 200% of that required for the longitudinal plane (compared to 50% permitted by Fig. AD-520.1), unless a tapered transition section is incorporated into the reinforcement and the shell, meeting the requirements of AD-420.

(d) the inside corner radius r_1 (see Fig. 4-613.1) is one-eighth to one-half of the shell thickness t;

(e) the outer corner radius r_2 (see Fig. 4-613.1) is large enough to provide a smooth transition between the nozzles and the shell. In addition, for opening diameters d in cylindrical shells and 2:1 ellipsoidal heads greater than 1½ shell thicknesses and in spherical shells greater than 3 shell thicknesses, the value of r_2 shall be equal to or larger than $\sqrt{2rt_n}$ and $t/2$.

(f) the radius r_3 (see Fig. 4-613.1) is equal to or larger than $\sqrt{rt_p}$ and $t_n/2$;

(g) where there are conflicts in geometry between the figures of Article D-5 or Article D-6 and the limitations of 4-613, the limitations of 4-613 shall govern;

(h) in the case of spherical shells and formed heads, at least 40% of the reinforcement is located on the outside surface of the nozzle–shell juncture.

4-614 Stress Indices for Laterals

Nomenclature is as follows:

M_B = in-plane bending moment acting on nozzle branch

M_B/Z_B = nominal stress due to in-plane moment M_B acting on the lateral nozzle

M_{BT} = transverse bending moment acting on nozzle

M_{BT}/Z_B = nominal stress due to transverse moment M_{BT} acting on nozzle

M_R = in-plane bending moment acting on vessel

M_R/Z_R = nominal stress due to in-plane moment M_R acting on the vessel

M_{RT} = transverse bending moment acting on vessel

M_{RT}/Z_R = nominal stress due to transverse moment M_{RT} acting on vessel

P = internal pressure

S = maximum stress intensity

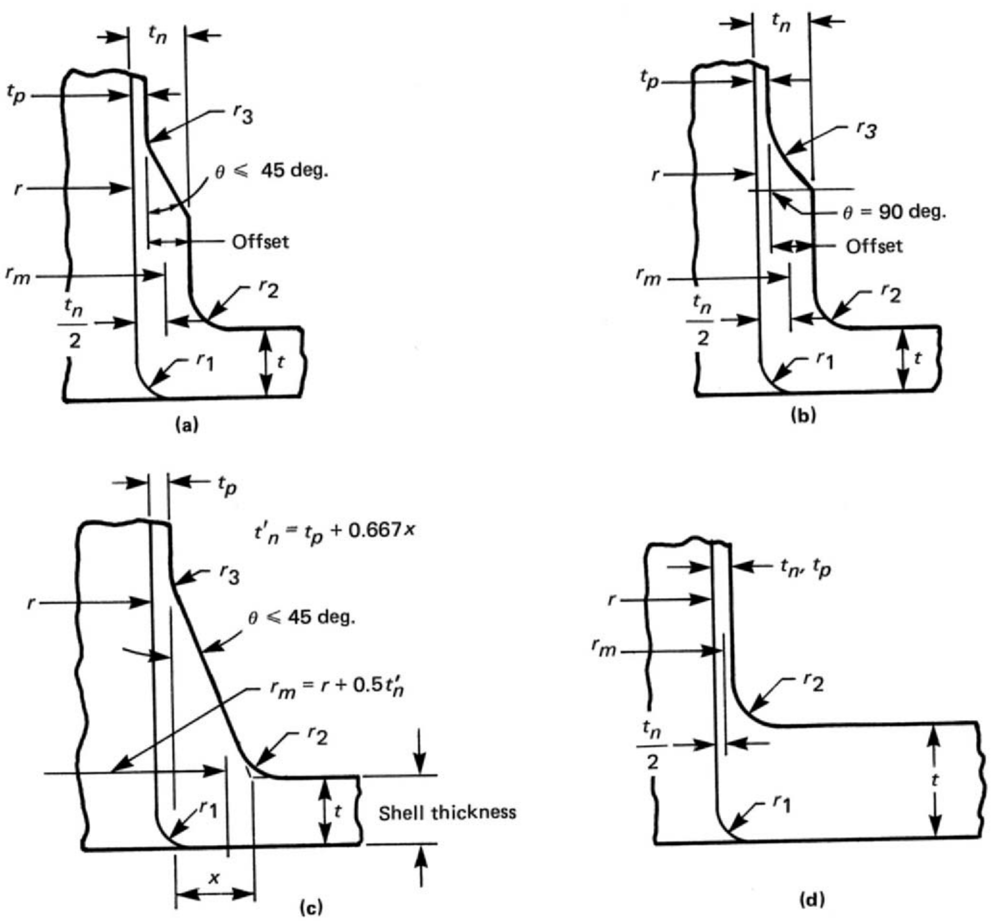


FIG. 4-613.1 NOZZLE NOMENCLATURE AND DIMENSIONS

t_P = nominal thickness of branch pipe

Z_B = least section modulus of lateral nozzle beyond the limits of reinforcement (such as at Section *A–A* in Fig. 4-614), in.^{3} (mm^3)

Z_R = section modulus of vessel shell, in.^{3} (mm^3)

θ = angle the axis of the nozzle makes with the normal to the vessel wall, deg

$\sigma_{\max}$ = maximum principal stress

When the following conditions are satisfied, the stress indices in Table 4-614 may be used:

(a) θ equals 45 deg; these indices may be used for angles θ less than 45 deg;

(b) nozzle is of circular cross section and has an axis that intersects the axis of the cylindrical vessel;

(c) design of the nozzle reinforcement is in accordance with the applicable rules of Article D-5;

(d) dimensional ratios are not greater than the following (*d, D,* and *t* are defined in 4-611):

Ratio	Maximum Value
D/t	40.0
d/D	0.5
$d/(Dt)^{1/2}$	3.0

The nominal pressure membrane stress to be used with the pressure indices in Table 4-614 is $P(D{+}t)/2t$ for Regions 1 and 2, and $P(d{+}t_P)/2t_P$ for Region 3.

4-620 EXPERIMENTAL STRESS ANALYSIS METHOD

4-621 Determination of Stress Intensities

The stress intensities for opening configurations which do not meet the requirements of Article D-5 and/or 4-613 shall be determined in accordance with the methods of Appendix 6.

TABLE 4-614
STRESS INDICES FOR LATERALS

Load	Stress	Region 1		Region 2		Region 3	
		Inside[1]	Outside[1]	Inside	Outside	Inside	Outside
Pressure P	σ_{max}	5.5	0.8	3.2	0.7	1.0	1.0
	S	5.75	0.8	3.5	0.75	1.2	1.1
In-plane branch moment	σ_{max}	0.1	0.1	0.5	0.5	1.0	1.6
	S	0.1	0.1	0.5	0.5	1.0	1.6
Vessel moment M_R or M_{RT}	σ_{max}	2.4	2.4	0.6	1.8	0.2	0.2
	S	2.7	2.7	0.7	2.0	0.3	0.3
Transverse nozzle moment M_{BT}	σ_{max}	0.13	. . .	0.06	. . .	. . .	2.50[2]
	S	0.22	. . .	0.07	. . .	. . .	2.50[2]

NOTES:

(1) Inside/outside refers to inside corner (pressure side)/outside fillet and in the plane of symmetry as shown in Fig. 4-614.

(2) Maximum stress/stress intensity in Region 3 for transverse moment M_{BT} occurs 90 deg away from in-plane moment.

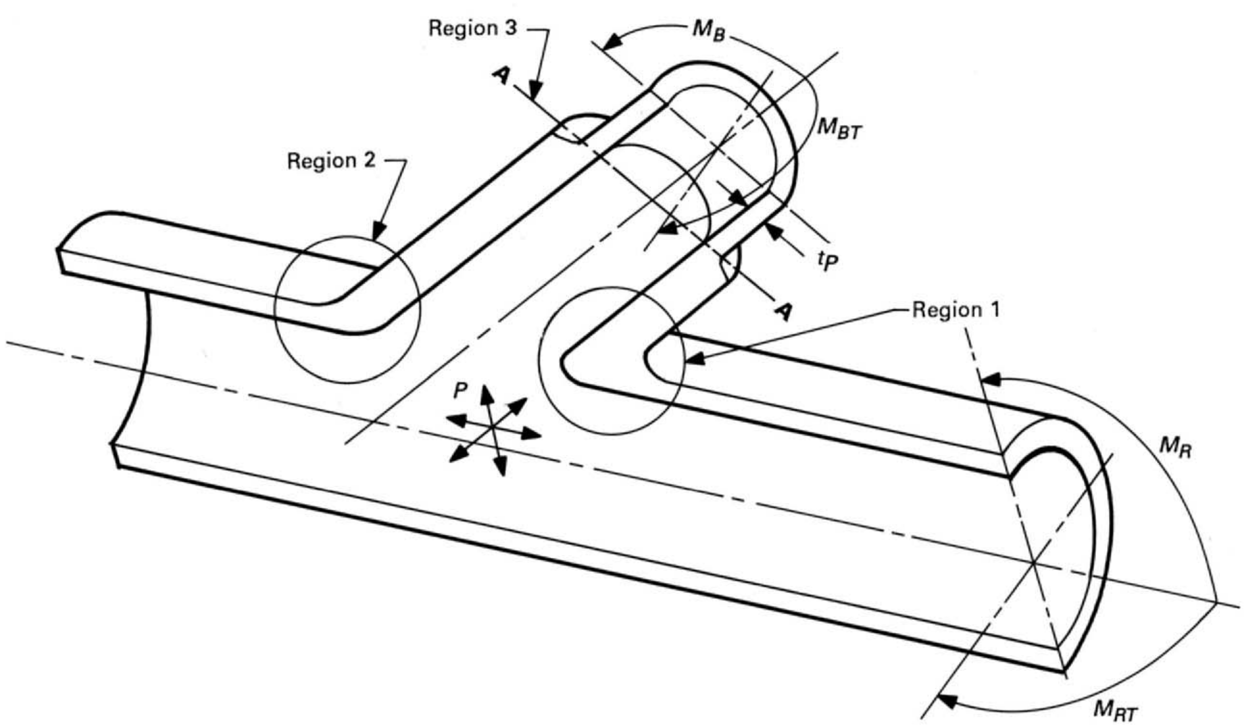


FIG. 4-614 LATERALS

4-622 Evaluation of Data for Similar but Slightly Different Configurations

In accordance with 6-102, reevaluation is not required for configurations for which there are available detailed experimental results that are consistent with the requirements of Appendix 6. In order that available experimental data may be interpreted as providing information pertinent to the analysis of slightly different configurations, thereby possibly minimizing the need for additional investigations, the following guidelines are presented.

(a) For an uncompensated opening or for an opening where the compensation is provided primarily by a uniform increase in vessel wall thickness, the stresses around the opening will increase with increasing d/D ratio of the opening (diameter of nozzle or opening to diameter of shell). Therefore, experimental data for a small d/D ratio cannot be safely applied to a larger d/D ratio but can be applied to a smaller d/D ratio provided the experiments were made at a d/D ratio < 0.5.

(b) For an uncompensated opening or for an opening where the compensation is provided primarily by a uniform increase in vessel wall thickness, the stresses around the opening will increase with increasing D/t ratio (thinner shell vessels). Therefore, experimental data for a relatively small D/t ratio cannot be safely applied to a larger D/t ratio, but can be applied to a smaller D/t ratio.

(c) Generally speaking, the stress data available in the literature are applicable only to single openings. Such data should be considered valid only for a connection sufficiently removed from another nozzle, opening, flange, or other major discontinuity that superposition of stresses will not produce an unacceptable value of stress intensity.

(d) Stresses at the outside juncture of a nozzle and shell are greatly influenced by the fillet or transition at the juncture. Generally speaking, stress data available in the literature are for certain specific fillet radii. Other factors being equal, these stress data may be considered valid for fillet radii equal to or greater than used in the test but should not be considered valid for smaller fillet radii or undefined fillets and transitions (such as for a triangular weld fillet, as commonly used).

ARTICLE 4-7
DISCONTINUITY STRESSES

4-700 GENERAL

(a) Pressure vessels usually contain regions where abrupt changes in geometry, material, or loading occur. These regions are known as *discontinuity areas* and the stresses associated with them are known as *discontinuity stresses.* The discontinuity stresses are required to satisfy the compatibility of deformations of these regions.

(b) This Article describes a general procedure for analyzing the discontinuity stresses. A numerical example is included to illustrate the procedure.

(c) To determine the principal stresses at a discontinuity, it is necessary to evaluate the stresses caused by:

(1) pressure;
(2) mechanical loads;
(3) thermal loads;
(4) discontinuity loads.

The stress intensities are then obtained by superposition of the stresses according to the rules given in 4-130.

4-710 INFORMATION REQUIRED

In order to perform a discontinuity analysis, the following information must be known:

(a) the dimensions of the vessel;

(b) the material properties (E, α, ν) of the component parts of the vessel (symbols as in 4-810);

(c) mechanical loads, such as pressure, dead weight, bolt loads, and pipe loads;

(d) temperature distribution in the component parts.

4-720 METHOD OF ANALYSIS

(a) The analysis of a pressure vessel containing discontinuity areas can be performed in a standard manner similar to the analysis of any statically indeterminate structure. The analysis is initiated by separating the vessel into shell elements of simple geometry (such as rings, cylinders, etc.) of which the structural behavior is known. The pressure, mechanical, and thermal loads acting on the structure are applied to the shell elements with a system of forces required to maintain the static equilibrium of each element. These loads and forces cause individual element deformations, which in general are not equal at the adjoining edges. The deformations at an element edge are defined as:

(1) radial displacement;
(2) rotation of meridian tangent.

A redundant moment and shear force must generally exist on the edges of the elements in order to have compatibility of deformations and restore continuity in the structure.

(b) At each juncture discontinuity, two equations can be written which express the equality of the combined deformations due to all the applied loads and the redundant forces and moments. One equation will express the equality of rotation; the other equation, the equality of displacement of the adjacent elements. The resulting system of simultaneous equations can be solved to obtain the redundant moment and shear force at each juncture.

4-721 Procedure for Discontinuity Analysis

The following are the basic steps to follow for determining the redundant shear and moment that may exist at a pressure vessel discontinuity.

(a) Separate the vessel into individual shell elements at locations of discontinuity.

(b) Calculate the edge deformations of each element, caused by a unit shear force and a unit moment at each edge. These values are known as *influence coefficients.* The deformations due to local flexibilities may be considered in the calculation of these influence coefficients.

(c) Calculate the edge deformations of each element, caused by loads other than redundant loads.

(d) Calculate the edge deformations of each element, caused by the temperature distributions.

(e) At each juncture of two elements, equate the total radial displacements and the total rotations of each element.

(f) Solve the final system of simultaneous equations for the redundant shears and moments.

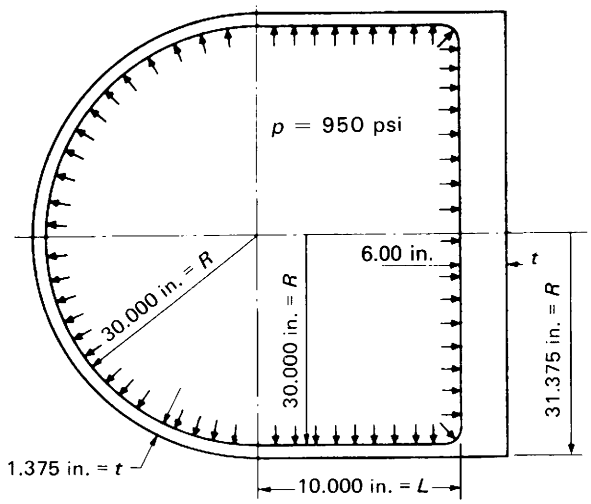


FIG. 4-730.1

4-722 Stresses

When the values of the redundant shear forces and moments have been determined, the stresses resulting from the redundant loadings may be computed by conventional methods. The final stresses for each element are determined by combining these stresses with the stresses which would exist in the individual shell elements of Step 1.

4-730 EXAMPLE ILLUSTRATING THE APPLICATION OF 4-721

Given

A pressure vessel as shown in Fig. 4-730.1. It is constructed of SA-302 Grade B steel and subjected to an internal pressure of 950 psi (6 200 kPa) at 300°F (150°C). The vessel consists of:

(a) a hemispherical head
inside radius $R = 30$ in.
thickness $t = 1.375$ in.

(b) a cylindrical shell
inside radius $R = 30$ in.
thickness $t = 1.375$ in.
length $L = 10$ in.

(c) a flat head
outside radius $R = 31.375$ in.
thickness $t = 6$ in.

Material properties assumed:

$E = 29 \times 10^6$ psi
$\nu = 0.3$

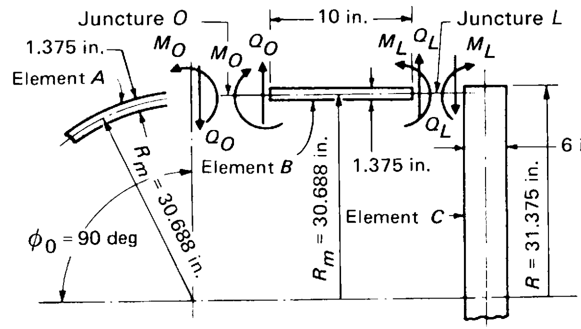


FIG. 4-730.2

Required

To calculate the discontinuity stresses at the locations of structural discontinuity.

Solution

Step 1. Separate the vessel at locations of discontinuity into individual elements. See Fig. 4-730.2.

Step 2. Calculate the influence coefficients.

Element A, Hemispherical Head:

From Article 4-3, 4-332(b), the lateral displacement and rotation at juncture O due to edge loads Q_o and M_o are given as:

$$w_{AO} = \delta_{AO} = -\frac{2R_m\lambda}{Et}Q_o + \frac{2\lambda^2}{Et}M_o$$

$$\theta_{AO} = -\frac{2\lambda^2}{Et}Q_o + \frac{4\lambda^3}{R_m Et}M_o$$

NOTE: For this case of a hemispherical shell, the lateral force H and the radial force Q are equal. Similarly, the lateral displacement δ and the radial displacement w are equal.

Substituting the given dimensions and material properties gives:

$$w_{AO} = \delta_{AO} = (-9.346327Q_o + 1.849550M_o) \times 10^{-6}$$

$$\theta_{AO} = (-1.849550Q_o + 0.731995M_o) \times 10^{-6}$$

Element B, Cylindrical Shell:

From Article 4-2, 4-232(a), the radial displacements and rotations at the edges O and L due to edge loadings Q_o, M_o, Q_L, and M_L are given as:

$$w_{BO} = (B_{11}/2\beta^3D)Q_o + (B_{12}/2\beta^2D)M_o + (G_{11}/2\beta^3D)Q_L + (G_{12}/2\beta^2D)M_L$$

$$-\theta_{BO} = (B_{12}/2\beta^2D)Q_o + (B_{22}/2\beta D)M_o + (G_{12}/2\beta^2D)Q_L + (G_{22}/2\beta D)M_L$$

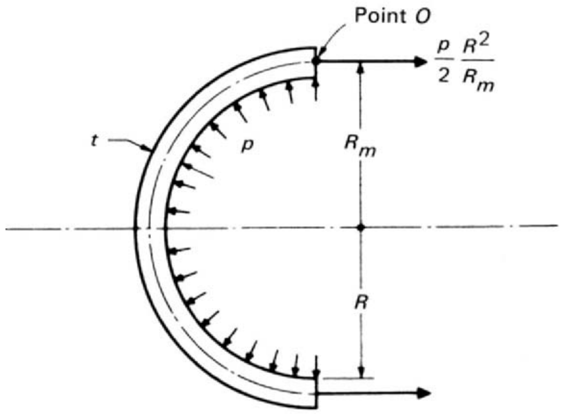


FIG. 4-730.3

$$w_{BL} = (G_{11}/2\beta^3 D)Q_o + (G_{12}/2\beta^2 D)M_o + (B_{11}/2\beta^3 D)Q_L + (B_{12}/2\beta^2 D)M_L$$

$$\theta_{BL} = (G_{12}/2\beta^2 D)Q_o + (G_{22}/2\beta D)M_o + (B_{12}/2\beta^2 D)Q_L + (B_{22}/2\beta D)M_L$$

Substituting the given dimensions and material properties gives:

$$w_{BO} = (10.697309Q_o + 2.114906M_o - 3.812809Q_L - 1.025641M_L) \times 10^{-6}$$

$$-\theta_{BO} = (2.114906Q_o + 0.792367M_o - 1.025641Q_L - 0.123127M_L) \times 10^{-6}$$

$$w_{BL} = (-3.812809Q_o - 1.025641M_o + 10.697309Q_L + 2.114906M_L) \times 10^{-6}$$

$$\theta_{BL} = (-1.025641Q_o - 0.123127M_o + 2.114906Q_L + 0.792367M_L) \times 10^{-6}$$

Element C, Flat Head:

From Article 4-5, 4-531.1(b), the radial displacement and rotation at juncture L due to edge loadings Q_L and M_L are given as:

$$w_{CL} = -\frac{2F_3}{3E(t/R)}Q_L + \frac{F_3}{ER(t/R)^2}M_L$$

$$\theta_{CL} = \frac{F_3}{ER(t/R)^2}Q_L - \frac{2F_3}{ER^2(t/R)^3}M_L$$

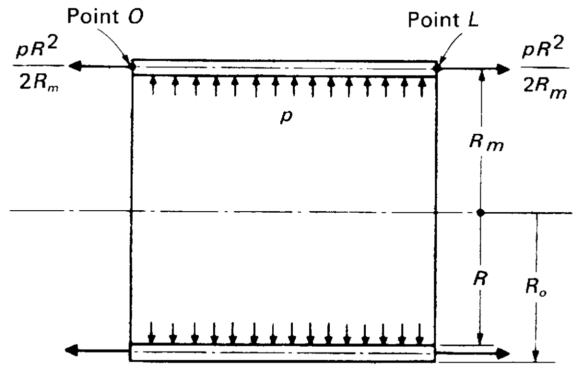


FIG. 4-730.4

Substituting the given dimensions and material properties gives:

$$w_{CL} = (-0.486320Q_L + 0.121580M_L) \times 10^{-6}$$

$$\theta_{CL} = (0.121580Q_L - 0.040530M_L) \times 10^{-6}$$

Step 3. Calculate the edge deformations due to the internal pressure.

Element A, Hemispherical Shell (See Fig. 4-730.3):

The lateral displacement of point O at the midsurface ($r = R_m$) of a hemispherical shell subjected to internal pressure is given by the expression:

$$w_o = \delta_o = p\frac{R^3}{2E(R_o^3 - R^3)R_m^2} \times [2R_m^3(1 - 2\nu) + R_o^3(1 + \nu)]$$

Substituting the dimensions, pressure, and material properties gives:

$$w_{AO(\text{pressure})} = 7{,}646 \times 10^{-6}$$

NOTE: An alternative expression may be used for the displacement of a thin hemispherical shell:

$$w = (1 - \nu)\frac{pR^2}{2Et}$$

There is no rotation resulting from the internal pressure and membrane forces as shown.

$$\theta_{AO(\text{pressure})} = 0$$

Element B, Cylindrical Shell (See Fig. 4-730.4):

The radial displacement of the midsurface of a closed end cylindrical shell subjected to internal pressure is given by the expression:

$$w = p\frac{R^2}{E(R_o^2 - R^2)R_m}[R_m^2(1 - 2\nu) + R_o^2(1 + \nu)]$$

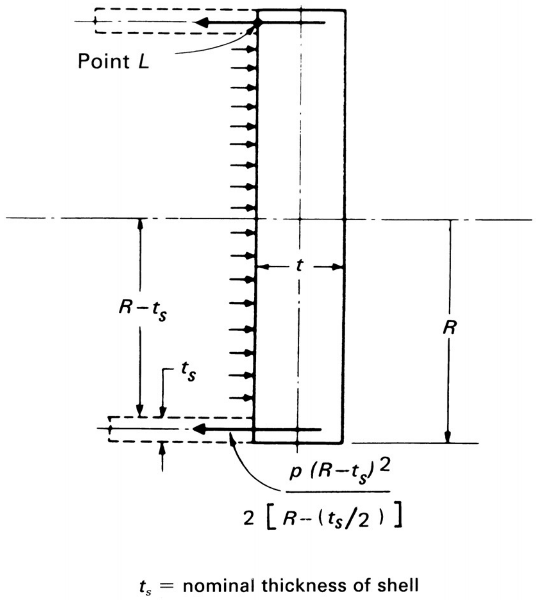


FIG. 4-730.5

Substituting the dimensions, pressure, and material properties gives:

$$w_{BO\,(\text{pressure})} = w_{BL(\text{pressure})} = 18{,}856 \times 10^{-6}$$

NOTE: An alternative expression may be used for the displacement of a thin cylindrical shell.

$$w = \left(1 - \frac{\nu}{2}\right)\frac{pRR_m}{Et}$$

There is no rotation resulting from internal pressure and the membrane forces shown.

$$\theta_{BO\,(\text{pressure})} = \theta_{BL(\text{pressure})} = 0$$

Element C, Flat Head (See Fig. 4-730.5):

The rotation of a flat head at point L due to internal pressure is given by Eq. (1) in 4-531.1(a):

$$\theta = \frac{F_1}{E(t/R)^3}\,p$$

Substituting the dimensions, pressure, and material properties gives:

$$\theta_{CL(\text{pressure})} = 4{,}399 \times 10^{-6}$$

The radial displacement at juncture L is given by Eq. (2) in 4-531.1(a):

$$w_{CL(\text{pressure})} = -\frac{t}{2}\,\theta_{CL} = -13{,}199 \times 10^{-6}$$

Step 4. Calculate the free deformations of the edges of each element caused by temperature distributions. In this example all parts of the vessel are at the same temperature and are of the same material; therefore, temperature deformations need not be considered.

Step 5. Equate the total lateral displacements and rotations of adjacent elements at each juncture.

Juncture O

$$w_{AO\,(\text{total})} = w_{BO\,(\text{total})}$$

$$(-9.346327Q_o + 1.849550M_o + 7{,}646) \times 10^{-6}$$
$$= (10.697309Q_o + 2.114906M_o - 3.812809Q_L$$
$$- 1.025641M_L + 18{,}856) \times 10^{-6} \quad (1)$$

$$\theta_{AO\,(\text{total})} = \theta_{BO\,(\text{total})}$$

$$(-1.849550Q_o + 0.731995M_o + 0) \times 10^{-6}$$
$$= (-2.114906Q_o - 0.792367M_o + 1.025641Q_L$$
$$+ 0.123127M_L + 0) \times 10^{-6} \quad (2)$$

Juncture L

$$w_{BL(\text{total})} = w_{CL(\text{total})}$$

$$(-3.812809Q_o - 1.025641M_o + 10.697309Q_L$$
$$+ 2.114906M_L + 18{,}856) \times 10^{-6}$$
$$= (-0.486320Q_L + 0.121580M_L - 13{,}199) \times 10^{-6} \quad (3)$$

$$\theta_{BL(\text{total})} = \theta_{CL(\text{total})}$$

$$(-1.025641Q_o - 0.123127M_o + 2.114906Q_L$$
$$+ 0.792367M_L + 0) \times 10^{-6}$$
$$= (0.121580Q_L - 0.040530M_L + 4{,}399) \times 10^{-6} \quad (4)$$

Combining like terms and multiplying through by 10^6 results in the following system of simultaneous equations which express compatibility at the junctures:

$$-20.04363Q_o - 0.265356M_o$$
$$+ 3.8128090Q_L + 1.025641M_L = 11{,}209 \quad (1)$$

$$0.265356Q_o + 1.52436M_o$$
$$- 1.025641Q_L - 0.123127M_L = 0 \quad (2)$$

$$-3.812809Q_o - 1.025641M_o$$
$$+ 11.183630Q_L + 1.993326M_L = -32{,}057 \quad (3)$$

$$-1.025641Q_o - 0.123127M_o$$
$$+ 1.993326Q_L + 0.832900M_L = 4{,}399 \quad (4)$$

Step 6. Solve the above equations for Q_o, M_o, Q_L, and M_L.

The results are:

$$Q_o = -808 \text{ lb/in.} = -0.808 \text{ kip/in.}$$

$$M_o = -2{,}977 \text{ in.-lb/in.} = -2.977 \text{ in.-kip/in.}$$

$$Q_L = -7151 \text{ lb/in.} = -7.151 \text{ kip/in.}$$

$$M_L = 20{,}963 \text{ in.-lb/in.} = 20.963 \text{ in.-kip/in.}$$

NOTE: A negative sign indicates that the actual direction of the loading is opposite to that chosen in Step 1.

Step 7. Compute the discontinuity stresses at each juncture due to the redundants Q_o, M_o, Q_L, and M_L.

To illustrate the procedure, these stresses will be computed in the cylindrical shell (element B) at both junctures O and L.

From 4-233:

$$\sigma_l(x) = \pm 6M(x)/t^2$$

$$\sigma_t(x) = Ew(x)/(R + t/2) \pm 6\nu M(x)/t^2$$

$$\sigma_r = 0$$

(a) Juncture O. At juncture O, $M(x) = M_o$ and $w(x) = w_o$.

NOTE: When computing $\sigma_t(x)$ only the radial displacement due to the redundant shear forces and moments should be used. The free displacements from Steps 3 and 4 should not be included.

$$w_{BO} = (10.697309Q_o + 2.114906M_o - 3.812809Q_L$$

$$- 1.025641M_L) \times 10^{-6}$$

$$= -0.009170 \text{ in.}$$

$$Ew_{BO} = -265.91 \text{ kip/in.}$$

$$M_o = -2.977 \text{ in.-kip/in.}$$

Inside surface

$$\sigma_l = 6(-2.977)/(1.375)^2 = -9.4 \text{ ksi}$$

$$\sigma_t = \frac{-265.91}{30.6875} + 6(0.3)(-2.97)/(1.375)^2$$

$$= -11.5 \text{ ksi}$$

$$\sigma_r = 0$$

Outside surface

$$\sigma_l = -6(-2.977)/(1.375)^2 = 9.4 \text{ ksi}$$

$$\sigma_t = \frac{265.91}{30.6875} - 6(0.3)(-2.97)/(1.375)^2$$

$$= -5.9 \text{ ksi}$$

$$\sigma_r = 0$$

(b) Juncture L. At juncture L, $M(x) = M_L$ and $w(x) = w_L$.

$$w_{BL} = (-3.812809Q_o - 1.025641M_o + 10.697309Q_L$$

$$+ 2.114906M_L) \times 10^{-6}$$

$$= -0.0260 \text{ in.}$$

$$Ew_{BL} = -754.87 \text{ kip/in.}$$

$$M_L = 20.963 \text{ in.-kip/in.}$$

Inside surface

$$\sigma_l = \frac{6(20.963)}{(1.375)^2} = 66.5 \text{ ksi}$$

$$\sigma_t = \frac{-754.87}{30.6875} + 6(0.3)(20.963)/(1.375)^2$$

$$= -4.7 \text{ ksi}$$

$$\sigma_r = 0$$

Outside surface

$$\sigma_l = -\frac{-6(20.963)}{(1.375)^2} = -66.5 \text{ ksi}$$

$$\sigma_t = \frac{-754.87}{30.6875} - 6(0.3)(20.963)/(1.375)^2$$

$$= -44.6 \text{ ksi}$$

$$\sigma_r = 0$$

NOTE: $E = 29 \times 10^6$ psi.

(c) The discontinuity stresses in the hemispherical shell may be computed by using the expressions given in 4-331 and 4-333.

(d) The discontinuity stresses in the flat head may be computed using the expressions given in 4-531.2.

Step 8. Compute the total stresses. The total stresses may be computed in any element at any juncture by combining the stresses due to the redundant shear forces and moments, as computed in Step 7, with the stresses resulting from all other loadings. In this case the stresses in the cylindrical shell, hemispherical shell, and flat head due to internal pressure may be computed by the expressions given in 4-221, 4-321, and 4-531.2, respectively. To illustrate the procedure, the total stresses in the cylindrical shell at junctures O and L will be computed.

The stresses in the cylindrical shell due to internal pressure may be computed from expressions (1), (2), and (3) in 4-221.

$$\sigma_l = p/(Y^2 - 1)$$

$$\sigma_t = p(1 + Z^2)/(Y^2 - 1)$$

$$\sigma_r = p(1 - Z^2)/(Y^2 - 1)$$

(a) Juncture O

Inside surface

$$Y = Z = \frac{R_o}{R} = \frac{31.375}{30.000} = 1.04583$$

$$p = 950 \text{ psi}$$

$$\sigma_l = 10{,}127 \text{ psi} = 10.1 \text{ ksi}$$

$$\sigma_t = 21{,}214 \text{ psi} = 21.2 \text{ ksi}$$

$$\sigma_r = -950 \text{ psi} = -1.0 \text{ ksi}$$

The stresses due to the redundant shear forces and moments were computed in Step 7 as:

$$\sigma_l = -9.4 \text{ ksi}$$

$$\sigma_t = -11.5 \text{ ksi}$$

$$\sigma_r = 0$$

The total stresses are:

$$\sigma_l = 10.1 + (-9.4) = 0.7 \text{ ksi}$$

$$\sigma_t = 21.2 + (-11.5) = 9.7 \text{ ksi}$$

$$\sigma_r = -1.0 + 0 = -1.0 \text{ ksi}$$

Outside surface

$$Z = 1$$

$$Y = 1.04583$$

$$\sigma_l = 10{,}127 \text{ psi} = 10.1 \text{ ksi}$$

$$\sigma_t = 20{,}264 \text{ psi} = 20.3 \text{ ksi}$$

$$\sigma_r = 0$$

The stresses due to the redundant shear forces and moments were computed as:

$$\sigma_l = 9.4 \text{ ksi}$$

$$\sigma_t = -5.9 \text{ ksi}$$

$$\sigma_r = 0$$

The total stresses are:

$$\sigma_l = 10.1 + (+9.4) = 19.5 \text{ ksi}$$

$$\sigma_t = 20.3 + (-5.9) = 14.4 \text{ ksi}$$

$$\sigma_r = 0 + (0) = 0$$

(b) Juncture L

Inside surface

The stresses due to the internal pressure are the same as at juncture O:

$$\sigma_l = 10.1 \text{ ksi}$$

$$\sigma_t = 21.2 \text{ ksi}$$

$$\sigma_r = -1.0 \text{ ksi}$$

The stresses due to the redundant shear forces and moments were computed as:

$$\sigma_l = 66.5 \text{ ksi}$$

$$\sigma_t = -4.7 \text{ ksi}$$

$$\sigma_r = 0$$

The total stresses are:

$$\sigma_l = 10.1 + (66.5) = 76.6 \text{ ksi}$$

$$\sigma_t = 21.2 + (-4.7) = 16.5 \text{ ksi}$$

$$\sigma_r = -1.0 + 0 = -1.0 \text{ ksi}$$

Outside surface

The stresses due to the internal pressure are the same as at juncture O:

$$\sigma_l = 10.1 \text{ ksi}$$

$$\sigma_t = 20.3 \text{ ksi}$$

$$\sigma_r = 0$$

The stresses due to redundant shear forces and moments were computed as:

$$\sigma_l = -66.5 \text{ ksi}$$

$$\sigma_t = -44.6 \text{ ksi}$$

$$\sigma_r = 0$$

The total stresses are:

$$\sigma_l = 10.1 + (-66.5) = -56.4 \text{ ksi}$$

$$\sigma_t = 20.3 + (-44.6) = -24.3 \text{ ksi}$$

$$\sigma_r = 0 + 0 = 0$$

Step 9. When evaluating the stresses in accordance with 4-134, the stress intensities at each location should be computed from the total principal stresses determined in Step 8.

When evaluating the stresses in accordance with 4-135 (Peak Stress Intensity), it is necessary to consider the influence of local stress concentrations upon the principal stresses determined in Step 8 before computing the stress intensities.

ARTICLE 4-8
THERMAL STRESSES

4-800 GENERAL

(a) Thermal stresses occur in a system, or part of a system, when thermal displacements (expansions or contractions) which would otherwise freely occur are partially or completely restrained.

(b) Thermal displacements may be induced by temperature distributions caused by heat transfer and internal heat generation.

(c) During transient conditions, the temperature distribution and thermal stresses vary with time. The analysis, therefore, requires consideration of the thermal stresses as a function of time during the transient.

4-810 INFORMATION NECESSARY TO CALCULATE THERMAL STRESSES

(a) In order to calculate thermal stresses, the following information must usually be known for each member comprising the system:

(1) the dimensions;

(2) the temperature distribution T as a function of a suitable coordinate system;

(3) the material properties:

(a) coefficient of thermal expansion α;

(b) modulus of elasticity E;

(c) Poisson's ratio ν.

α and E are temperature dependent quantities. Tables TE-1, TE-2, TE-3, TE-4, TM-1, TM-2, TM-3, and TM-4 in Subpart 2 of Section II, Part D provide these values for Code materials.

(b) Frequently, it is accurate enough to consider E and α for each material as constant at their instantaneous values for the average temperature range under consideration. If the lower limit of the temperature range is ambient, the instantaneous value of α for the average temperature coincides with the mean coefficient of thermal expansion.

4-820 METHOD OF CALCULATION

If closed form expressions for the thermal stresses are not available, the following procedure may be used for computing the thermal stress for a specified time θ.

(a) Express the temperature distribution T for each component as a function of the space coordinates t, l, and r.

(b) Divide the system (which may be of irregular shape or of complex geometry) into "free bodies" of simple shape (i.e., rings, cylinders, spherical shells, etc.).

(c) Calculate the "free body" stresses and deformations for each component resulting from the temperature distribution.

(d) Calculate the discontinuity thermal stresses by means of discontinuity analysis as described in Article 4-7.

(e) Superimpose the stresses determined in (c) and (d) above to obtain the combined thermal stresses.

4-850 LAYERED VESSELS

When calculating thermal stresses in layered pressure vessels, consideration shall be given to heat-transfer resistance at layer contact surfaces.

ARTICLE 4-9
STRESSES IN PERFORATED FLAT PLATES

4-900 PERFORATED FLAT PLATES

(a) This Article contains a method of analysis for flat perforated plates when subjected to directly applied loads or loadings resulting from structural interaction with adjacent members. This method applies to perforated plates which satisfy the following conditions.

(1) The holes are in an array of equilateral triangles.

(2) The holes are circular.

(3) There are 19 or more holes.

(4) The ligament efficiency is not less than 0.1 nor greater than 0.6 ($0.1 \le \eta \le 0.6$).

(b) The in-plane stiffening effect of the tubes in the perforations may be included in the analysis. The extent to which the tubes stiffen the perforated plate depends on the materials, the manufacturing processes, operating conditions, and degree of corrosion. This stiffening effect may be included in the calculations by including part or all of the tube walls in the ligament efficiency used to obtain the effective elastic constants of the plate. Such stiffening may either increase or decrease stresses in the plate itself and in the attached shells.

(c) The methods contained in this Article do not account for the staying action from tubes. Where applicable, the stiffening effect resulting from the staying action of the tubes may be incorporated into the solution, provided that an analysis is made.

(d) Article 4-9, 4-900 is not applicable to perforated flat plates of layered construction under these rules.

4-910 NOMENCLATURE

E = Young's modulus for plate material

E^* = effective Young's modulus for perforated plate (see Fig. 4-920.1 or Table 4-920.1)

E_t = Young's modulus for tube material

K = stress multiplier for stresses averaged across the width of the ligament but not through the thickness (see Fig. 4-930.1)

K_m = ratio of peak stress in reduced ligament to the peak stress in normal ligament

K_r = stress multiplier for circumferential stress in the plate rim (see Fig. 4-930.6)

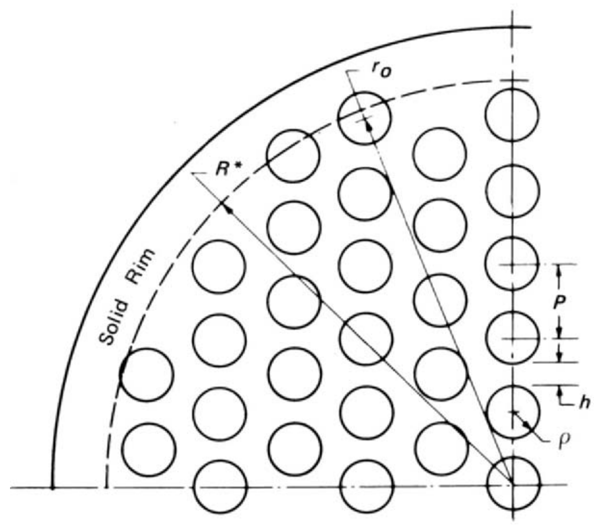


FIG. 4-910.1

K_{skin} = stress multiplier for thermal skin stress (see Fig. 4-940.1)

M = radial moment acting at edge of plate, in.-lb/in. (N-mm/mm) of circumference

P = nominal distance between hole centerlines (pitch)

Q = radial force acting at edge of plate, lb/in. (N/mm) of circumference

R^* = the effective radius of the perforated plate
$= r_o + \frac{1}{4}(P - h)$

S = stress intensity (see 4-931)

T_m = mean temperature averaged through the thickness of the plate

T_s = temperature of the surface of the plate

W = total ring load acting on plate (see Fig. 4-921.2)

Y = stress multiplier for peak ligament stresses (see Fig. 4-930.2)

c = radius of ring load (see Fig. 4-921.2)

h = nominal width of ligament at the minimum cross section

p_i = pressure inside tubes

p_s = pressure on surface where stress is computed, p_1 or p_2
p_1, p_2 = pressures acting on surfaces of the plate
Δp = differential pressure across the plate
r = designation of radial location in plate
r_o = radial distance from center of plate to center of outermost hole
t = thickness of plate
t_t = tube wall thickness
w = radial displacement of plate edge, in. (mm)
x = axis of symmetry of hole pattern through the smaller ligament thickness (see Figs. 4-930.3, 4-930.4, and 4-930.5)
y = axis of symmetry of hole pattern, perpendicular to x axis
ln = $\log_e$
α = coefficient of thermal expansion
β = biaxiality ratio $= \left(\frac{\sigma_r}{\sigma_\theta} \text{ or } \frac{\sigma_\theta}{\sigma_r}\right)$ or $\left(\frac{\sigma_1}{\sigma_2} \text{ or } \frac{\sigma_2}{\sigma_1}\right)$, where $-1 \leq \beta \leq 1$
η = ligament efficiency $= h/P$
θ = rotation of plate edge, radians
ν = Poisson's ratio
ν^* = effective Poisson's ratio for perforated plate (see Fig. 4-920.1 or Table 4-920.1)
ρ = radius of holes in the plate
σ_{ave} = larger absolute value of σ_r or σ_θ [see 4-931.1(a)]
σ_r = radial stresses in the equivalent solid plate
$\overline{\sigma}_r$ = radial stress averaged through the depth of the equivalent solid plate
σ_{rim} = nominal circumferential stress in solid rim
σ_{skin} = thermal skin stress
σ_1, σ_2 = principal stress in the plane of the equivalent solid plate (see 4-931.2)
σ_θ = tangential stress in the equivalent solid plate

4-920 ANALYSIS OF CIRCULAR PERFORATED AREA

(a) The analysis method for perforated plates presented in this Article utilizes the concept of the *equivalent solid plate*. In this method, the perforated plate is replaced by a solid plate which is geometrically similar to the perforated plate but has modified values of the elastic constants.

(b) The elastic modulus E and Poisson's ratio ν are replaced by the effective elastic modulus E^* and effective Poisson's ratio ν^* of the perforated plate, and conventional formulas for plates are used to determine the deformations and nominal stresses for the equivalent solid plate. The deformations so computed may be used directly in evaluating interaction effects. The actual values of the stress intensities in the perforated plate are determined by applying multiplying factors to the nominal stresses computed for the equivalent solid plate.

(c) The effective elastic constants are functions of the ligament efficiency η. The values are given in Fig. 4-920.1 or Table 4-920.1 for the range of $0.1 \leq \eta \leq 0.6$ in the form of ν^* versus η (for a material with $\nu = 0.3$), and E^*/E versus η. The stress multipliers are given in Figs. 4-930.1 through 4-930.7. The Y factors presented in Figs. 4-930.3 and 4-930.4 represent the largest values occurring through the thickness at the given angular position.

(d) The region of the perforated plate outside the effective radius R^* is called the plate rim. This unperforated portion of the plate may be considered as a separate connecting member (a ring or cylinder) and the structure may be analyzed in accordance with the procedures of Article 4-7.

4-921 Analysis of the Equivalent Solid Plate

In the following paragraphs formulas are given for the nominal stresses and edge displacements for the equivalent solid circular plate under various axisymmetric load conditions.

4-921.1 Edge Loads (See Fig. 4-921.1)

(a) Stresses at any location on the surface of the equivalent solid plate:

$$\sigma_r = \sigma_\theta = \frac{Q}{t} \pm \frac{6M}{t^2} \qquad (1)$$

When double signs are used, the upper sign applies to the top surface as shown in the Figure.

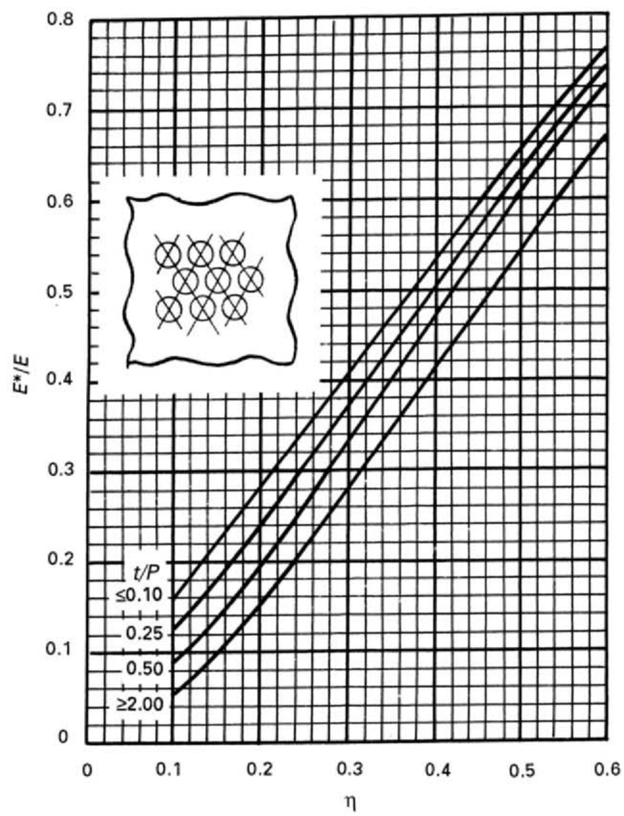
(b) Edge displacements of midplane at R^*:

$$w = \frac{R^*}{E^*t}(1 - \nu^*)Q \qquad (1)$$

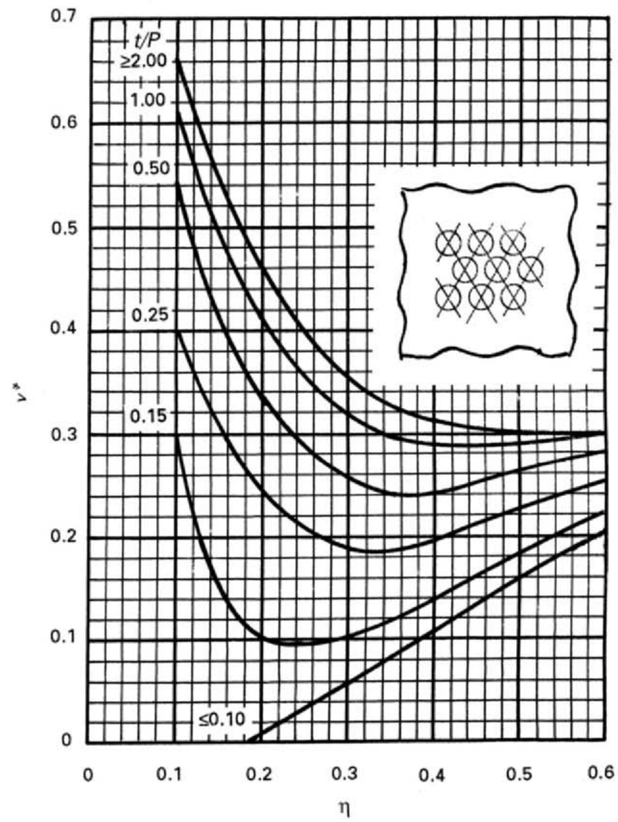
$$\theta = -\frac{12R^*}{E^*t^3}(1 - \nu^*)M \qquad (2)$$

4-921.2 Ring Loads Transverse to the Plane of the Plate (See Fig. 4-921.2)

(a) Stresses at any radial location r on the surfaces of the equivalent solid plate:



(a) E^*/E (Equilateral Triangular Pattern)



(b) ν^* (Equilateral Triangular Pattern)

GENERAL NOTE: See Table 4-920.1 for formulas.

FIG. 4-920.1 CURVES OF THE DETERMINATION OF E^*/E AND ν^*
(Equilateral Triangular Pattern)

TABLE 4-920.1
POLYNOMIAL COEFFICIENTS α_i AND β_j FOR THE DETERMINATION OF E^*/E AND ν^*
(Equilateral Triangular Pattern)

(a) Equilateral Triangular Pattern $E^*/E = \alpha_0 + \alpha_1\eta + \alpha_2\eta^2 + \alpha_3\eta^3 + \alpha_4\eta^4$

t/P	α_0	α_1	α_2	α_3	α_4
0.10	0.0353	1.2502	−0.0491	0.3604	−0.6100
0.25	0.0135	0.9910	1.0080	−1.0498	0.0184
0.50	0.0054	0.5279	3.0461	−4.3657	1.9435
2.00	−0.0029	0.2126	3.9906	−6.1730	3.4307

(b) Equilateral Triangular Pattern $\nu^* = \beta_0 + \beta_1\eta + \beta_2\eta^2 + \beta_3\eta^3 + \beta_4\eta^4$

t/P	β_0	β_1	β_2	β_3	β_4
0.10	−0.0958	0.6209	−0.8683	2.1099	−1.6831
0.15	0.8897	−9.0855	36.1435	−59.5425	35.8223
0.25	0.7439	−4.4989	12.5779	−14.2092	5.7822
0.50	0.9100	−4.8901	12.4325	−12.7039	4.4298
1.00	0.9923	−4.8759	12.3572	−13.7214	5.7629
2.0	0.9966	−4.1978	9.0478	−7.9955	2.2398

GENERAL NOTES:

(a) For both parts (a) and (b) of this Table, these coefficients are only valid for $0.1 \le \eta \le 0.6$.

(b) For both parts (a) and (b) of this Table: for values of t/P lower than 0.1, use $t/P = 0.1$; for values of t/P higher than 2.0, use $t/P = 2.0$.

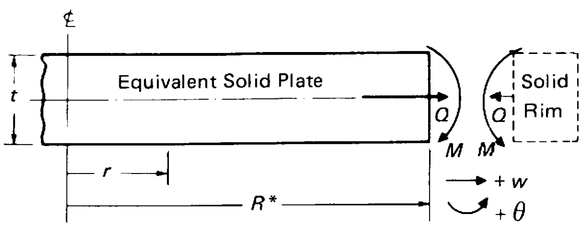


FIG. 4-921.1

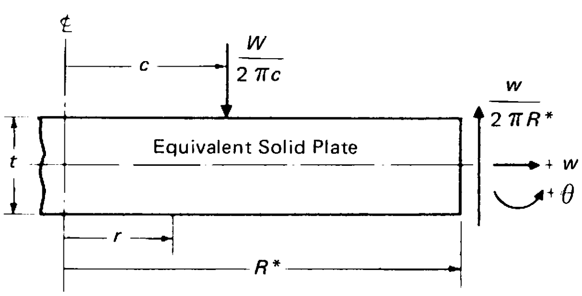


FIG. 4-921.2

For $r \le c$

$$\sigma_r = \sigma_\theta = \mp \frac{3W}{2\pi t^2}\left[\frac{1}{2}(1-\nu^*) - \frac{1}{2}(1-\nu^*)\left(\frac{c}{R^*}\right)^2 + (1+\nu^*)\ln\frac{R^*}{c}\right] \quad (1)$$

For $r > c$

$$\sigma_r = \mp \frac{3W}{2\pi t^2}\left[\frac{1}{2}(1-\nu^*)\left(\frac{c}{r}\right)^2 - \frac{1}{2}(1-\nu^*)\left(\frac{c}{R^*}\right)^2 + (1+\nu^*)\ln\frac{R^*}{r}\right] \quad (2)$$

$$\sigma_\theta = \mp \frac{3W}{2\pi t^2}\left[(1-\nu^*) - \frac{1}{2}(1-\nu^*)\left(\frac{c}{r}\right)^2 - \frac{1}{2}(1-\nu^*)\left(\frac{c}{R^*}\right)^2 + (1+\nu^*)\ln\frac{R^*}{r}\right] \quad (3)$$

(b) Edge displacements of midplane at $r = R^*$:

$$w = 0 \quad (1)$$

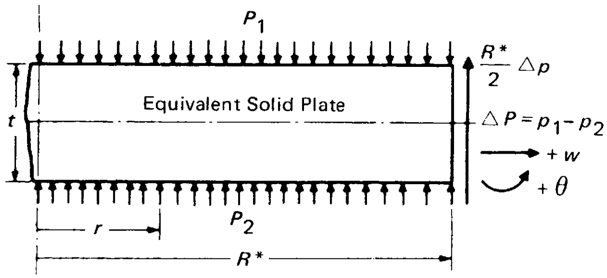


FIG. 4-921.3

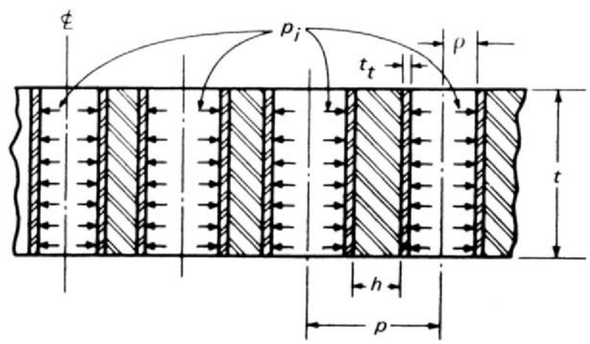


FIG. 4-921.4

$$\theta = \frac{3R^*}{\pi E^* t^3}(1 - \nu^*)\left[1 - \left(\frac{c}{R^*}\right)^2\right][W] \qquad (2)$$

4-921.3 Uniformly Distributed Pressure Loads (See Fig. 4-921.3)

(a) Stresses at any location r on the surfaces of the equivalent solid plate:

$$\sigma_r = \mp \frac{3}{8}\left(\frac{R^*}{t}\right)^2 (3 + \nu^*)\left[1 - \left(\frac{r}{R^*}\right)^2\right][\Delta p] \qquad (1)$$

$$\sigma_\theta = \mp \frac{3}{8}\left(\frac{R^*}{t}\right)^2 \left[(3 + \nu^*) - (1 + 3\nu^*)\left(\frac{r}{R^*}\right)^2\right][\Delta p] \qquad (2)$$

(b) Edge displacement of midplane at $r = R^*$:

$$w = \frac{\nu R^*}{E}\frac{(p_1 + p_2)}{2} \qquad (1)$$

$$\theta = \frac{3}{2}\frac{(R^*)^3}{E^* t^3}(1 - \nu^*)[\Delta p] \qquad (2)$$

4-921.4 Pressure in Tubes or Perforations (See Fig. 4-921.4)

(a) Stresses at any location in the equivalent solid plate:

$$\sigma_r = \sigma_\theta = \frac{h}{P}\frac{(P - h - 2t_t)}{\left(h + 2\frac{E_t}{E}t_t\right)} p_i \qquad (1)$$

(b) Edge displacements of midplane at $r = R^*$:

$$w = \frac{R^*}{E}\left[\frac{E}{\overline{E}^*}(1 - \nu^*) - (1 - \nu)\right] p_i \qquad (1)$$

where $\overline{E}^*/E$ and ν^* should be evaluated for the ligament efficiency:

$$\frac{h}{P} = \frac{h + \frac{2E_t}{E} t_t}{P}$$

using Fig. 4-920.1;

$$\theta = 0 \qquad (2)$$

4-930 STRESS INTENSITIES AND STRESS LIMITS FOR PERFORATED PLATES

In the following paragraphs formulas are given for the stress intensities in a perforated plate using the stresses determined for the equivalent solid plate.

4-931 Typical Ligaments in a Uniform Pattern

4-931.1 Mechanical and Pressure Loads on Circular Plates

(a) The stress intensity, based on stresses averaged across the minimum ligament width and through the thickness of the plate, is limited according to 4-131 and is computed from the larger of

$$S = \frac{P}{h}\sqrt{\left(\frac{\Delta p R^*}{t} + \frac{W}{\pi t R^*}\right)^2 + (\overline{\sigma}_r)^2} \qquad (1)$$

or

$$S = \frac{1}{2}\frac{P}{h}\left\{\sqrt{\left(\frac{\Delta p R^*}{t} + \frac{W}{\pi t R^*}\right)^2 + (\overline{\sigma}_r)^2} + \overline{\sigma}_r + \frac{2p_i h}{P}\right\} \qquad (2)$$

where only the positive root is used.

(1) The first term under the radical reflects the effect of the transverse shear stress due to the mechanical and pressure loads. It is a maximum in the outermost ligament of the perforated region, but it may be determined for any radius, larger than c, by substituting r for R^* in the expression. For $r < c$, the $W/\pi t R^*$ term should be omitted.

(2) $\overline{\sigma}_r$ is the stress resulting from applied in-plane loading averaged through the thickness of the equivalent solid plate. It includes the stresses due to pressure in the tubes or perforations given in 4-921.4. No bending stresses are included.

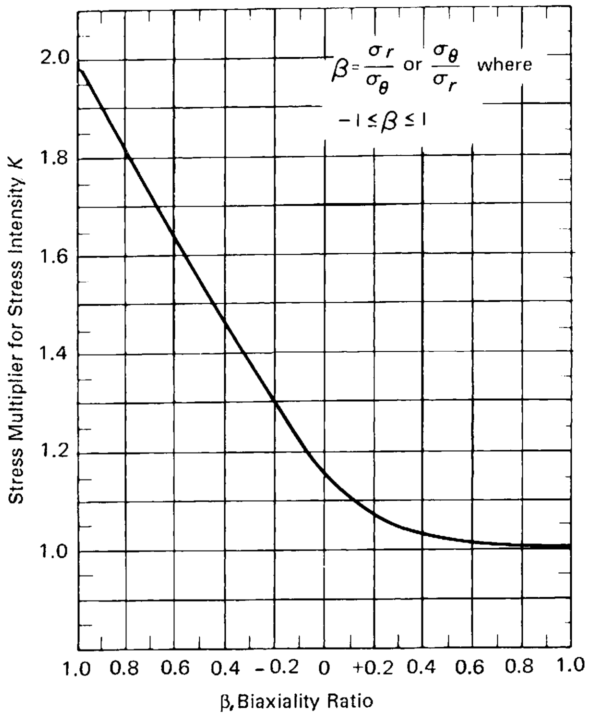


FIG. 4-930.1

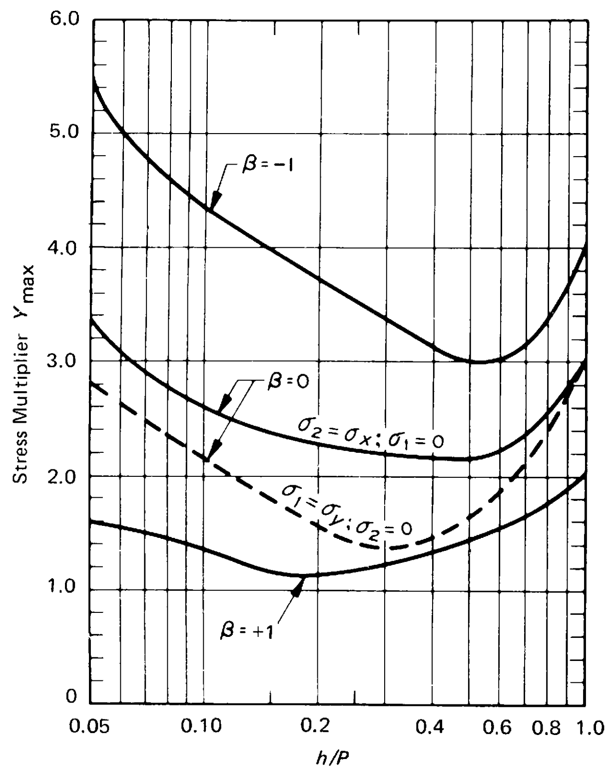


FIG. 4-930.2

(b) The stress intensity, based on stresses averaged across the minimum ligament width but not through the thickness of the plate, is limited according to 4-133 and is computed from

$$S = K \frac{P}{h} \sigma_{ave} \qquad (1)$$

where

K = stress multiplier from Fig. 4-930.1
σ_{ave} = the larger value of σ_r or σ_θ, caused by mechanical loading and structural interaction with adjacent members, computed as the sum of the surface stresses in the equivalent solid plate using the applicable formulas in 4-920. Effects of temperature are not included.

4-931.2 Combined Mechanical and Thermal Effects

(a) The range of the stress intensity based on stresses averaged across the minimum ligament width but not through the thickness of the plate is limited according to 4-134 and is computed from

$$S_m = K \frac{P}{h} \sigma_1 \qquad (1)$$

where

K = stress multiplier from Fig. 4-930.1
σ_1 = the larger absolute value of σ_r or σ_θ, caused by mechanical loading or structural interaction with adjacent members, computed as the sum of the surface stresses in the equivalent solid plate using the applicable formulas in 4-920 and 4-940. The effects of temperature are included in the consideration of the structural interaction with adjacent members.

(b) The peak stress intensity due to all loadings is limited by cumulative fatigue considerations as described in 5-100 and is given by:

$$S_m = Y_{max} \frac{P}{h} \sigma_1 + p_s \qquad (1)$$

where

p_s = pressure on the surface where the stress is being computed
σ_1 = principal stress having the larger absolute value in the plate of the equivalent solid plate
σ_2 = principal stress having the smaller absolute value in the plate of the equivalent solid plate

Y_{max} = stress multiplier given in Fig. 4-930.2 as a function of the biaxiality $\beta = \sigma_2/\sigma_1$

(1) Equivalent solid plate stresses due to various loads should be superimposed in order to obtain σ_1 and σ_2, before any multipliers are applied, and the signs of σ_1 and σ_2 should be maintained.

(2) The solid curves in Fig. 4-930.2 give the maximum stress multipliers for the worst angular orientation of σ_1 and σ_2 with respect to the axes of symmetry x and y of the hole pattern. In some cases, the worst orientation may not exist anywhere in the plate and the use of lower stress multipliers is justified. An important case concerns the thermal stress produced by a temperature gradient across the diametral lane in a perforated plate. Such a gradient causes a uniaxial stress oriented parallel to the diametral lane. If the diametral lane is parallel to the y axis as shown in Fig. 4-930.3, the stress multiplier given by the dashed line in Fig. 4-930.2 may be used.

(c) Equation (1) will give the maximum stress intensity for any loading system. Equation (1) is not adequate for more complex cyclic histories where the angular orientation of the maximum stress intensity varies during the cycle. In such cases, it is necessary to compute the stress history at each angular orientation ϕ using Eq. (2):

$$S_\phi = Y_1 \frac{P}{h} \sigma_1 + Y_2 \frac{P}{h} \sigma_2 + p_s \quad (2)$$

where

S_ϕ = peak stress intensity at the angular orientation ϕ

Y_1, Y_2 = stress multipliers given in Figs. 4-930.3, 4-930.4, and 4-930.5 for various orientations of the principal stresses, σ_1 and σ_2, computed for the equivalent solid plate. Note that these figures give stress multipliers for particular angular orientations only. The graph for the angular orientation closest to the actual angular orientation should be used. This is sufficiently accurate since the maximum possible difference between the actual orientation and the nearest orientation given in Figs. 4-930.3, 4-930.4, and 4-930.5 is only 7.5 deg. Examples for the computation of S_ϕ are given below.

Example 1: The combined stresses in the equivalent solid plate for a perforated plate of 0.05 ligament efficiency were computed at a point as

$$\sigma_r = 750 \text{ psi}$$

$$\sigma_\phi = -1{,}100 \text{ psi}$$

and σ_r is rotated 12 deg, measured from the y axis of the hole pattern. To determine the value of σ_ϕ at 40 deg from the y axis, use the following procedure: let $\sigma_1 = \sigma_r$, $\sigma_2 = \sigma_\theta$. Since the angular orientation of 12 deg is closest to 15 deg, use Fig. 4-930.5 for the stress multipliers. Read at $\phi = 40$ deg on Scale A: $Y_1 = +1.65$; on Scale B: $Y_2 = -0.70$. Then, from 4-931.2(b), Eq. (2), the peak stress intensity is computed as

$$S_\phi = \frac{1}{0.05}(+1.65)(750) + \frac{1}{0.05}(-0.70)(-1{,}100)$$

$$= 40{,}200 \text{ psi}$$

Example 2: For the same plate as above, at another point, the direction of σ_r coincides with the x axis. Let $\sigma_r = \sigma_2$, $\sigma_\theta = \sigma_1$. Read at $\phi = 40$ deg, from Fig. 4-930.3, $Y_1 = +2.75$, and from Fig. 4-930.4, $Y_2 = -1.80$. Then:

$$S_\phi = \frac{1}{0.05}(2.75)(-1{,}100) + \frac{1}{0.05}(-1.80)(750)$$

$$= -87{,}500 \text{ psi}$$

(d) The peak stress intensity at the outermost hole is computed from

$$S = K_r \sigma_{rim} + p_s \quad (1)$$

where

K_r = a stress multiplier from Fig. 4-930.6

σ_{rim} = nominal circumferential stress in the rim

(e) The stresses given by Eqs. (1) and (2) of 4-931.2(b) and Eq. (1) of 4-931.2(c) are limited by cumulative fatigue consideration as described in 5-100, Analysis for Cyclic Operation.

4-932 Irregular Ligament Patterns or Thin Ligaments in a Normally Uniform Pattern

In an irregular or thin ligament in a nominally uniform pattern, the stresses are determined as required below.

(a) The stress intensity, based upon the ligament stresses averaged across the ligament width and through the plate thickness, due to pressure plus other mechanical loads, is limited to $3.0S_m$ in accordance with Fig. 4-130.1. The appropriate value is computed according to 4-931.1(a), where h_a (the actual width of the thin ligament) is used in place of the nominal width h.

(b) The peak stress intensity in the thin ligament, due to mechanical loading and structural interaction with adjacent members, including thermal effects, is limited by cumulative fatigue considerations. This peak stress intensity is computed by multiplying the peak stress intensity for a nominal thickness ligament by the K_m value given in Fig. 4-930.7.

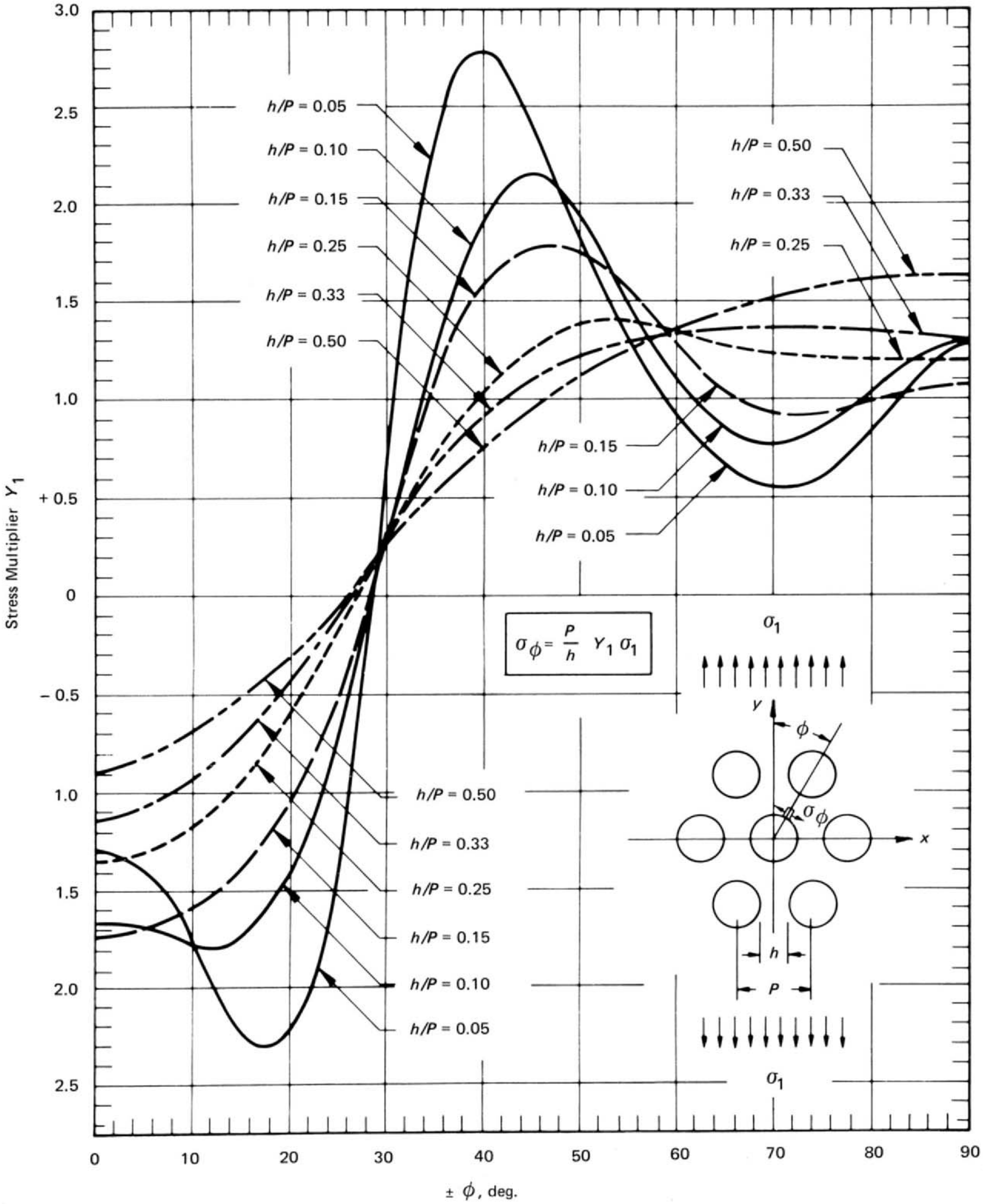

3.0
2.5
2.0
1.5
1.0
+ 0.5
0
− 0.5
1.0
1.5
2.0
2.5
Stress Multiplier Y_1
0
10
20
30
40
50
60
70
80
90
± ϕ, deg.
h/P = 0.05
h/P = 0.10
h/P = 0.15
h/P = 0.25
h/P = 0.33
h/P = 0.50
h/P = 0.50
h/P = 0.33
h/P = 0.25
h/P = 0.15
h/P = 0.10
h/P = 0.05
h/P = 0.50
h/P = 0.33
h/P = 0.25
h/P = 0.15
h/P = 0.10
h/P = 0.05
$\sigma_\phi = \frac{P}{h} Y_1 \sigma_1$
σ_1
y
x
ϕ
σ_ϕ
h
P
σ_1

FIG. 4-930.3

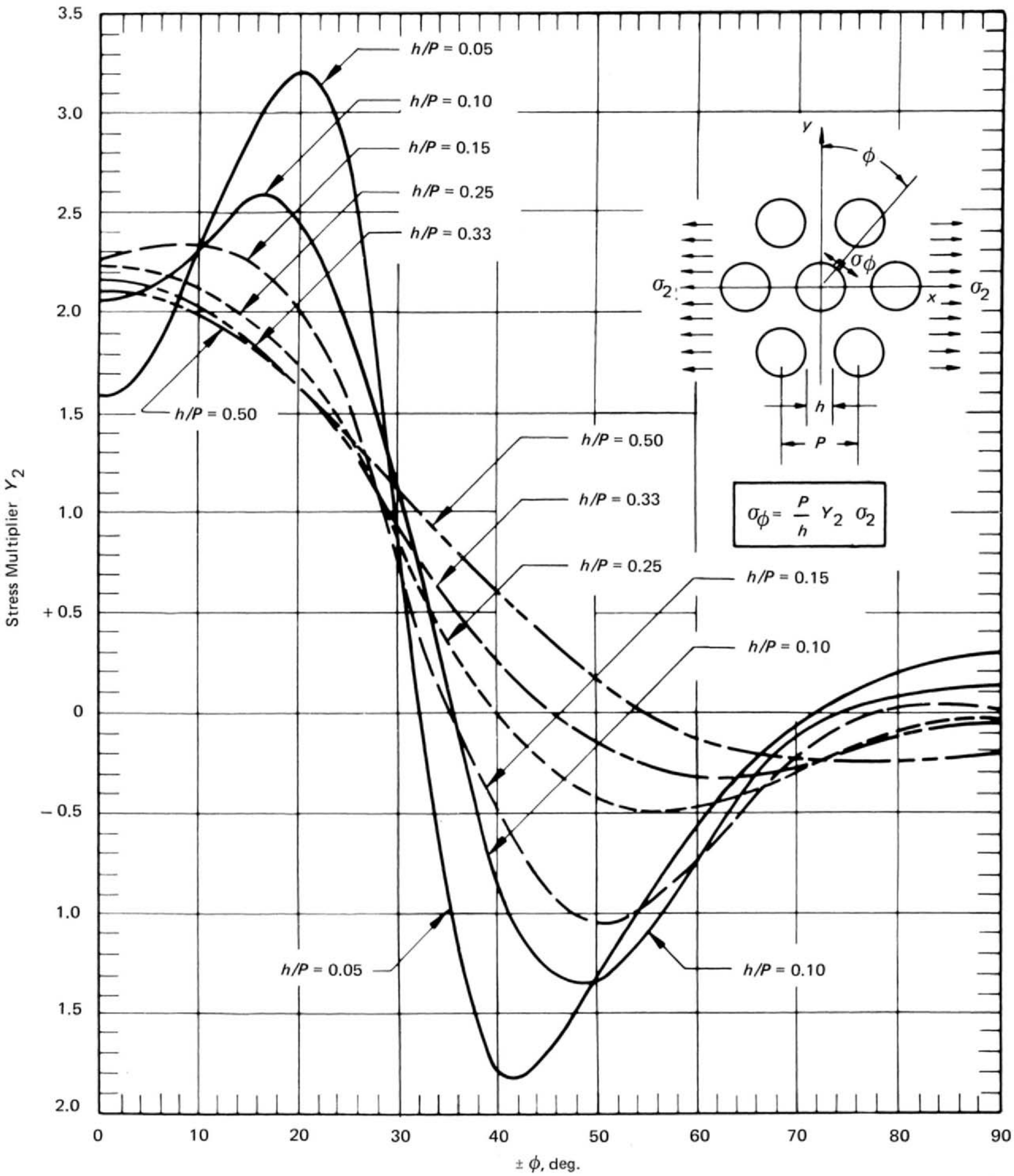
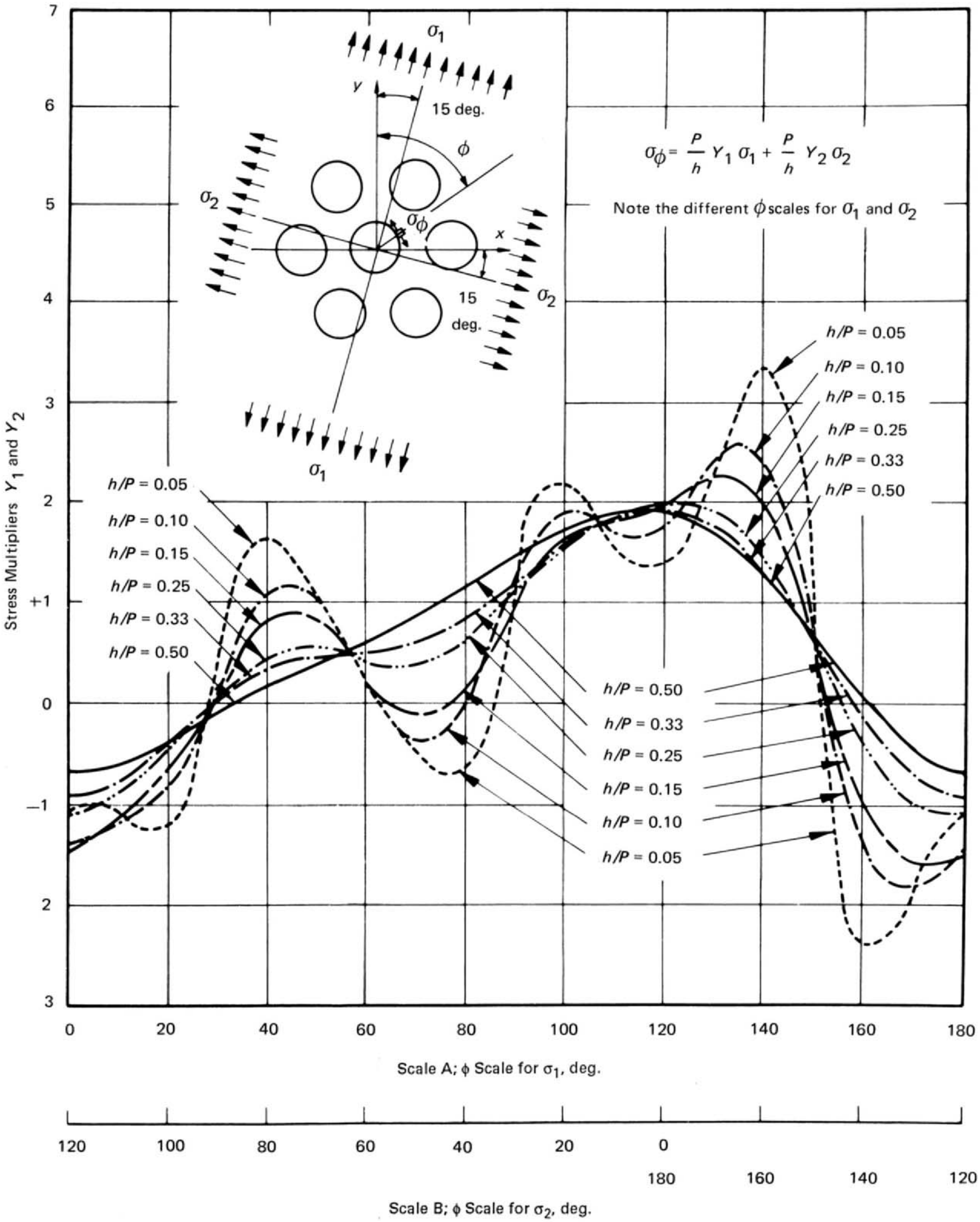

h/P = 0.05
h/P = 0.10
h/P = 0.15
h/P = 0.25
h/P = 0.33
h/P = 0.50
h/P = 0.50
h/P = 0.33
h/P = 0.25
h/P = 0.15
h/P = 0.10
h/P = 0.05
h/P = 0.10
y
φ
σφ
σ2
σ2
x
h
P
σφ = P/h Y2 σ2
Stress Multiplier Y2
± φ, deg.
3.5
3.0
2.5
2.0
1.5
1.0
+ 0.5
0
– 0.5
1.0
1.5
2.0
0
10
20
30
40
50
60
70
80
90

FIG. 4-930.4



σ_1
y
15 deg.
ϕ
σ_2
σ_ϕ
x
15
deg.
σ_2
σ_1
$\sigma_\phi = \frac{P}{h} Y_1 \sigma_1 + \frac{P}{h} Y_2 \sigma_2$
Note the different ϕ scales for σ_1 and σ_2
Stress Multipliers Y_1 and Y_2
h/P = 0.05
h/P = 0.10
h/P = 0.15
h/P = 0.25
h/P = 0.33
h/P = 0.50
7
6
5
4
3
2
+1
0
−1
2
3
0
20
40
60
80
100
120
140
160
180
Scale A; ϕ Scale for σ_1, deg.
120
100
80
60
40
20
0
180
160
140
120
Scale B; ϕ Scale for σ_2, deg.

FIG. 4-930.5

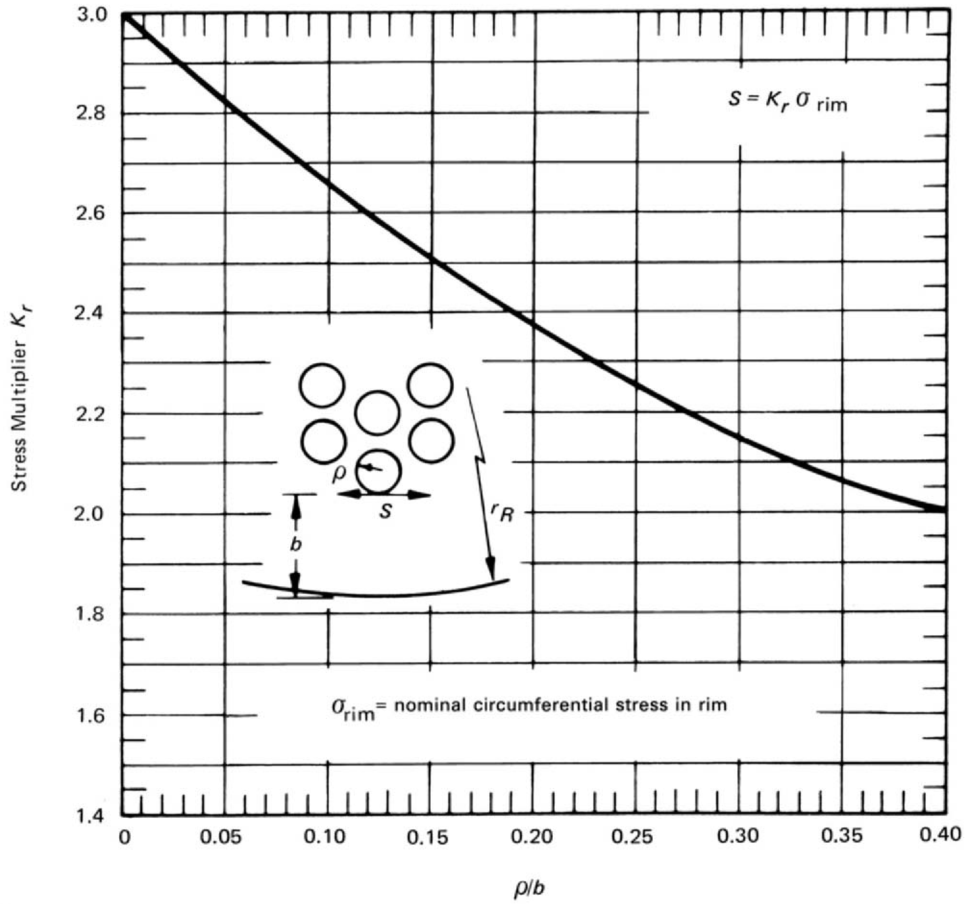


FIG. 4-930.6

(c) The peak stress intensity in a nominal ligament is calculated as indicated in 4-931.2(b).

4-940 THERMAL SKIN EFFECT

(a) General Considerations. In certain cases, the temperature gradient through the thickness of a perforated plate can be closely approximated by a step change in the metal temperature near the surface of the plate. In such a case, significant thermal stresses develop only in the skin layer of the plate at the surface where the temperature change occurs and the thermal stresses in the remainder of the plate are negligible.

(b) Peak Stress Intensity. The maximum thermal skin stress on the surface of a perforated plate can be computed from the equation:

$$\sigma_{skin} = K_{skin} Y_{max} \left(\frac{P}{h}\right)\left(\frac{E\alpha}{1-\nu}\right)(T_m - T_s) \qquad (1)$$

where

E, α, ν = unmodified material constants

Y_{max} = stress multiplier from Fig. 4-930.1, for $\beta = +1$

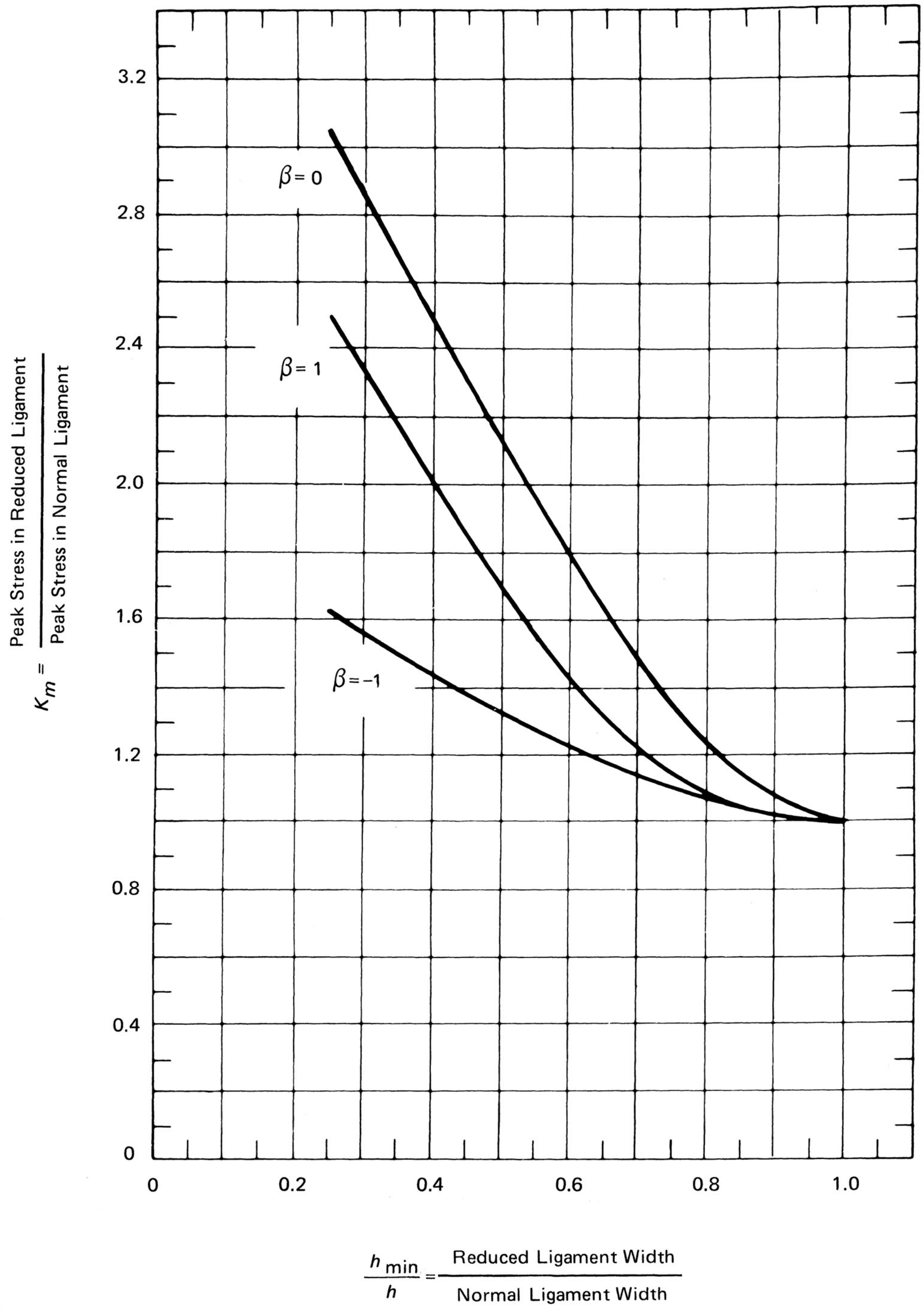
T_m = mean temperature of the plate

T_s = temperature of the plate at the surface under consideration

P, h = pitch and ligament width, respectively

(c) Peak Stress Intensities When Thermal Skin Stresses Are Included. When thermal skin stresses are to be combined with other stresses to obtain the peak stress intensity, Eq. (1) above may not be used. In such a case the thermal stresses at any location on the surface of the equivalent solid plate are given by:

$$\sigma_r = \sigma_\theta = K_{skin} \frac{E\alpha}{1-\nu}(T_m - T_s) \qquad (2)$$



3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0
β = 0
β = 1
β = −1
$K_m = \frac{\text{Peak Stress in Reduced Ligament}}{\text{Peak Stress in Normal Ligament}}$
0
0.2
0.4
0.6
0.8
1.0
$\frac{h_{min}}{h} = \frac{\text{Reduced Ligament Width}}{\text{Normal Ligament Width}}$

FIG. 4-930.7

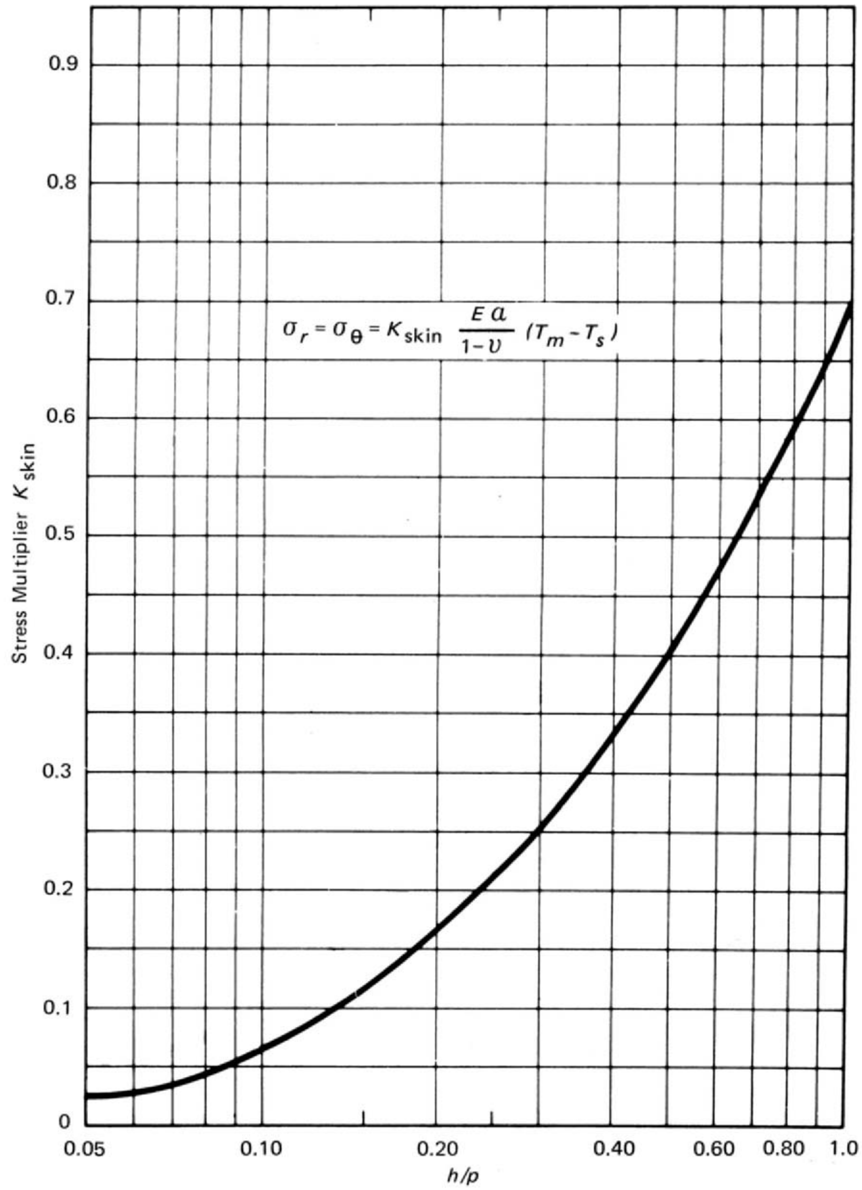


FIG. 4-940.1

where

K_{skin} = a stress ratio from Fig. 4-940.1
T_m = mean temperature of the plate
T_s = surface temperature of the plate
E, α = material constants, unmodified

The equivalent solid plate stresses given by Eq. (2) can then be combined with other solid plate stresses, and the method given in 4-931.2(b) can be used to obtain the peak stress intensity.

MANDATORY APPENDIX 5
DESIGN BASED ON FATIGUE ANALYSIS

ARTICLE 5-1

5-100 ANALYSIS FOR CYCLIC OPERATION

The suitability of a vessel component for specified operating conditions involving cyclic application of loads and thermal conditions shall be determined by the methods described herein, except that the suitability of high strength bolts shall be determined by the methods of 5-120 and the possibility of thermal stress ratchet shall be investigated in accordance with 5-130. If the specified operation of the vessel meets all of the conditions of AD-160, no analysis for cyclic operation is required and it may be assumed that the peak stress limit discussed in 4-135 has been satisfied by compliance with the applicable requirements for materials, design, fabrication, testing, and inspection of this Division. If the operation does not meet all the conditions of AD-160, a fatigue analysis shall be made in accordance with 5-110 or a fatigue test shall be made in accordance with 6-170.

5-101 Allowable Amplitude of Alternating Stresses

The conditions and procedures of AD-160 and 5-110 are based on a comparison of peak stresses with strain cycling fatigue data. The strain cycling fatigue data are represented by the design fatigue strength curves of Figs. 5-110.1, Figs. 5-110.1.1, 5-110.2.1, 5-110.2.2, 5-110.2.3, 5-110.3, and 5-110.4.[1] These curves show the allowable amplitude S_a of the alternating stress component (one-half of the alternating stress range) plotted against the number of cycles. This stress amplitude is calculated on the assumption of elastic behavior and hence has the dimensions of stress, but it does not represent a real stress when the elastic range is exceeded. The fatigue curves are obtained from uniaxial strain cycling data in which the imposed strains have been multiplied by the elastic modulus and a design margin has been provided, so as to make the calculated stress intensity and amplitude and the allowable stress amplitude directly comparable. As an exception to the use of strain controlled test data, Fig. 5-110.2.2 curves B and C are based on load controlled fatigue data. The curves have been adjusted, where necessary, to include the maximum effects of mean stress, which is the condition where the stress fluctuates about a mean value which is different from zero. As a consequence of this procedure, it is essential that the requirements of 4-135 and 4-137 be satisfied at all times, with transient stresses included, and that the calculated value of the alternating stress intensity be proportional to the actual strain amplitude. To evaluate the effect of alternating stresses of varying amplitudes, a linear damage relation is assumed in 5-110.3(e).

5-102 Loadings to Be Considered

The loadings to be considered shall include those loads that are due to testing of the vessel when such testing is in addition to that required by this Division.

5-110 DESIGN FOR CYCLIC LOADING

5-110.1 Determination of Vessel's Ability to Withstand Cyclic Loading. If the specified operation of the vessel does not meet the condition of AD-160, the ability of the vessel to withstand the specified cyclic operation without fatigue failure shall be determined as provided hereinafter. The determination shall be made on the basis of the stresses at a point of the vessel and the allowable stress cycles shall be adequate for the specified operation at every point. Only the stresses due to the specified cycle of operation need be considered; stresses produced by

[1] The tests on which the design curves are based did not include tests at temperatures in the creep range or in the presence of unusually corrosive environments, either of which might accelerate fatigue failure. Therefore, these curves are not applicable at operating temperatures for which creep is a significant factor. In addition, the designer shall evaluate separately any effects on fatigue life which might result from an unusually corrosive environment.

any load or thermal condition which does not vary during the cycle need not be considered, since they are mean stresses and the maximum possible effect of mean stress is included in the fatigue design curves.

5-110.2 Significance of Compliance With Requirements for Cyclic Loading. Compliance with these requirements means only that the vessel is suitable from the standpoint of possible fatigue failure; complete suitability for the specified operation is also dependent on meeting the general stress limits of 4-130 and any applicable special stress limits of 5-130.

5-110.3 Cyclic Loading Design Procedure. Subparagraphs 5-110.3(a) and 5-110.3(b) apply to the determination of primary plus secondary stress intensity range (see 4-134) and peak stress intensity range (see 4-135).

(a) When Principal Stress Direction Does Not Change. For any case in which the directions of the principal stresses at the point being considered do not change during the cycle, the following steps shall be followed to determine the alternating stress intensity.

(1) Principal Stresses. Consider the values of the three principal stresses at the point versus time for the complete stress cycle. These are designated as σ_1, σ_2, and σ_3 for later identification.

(2) Stress Differences. Determine the stress differences

$$S_{12} = \sigma_1 - \sigma_2$$

$$S_{23} = \sigma_2 - \sigma_3$$

$$S_{31} = \sigma_3 - \sigma_1$$

versus time for the complete cycle. In what follows, the symbol S_{ij} is used to represent any one of three stress differences.

(3) Stress Intensity Range. Determine the extremes of the range through which each stress difference S_{ij} fluctuates, and find the absolute magnitude of this range for each S_{ij}. Call the largest absolute magnitude of these values S_{rij}.

(b) When Principal Stress Direction Changes. For any case in which the directions of the principal stresses at the point being considered do change during the stress cycle, it is necessary to use the following more general procedure.

(1) Consider the values of the six stress components σ_t, σ_l, σ_r, τ_{lt}, τ_{lr}, and τ_{rt} versus time for the complete stress cycle.

(2) Choose a point in time when the conditions are one of the extremes for the cycle (either maximum or minimum, algebraically) and identify the stress components at this time by the subscript *i*. In most cases it will be possible to choose at least one time during the cycle when the conditions are known to be extreme. In some cases it may be necessary to try different points in time to find the one which results in the largest value of alternating stress intensity.

(3) Subtract each of the six stress components σ_{ti}, σ_{li}, etc., from the corresponding stress components σ_t, σ_l, etc., at each point in time during the cycle and call the resulting components σ'_t, σ'_l, etc.

(4) At each point in time during the cycle, calculate the principal stresses σ'_1, σ'_2, and σ'_3 derived from the six stress components σ'_t, σ'_l, etc. Note that the directions of the principal stresses may change during the cycle, but each principal stress retains its identity as it rotates.

(5) Determine the stress differences,

$$S''_{12} = \sigma'_1 - \sigma'_2$$

$$S''_{23} = \sigma'_2 - \sigma'_3$$

$$S''_{31} = \sigma'_3 - \sigma'_1$$

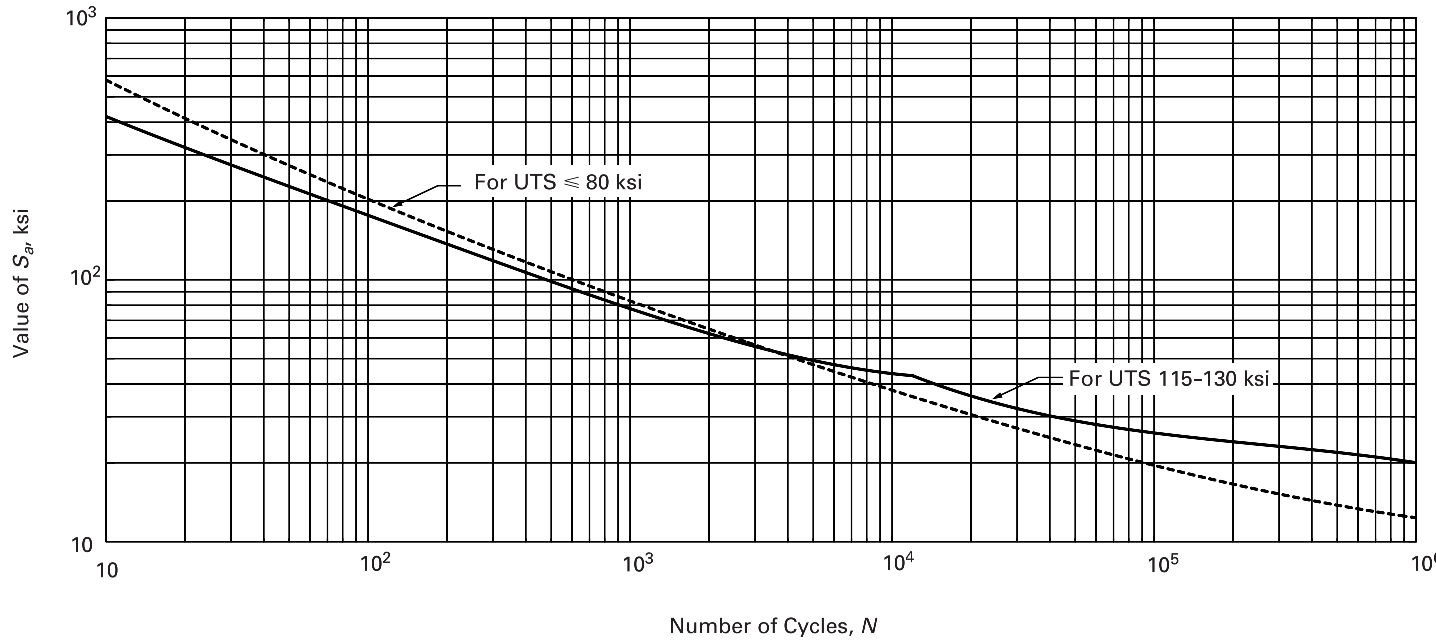
versus time for the complete cycle and find the largest absolute magnitude of any stress difference at any time. Call this value S_{rij}.

(c) When evaluating the limits for the primary plus secondary stress intensity range, S_{rij} is compared to the $3S_m$ limit (see 4-134).

(d) The alternating stress intensity S_{alt} is one half the value of S_{rij}.

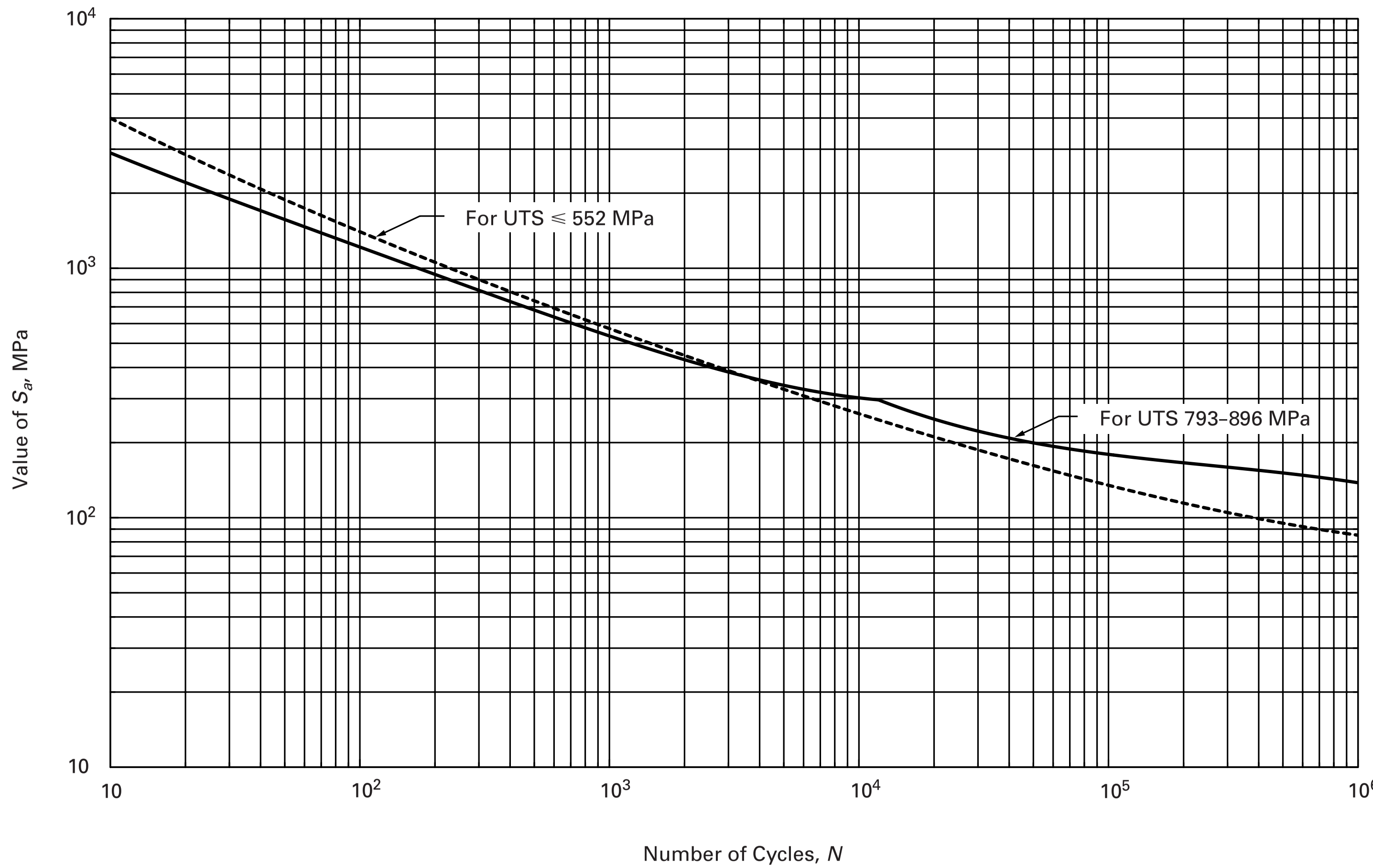
(e) Design Fatigue Curves. Figures 5-110.1, 5-110.1.1, 5-110.2.1, 5-110.2.2, 5-110.3, and 5-110.4 contain applicable design fatigue curves for some of the materials permitted by this Division [see AM-100(c)]. When more than one curve is presented for a given material, the applicability of each is identified. Where curves for various strength levels of a material are given, linear interpolation may be used for intermediate strength levels of these materials. As used herein, the strength level is the specified minimum room temperature value. The design fatigue curves are defined over a cyclic range of 10 to 10^6 cycles, except that for nickel–chromium–molybdenum–iron alloy, a cyclic range of 10 to 10^8 cycles is provided in Fig. 5-110.4 and that for carbon, low alloy, series 4XX, high alloy, and high tensile steels, and for series 3XX high alloy steels, nickel–chromium–iron alloy, nickel–iron–chromium alloy, and nickel–copper alloy, the design fatigue curves are extended to 10^{11} cycles in Figs. 5-110.1.1 and 5-110.2.2. Criteria for the use of the latter curves are given in Fig. 5-110.2.2 and are also presented graphically by the flowchart given in Fig. 5-110.2.3.

(f) Use of Design Fatigue Curve. Multiply S_{alt} [as determined in (a) or (b)] by the ratio of the modulus of



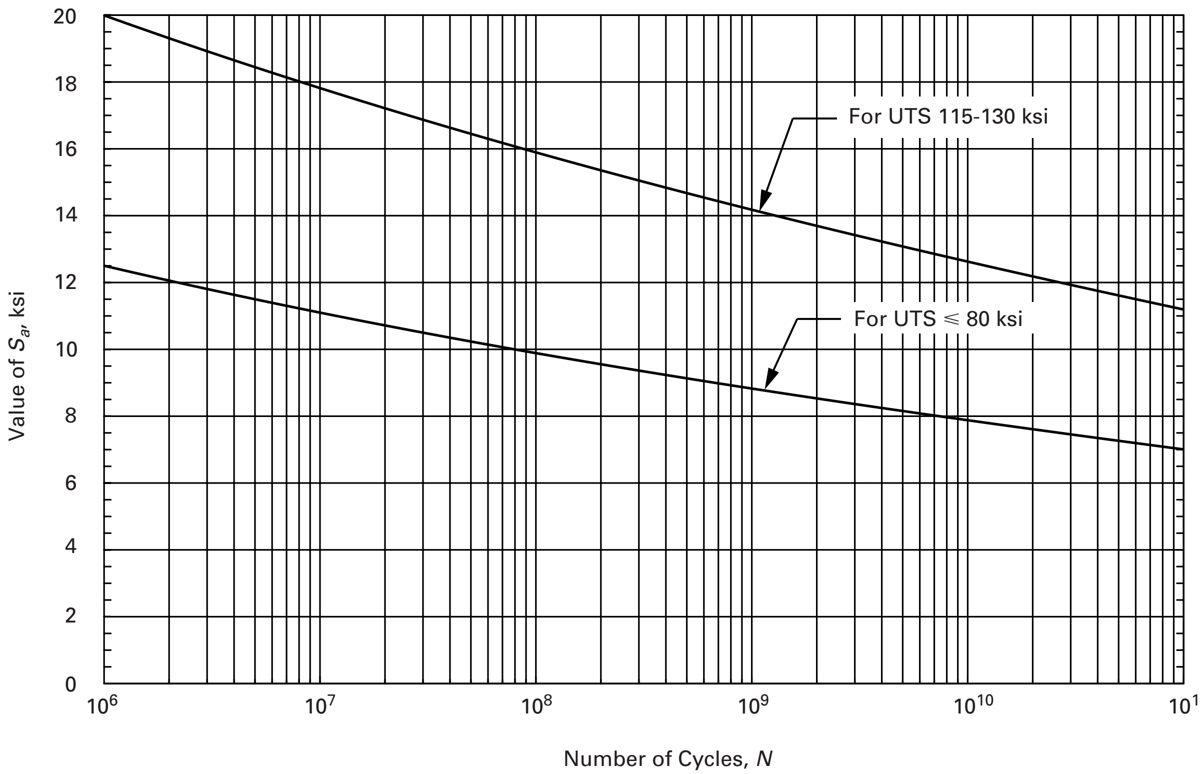
GENERAL NOTES:
(a) $E = 30 \times 10^6$ psi.
(b) Interpolate for UTS 80.0–115.0 ksi.
(c) Table 5-110.1 contains tabulated values and a formula for an accurate interpolation of these curves.

FIG. 5-110.1 DESIGN FATIGUE CURVES FOR CARBON, LOW ALLOY, SERIES 4XX, HIGH ALLOY STEELS AND HIGH TENSILE STEELS FOR TEMPERATURES NOT EXCEEDING 700°F AND $N \leq 10^6$ (USE FIG. 5-110.1.1 FOR $N \geq 10^6$)



GENERAL NOTES:
(a) $E = 207 \times 10^3$ MPa.
(b) Interpolate for UTS 552-793 MPa.
(c) Table 5-110.1 contains tabulated values and a formula for an accurate interpolation of these curves.

FIG. 5-110.1M DESIGN FATIGUE CURVES FOR CARBON, LOW ALLOY, SERIES 4XX, HIGH ALLOY STEELS AND HIGH TENSILE STEELS FOR TEMPERATURES NOT EXCEEDING 371°C AND $N \leq 10^6$ (USE FIG. 5-110.1.1M FOR $N \geq 10^6$)



GENERAL NOTES:
(a) $E = 30 \times 10^6$ psi.
(b) Interpolate for UTS 80–115 ksi.
(c) Table 5-110.1 contains tabulated values and a formula for an accurate interpolation of these curves.

FIG. 5-110.1.1 DESIGN FATIGUE CURVES FOR CARBON, LOW ALLOY, SERIES 4XX, HIGH ALLOY STEELS AND HIGH TENSILE STEELS FOR TEMPERATURES NOT EXCEEDING 700°F AND $N \geq 10^6$ (USE FIG. 5-110.1 FOR $N \leq 10^6$)

elasticity given on the design fatigue curve to the value used in the analysis. Enter the applicable design fatigue curve at this value on the ordinate axis and find the corresponding number of cycles on the axis of abscissas. If the operational cycle being considered is the only one which produces significant fluctuating stresses, this is the allowable number of cycles.

(g) Cumulative Damage. If there are two or more types of stress cycle which produce significant stresses, their cumulative effect shall be evaluated as given below.

(1) Designate the specified number of times each type of stress cycle of types 1, 2, 3, etc., will be repeated during the life of the vessel as n_1, n_2, n_3, etc., respectively. In determining n_1, n_2, n_3, etc., consideration shall be given to the superposition of cycles of various origins which produce a total stress difference range greater than the stress difference ranges of the individual cycles. For example, if one type of stress cycle produces 1,000 cycles of a stress difference variation from zero to +60,000 psi (+400 MPa) and another type of stress cycle produces 10,000 cycles of a stress difference variation from zero to −50,000 psi (−350 MPa), the two types of cycle to be considered are defined by the following parameters:

Type 1 cycle:

$$n_1 = 1{,}000$$

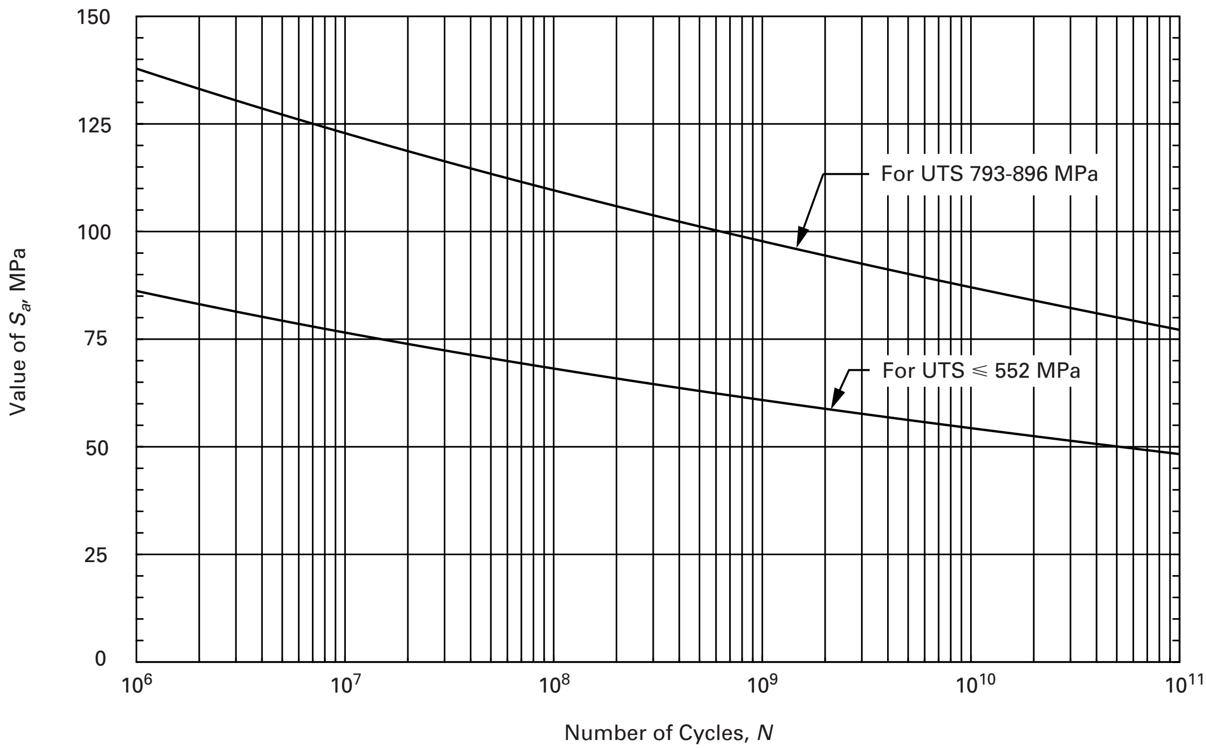
$$S_{\text{alt 1}} = (60{,}000 + 50{,}000)/2 = 55{,}000 \text{ psi (375 MPa)}$$

Type 2 cycle:

$$n_2 = 9{,}000$$

$$S_{\text{alt 2}} = (50{,}000 + 0)/2 = 25{,}000 \text{ psi (170 MPa)}$$

(2) For each type of stress cycle, determine the alternating stress intensity S_{alt} by the procedures of (a) or (b) above. Call these quantities $S_{\text{alt 1}}$, $S_{\text{alt 2}}$, $S_{\text{alt 3}}$, etc.



GENERAL NOTES:
(a) $E = 207 \times 10^3$ MPa.
(b) Interpolate for UTS 552–793 MPa.
(c) Table 5-110.1 contains tabulated values and a formula for an accurate interpolation of these curves.

FIG. 5-110.1.1M DESIGN FATIGUE CURVES FOR CARBON, LOW ALLOY, SERIES 4XX, HIGH ALLOY STEELS AND HIGH TENSILE STEELS FOR TEMPERATURES NOT EXCEEDING 371°C AND $N \geq 10^6$ (USE FIG. 5-110.1 FOR $N \leq 10^6$)

(3) For each value $S_{alt\ 1}$, $S_{alt\ 2}$, $S_{alt\ 3}$, etc., use the applicable design fatigue curve to determine the maximum number of repetitions which would be allowable if this type of cycle were the only one acting. Call these values N_1, N_2, N_3, etc.

(4) For each type of stress cycle, calculate the usage factors U_1, U_2, U_3, etc., from

$$U_1 = n_1/N_1$$

$$U_2 = n_2/N_2$$

$$U_3 = n_3/N_3$$

etc.

(5) Calculate the cumulative usage factor U from

$$U = U_1 + U_2 + U_3 + \ldots$$

etc.

(6) The cumulative usage factor U shall not exceed 1.0.

5-111 Local Structural Discontinuities

These effects shall be evaluated for all conditions using stress concentration factors determined from theoretical, experimental, or photoelastic studies or finite element stress analysis techniques. Experimentally determined fatigue strength reduction factors may be used when determined in accordance with the procedures of 6-180, in lieu of specific values when provided in this Division and except for high strength alloy steel bolts and studs for which the requirements of 5-110 shall apply when using the design fatigue curve of Fig. 5-120.1. Except for the case of crack-like defects, no fatigue strength reduction factor greater than five need be used.

5-112 Fillet Welds

Fillet welds shall not be used in vessels for joints of Categories A, B, C, or D (see Fig. AD-400.1), except as permitted for joints of Category C for slip-on flanges (see

TABLE 5-110.1
TABULATED VALUES OF S_a FROM FIGURES INDICATED

Customary Units (ksi)

Figure	Curve	Number of Cycles[1]									
		1E1	2E1	5E1	1E2	2E2	5E2	8.5E2[2]	1E3	2E3	5E3
5-110.1	UTS 115–130 ksi	420	320	230	175	135	100	. . .	78	62	49
5-110.1	UTS ≤ 80 ksi	580	410	275	205	155	105	. . .	83	64	48
5-110.1.1	UTS 115–130 ksi	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
5-110.1.1	UTS ≤ 80 ksi	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
5-110.2.1	. . .	708	512	345	261	201	148	. . .	119	97	76
5-110.2.2	A	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
5-110.2.2	B	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
5-110.2.2	C	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
5-110.3	S_y = 18.0 ksi	260	190	125	95	73	52	. . .	44	36	28.5
5-110.3	S_y = 30.0 ksi	260	190	125	95	73	52	. . .	44	36	28.5
5-110.3	S_y = 45.0 ksi	260	190	125	95	73	52	46	39	24.5	15.5
5-110.4	. . .	708	512	345	261	201	148	. . .	119	97	76
5-120.1	MNS[3] ≤ 2.7S_m	1,150	760	450	320	225	143	. . .	100	71	45
5-120.1	MNS[3] = 3S_m	1,150	760	450	300	205	122	. . .	81	55	33

SI Units (MPa)

Figure	Curve	Number of Cycles[1]									
		1E1	2E1	5E1	1E2	2E2	5E2	8.5E2[2]	1E3	2E3	5E3
5-110.1	UTS 793–896 MPa	2 896	2 206	1 586	1 207	931	690	. . .	538	427	338
5-110.1	UTS ≤ 552 MPa	3 999	2 827	1 896	1 413	1 069	724	. . .	572	441	331
5-110.1.1	UTS 793–896 MPa	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
5-110.1.1	UTS ≤ 552 MPa	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
5-110.2.1	. . .	4 882	3 530	2 379	1 800	1 386	1 020	. . .	821	669	524
5-110.2.2	A	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
5-110.2.2	B	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
5-110.2.2	C	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
5-110.3	S_y = 134 MPa	1 793	1 310	862	655	503	359	. . .	303	248	197
5-110.3	S_y = 207 MPa	1 793	1 310	862	655	503	359	. . .	303	248	197
5-110.3	S_y = 310 MPa	1 793	1 310	862	655	503	359	317	269	169	107
5-110.4	. . .	4 882	3 530	2 379	1 800	1 386	1 020	. . .	821	669	524
5-120.1	MNS[3] ≤ 2.7S_m	7 929	5 240	3 103	2 206	1 551	986	. . .	690	490	310
5-120.1	MNS[3] = 3S_m	7 929	5 240	3 103	2 069	1 413	841	. . .	558	379	228

GENERAL NOTES:

(a) All notes in the referenced figures apply to these data.

(b) Interpolation between tabular values is permissible based upon data representation by straight lines on a log-log plot. Accordingly, for $S_i > S > S_j$,

$$\frac{N}{N_i} = \left(\frac{N_j}{N_i}\right)^{[\log(S_i/S)]/\log(S_i/S_j)}$$

where

S, S_i, S_j = values of S_a

N, N_i, N_j = corresponding number of cycles from design fatigue data

Example: From data in the table, use the interpolation formula above to find the number of cycles N for S_a = 53.5 ksi (370 MPa) when UTS ≤ 80 ksi (552 MPa) in Fig. 5-110.1.

$$\frac{N}{2{,}000} = \left(\frac{5{,}000}{2{,}000}\right)^{[\log(64/53.5)]/\log(64/48)}$$

$$N = 3{,}540 \text{ cycles}$$

TABLE 5-110.1
TABULATED VALUES OF S_a FROM FIGURES INDICATED

Customary Units (ksi)																	
Number of Cycles [1]																	
1E4	1.2E4 [2]	2E4	5E4	1E5	2E5	5E5	1E6	2E6	5E6	1E7	2E7	5E7	1E8	1E9	1E10	1E11
44	43	36	29	26	24	22	20	...	...	...	...	...	...	...	...	...
38	...	31	23	20	16.5	13.5	12.5	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	20.0	...	...	17.8	...	...	15.9	14.2	12.6	11.2
...	...	...	...	...	...	...	12.5	...	...	11.1	...	...	9.9	8.8	7.9	7.0
64	...	55.5	46.3	40.8	35.9	31.0	28.3	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	28.2	26.9	25.7	25.1	24.7	24.3	24.1	23.9	23.8	23.7
...	...	...	...	...	...	...	28.2	22.8	19.8	18.5	17.7	17.2	17.0	16.8	16.6	16.5
...	...	...	...	...	...	...	28.2	22.8	18.4	16.4	15.2	14.3	14.1	13.9	13.7	13.6
24.5	...	21	17	15	13.5	12.5	12.0	...	...	...	...	...	...	...	...	...
24.5	...	19.5	15	13	11.5	9.5	9.0	...	...	...	...	...	...	...	...	...
12	...	9.6	7.7	6.7	6.0	5.2	5.0	...	...	...	...	...	...	...	...	...
64	...	56	46.3	40.8	35.9	26.0	20.7	18.7	17.0	16.2	15.7	15.3	15.0	...	...	...
34	...	27	22	19	17	15	13.5	...	...	...	...	...	...	...	...	...
22.5	...	15	10.5	8.4	7.1	6	5.3	...	...	...	...	...	...	...	...	...

SI Units (MPa)																
Number of Cycles [1]																
1E4	1.2E4 [2]	2E4	5E4	1E5	2E5	5E5	1E6	2E6	5E6	1E7	2E7	5E7	1E8	1E9	1E10	1E11
303	296	248	200	179	165	152	138	...	...	...	...	...	...	...	...	...
262	...	214	159	138	114	93	86	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	138	...	...	123	...	...	110	98	87	77
...	...	...	...	...	...	...	86	...	...	77	...	...	68	61	54	48
441	...	383	319	281	248	214	195	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	194	185	177	173	170	168	166	165	164	163
...	...	...	...	...	...	...	194	157	137	128	122	119	117	116	114	114
...	...	...	...	...	...	...	194	157	127	113	105	99	97	96	94	94
169	...	145	117	103	93	86	83	...	...	...	...	...	...	...	...	...
169	...	134	103	90	79	66	62	...	...	...	...	...	...	...	...	...
83	...	66	53	46	41	36	34	...	...	...	...	...	...	...	...	...
441	...	386	319	281	248	179	143	129	117	112	108	105	103	...	...	...
234	...	186	152	131	117	103	93	...	...	...	...	...	...	...	...	...
155	...	103	72	58	49	41	37	...	...	...	...	...	...	...	...	...

NOTES:
(1) Number of cycles indicated shall be read as follows: $IEJ = I \times 10^J$, e.g., $5E2 = 5 \times 10^2$ or 500.
(2) These data points are included to provide accurate representation of curves at branches or cusps.
(3) Maximum nominal stress.

AD-413 and AD-711.1) and for joints of Category D as permitted in Article D-6. Fillet welds may be used for attachments to pressure vessels using one-half the stress limits of 4-131 through 4-134 for primary and secondary stresses. Evaluation for cyclic loading shall be made in accordance with Appendix 5 using a fatigue strength reduction factor of four and shall include consideration of temperature differences between the vessel and the attachment and expansion or contraction of the vessel produced by internal or external pressure.

5-120 FATIGUE ANALYSIS OF BOLTS

Unless the vessel on which they are installed meets all the conditions of AD-160 and thus requires no fatigue analysis, the suitability of bolts for cyclic operation shall be determined in accordance with the procedures which follow.

(a) Bolts made of materials which have minimum specified tensile strengths of less than 100,000 psi (689 MPa) shall be evaluated for cyclic operation by the

methods of 5-110, using the applicable design fatigue curve, Figs. 5-110.1, 5-110.1.1, 5-110.2.1, 5-110.2.2, 5-110.2.3, 5-110.3, and 5-110.4, and an appropriate stress concentration factor (see 5-122).

(b) High strength alloy steel bolts and studs may be evaluated for cyclic operation by the methods of 5-110 using the design fatigue curve of Fig. 5-120.1, provided:

(1) the material is one of the following: SA-193 Grade B7 or B16, SA-320 Grade L43, SA-540 Grades B23 and B24, heat treated in accordance with Section 5 of SA-540;

(2) the maximum value of the service stress at the periphery of the bolt cross section (resulting from direct tension plus bending and neglecting stress concentrations) shall not exceed $2.7S_m$, if the higher of the two fatigue design curves given in Fig. 5-120.1 is used (the $2.0S_m$ limit for direct tension is unchanged);

(3) threads shall be of a "V" type, having a minimum thread root radius no smaller than 0.003 in. (0.075 mm);

(4) fillet radii at the end of the shank shall be such that the ratio of fillet radius to shank diameter is not less than 0.060;

(5) the fatigue strength reduction factor used in the fatigue evaluation shall not be less than 4.0.

5-121 Acceptability for Cyclic Operation

The bolts shall be acceptable for the specified cyclic application of loads and thermal stresses provided the cumulative usage factor U, as determined in 5-110.3(e), does not exceed 1.0.

5-122 Fatigue Strength Reduction Factor for Threads

Unless it can be shown by analysis or test that a lower value is appropriate, the fatigue strength reduction factor used in the fatigue evaluation of threaded members shall not be less than 4.0.

5-130 THERMAL STRESS RATCHET IN SHELL

It should be noted that under certain combinations of steady state and cyclic loadings there is a possibility of large distortions developing as the result of ratchet action; that is, the deformation increases by a nearly equal amount for each cycle. Examples of this phenomenon are treated herein and in 5-140.

(a) The limiting value of the maximum cyclic thermal stress permitted in a shell loaded by steady state internal pressure in order to prevent cyclic growth in diameter is as follows. Let

y' = maximum allowable thermal stress computed on an elastic basis, divided by the yield strength[2] S_y

x = maximum general membrane stress due to pressure divided by the yield strength[2] S_y

Case 1. Linear variation of temperature through the shell wall:

$$y' = \frac{1}{x} \text{ for } 0 < x < 0.5$$

$$y' = 4(1 - x) \text{ for } 0.5 < x < 1.0$$

Case 2. Parabolic constantly increasing or constantly decreasing variation of temperature through the shell wall:

$$y' = 5.2(1 - x) \text{ for } 0.615 < x < 1.0$$

and approximately for $x < 0.615$ as follows:

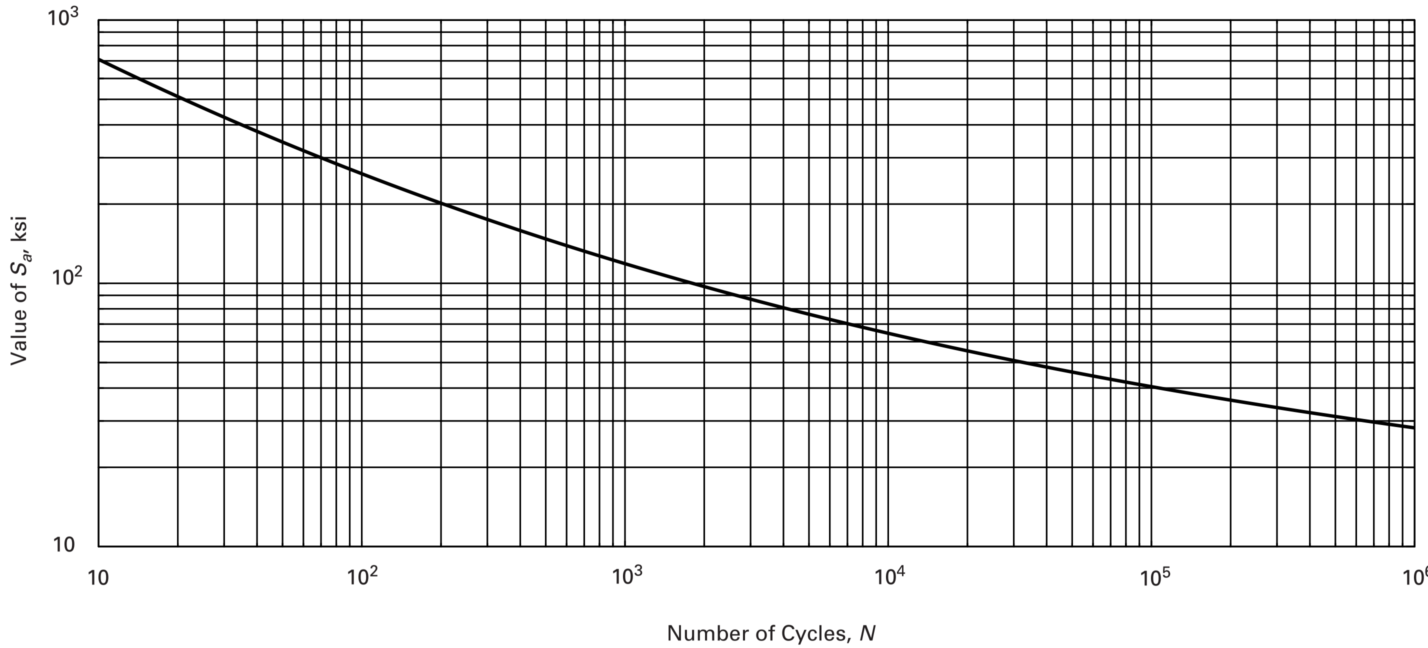
For x =	0.3	0.4	0.5
y' =	4.65	3.55	2.70

(b) Use of the yield strength S_y in the above relations instead of the proportional limit allows a small amount of growth during each cycle until strain hardening raises the proportional limit to S_y. If the yield strength of the material is higher than two times the S_a value at 10^{11} cycles in the applicable fatigue curve of Fig. 5-110.1.1 or Fig. 5-110.2.2 for the material, the latter value shall be used, if there are to be a large number of cycles, because strain softening may occur.

5-140 PROGRESSIVE DISTORTION OF NONINTEGRAL CONNECTIONS

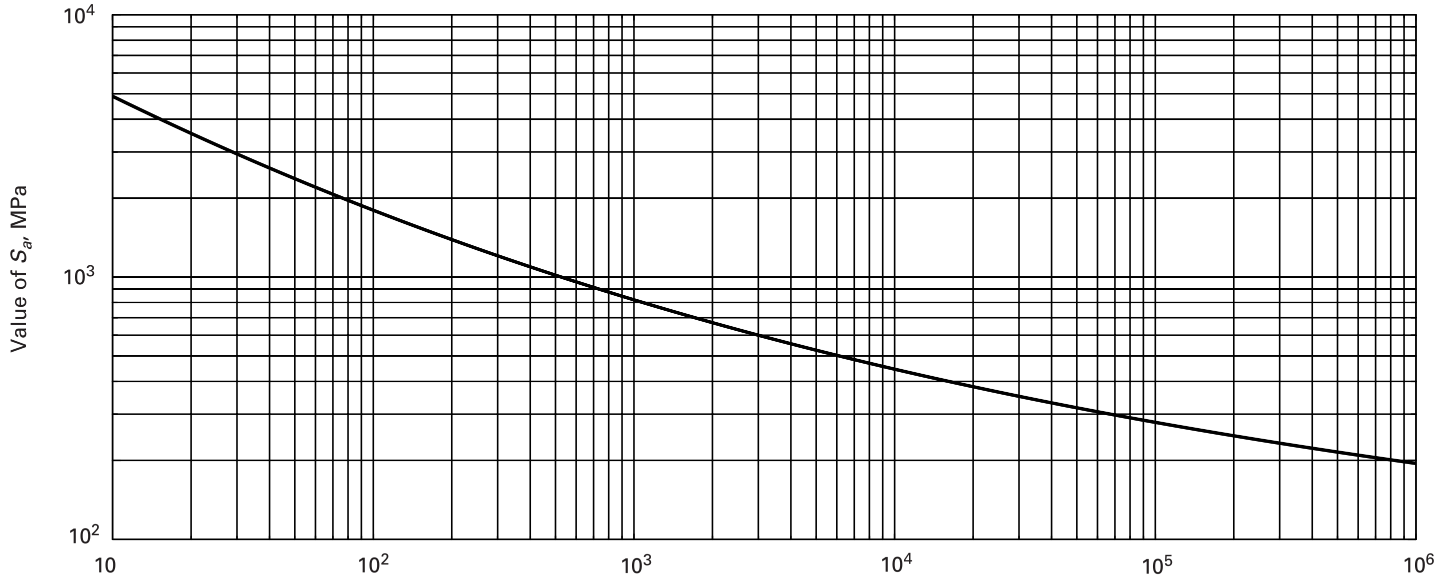
Screwed-on caps, screwed-in plugs, shear ring closures, and breech lock closures are examples of nonintegral connections which are subject to failure by bellmouthing or other types of progressive deformation. If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operating cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can eventually lose engagement. Therefore primary plus secondary stress intensities (4-134) which result in slippage between the parts of a nonintegral connection in which disengagement could occur as a result of progressive distortion shall be limited to the allowable stress limits given in 4-131 and 4-132.

[2] It is permissible to use $1.5S_m$ whenever it is greater than S_y.



GENERAL NOTES:
(a) $E = 28.3 \times 10^6$ psi.
(b) Table 5-110.1 contains tabulated values and a formula for an accurate interpolation of this curve.

FIG. 5-110.2.1 DESIGN FATIGUE CURVE FOR SERIES 3XX HIGH ALLOY STEELS, NICKEL–CHROMIUM–IRON ALLOY, NICKEL–IRON–CHROMIUM ALLOY, AND NICKEL–COPPER ALLOY FOR TEMPERATURES NOT EXCEEDING 800°F AND $S_a > 28.2$ ksi (USE FIG. 5-110.2.2 FOR $S_a \leq 28.2$ ksi)

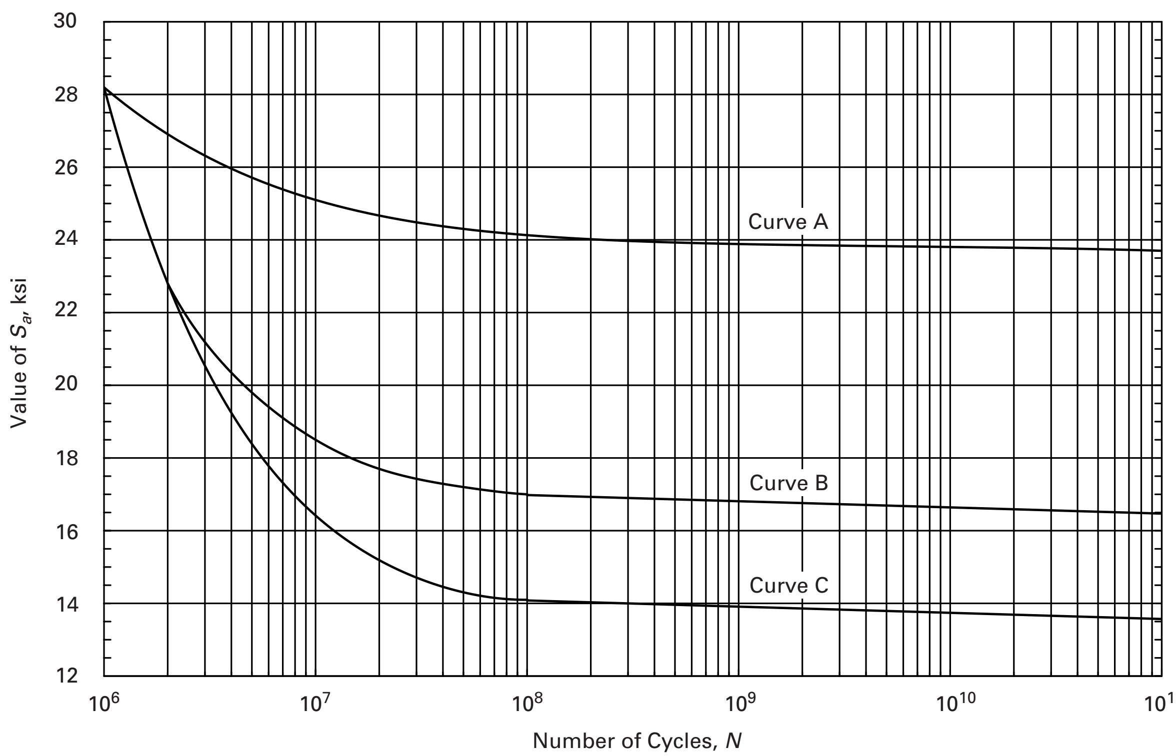


GENERAL NOTES:
(a) $E = 195 \times 10^3$ MPa.
(b) Table 5-110.1 contains tabulated values and a formula for an accurate interpolation of this curve.

FIG. 5-110.2.1M DESIGN FATIGUE CURVE FOR SERIES 3XX HIGH ALLOY STEELS, NICKEL–CHROMIUM–IRON ALLOY, NICKEL–IRON–CHROMIUM ALLOY, AND NICKEL–COPPER ALLOY FOR TEMPERATURES NOT EXCEEDING 427°C AND $S_a > 195$ MPa (USE FIG. 5-110.2.2 FOR $S_a \leq 195$ MPa)

Criteria for the Use of the Curves in This Figure

Curve	Elastic Analysis of Material Other Than Welds and Heat Affected Zones	Elastic Analysis of Welds and Heat Affected Zones
A	(P_L + P_b + Q) range ≤ 27.2 ksi	. . .
B	(P_L + P_b + Q) range > 27.2 ksi and S_a corrected for applied mean stress	(P_L + P_b + Q) range ≤ 27.2 ksi
C	(P_L + P_b + Q) range > 27.2 ksi	(P_L + P_b + Q) range > 27.2 ksi

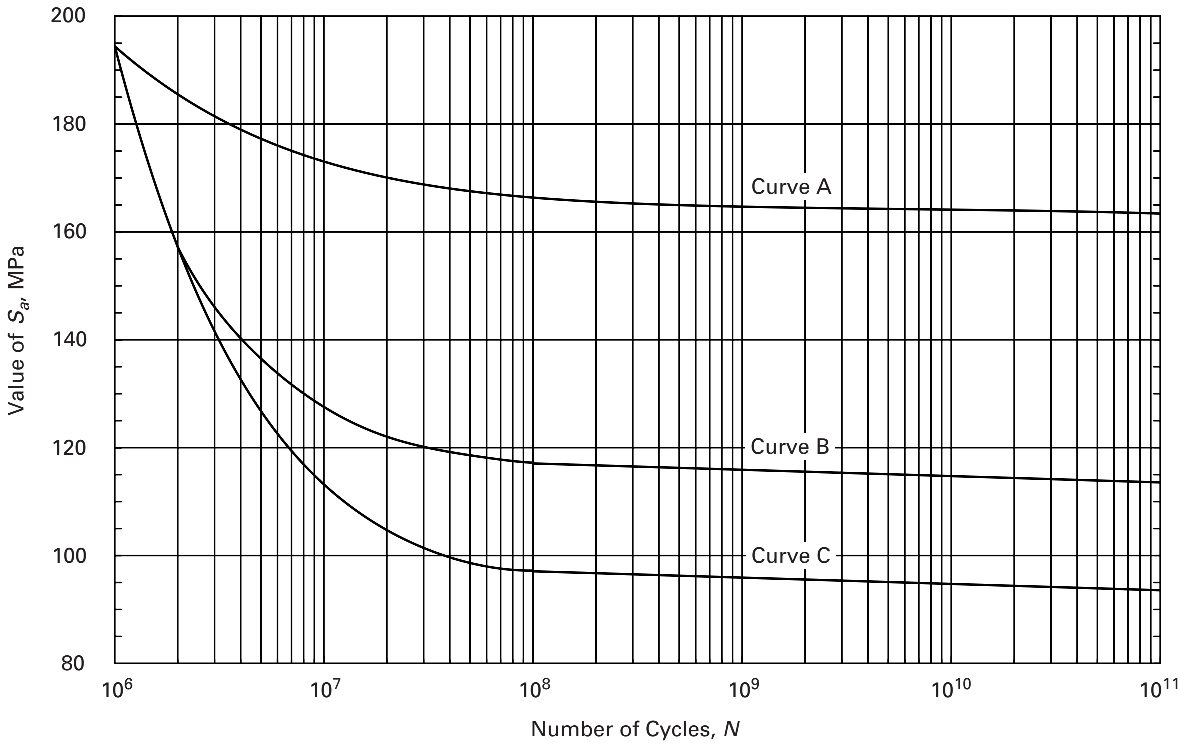


GENERAL NOTES:
(a) $E = 28.3 \times 10^6$ psi.
(b) Table 5-110.1 contains tabulated values for an accurate interpolation of these curves.
(c) Thermal bending stresses resulting from axial and radial gradients are excluded from Q.
(d) Curve A is also to be used with inelastic analysis with $S_a = \frac{1}{2}\Delta\epsilon_t E$, where $\Delta\epsilon_t$ is the total effective strain range.
(e) The maximum effect of retained mean stress is included in Curve C.

FIG. 5-110.2.2 DESIGN FATIGUE CURVE FOR SERIES 3XX HIGH ALLOY STEELS, NICKEL–CHROMIUM–IRON ALLOY, NICKEL–IRON–CHROMIUM ALLOY, AND NICKEL–COPPER ALLOY FOR TEMPERATURES NOT EXCEEDING 800°F AND S_a ≤ 28.2 ksi (USE FIG. 5-110.2.1 FOR S_a > 28.2 ksi)

Criteria for the Use of the Curves in This Figure

Curve	Elastic Analysis of Material Other Than Welds and Heat Affected Zones	Elastic Analysis of Welds and Heat Affected Zones
A	$(P_L + P_b + Q)$ range ≤ 188 MPa	. . .
B	$(P_L + P_b + Q)$ range > 188 MPa and S_a corrected for applied mean stress	$(P_L + P_b + Q)$ range ≤ 188 MPa
C	$(P_L + P_b + Q)$ range > 188 MPa	$(P_L + P_b + Q)$ range > 188 MPa



GENERAL NOTES:

(a) $E = 195 \times 10^3$ MPa.

(b) Table 5-110.1 contains tabulated values for an accurate interpolation of these curves.

(c) Thermal bending stresses resulting from axial and radial gradients are excluded from Q.

(d) Curve A is also to be used with inelastic analysis with $S_a = \frac{1}{2}\Delta\epsilon_t E$, where $\Delta\epsilon_t$ is the total effective strain range.

(e) The maximum effect of retained mean stress is included in Curve C.

FIG. 5-110.2.2M DESIGN FATIGUE CURVE FOR SERIES 3XX HIGH ALLOY STEELS, NICKEL–CHROMIUM–IRON ALLOY, NICKEL–IRON–CHROMIUM ALLOY, AND NICKEL–COPPER ALLOY FOR TEMPERATURES NOT EXCEEDING 427°C AND $S_a \leq 195$ MPa (USE FIG. 5-110.2.1 FOR $S_a > 195$ MPa)

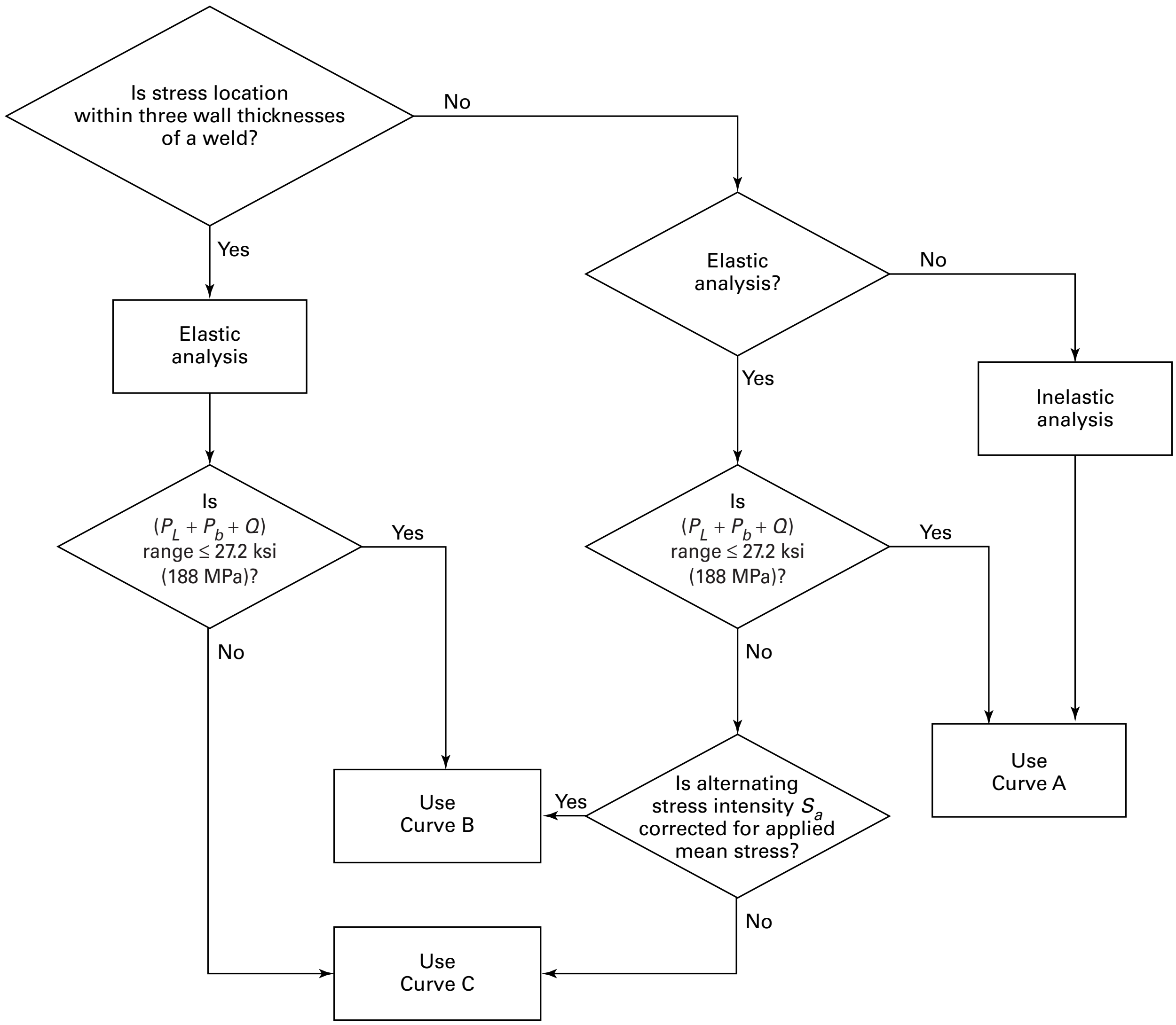


FIG. 5-110.2.3 GRAPHICAL PRESENTATION OF CRITERIA FOR USE OF CURVES IN FIG. 5-110.2.2

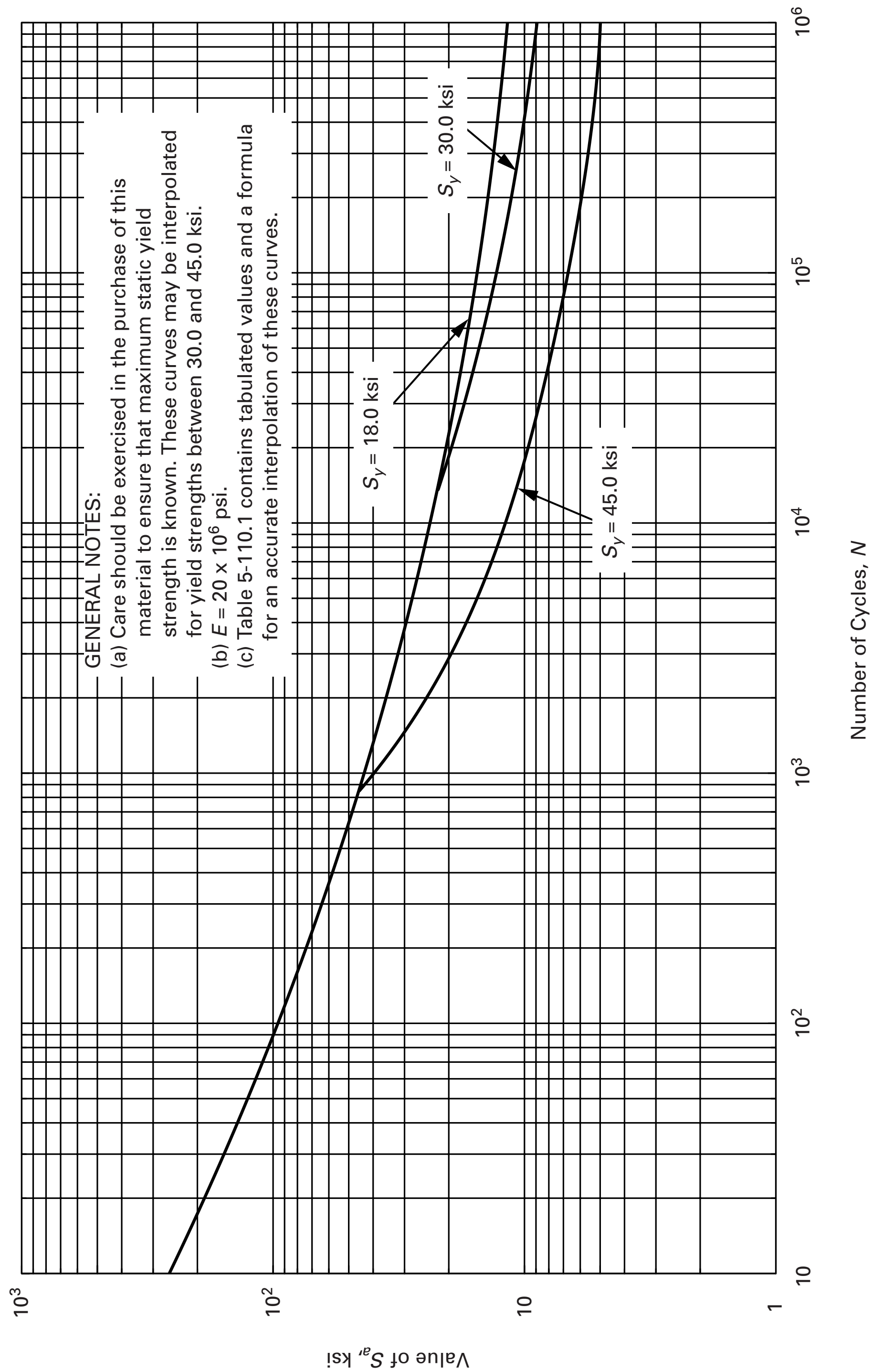


FIG. 5-110.3 DESIGN FATIGUE CURVE FOR WROUGHT 70–30 COPPER–NICKEL FOR TEMPERATURES NOT EXCEEDING 700°F

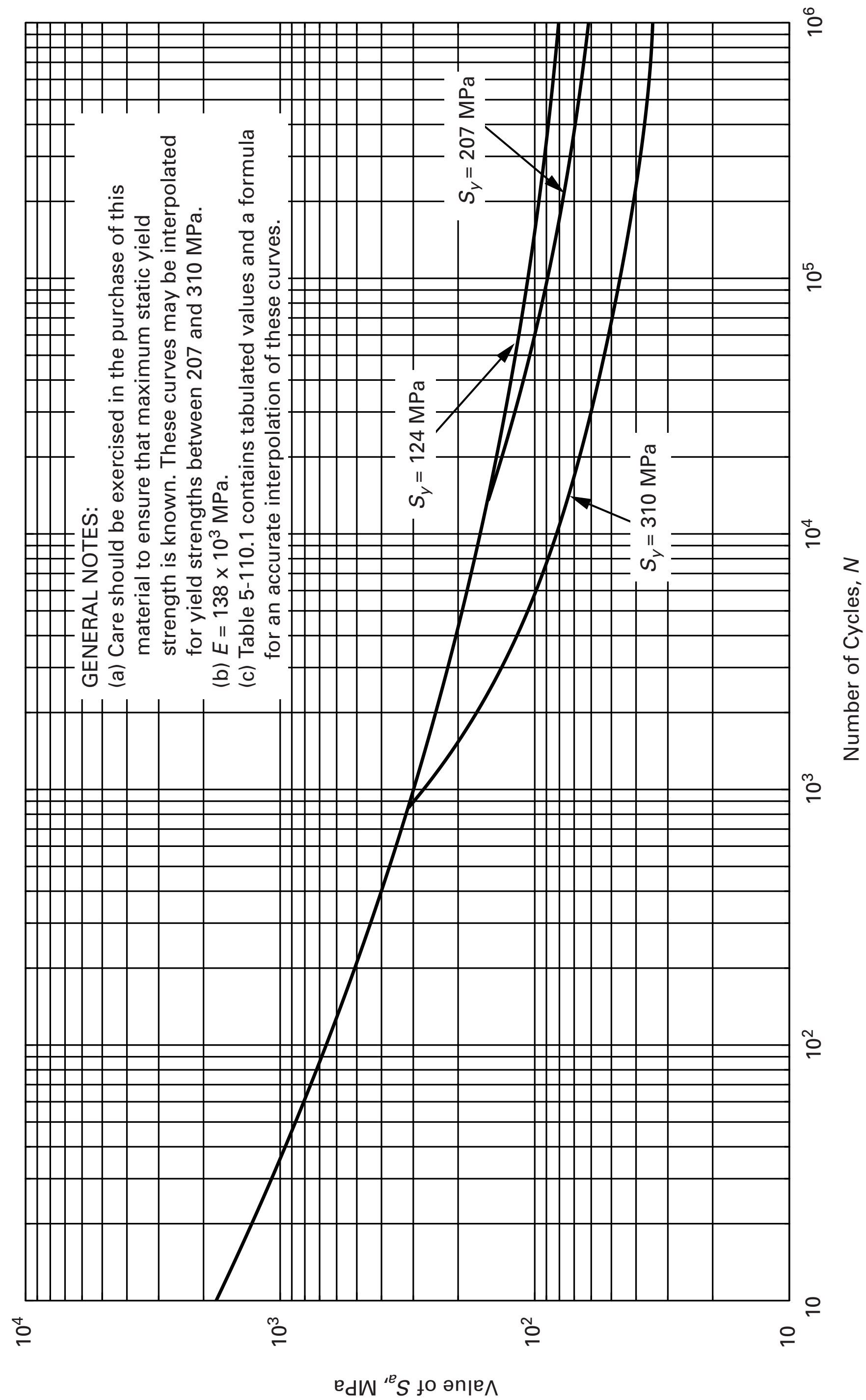
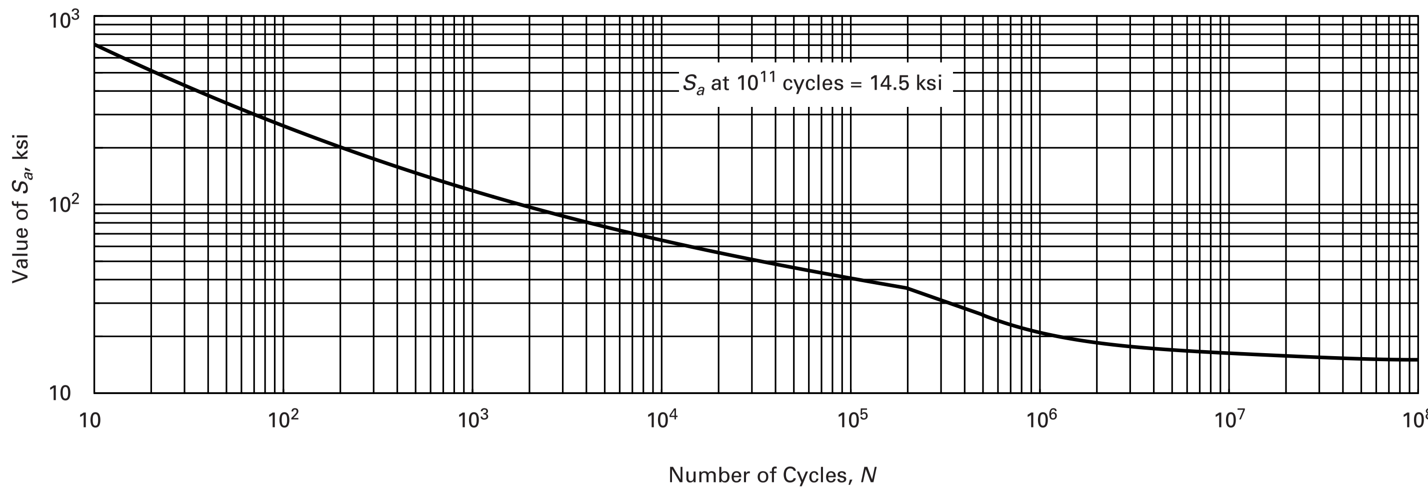
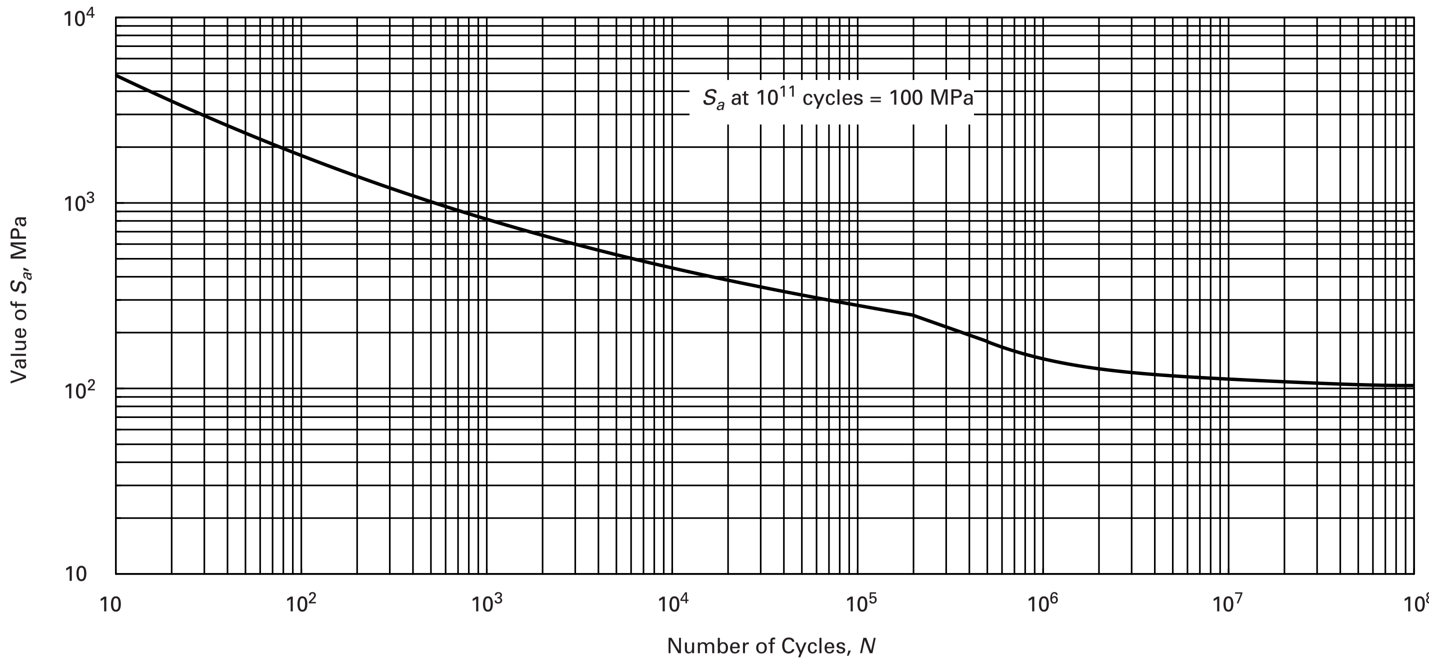


FIG. 5-110.3M DESIGN FATIGUE CURVE FOR WROUGHT 70 COPPER–30 NICKEL FOR TEMPERATURES NOT EXCEEDING 371°C



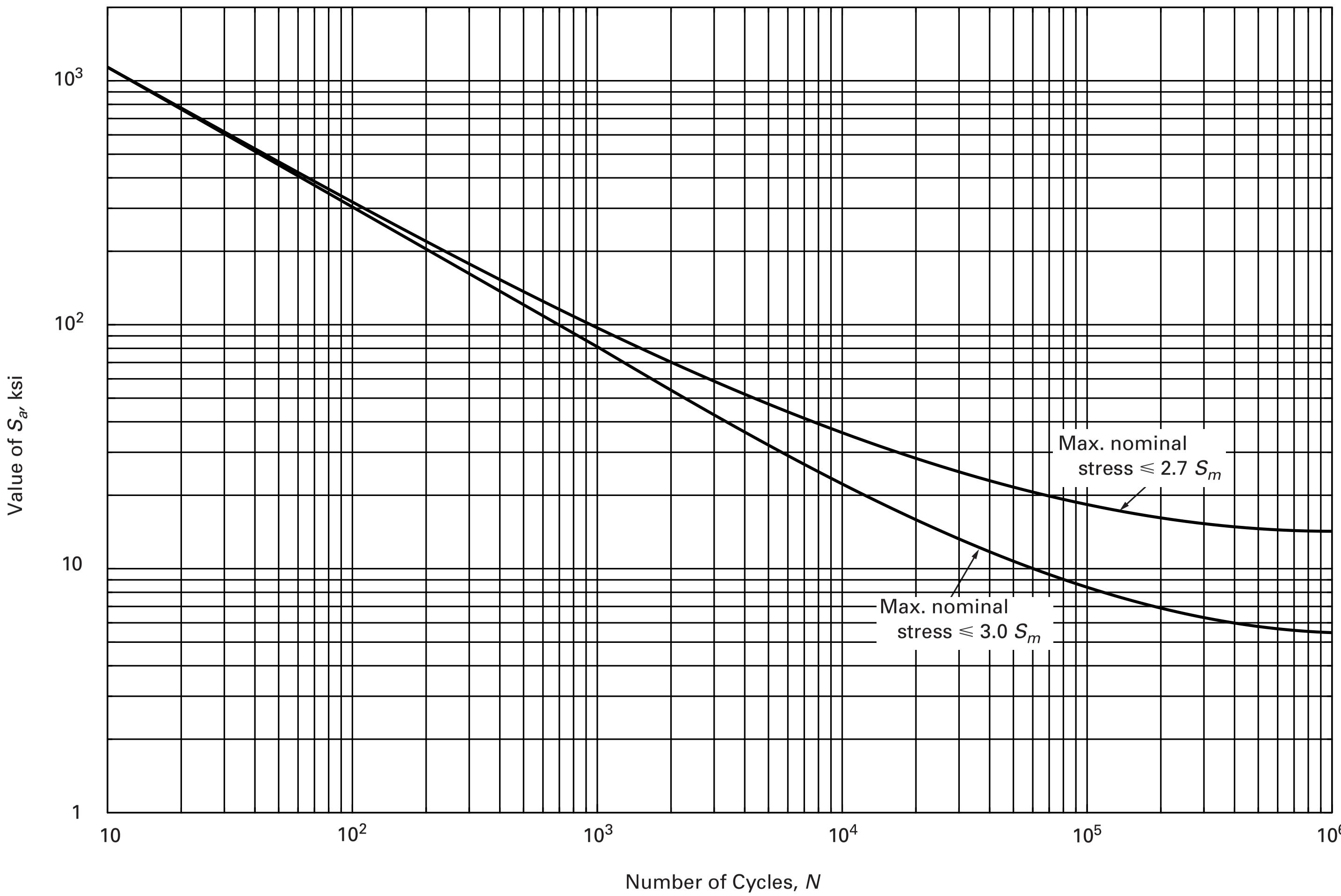
GENERAL NOTES:
(a) $E = 28.3 \times 10^6$ psi.
(b) Table 5-110.1 contains tabulated values and a formula for an accurate interpolation of this curve.

FIG. 5-110.4 DESIGN FATIGUE CURVE FOR NICKEL–CHROMIUM–MOLYBDENUM–IRON, ALLOYS X, G, C-4, AND C-276 FOR TEMPERATURES NOT EXCEEDING 800°F



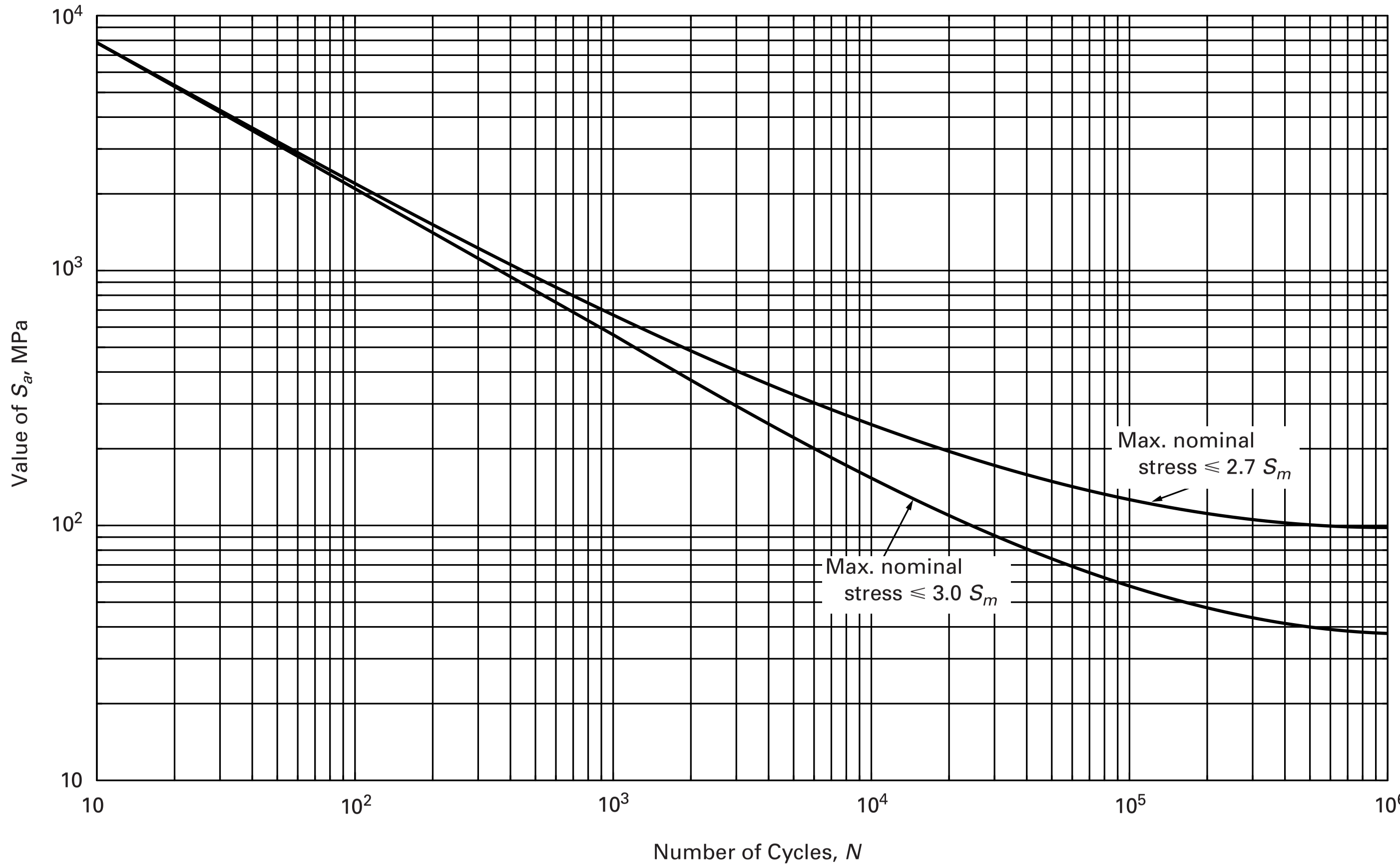
GENERAL NOTES:
(a) $E = 195 \times 10^3$ MPa.
(b) Table 5-110.1 contains tabulated values and a formula for an accurate interpolation of this curve.

FIG. 5-110.4M DESIGN FATIGUE CURVE FOR NICKEL–CHROMIUM–MOLYBDENUM–IRON, ALLOYS X, G, C-4, AND C-276 FOR TEMPERATURES NOT EXCEEDING 427°C



GENERAL NOTES:
(a) $E = 30 \times 10^6$ psi.
(b) Table 5-110.1 contains tabulated values and a formula for accurate interpolation of these curves.

FIG. 5-120.1 DESIGN FATIGUE CURVE FOR HIGH STRENGTH STEEL BOLTING FOR TEMPERATURES NOT EXCEEDING 700°F



GENERAL NOTES:
(a) $E = 207 \times 10^3$ MPa.
(b) Table 5-110.1 contains tabulated values and a formula for accurate interpolation of these curves.

FIG. 5-120.1M DESIGN FATIGUE CURVE FOR HIGH STRENGTH STEEL BOLTING FOR TEMPERATURES NOT EXCEEDING 371°C

MANDATORY APPENDIX 6
EXPERIMENTAL STRESS ANALYSIS

ARTICLE 6-1

6-100 GENERAL REQUIREMENTS

6-101 When Experimental Stress Analysis Is Required

The critical or governing stresses in parts for which theoretical stress analysis is inadequate or for which design values are unavailable shall be substantiated by experimental stress analysis.

6-102 When Reevaluation Is Not Required

Reevaluation is not required for configurations for which there are available detailed experimental results that are consistent with the requirements of this Article.

6-103 Discounting of Corrosion Allowance, etc.

The test procedures followed and the interpretation of the results shall be such as to discount the effects of material added to the thickness of members, such as corrosion allowance or other material which cannot be considered as contributing to the strength of the part.

6-110 TYPES OF TESTS

Tests may be run in order to determine governing stresses, collapse load, or the adequacy of a part for cyclic loading.

6-111 Tests for Determination of Governing Stresses

Permissible types of tests for the determination of governing stresses are strain measurement tests and photoelastic tests. Brittle coating tests may be used only for the purpose described in 6-141. Results of displacement measurement tests and tests to destruction are not acceptable for governing stress determination.

6-112 Tests for Determination of Collapse Load

Strain measurement tests may be used for the determination of collapse load. Distortion measurement tests may be used for the determination of collapse load if it can be clearly shown that the test setup and the instrumentation used will give valid results for the configuration on which the measurements are made. Brittle coating tests and tests to destruction may not be used to determine collapse load.

6-113 Fatigue Tests

Fatigue tests may be used to evaluate the adequacy of a part for cyclic loading, as described in 6-170.

6-120 STRAIN MEASUREMENT TEST PROCEDURE

6-121 Requirements for Strain Gages

Strain gages may be used of any type capable of indicating strains to 0.00005 in./in. (0.00005 mm/mm) (0.005%). It is recommended that the gage length be such that the maximum strain within the gage length does not exceed the average strain within the gage length by more than 10%. Instrumentation shall be such that both surface principal stresses may be determined at each gage location in the elastic range of material behavior at that gage location. A similar number and orientation of gages at each gage location are required to be used in tests beyond the elastic range of material behavior. The strain gages and cements that are used shall be shown to be reliable for use on the material surface finish and configuration considered to strain values at least 50% higher than those expected.

6-122 Use of Models for Strain or Distortion Measurements

Except in tests made for the measurement of collapse load, strain gage data may be obtained from the actual component or from a model component of any scale that meets the gage length requirements of 6-121. The model material need not be the same as the component material but shall have an elastic modulus which is either known or has been measured at the test conditions. The requirements of dimensional similitude shall be met as possible.

In the case of collapse load tests, only full scale models, prototypical in all respects, are permitted unless the experimenter can clearly demonstrate the validity of the scaling laws used.

6-130 PHOTOELASTIC TEST PROCEDURE

Either two-dimensional or three-dimensional techniques may be used as long as the model represents the structural effects of the loading.

6-140 TEST PROCEDURES

6-141 Location of Test Gages

In tests for determination of governing stresses, sufficient locations on the vessel shall be investigated to ensure that measurements are taken at the most critical areas. The location of the critical areas and the optimum orientation of test gages may be determined by a brittle coating test.

In tests made for the measurement of collapse load, sufficient measurements must be taken so that all areas which have any reasonable probability of indicating a minimum collapse load are adequately covered. If strain gages are used to determine the collapse load, particular care should be given to assuring that strains (either membrane, bending, or a combination) are being measured which are actually indicative of the load carrying capacity of the structure. If distortion measurement devices are used, care should be given to assure that it is the change in cardinal dimensions or deflections which are measured, such as diameter or length extension, or beam or plate deflections that are indicative of the tendency of the structure to actually collapse.

6-142 Requirements for Pressure Gages

Pressure gages shall meet the requirements of Article T-5.

6-143 Application of Pressure or Load

In tests for determining governing stresses, the internal pressure or mechanical load shall be applied in such increments that the variation of strain with load can be plotted so as to establish the ratio of stress to load in the elastic range. If the first loading results in strains which are not linearly proportional to the load, it is permissible to unload and reload successively until the linear proportionality has been established. When frozen stress photoelastic techniques are used, only one load value can be applied, in which case the load shall not be so high as to result in deformations that invalidate the test results.

In tests made for the measurement of collapse load, the proportional load shall be applied in sufficiently small increments so that an adequate number of data points for each gage are available for statistical analysis in the linear elastic range of behavior. All gages should be evaluated prior to increasing the load beyond this value. A least square fit (regression) analysis shall be used to obtain the best fit straight line and the confidence interval shall be compared to preset values for acceptance or rejection of the strain gage or other instrumentation. Unacceptable instrumentation will be replaced and the replacement instrumentation tested in the same manner.

After all instrumentation has been deemed acceptable, the test should be continued on a strain or displacement controlled basis with adequate time permitted between load changes for all metal flow to be completed.

6-150 INTERPRETATION OF RESULTS

6-151 Interpretation to Be on Elastic Basis

The experimental results obtained shall be interpreted on an elastic basis to determine the stresses corresponding to the design loads; that is, in the evaluation of stresses from strain gage data, the calculations shall be performed under the assumption that the material is elastic. The elastic constants used in the evaluation of experimental data shall be those applicable to the test material at the test temperature.

6-152 Required Extent of Stress Analysis

The extent of experimental stress analysis performed shall be sufficient to determine the governing stresses for which design values are unavailable, as described in 6-101. When possible, combined analytical and experimental methods shall be used to distinguish between primary, secondary, and local stresses so that each combination of categories can be controlled by the applicable stress limit.

6-153 Criterion of Collapse Load

For distortion measurement tests, the loads are plotted as the ordinate and the measured deflections are plotted as the abscissa. For strain gage tests, the loads are plotted

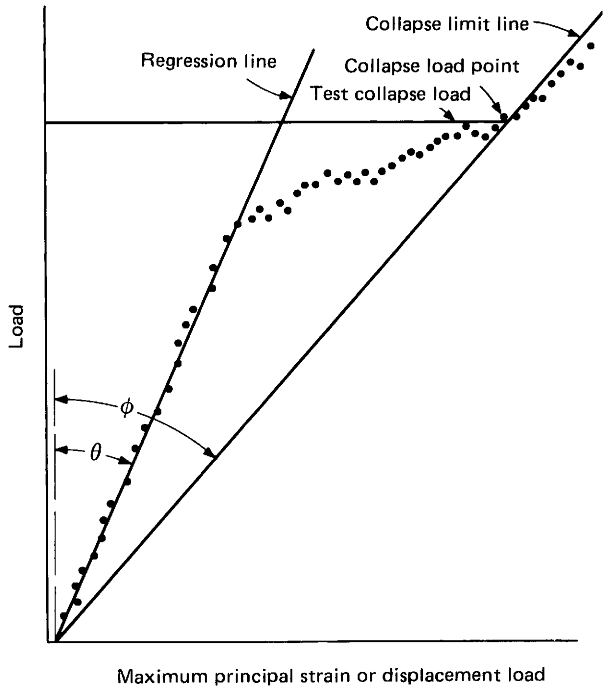


FIG. 6-153 CONSTRUCTION OF CURVE TO DETERMINE COLLAPSE LOAD ACCORDING TO 6-153

as the ordinate and the maximum principal strains on the surface as the abscissa.

The least square fit (regression) line as determined from the data in the linear elastic range is drawn on each plot considered. The angle that the regression line makes with the ordinate is called θ. A second straight line, hereafter called the *collapse limit line*, is drawn through the intersection of the regression line with the abscissa so that it makes an angle ϕ of $\tan^{-1}$ (2 tan θ) with the ordinate. The test collapse load is determined from the maximum principal strain or deflection value of the first data point for which there are three successive data points that lie *outside* of the collapse limit line. This first data point is called the *collapse load point*. The test collapse load is taken as the load on the collapse limit line which has the maximum principal strain or deflection of the collapse load point. The collapse load used for design or evaluation purposes shall be the test collapse load multiplied by the ratio of the material yield strength at design temperature to the test material yield strength at the test temperature. Careful attention shall be given to assuring that proper consideration is given to the actual "as-built" dimensions of the test model when correlating the collapse load of the test model to that expected for the actual structure being designed.

6-160 INSPECTION AND REPORTS

Tests conducted in accordance with this paragraph need not be witnessed by the Inspector. However, a detailed report of the test procedure and the results obtained shall be included with the Design Report. The Report shall show that the instrumentation used was within calibration.

6-170 VESSELS SUBJECT TO CYCLIC LOADING

(a) Experimental methods constitute a reliable means of evaluating the capability of a structural component to withstand cyclic loading. In addition, when it is desired to use higher peak stresses than can be justified by the methods of 6-100 through 6-170 and the fatigue curves, Figs. 5-110.1, 5-110.2.1, 5-110.2.2, 5-110.2.3, 5-110.3, and 5-110.4, the adequacy of a part to withstand cyclic loading may be demonstrated by means of a fatigue test. The fatigue test shall not be used, however, as justification for exceeding the allowable values of primary or primary plus secondary stresses.

(b) When a fatigue test is used to demonstrate the adequacy of a component or a portion thereof to withstand cyclic loading, a description of the test shall be included in the Design Report (see AG-302.2). This description shall contain sufficient detail to show compliance with the requirements of this paragraph.

(c) The following requirements shall be met.

(1) The test component or portion thereof shall be constructed of material having the same composition and subjected to mechanical working and heat treating so as to produce mechanical properties equivalent to those of the material in the prototype component. Geometrical similarity must be maintained, at least in those portions whose ability to withstand cyclic loading is being investigated and in those adjacent areas which affect the stresses in the portion under test.

(2) The test component or portion thereof shall withstand the number of cycles as set forth in (3) below before failure occurs. Failure is herein defined as a propagation of a crack through the entire thickness, such as would produce a measurable leak in a pressure retaining member.

(3) The minimum number of cycles (hereinafter referred to as test cycles N_T) which the component must withstand, and the magnitude of the loading (hereinafter referred to as the test loading S_T) to be applied to the component during test, shall be determined by multiplying the design service cycles N_D by a specified factor K_{TN} and the design service loads S_{atm} by K_{TS}. Values of these factors shall be determined by means of the test

parameter ratio diagram, the construction of which is as follows and is illustrated in Fig. 6-170.1.

(a) Project a vertical line from the design service cycles N_D on the abscissa of the S_a versus N diagram, to intersect the fatigue design curve, S_a of Figs. 5-110.1, 5-110.2.1, 5-110.2.2, 5-110.2.3, 5-110.3, and 5-110.4, to an ordinate value of K_s [see (7) below] times S_{aD}. Label this point A.

(b) Extend a horizontal line through the point D until its length corresponds to an abscissa value of K_n [see (7) below] times N_D. Label this point B.

(c) Connect the points A and B. The segments AB embrace all the allowable combinations of K_{TS} and K_{TN} [see (5) for accelerated testing]. Any point C on this segment may be chosen at the convenience of the tester. Referring to Fig. 6-170.1, the factors K_{TS} and K_{TN} are defined by:

$$K_{TS} = \frac{\text{Value of the ordinate at point } C}{\text{Value of the ordinate at point } D}$$

$$K_{TN} = \frac{\text{Value of abscissa at point } C}{\text{Value of abscissa at point } D}$$

Thus

$$P_T \text{ (test loading)} = K_{TS} \times \text{design service loading}$$

$$N_T \text{ (test cycles)} = K_{TN} \times \text{design service cycles}$$

(4) It should be noted that if the test article is not a full size component but a geometrically similar model, the value P_T would have to be adjusted by the appropriate scale factor, to be determined from structural similitude principles, if the loading is other than pressure. The number of cycles that the component must withstand during this test without failure must not be less than N_T, while subjected to a cyclic test loading P_T which shall be adjusted, if required, using model similitude principles if the component is not full size.

(5) Accelerated fatigue testing (test cycles N_T are less than design cycles N_D) *may be* conducted if the design cycles N_D are greater than 10^4 and the testing conditions are determined by the following procedures which are illustrated in Fig. 6-170.2. In this Figure, the points A, B, and D correspond to similar labeled points in Fig. 6-170.1.

(a) The minimum number of test cycles $N_{T\,\min}$ shall be:

$$N_{T\,\min} = 10^2 \sqrt{N_D}$$

Project a vertical line through $N_{T\,\min}$ on the abscissa of the S_a versus N diagram such that it intersects and extends beyond the fatigue design curve.

(b) Construct a curve through the point A and intersect the vertical projection of N_T [see 6-170(c)(5)(a)] by multiplying every point on the fatigue design curve by the factor K_s [see 6-170(c)(3)(a)]. Label the intersection of this curve and the vertical projection of $N_{T\min}$ as A'.

(c) Any point C on the segment A, A', B determines the allowable combinations of K_{TS} and K_{TN}. The factors K_{TS} and K_{TN} are obtained in the same manner as in 6-170(c)(3).

(6) In certain instances, it may be desirable (or possible) in performing the test to increase only the loading or number of cycles, but not both, in which event two special cases of interest result from the above general case.

(a) Case 1 (Factor Applied to Cycles Only). In this case $K_{TS} = 1$ and

$$K_{TN} = \frac{\text{Value of abscissa at point } B}{\text{Value of abscissa at point } D}$$

The number of test cycles that the component must withstand during this test must, therefore, not be less than

$$N_T = K_{TN} \times \text{design service cycles}$$

while subjected to the cyclic design service loading, adjusted as required, if a model is used.

(b) Case 2 (Factor Applied to Loading Only). In this case $K_{TN} = 1$ and

$$K_{TS} = \frac{\text{Value of the ordinate at point } A}{\text{Value of the ordinate at point } D}$$

The component must, therefore, withstand a number of cycles at least equal to the number of design service cycles, while subjected to a cyclic test loading

$$P_T = K_{TS} \times \text{design service loading}$$

again adjusted as required, if a model is used.

(7) The values of K_s and K_n are the multiples of factors which account for the effects of size, surface finish, cyclic rate, temperature, and the number of replicate tests performed. They shall be determined as follows:

K_n = $(K_s)^{4.3}$ but shall never be allowed to be less than 2.6

K_s = $K_{s\ell} \times K_{sf} \times K_{sc} \times K_{st} \times K_{ss}$ but shall never be allowed to be less than 1.25

K_{sc} = factor for differences in design fatigue curves at various temperatures

$$= \frac{S_a N \text{ at } T_c}{S_a N \text{ at design temperature}} \times \frac{S_a 10^n \text{ at test temperature}}{S_a 10^n \text{ at } T_c} \text{ where}$$

$S_a 10^n$ = S_a from the applicable fatigue design curve at the maximum number of cycles defined on the curve

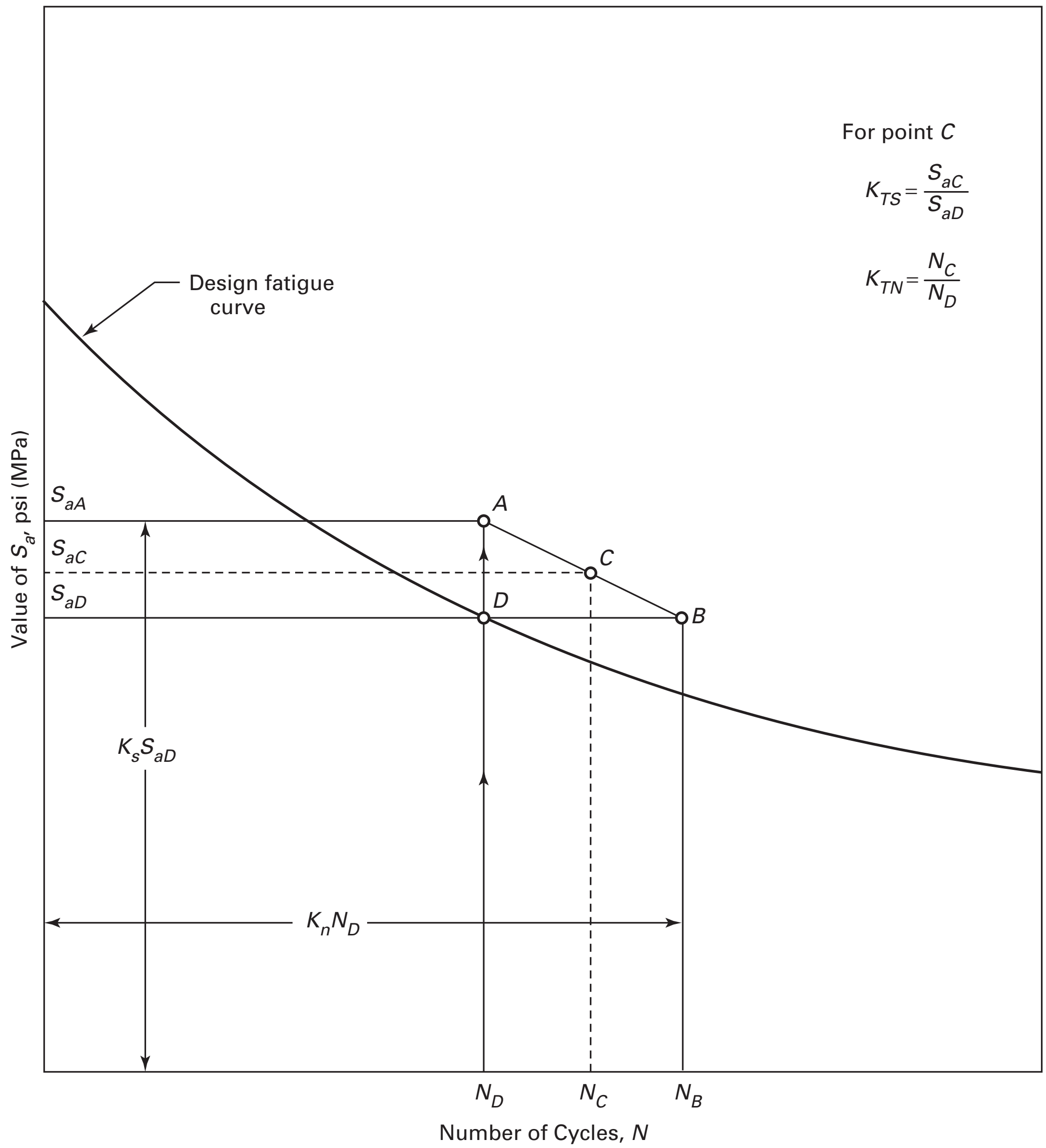


FIG. 6-170.1 CONSTRUCTION OF THE TESTING PARAMETER RATIO DIAGRAM

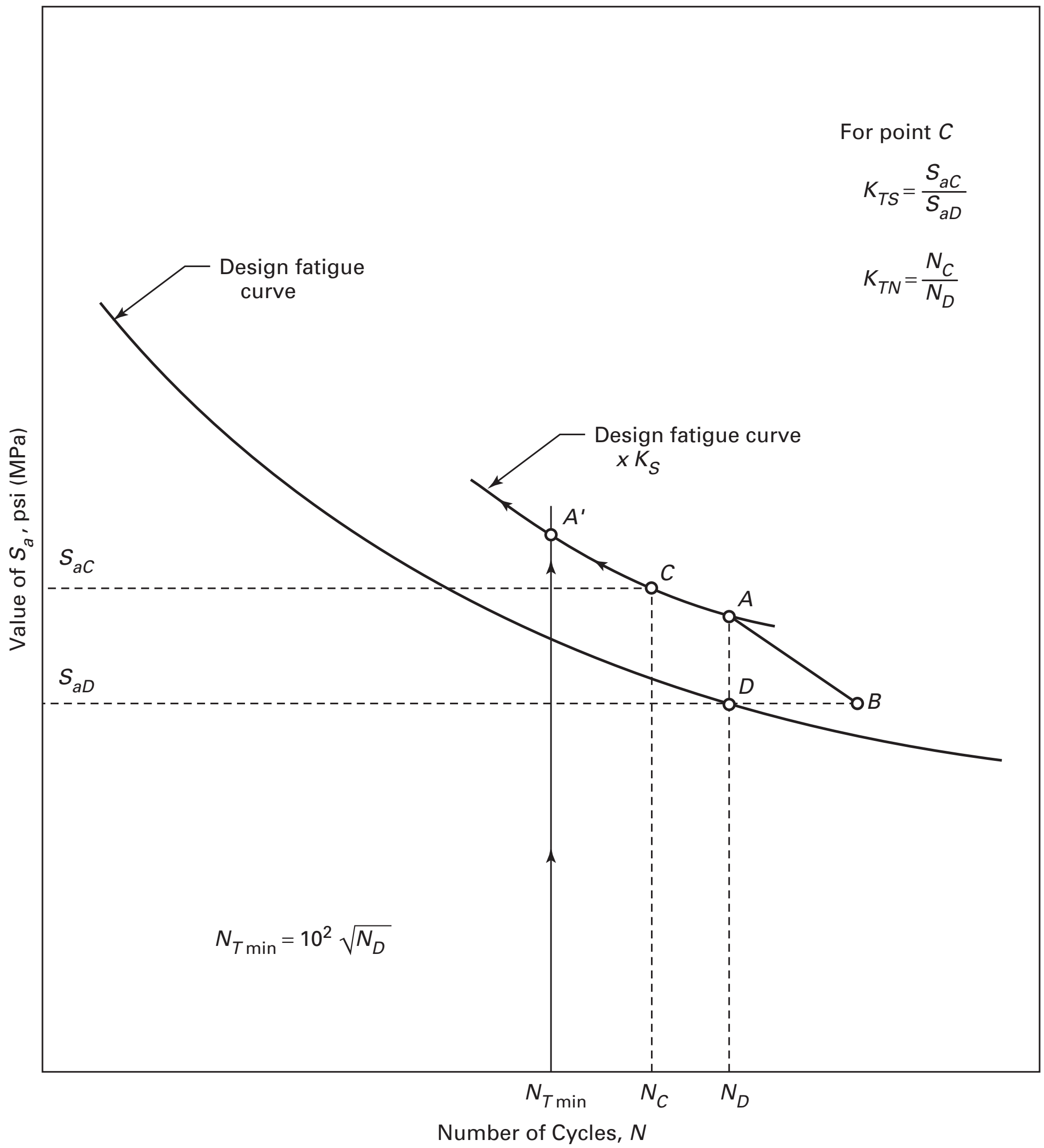


FIG. 6-170.2 CONSTRUCTION OF THE TESTING PARAMETER RATIO DIAGRAM FOR ACCELERATED TESTS

T_c = 700°F (370°C) for carbon and low alloy steels and 800°F (425°C) for austenitic stainless steels and nickel–chrome–iron alloy

$K_{s\ell}$ = factor for the effect of size on fatigue life

$= 1.5 - 0.5\left(\frac{LM}{LP}\right)$ where

$\left(\frac{LM}{LP}\right)$ = the ratio of linear model size to prototype size

K_{sf} = factor for the effect of surface finish

$= 1.175 - 0.175\left(\frac{SFM}{SFP}\right)$ where

$\left(\frac{SFM}{SFP}\right)$ = the ratio of model surface finish to prototype surface finish expressed in microinches arithmetic average (AA)

K_{st} = factor for the effect of test temperature

$= \frac{S_aN \text{ at test temperature}}{S_aN \text{ at design temperature}}$ where

$S_aN = S_a$ from applicable fatigue curve at N cycles

K_{ss} = factor for the statistical variation in test results

$= 1.470 - 0.044 \times$ number of replicate tests

No value of $K_{s\ell}$, K_{sf}, K_{sc}, K_{st}, or K_{ss} less than 1.0 may be used in calculating K_s.

6-180 DETERMINATION OF FATIGUE STRENGTH REDUCTION FACTORS

Experimental determination of fatigue strength reduction factors shall be in accordance with the following procedures.

(a) The test part shall be fabricated from a material within the same P-Number grouping of QW/QB-422 of Section IX and shall be subjected to the same heat treatment as the component.

(b) The stress level in the specimen shall be such that the stress intensity does not exceed the limit prescribed by 4-134 and so that failure does not occur in less than 1,000 cycles.

(c) The configuration, surface finish, and stress state of the specimen shall closely simulate those expected in the components. In particular, the stress gradient shall not be more abrupt than that expected in the component.

(d) The cyclic rate shall be such that appreciable heating of the specimen does not occur.

(e) The fatigue strength reduction factor shall preferably be determined by performing tests on "notched" and "unnotched" specimens and calculated as the ratio of the "unnotched" stress to the "notched" stress for failure.

MANDATORY APPENDIX 8
ROUNDED INDICATIONS CHARTS ACCEPTANCE STANDARD FOR RADIOGRAPHICALLY DETERMINED ROUNDED INDICATIONS IN WELDS

8-100 APPLICABILITY OF THESE STANDARDS

These standards are applicable to ferritic, austenitic, and nonferrous materials.

8-110 TERMINOLOGY

(a) Rounded Indications. Indications with a maximum length of three times the width or less on the radiograph are defined as rounded indications. These indications may be circular, elliptical, conical, or irregular in shape and may have tails. When evaluating the size of an indication, the tail shall be included. The indication may be from any source in the weld, such as porosity, slag, or tungsten.

(b) Aligned Indications. A sequence of four or more rounded indications shall be considered to be aligned when they touch a line parallel to the length of the weld drawn through the center of the two outer rounded indications.

(c) Thickness t. t is the thickness of the weld, excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t.

8-120 ACCEPTANCE CRITERIA

(a) Image Density. Density within the image of the indication may vary and is not a criterion for acceptance or rejection.

(b) Relevant Indications (See Table 8-1 for Examples). Only those rounded indications which exceed the following dimensions shall be considered relevant:

(1) $^1/_{10}t$ for t less than $^1/_8$ in. (3 mm);

(2) $^1/_{64}$ in. (0.4 mm) for t $^1/_8$ in. (3 mm) to $^1/_4$ in. (6 mm), inclusive;

(3) $^1/_{32}$ in. (0.8 mm) for t greater than $^1/_4$ in. (6 mm) to 2 in. (50 mm), inclusive;

(4) $^1/_{16}$ in. (1.5 mm) for t greater than 2 in. (50 mm).

(c) Maximum Size of Rounded Indications (See Table 8-1 for Examples). The maximum permissible size of any indication shall be $^1/_4$ t or $^5/_{32}$ in. (4 mm), whichever is smaller, except that an isolated indication separated from an adjacent indication by 1 in. (25 mm) or more may be $^1/_3$ t or $^1/_4$ in. (6 mm), whichever is less. For t greater than 2 in. (50 mm), the maximum permissible size of an isolated indication shall be increased to $^3/_8$ in. (10 mm).

(d) Aligned Rounded Indications. Aligned rounded indications are acceptable when the summation of the diameters of the indications is less than t in a length of $12t$ (see Fig. 8-1). The length of groups of aligned rounded indications and the spacing between the groups shall meet the requirements of Fig. 8-2.

(e) Spacing. The distance between adjacent rounded indications is not a factor in determining acceptance or rejection, except as required for isolated indications or groups of aligned indications.

(f) Rounded Indications Charts. The rounded indications as determined from the radiographic film shall not exceed that shown in the charts.

The charts in Figs. 8-3 illustrate various types of assorted, randomly dispersed and clustered rounded indications for different weld thicknesses greater than $^1/_8$ in. (3 mm). These charts represent the maximum acceptable concentration limits for rounded indications.

The chart for each thickness range represents full-scale 6 in. (150 mm) radiographs, and shall not be enlarged or reduced. The distributions shown are not necessarily the patterns that may appear on the radiograph, but are typical of the concentration and size of indications permitted.

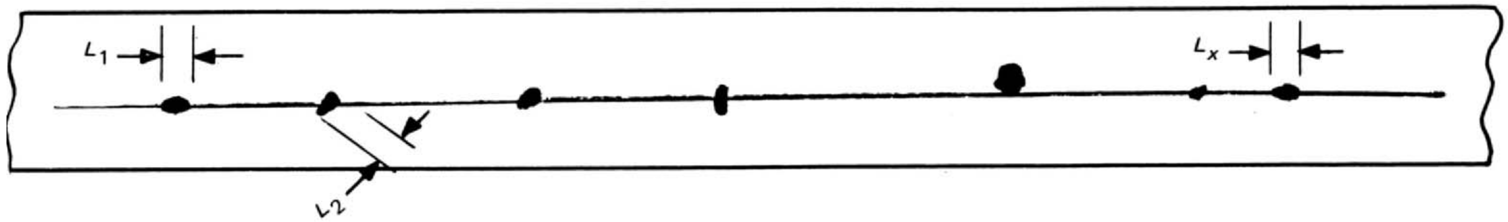
TABLE 8-1
(Examples Only)

Customary Units			
	Maximum Size of Acceptable Rounded Indications, in.		
Thickness t, in.	Random	Isolated	Maximum Size of Nonrelevant Indication, in.
Less than $1/8$	$1/4 t$	$1/3 t$	$1/10 t$
$1/8$	0.031	0.042	0.015
$3/16$	0.047	0.063	0.015
$1/4$	0.063	0.083	0.015
$5/16$	0.078	0.104	0.031
$3/8$	0.091	0.125	0.031
$7/16$	0.109	0.146	0.031
$1/2$	0.125	0.168	0.031
$9/16$	0.142	0.188	0.031
$5/8$	0.156	0.210	0.031
$11/16$	0.156	0.230	0.031
$3/4$ to 2, incl.	0.156	0.250	0.031
Over 2	0.156	0.375	0.063

SI Units			
	Maximum Size of Acceptable Rounded Indications, mm		
Thickness t, mm	Random	Isolated	Maximum Size of Nonrelevant Indication, mm
Less than 3	$1/4 t$	$1/3 t$	$1/10 t$
3	0.79	1.07	0.38
5	1.19	1.60	0.38
6	1.60	2.11	0.38
8	1.98	2.64	0.79
9	2.31	3.18	0.79
11	2.77	3.71	0.79
13	3.18	4.27	0.79
14	3.61	4.78	0.79
16	3.96	5.33	0.79
17	3.96	5.84	0.79
19 to 50, incl.	3.96	6.35	0.79
Over 50	3.96	9.53	1.60

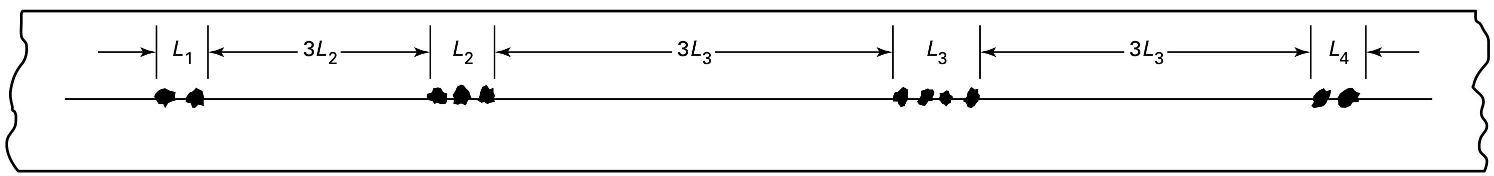
(g) Weld Thickness t Less Than $1/8$ in. (3 mm). For t less than $1/8$ in. (3 mm), the maximum number of rounded indications shall not exceed 12 in a 6 in. (150 mm) length of weld. A proportionally fewer number of indications shall be permitted in welds less than 6 in. (150 mm) in length.

(h) Clustered Indications. The illustrations for clustered indications show up to four times as many indications in a local area as that shown in the illustrations for random indications. The length of an acceptable cluster shall not exceed the lesser of 1 in. (25 mm) or $2t$. Where more than one cluster is present, the sum of the lengths of the clusters shall not exceed 1 in. (25 mm) in a 6 in. (150 mm) length of weld.



Sum of L_1 to L_x shall be less than t in a length of $12t$.

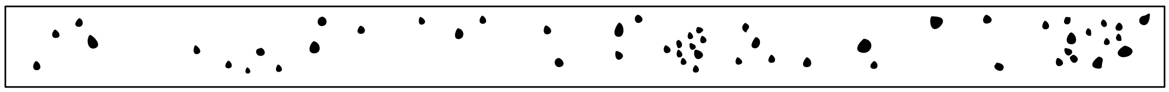
FIG. 8-1 ALIGNED ROUNDED INDICATIONS



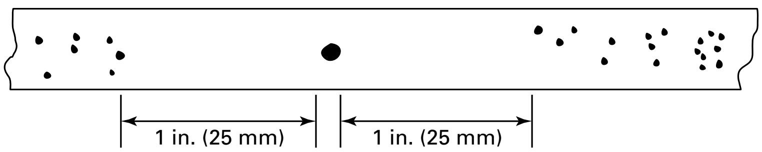
The sum of the group lengths shall be less than t in a length of $12t$.

Maximum Group Length	Minimum Group Spacing
$L = 1/4$ in. (6 mm) for $t < 3/4$ in. (19 mm)	$3L$, where L is the length of the longest adjacent group being evaluated
$L = 1/3\,t$ for $3/4$ in. (19 mm) $\leq t \leq 2\,1/4$ in. (56 mm)	
$L = 3/4$ in. (19 mm) for $t > 2\,1/4$ in. (56 mm)	

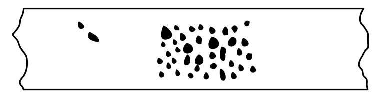
FIG. 8-2 GROUPS OF ALIGNED ROUNDED INDICATIONS



(a) Random Rounded Indications [Note (1)]



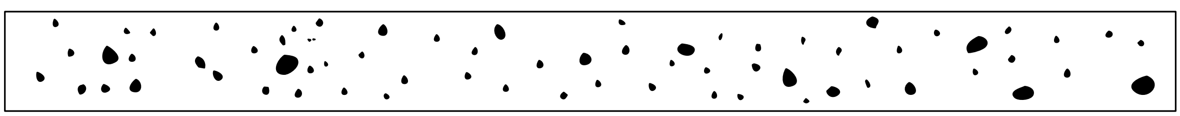
(b) Isolated Indication [Note (2)]



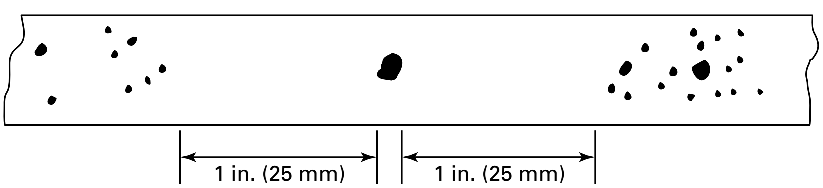
(c) Cluster

NOTES:
(1) Typical concentration and size permitted in any 6 in. (150 mm) length of weld.
(2) Maximum size per Table 8-1.

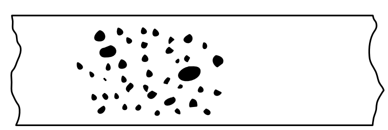
FIG. 8-3.1 CHARTS FOR t 1⁄8 in. (3 mm) TO 1⁄4 in. (6 mm), INCLUSIVE



(a) Random Rounded Indications [Note (1)]



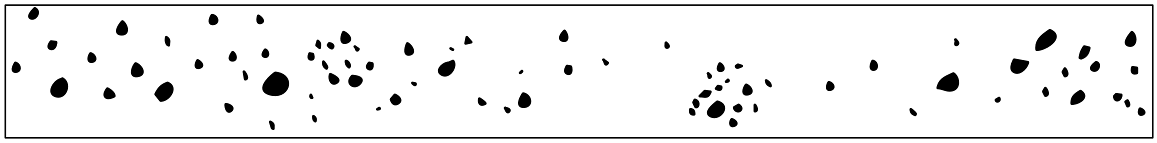
(b) Isolated Indication [Note (2)]



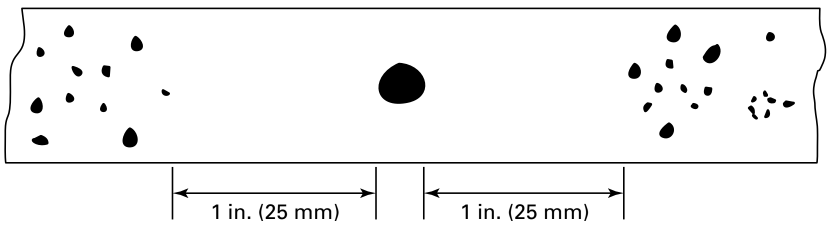
(c) Cluster

NOTES:
(1) Typical concentration and size permitted in any 6 in. (150 mm) length of weld.
(2) Maximum size per Table 8-1.

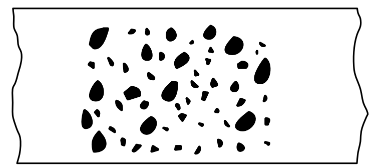
FIG. 8-3.2 CHARTS FOR t OVER 1⁄4 in. (6 mm) TO 3⁄8 in. (10 mm), INCLUSIVE



(a) Random Rounded Indications [Note (1)]



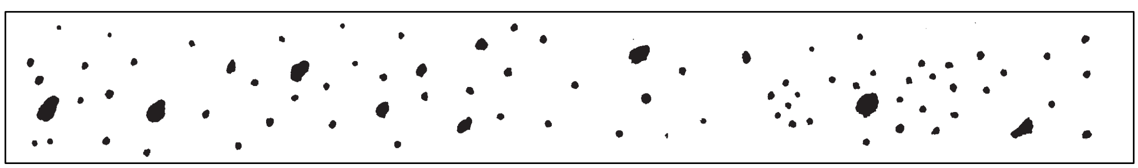
(b) Isolated Indication [Note (2)]



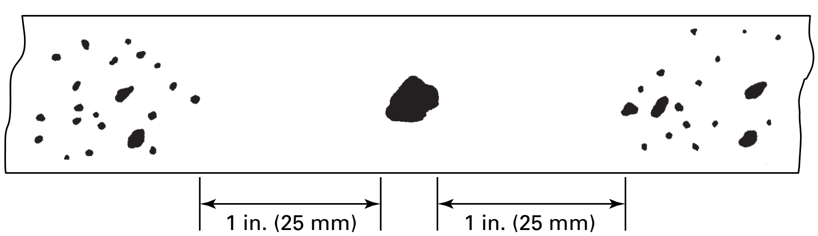
(c) Cluster

NOTES:
(1) Typical concentration and size permitted in any 6 in. (150 mm) length of weld.
(2) Maximum size per Table 8-1.

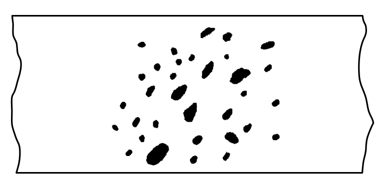
FIG. 8-3.3 CHARTS FOR t OVER 3/8 in. (10 mm) TO 3/4 in. (19 mm), INCLUSIVE



(a) Random Rounded Indications [Note (1)]



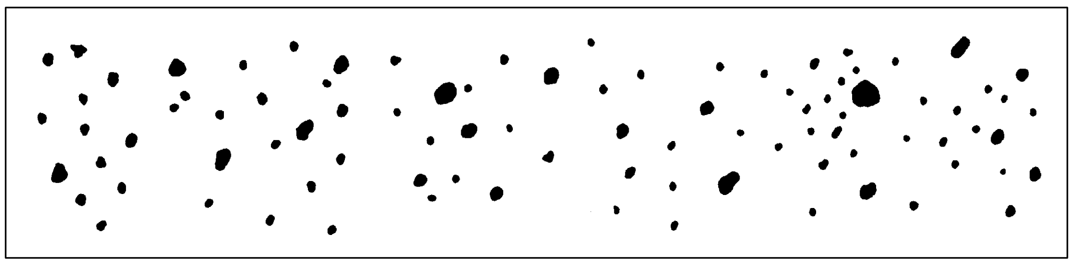
(b) Isolated Indication [Note (2)]



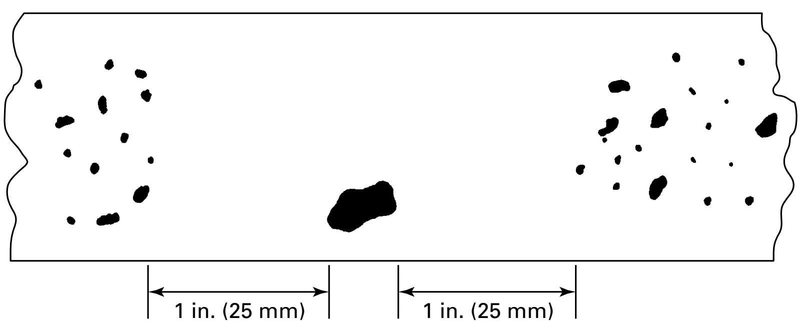
(c) Cluster

NOTES:
(1) Typical concentration and size permitted in any 6 in. (150 mm) length of weld.
(2) Maximum size per Table 8-1.

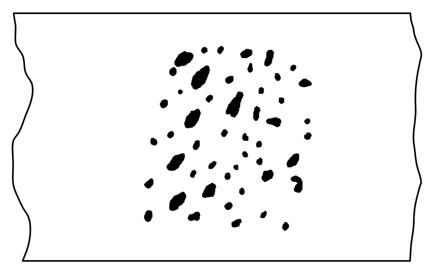
FIG. 8-3.4 CHARTS FOR t OVER 3/4 in. (19 mm) TO 2 in. (50 mm), INCLUSIVE



(a) Random Rounded Indications [Note (1)]



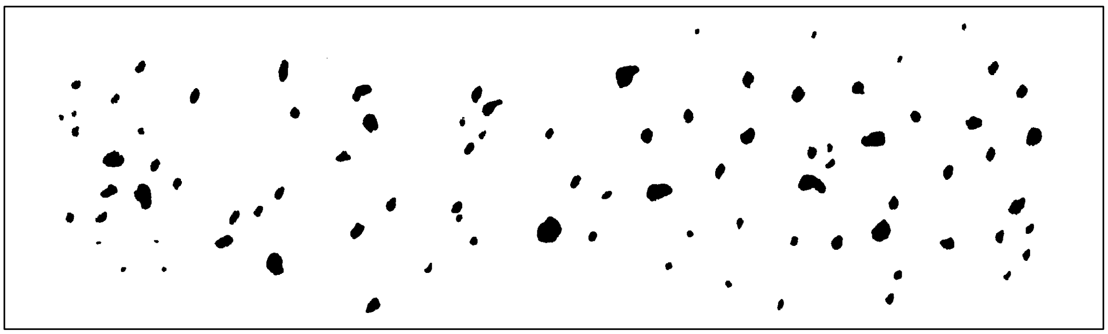
(b) Isolated Indication [Note (2)]



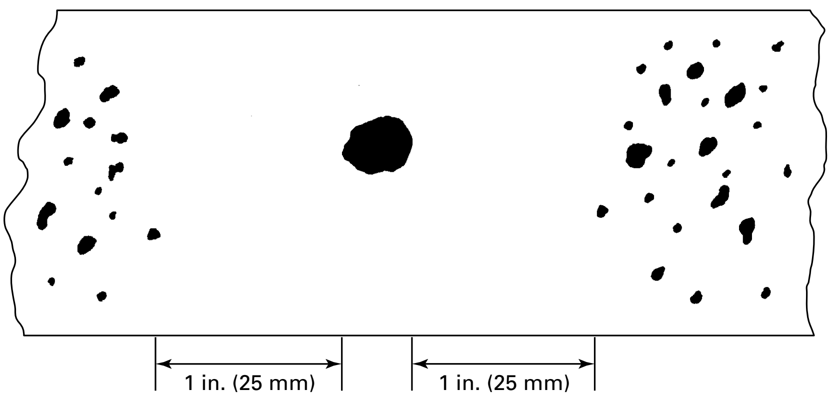
(c) Cluster

NOTES:
(1) Typical concentration and size permitted in any 6 in. (150 mm) length of weld.
(2) Maximum size per Table 8-1.

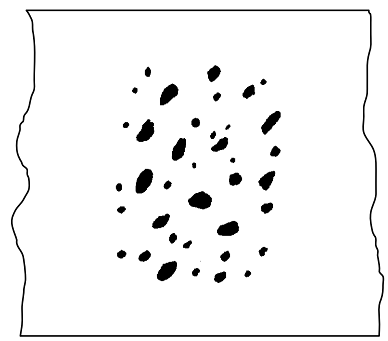
FIG. 8-3.5 CHARTS FOR *t* OVER 2 in. (50 mm) TO 4 in. (100 mm), INCLUSIVE



(a) Random Rounded Indications [Note (1)]



(b) Isolated Indication [Note (2)]



(c) Cluster

NOTES:
(1) Typical concentration and size permitted in any 6 in. (150 mm) length of weld.
(2) Maximum size per Table 8-1.

FIG. 8-3.6 CHARTS FOR *t* OVER 4 in. (100 mm)

MANDATORY APPENDIX 9
NONDESTRUCTIVE EXAMINATION

ARTICLE 9-1
MAGNETIC PARTICLE EXAMINATION

9-100 SCOPE

(a) This Appendix provides procedures which shall be followed whenever magnetic particle examination is specified in this Division.

(b) Article 7 of Section V shall be applied for the detail requirements in methods and procedures, and the additional requirements specified within this Appendix.

(c) Magnetic particle examination shall be performed in accordance with a written procedure certified by the Manufacturer to be in accordance with the requirements of T-150 of Section V.

9-110 CERTIFICATION OF COMPETENCE OF NONDESTRUCTIVE EXAMINER

Personnel conducting the magnetic particle examination shall be qualified in accordance with AI-311.

9-120 EVALUATION OF INDICATIONS

Indications will be revealed by retention of magnetic particles. All such indications are not necessarily imperfections, however, since excessive surface roughness, magnetic permeability variations (such as at the edge of heat affected zones), etc., may produce similar indications.

An indication of an imperfection may be larger than the imperfection that causes it; however, the size of the indication is the basis for acceptance evaluation. Only indications that have any dimension greater than $^1/_{16}$ in. (1.5 mm) shall be considered relevant.

(a) A linear indication is one having a length greater than three times the width.

(b) A rounded indication is one of circular or elliptical shape with a length equal to or less than three times its width.

9-130 ACCEPTANCE STANDARDS

These acceptance standards shall apply unless other more restrictive standards are specified for specific materials or applications within this Division.

All surfaces to be examined shall be free of:

(a) relevant linear indications;

(b) relevant rounded indications greater than $^3/_{16}$ in. (5 mm);

(c) four or more relevant rounded indications in a line separated by $^1/_{16}$ in. (1.5 mm) or less, edge-to-edge.

9-140 REPAIR REQUIREMENTS

Unacceptable imperfections shall be removed and reexamination made to assure complete removal. Whenever an imperfection is removed by chipping or grinding and subsequent repair by welding is not required, the excavated area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners. Where welding is required after removal of an imperfection, the area shall be cleaned and welding performed in accordance with a qualified welding procedure.

9-140.1 Treatment of Indications Believed Nonrelevant. Any indication which is believed to be nonrelevant shall be regarded as an imperfection unless it is shown by reexamination by the same method or by the use of other nondestructive methods and/or by surface conditioning that no unacceptable imperfection is present.

9-140.2 Examination of Areas From Which Imperfections Have Been Removed. After an imperfection is thought to have been removed and prior to making weld repairs, the area shall be examined by suitable methods to assure the imperfection has been eliminated.

9-140.3 Reexamination of Repair Areas. After repairs have been made, the repaired area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners, and reexamined by the magnetic particle method and by all other methods of examination that were originally required for the affected area, except that, when the depth of repair is less than the radiographic sensitivity required, reradiography may be omitted.

ARTICLE 9-2
LIQUID PENETRANT EXAMINATION

9-200 SCOPE

(a) This Article describes methods which shall be employed whenever liquid penetrant examination is specified in this Division.

(b) Article 6 of Section V shall be applied for detail requirements in methods, procedures and qualifications, unless specified within this Article.

(c) Liquid penetrant examination shall be performed in accordance with a written procedure certified by the Manufacturer to be in accordance with the requirements of T-150 of Section V.

9-210 CERTIFICATION OF COMPETENCE OF NONDESTRUCTIVE EXAMINER

Personnel conducting the liquid penetrant examination shall be qualified in accordance with AI-311.

9-220 EVALUATION OF INDICATIONS

An indication of an imperfection may be larger than the imperfection that causes it; however, the size of the indication is the basis for acceptance evaluation. Only indications with major dimensions greater than $^1/_{16}$ in. (1.5 mm) shall be considered relevant.

(a) A *linear* indication is one having a length greater than three times the width.

(b) A *rounded* indication is one of circular or elliptical shape with the length equal to or less than three times the width.

(c) Any questionable or doubtful indications shall be reexamined to determine whether or not they are relevant.

9-230 ACCEPTANCE STANDARDS

These acceptance standards shall apply unless other more restrictive standards are specified for specific materials or applications within this Division.

All surfaces to be examined shall be free of:

(a) relevant linear indications;

(b) relevant rounded indications greater than $^3/_{16}$ in. (5 mm);

(c) four or more relevant rounded indications in a line separated by $^1/_{16}$ in. (1.5 mm) or less (edge-to-edge).

9-240 REPAIR REQUIREMENTS

Unacceptable imperfections shall be removed and reexamination made to assure complete removal. Whenever an imperfection is removed by chipping or grinding and subsequent repair by welding is not required, the excavated area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners. Where welding is required after removal of an imperfection, the area shall be cleaned and welding performed in accordance with a qualified welding procedure.

9-240.1 Treatment of Indications Believed Nonrelevant. Any indication which is believed to be nonrelevant shall be regarded as an imperfection unless it is shown by reexamination by the same method or by the use of other nondestructive methods and/or by surface conditioning that no unacceptable imperfection is present.

9-240.2 Examination of Areas From Which Imperfections Have Been Removed. After an imperfection is thought to have been removed and prior to making weld repairs, the area shall be examined by suitable methods to assure the imperfection has been eliminated.

9-240.3 Reexamination of Repair Areas. After repairs have been made, the repaired area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners and reexamined by the liquid penetrant method and by all other methods of examination that were originally required for the affected area, except that, when the depth of repair is less than the radiographic sensitivity required, reradiography may be omitted.

ARTICLE 9-3
ULTRASONIC EXAMINATION OF WELDS

9-300 SCOPE

(a) This Article describes methods which shall be employed when ultrasonic examination of welds is specified in this Division.

(b) Article 4 of Section V shall be applied for detail requirements in methods, procedures, and qualifications, unless otherwise specified within this Article.

(c) Ultrasonic examination shall be performed in accordance with a written procedure certified by the Manufacturer to be in accordance with the requirements of T-150 of Section V.

9-310 CERTIFICATION OF COMPETENCE OF NONDESTRUCTIVE EXAMINER

The Manufacturer shall certify that personnel performing and evaluating ultrasonic examinations required by this Division have been qualified and certified in accordance with their employer's written practice. SNT-TC-1A[1] shall be used as a guideline for employers to establish their written practice for qualification and certification of their personnel. Alternatively, the ASNT Central Certification Program (ACCP) or CP-189[1] may be used to fulfill the examination and demonstration requirements of SNT-TC-1A and the employer's written practice. Provisions for training, experience, qualification, and certification of NDE personnel shall be described in the Manufacturer's Quality Control System.

9-320 ACCEPTANCE/REJECTION STANDARDS

These standards shall apply unless other standards are specified for specific applications within this Division.

All imperfections that produce an amplitude greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such imperfections and evaluate them in terms of the acceptance standards given in (a) and (b) below.

(a) Imperfections that are interpreted to be cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

(b) All other linear type imperfections are unacceptable if the amplitude exceeds the reference level and the length of the imperfection exceeds the following:

(1) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm)

(2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. (19 mm) to $2\frac{1}{4}$ in. (57 mm)

(3) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (57 mm)

where t is the thickness of the weld, excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t.

9-330 REPORT OF EXAMINATION

The Manufacturer shall prepare a report of the ultrasonic examination and a copy of this report shall be retained by the Manufacturer until the Manufacturer's Data Report has been signed by the Inspector. The Report shall contain the information required by Section V. In addition, a record of repaired areas shall be noted as well as the results of the reexamination of the repaired areas. The Manufacturer shall also maintain a record of all reflections from uncorrected areas having responses that exceed 50% of the reference level. This record shall locate each area, the response level, the dimensions, the depth below the surface, and the classification.

[1] Recommended Practice No. SNT-TC-1A, ACCP, and CP-189 are published by American Society for Nondestructive Testing, Inc., 1711 Arlingate Lane, P.O. Box 28518, Columbus, Ohio 43228-0518.

MANDATORY APPENDIX 10
CAPACITY CONVERSIONS FOR SAFETY VALVES

10-100 REQUIREMENTS FOR CAPACITY CONVERSIONS

(a) The capacity of a safety or safety relief valve in terms of a gas or vapor other than the medium for which the valve was officially rated shall be determined by application of the following formulas:[1]

For steam:

(U.S. Customary Units)

$$W_s = 51.5\ KAP$$

(SI Units)

$$W_s = 5.25\ KAP$$

For air:

$$W_a = CKAP\sqrt{\frac{M}{T}}$$

where

C = 356 for U.S. customary units (27.03 for SI units)
M = 28.97 mol. wt.
T = 520 for U.S. customary units (293 for SI units) when W_a is the rated capacity

For any gas or vapor:

$$W = CKAP\sqrt{\frac{M}{T}}$$

where

W_s = rated capacity, lb/hr (kg/hr) of steam
W_a = rated capacity, converted to lb/hr (kg/hr) of air at 60°F (20°C), inlet temperature
W = flow of any gas or vapor, lb/hr (kg/hr)
C = constant for gas or vapor which is a function of the ratio of specific heats $k = c_p/c_v$ (see Fig. 10-100.1)
K = coefficient of discharge (see AR-523)
A = actual discharge area of the safety valve, sq in. (mm^2)
P = (set pressure × 1.10) plus atmospheric pressure, psia (MPa absolute)
M = molecular weight
T = absolute temperature at inlet [°F + 460 (K)]

These formulas shall also be used when the required flow of any gas or vapor is known and it is necessary to compute the rated capacity of steam or air.

(b) Molecular weights of some of the common gases and vapors are given in Table 10-100.1.

(c) For hydrocarbon vapors, where the actual value of k is not known, the conservative value $k = 1.001$ has been commonly used and the formula becomes:

(U.S. Customary Units)

$$W = 315\ KAP\sqrt{\frac{M}{T}}$$

(SI Units)

$$W = 23.95\ KAP\sqrt{\frac{M}{T}}$$

(d) When desired, as in the case of light hydrocarbons, the compressibility factor Z may be included in the formulas for gases and vapors as follows:

$$W = CKAP\sqrt{\frac{M}{ZT}}$$

Example 1

GIVEN: A safety valve bears a certified capacity rating of 3020 lb/hr of steam for a pressure setting of 200 psi.

PROBLEM: What is the relieving capacity of that valve in terms of air at 100°F for the same pressure setting?

---

[1] Knowing the official rating capacity of a safety valve which is stamped on the valve, it is possible to determine the overall value of KA in either of the following formulas in cases where the value of these individual terms is now known:

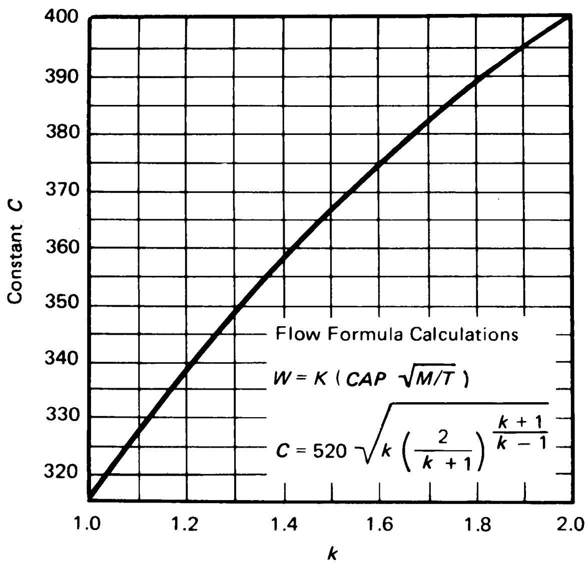
Official Rating in Steam

$$KA = \frac{W_s}{51.5P}$$

Official Rating in Air

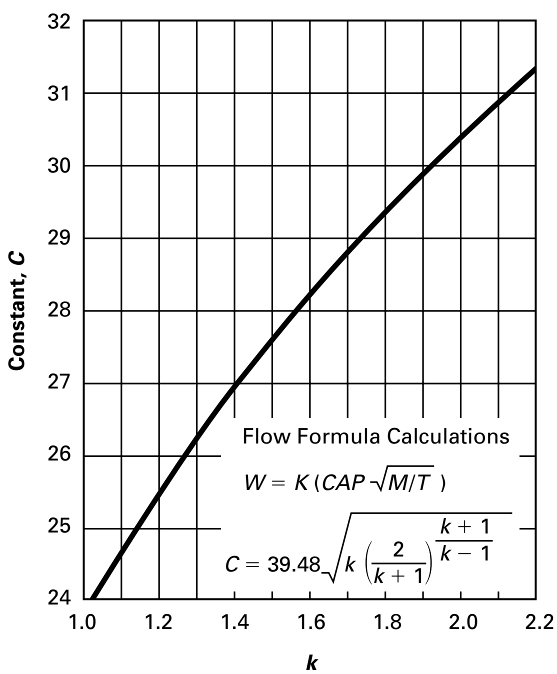
$$KA = \frac{W_a}{CP}\sqrt{\frac{T}{M}}$$

This value for KA is then substituted in the above formulas to determine the capacity of the safety valve in terms of the new gas or vapor.



k	Constant C	k	Constant C	k	Constant C
1.00	315	1.26	343	1.52	366
1.02	318	1.28	345	1.54	368
1.04	320	1.30	347	1.56	369
1.06	322	1.32	349	1.58	371
1.08	324	1.34	351	1.60	372
1.10	327	1.36	352	1.62	374
1.12	329	1.38	354	1.64	376
1.14	331	1.40	356	1.66	377
1.16	333	1.42	358	1.68	379
1.18	335	1.44	359	1.70	380
1.20	337	1.46	361	2.00	400
1.22	339	1.48	363	2.20	412
1.24	341	1.50	364	...	...

FIG. 10-100.1 CONSTANT C FOR GAS OR VAPOR RELATED TO RATIO OF SPECIFIC HEATS ($k = c_p/c_v$)



k	Constant C	k	Constant C	k	Constant C
1.001	23.95	1.26	26.05	1.52	27.80
1.02	24.12	1.28	26.20	1.54	27.93
1.04	24.30	1.30	26.34	1.56	28.05
1.06	24.47	1.32	26.49	1.58	28.17
1.08	24.64	1.34	26.63	1.60	28.29
1.10	24.81	1.36	26.76	1.62	28.40
1.12	24.97	1.38	26.90	1.64	28.52
1.14	25.13	1.40	27.03	1.66	28.63
1.16	25.29	1.42	27.17	1.68	28.74
1.18	25.45	1.44	27.30	1.70	28.86
1.20	25.60	1.46	27.43	2.00	30.39
1.22	25.76	1.48	27.55	2.20	31.29
1.24	25.91	1.50	27.68	...	...

FIG. 10-100.1M CONSTANT C FOR GAS OR VAPOR RELATED TO RATIO OF SPECIFIC HEATS ($k = c_p/c_v$)

TABLE 10-100.1
MOLECULAR WEIGHTS OF GASES AND VAPORS

Air	28.97	Refrigerant 22	86.48
Acetylene	26.04	Refrigerant 114	170.90
Ammonia	17.03	Hydrogen	2.02
Butane	58.12	Hydrogen Sulfide	34.08
Carbon Dioxide	44.01	Methane	16.04
Chlorine	70.91	Methyl Chloride	50.48
Ethane	30.07	Nitrogen	28.02
Ethylene	28.05	Oxygen	32.00
Refrigerant 11	137.371	Propane	44.09
Refrigerant 12	120.9	Sulfur Dioxide	64.06

SOLUTION:
For steam:

$$W_s = 51.5KAP$$

$$3{,}020 = 51.5KAP$$

$$KAP = \frac{3{,}020}{51.5} = 58.5$$

For air:

$$W_a = CKAP\sqrt{\frac{M}{T}}$$

$$= 356KAP\sqrt{\frac{28.97}{460 + 100}}$$

$$= (356)\ (58.5)\sqrt{\frac{28.97}{560}}$$

$$= 4{,}750 \text{ lb/hr}$$

Example 2

GIVEN: It is required to relieve 5,000 lb/hr of propane from a pressure vessel through a safety valve set to relieve at a pressure of P_s, psi, and with an inlet temperature of 125°F.

PROBLEM: What total capacity in pounds of steam per hour in safety valves must be furnished?

SOLUTION:
For propane:

$$W = CKAP\sqrt{\frac{M}{T}}$$

Value of C is not definitely known. Use the conservative value $C = 315$:

$$5{,}000 = 315KAP\sqrt{\frac{44.09}{460 + 125}}$$

$$KAP = 57.7$$

For steam:

$$W_s = 51.5KAP = (51.5)(57.7)$$

$$= 2{,}790 \text{ lb/hr set to relieve at } P_s \text{, psi}$$

Example 3

GIVEN: It is required to relieve 1,000 lb of ammonia per hour from a pressure vessel at 150°F.

PROBLEM: What is the required total capacity in pounds of steam per hour at the same pressure setting?

SOLUTION:
For ammonia:

$$W = CKAP\sqrt{\frac{M}{T}}$$

Manufacturer and user agree to use $k = 1.33$. From Fig. 10-100.1, $C=350$:

$$1{,}000 = 350KAP\sqrt{\frac{17.03}{460 + 150}}$$

$$KAP = 17.10$$

For steam:

$$W_s = 51.5KAP = (51.5)\ (17.10)$$

$$= 880 \text{ lb/hr}$$

Example 4

GIVEN: A safety valve bearing a certified rating of 10,000 cu ft/min of air at 60°F and 14.7 psia (atmospheric pressure).

PROBLEM: What is the flow capacity of this safety valve in pounds of saturated steam per hour for the same pressure setting?

SOLUTION:
For air:

Weight (of dry air at 60°F and 14.7 psia) = 0.0766 lb/cu ft

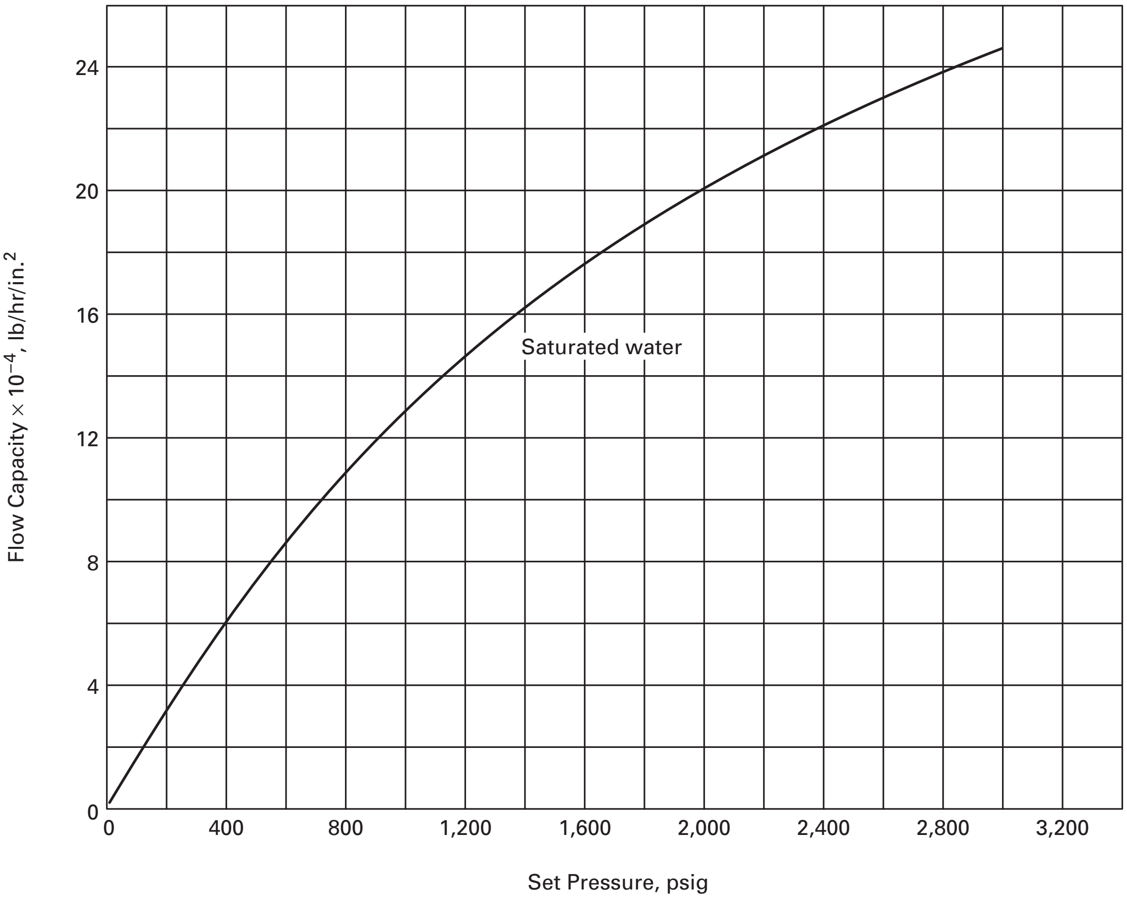


FIG. 10-101.1 FLOW CAPACITY CURVE FOR RATING NOZZLE TYPE SAFETY VALVES ON SATURATED WATER (BASED ON 10% OVERPRESSURE)

$$W_a = 10{,}000 \times 0.0766 \times 60 = 45{,}960 \text{ lb/hr}$$

$$45{,}960 = 356KAP\sqrt{\frac{28.97}{460 + 60}}$$

$$KAP = 546$$

For steam:

$$W_s = 51.5KAP = (51.5)(546)$$

$$= 28{,}200 \text{ lb/hr}$$

NOTE: Before converting the capacity of a safety valve from any gas to steam, the requirements of AR-511 must be met.

10-101 Nozzle Type Valves

(a) Since it is realized that the saturated water capacity is configuration sensitive, the following applies only to those valves that have a nozzle type construction (throat to inlet diameter ratio of 0.25 to 0.80 with a continuously contoured change and have exhibited a coefficient K_D in excess of 0.90). No saturated water rating shall apply to other types of construction.

NOTE: The Manufacturer, user, and Inspector are all cautioned that for the following rating to apply, the valve shall be continuously subjected to saturated water. If, after initial relief, the flow media changes to quality steam, the valve shall be rated as per dry saturated steam. Valves installed on vessels or lines containing steam–water mixture shall be rated on dry saturated steam.

(b) To determine the saturated water capacity of a valve currently rated under AR-520 and meeting the requirements of (a) above, refer to Fig. 10-101.1. Enter the graph at the set pressure of the valve, move vertically upward to the saturated water line, and read horizontally the relieving capacity. This capacity is the theoretical, isentropic value arrived at by assuming equilibrium flow and calculated values for the critical pressure ratio.

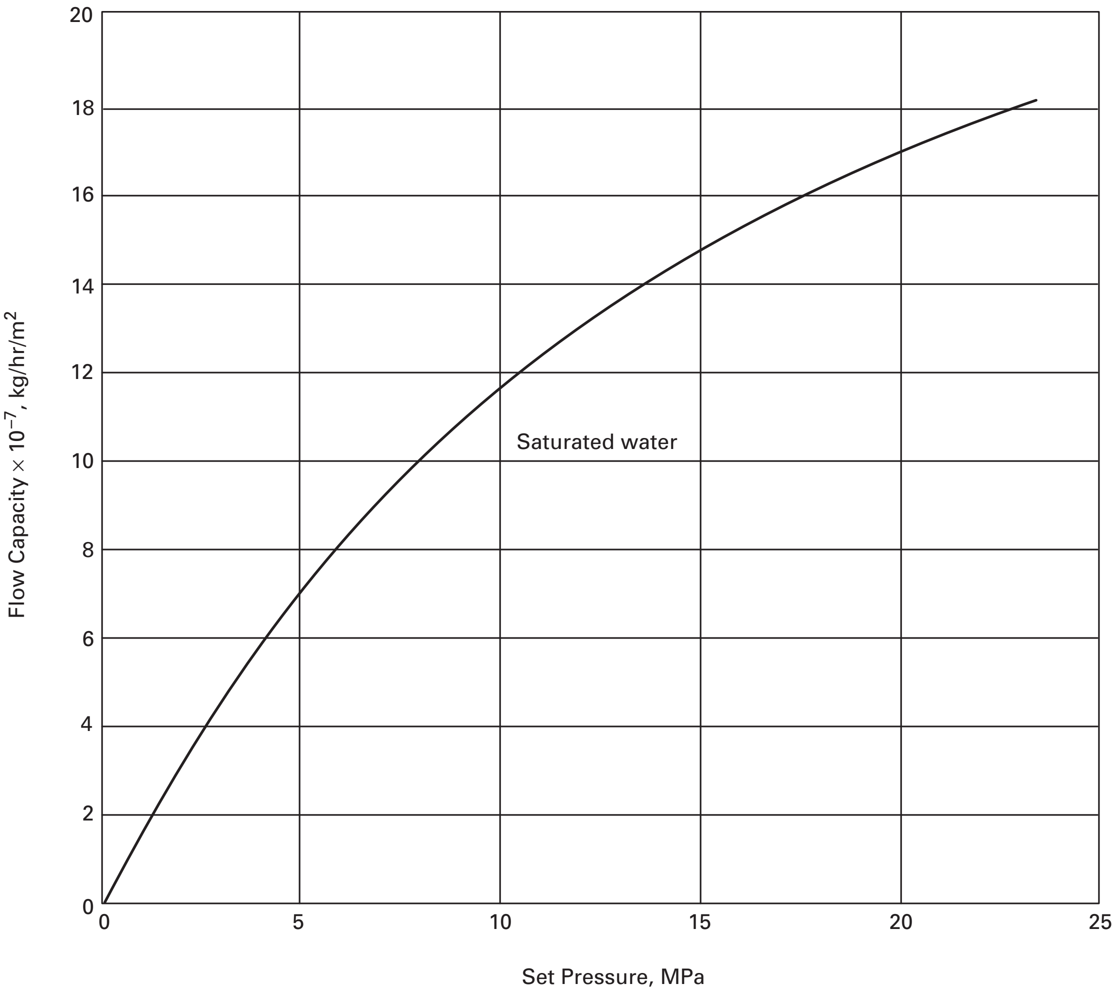


FIG. 10-101.1M FLOW CAPACITY CURVE FOR RATING NOZZLE TYPE SAFETY VALVES ON SATURATED WATER (BASED ON 10% OVERPRESSURE)

MANDATORY APPENDIX 18
QUALITY CONTROL SYSTEM

04 18-100 GENERAL

The Manufacturer or Assembler shall have and maintain a Quality Control System which will establish that all Code requirements, including material, design, fabrication, examination (by the Manufacturer or Assembler), and inspection of vessels and vessel parts (by the Inspector), will be met. The Quality Control Systems of UV stamp holders shall include the duties of a Certified Individual, as required by this Division. The Certified Individual authorized to provide oversight may also serve as the certificate holder's authorized representative for signing data reports or certificates of conformance. Provided that Code requirements are suitably identified, the system may include provisions for satisfying any requirements by the Manufacturer, Assembler, or user which exceed minimum Code requirements and may include provisions for quality control of non-Code work. In such systems, the Manufacturer of vessels and vessel parts may make changes in parts of the system which do not affect the Code requirements without securing acceptance by the Inspector (see AG-303). Before implementation, revisions to Quality Control Systems of Manufacturers and Assemblers of pressure relief valves shall have been found acceptable by the ASME designated organization if such revisions affect Code requirements.

The system that the Manufacturer or Assembler uses to meet the requirements of this Division must be one suitable for his own circumstances. The necessary scope and detail of the system shall depend on the complexity of the work[1] performed and on the size and complexity of the Manufacturer's organization.[2] A written description of the system the Manufacturer or Assembler will use to produce a Code item shall be available for review. Depending upon the circumstances, the description may be brief or voluminous.

[1] The complexity of the work includes factors such as design simplicity versus complexity, the types of materials and welding procedures used, the thickness of materials, the types of nondestructive examinations applied, and whether heat treatments are applied.

[2] The size and complexity of the organization includes factors such as the number of employees, the experience level of employees, the number of Code items produced, and whether the factors defining the complexity of the work cover a wide or narrow range.

The written description may contain information of a proprietary nature relating to the Manufacturer's processes. Therefore, the Code does not require any distribution of this information except for the Inspector, ASME Designee, or ASME designated organization as covered by 18-123(c) and 18-124(c). It is intended that information learned about the system in connection with the evaluation will be treated as confidential and that all loaned descriptions will be returned to the Manufacturer or Assembler upon completion of the evaluation.

18-110 OUTLINE OF FEATURES TO BE INCLUDED IN THE WRITTEN DESCRIPTION OF THE QUALITY CONTROL SYSTEM

The following is a guide to some of the features which should be covered in the written description of the Quality Control System and is equally applicable to both shop and field work.

(a) See AI-101 and AI-102.

(b) The complexity of the work includes factors such as design simplicity versus complexity, the types of materials and welding procedures used, the thickness of materials, the types of nondestructive examinations applied, and whether heat treatments are applied.

(c) The size and complexity of the Manufacturer's or Assembler's organization includes factors such as the number of employees, the experience level of employees, the number of vessels produced, and whether the factors defining the complexity of the work cover a wide or narrow range.

18-111 AUTHORITY AND RESPONSIBILITY

The authority and responsibility of those in charge of the Quality Control System shall be clearly established. Persons performing quality control functions shall have sufficient and well-defined responsibility, the authority, and the organizational freedom to identify quality control problems and to initiate, recommend, and provide solutions.

18-112 ORGANIZATION

An organization chart showing the relationship between management and engineering, purchasing, manufacturing, field construction, inspection, and quality control is required to reflect the actual organization. The purpose of this chart is to identify and associate the various organizational groups with the particular function for which they are responsible. The Code does not intend to encroach on the Manufacturer's or Assembler's right to establish, and from time to time to alter, whatever form of organization the Manufacturer or Assembler considers appropriate for its Code work.

18-113 DRAWINGS, DESIGN CALCULATIONS, AND SPECIFICATION CONTROL

The Manufacturer's or Assembler's Quality Control System shall provide procedures which will assure that the latest applicable drawings, design calculations, specifications, and instructions, required by the Code, as well as authorized changes, are used for manufacture, examination, inspection, and testing. The system shall insure that authorized changes are included, when appropriate, in the User's Design Specification and/or in the Manufacturer's Design Report.

18-114 MATERIAL CONTROL

The Manufacturer or Assembler shall include a system of receiving control which will insure that the material received is properly identified and has documentation including required material certifications or material test reports to satisfy Code requirements as ordered. The system material control shall insure that only the intended material is used in Code construction.

18-115 EXAMINATION AND INSPECTION PROGRAM

The Manufacturer's or Assembler's Quality Control System shall describe the fabrication operations, including examination, sufficiently to permit the Inspector, ASME Designee, or an ASME designated organization to determine at what stages specific inspections are to be performed.

18-116 CORRECTION OF NONCONFORMITIES

There shall be a system agreed upon with the Inspector for correction of nonconformities. A nonconformity is any condition which does not comply with the applicable rules of this Division. Nonconformities must be corrected or eliminated in some way before the completed component can be considered to comply with this Division.

18-117 WELDING

The Quality Control System shall include provisions for indicating that welding conforms to requirements of Section IX as supplemented by this Division. Manufacturers intending to use AWS standard welding procedures shall describe control measures used to assure that welding meets the requirements of this Division and Section IX.

18-118 NONDESTRUCTIVE EXAMINATION

The Quality Control System shall include provisions for identifying nondestructive examination procedures the Manufacturer or Assembler will apply to conform with the requirements of this Division.

18-119 HEAT TREATMENT

The Quality Control System shall provide controls to ensure that heat treatments as required by the rules of this Division are applied. Means shall be indicated by which the Inspector, ASME Designee, or an ASME designated organization can satisfy itself that these Code heat treatment requirements are met. This may be by review of furnace time–temperature records or by other methods as appropriate.

18-120 CALIBRATION OF MEASUREMENT AND TEST EQUIPMENT

The Manufacturer or Assembler shall have a system for the calibration of examination, measuring, and test equipment used in fulfillment of requirements of this Division.

18-121 RECORDS RETENTION

The Manufacturer or Assembler shall have a system for the maintenance of Data Reports and records as required by this Division.

18-122 SAMPLE FORMS

The forms used in this Quality Control System and any detailed procedures for their use shall be available for review. The written description shall make necessary references to these forms.

18-123 INSPECTION OF VESSELS AND VESSEL PARTS

(a) Inspection of vessels and vessel parts shall be by the Inspector as defined in AI-110.

(b) The written description of the Quality Control System shall include reference to the Inspector.

(c) The Manufacturer shall make available to the Inspector, at the Manufacturer's plant or construction site, a current copy of the written description of the Quality Control System.

(d) The Manufacturer's Quality Control System shall provide for the Inspector at the Manufacturer's plant to have access to the User's Design Specification, the Manufacturer's Design Report, and all drawings, calculations, specifications, procedures, process sheets, repair procedures, records, test results, and any other documents as necessary for the Inspector to perform his duties in accordance with this Division. The Manufacturer may provide such access either to his own files of such documents or by providing copies to the Inspector.

18-124 INSPECTION OF PRESSURE RELIEF VALVES

(a) Inspection of manufacturing and/or assembly of pressure relief valves shall be by a representative from an ASME designated organization as described in AR-220(a).

(b) The written description of the Quality Control System shall include reference to the ASME designated organization.

(c) The valve Manufacturer or Assembler shall make available to a representative from an ASME designated organization, at the Manufacturer's or Assembler's plant, a current copy of the written description of the applicable Quality Control System.

(d) The valve Manufacturer's or Assembler's Quality Control System shall provide for a representative from an ASME designated organization to have access to all drawings, calculations, specifications, procedures, process sheets, repair procedures, records, test results, and any other documents as necessary for a representative from an ASME designated organization to perform his duties in accordance with this Division. The Manufacturer may provide such access either to his own files of such documents or by providing copies to the designee.

MANDATORY APPENDIX 19
DEFINITIONS

19-100 INTRODUCTION

This Appendix contains definitions of terms generally used in this Division. Definitions of terms relating to a specific application, such as for stress analysis or layered vessels, may be found in related parts of this Division.

19-200 DEFINITION OF TERMS

acceptance by the Inspector: where words such as "acceptance by the Inspector" and/or "accepted by the Inspector" are used in this Division, they shall be understood to mean that the Inspector has reviewed a subject in accordance with his duties as required by the rules of this Division and after such review is able to sign the Certificate of Inspection for the applicable Manufacturer's Data Report Form. Such words do not imply assumption by the Inspector of any of the responsibilities of the Manufacturer.

angle joint: a joint between two members located in intersecting planes between 0 deg (a butt joint) and 90 deg (a corner joint).

ASME Designated Organization: an entity authorized by ASME to perform administrative functions on its behalf.

ASME Designee: an individual authorized by ASME to perform administrative functions on its behalf. The ASME Designee performs reviews, surveys, audits, and examinations of organizations or persons holding or applying for accreditation or certification in accordance with the ASME code or standard.

basic material specification: a description of the identifying characteristics of a material (product form, ranges of composition, mechanical properties, methods of production, etc.) together with the sampling, testing, and examination procedures to be applied to production lots of such material to verify acceptable conformance to the intended characteristics.

bolt: a threaded fastener with a head on one end.

certificate of compliance: a document by which the Material Manufacturer or Supplier certifies that the material represented has been produced and tested in accordance with the requirements of the basic material specification shown on the certificate. Signatures are not required to appear on certificates of compliance. Objective evidence of compliance with the requirements of the material specification shall be maintained in the records of the Material Manufacturer or Supplier.

clad vessel: a vessel made from a base material having a corrosion resistant material either integrally bonded or weld metal overlaid to the base of less resistant material.

design metal temperature: the temperature used in design based on the actual metal temperature expected under operating conditions for the part considered at the designated coincident pressure. When the occurrence of different metal temperatures during operation can be definitely predicted for different zones of a vessel, the design of the different zones may be based on their predicted temperatures (see AD-121.2).

design pressure: the pressure at the top of the vessel which, together with the applicable coincident (metal) temperature, is stamped on the nameplate. The pressure at the top of the vessel is also the basis for the pressure setting of the pressure relief devices protecting the vessel (see A-108).

liquid penetrant examination (PT): a method of nondestructive examination which provides for the detection of imperfections open to the surface in ferrous and nonferrous materials which are nonporous. Typical imperfections detectable by this method are cracks, seams, laps, cold shuts, and laminations.

magnetic particle examination (MT): a method of detecting cracks and similar imperfections at or near the surface in iron and the magnetic alloys of steel. It consists of properly magnetizing the material and applying finely divided magnetic particles which form patterns indicating the imperfections.

material: any substance or product form which is covered by an SA, SB, or SFA material specification in Section II or any other material permitted by the Code.

Material Manufacturer: the organization which performs or supervises and directly controls one or more of the operations which affect the material properties required by the basic material specification. The Material Manufacturer certifies the results of one or more of the tests, examinations, repairs, or treatments required by the basic material specification.

Material Supplier: the organization which supplies material furnished and certified by a Material Manufacturer, but which does not perform any operation intended to affect the material properties required by the basic material specification. The Material Supplier may perform and certify the results of tests, examinations, repairs, and treatments not performed by the Material Manufacturer.

Material Test Report: a document, or documents, on which are recorded the results of tests, examinations, repairs, or treatments required by the basic material specification to be reported. Supplementary or special requirements in addition to the requirements of the basic material specification may also be included on the Material Test Report. All such documents shall identify the applicable material specification and shall be identified to the material represented. When preparing a Material Test Report, a Material Manufacturer may transcribe data produced by other organizations provided he accepts responsibility for the accuracy and authenticity of the data and maintains a file containing the test report from the originator of the data. In such instances, the Material Manufacturer shall identify on the Material Test Report the source of the data and the location of the file containing the test report from the originator of the data. Signatures are not required to appear on Material Test Reports. A Material Supplier shall not transcribe data certified by a Material Manufacturer, but shall furnish a copy of that certification, supplemented as necessary by additional documents which certify the results of tests, examinations, repairs, or treatments required by the basic material specification and performed by the Material Supplier.

normal operation: any set of operating conditions other than startup and shutdown which are specified for the vessel to perform its intended function.

operating pressure: the pressure at the top of the vessel at which it normally operates. The operating pressure shall not exceed the design pressure and is usually kept at a suitable level below it to prevent the frequent opening of the pressure relieving devices.

porosity: gas pockets or voids in metal.

radiographic examination (RT): a method of detecting imperfections in materials by passing X-ray or nuclear radiation through the material and presenting their image on a recording medium.

safety valve set pressure: see ASME PTC 25.

stud: a threaded fastener without a head, with threads on one end or both ends, or threaded full length.

test pressure: the pressure to be applied at the top of the vessel during the test. This pressure plus any pressure due to static head at any point under consideration is used in the applicable formula to check the vessel under test conditions (see AT-300, AT-301, and AT-410).

ultrasonic examination (UT): a method of detecting imperfections in materials by passing ultrasonic vibrations (frequencies normally 1 MHz to 5 MHz) through the material.

vessel Manufacturer: any manufacturer who constructs an item, such as a pressure vessel, vessel component, or part, in accordance with the rules of this Division and who holds an ASME Certificate of Authorization to apply the Code symbol stamp to such an item.

MANDATORY APPENDIX 20
REQUIREMENTS FOR HUBS OF TUBESHEETS AND FLAT HEADS MACHINED FROM PLATE

20-100 SCOPE

This Appendix covers the requirements for hubs of tubesheets and flat heads machined from plate.

20-200 MATERIAL

Plate shall be manufactured by a process that produces material having through thickness properties which are at least equal to those specified in the material specification. Such plate can be but is not limited to that produced by methods such as electroslag (ESR) and vacuum arc remelt (VAR). The plate must be tested and examined in accordance with the requirements of the material specification and the additional requirements specified in the following paragraphs.

Test specimens, in addition to those required by the material specifications, shall be taken in a direction parallel to the axis of the hub and as close to the hub as practical, as shown in Fig. AD-701.1. At least two tensile test specimens shall be taken from the plate in the proximity of the hub, with one specimen taken from the center third of the plate width as rolled, and the second specimen taken at 90 deg around the circumference from the other specimen. Both specimens shall meet the tensile and yield requirements of the SA material specification. All the dimensional requirements of Fig. AD-701.1 shall apply.

Subsize test specimens conforming to the requirements of Fig. 5 of SA-370 may be used if necessary, in which case the value for "elongation in 2 in. (50 mm)," required by the material specification, shall apply to the gage length specified in Fig. 5.

The reduction of area shall not be less than 30%. (For those materials for which the material specification requires a reduction of area value greater than 30%, the higher value must be met.)

20-300 EXAMINATION REQUIREMENTS

Each part shall be examined as follows.

(a) Before and after machining, the part, regardless of thickness, shall be ultrasonically examined by the straight beam technique in accordance with SA-388. The examination shall be in two directions approximately at right angles, i.e., from the cylindrical or flat rectangular surfaces of the hub and in the axial direction of the hub.

The part shall be unacceptable:

(1) if the examination results show one or more indications accompanied by loss of back reflection larger than 60% of the reference back reflection;

(2) if the examination results show indications larger than 40% of the reference back reflection when accompanied by a 40% loss of back reflection.

(b) Before welding the hub of the tubesheet or flat head to the adjacent shell, the hub shall be examined by magnetic particle or liquid penetrant methods in accordance with Appendix 9, Article 9-1 or 9-2.

(c) After welding, the weld and the area of the hub for at least $^1/_2$ in. (13 mm) from the edge of the weld shall be 100% radiographed in accordance with Article I-5. As an alternate, the weld and hub area adjacent to the weld may be ultrasonically examined in accordance with Article 9-3.

20-400 DATA REPORTS AND MARKING

Whenever the provisions of this Appendix are used, they shall be indicated on the Data Report by the Appendix identification. Special markings are not required unless indicated.

MANDATORY APPENDIX 21
SUBMITTAL OF TECHNICAL INQUIRIES TO THE BOILER AND PRESSURE VESSEL COMMITTEE

21-100 INTRODUCTION

The ASME Boiler and Pressure Vessel Committee and its Subcommittees, Subgroups, and Working Groups meet regularly to consider revisions of the Code rules, new Code rules as dictated by technological development, Code Cases, and Code interpretations. This Appendix provides guidance to Code users for submitting technical inquiries to the Committee. Technical inquiries include requests for revisions or additions to the Code rules, requests for Code Cases, and requests for Code interpretations.

Code Cases may be issued by the Committee when the need is urgent. Code Cases clarify the intent of existing Code requirements or provide alternative requirements. Code Cases are written as a question and a reply, and are usually intended to be incorporated into the Code at a later date. Code interpretations provide the meaning of or the intent of existing rules in the Code and are also presented as a question and a reply. Both Code Cases and Code interpretations are published by the Committee.

The Code rules, Code Cases, and Code interpretations established by the Committee are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design, or as limiting in any way the freedom of manufacturers or constructors to choose any method of design or any form of construction that conforms to the Code rules.

As an alternative to the requirements of this Appendix, members of the Committee and its Subcommittees, Subgroups, and Working Groups may introduce requests for Code revisions or additions, Code Cases, and Code interpretations at their respective Committee meetings or may submit such requests to the Secretary of a Subcommittee, Subgroup, or Working Group.

Inquiries that do not comply with the provisions of this Appendix or that do not provide sufficient information for the Committee's full understanding may result in the request being returned to the inquirer with no action.

21-200 INQUIRY FORMAT

Submittals to the Committee shall include:

(a) Purpose. Specify one of the following:

(1) revision of present Code rule(s)

(2) new or additional Code rule(s)

(3) Code Case

(4) Code interpretation

(b) Background. Provide the information needed for the Committee's understanding of the inquiry, being sure to include reference to the applicable Code Section, Division, Edition, Addenda, paragraphs, figures, and tables. Preferably, provide a copy of the specific referenced portions of the Code.

(c) Presentations. The inquirer may desire or be asked to attend a meeting of the Committee to make a formal presentation or to answer questions from the Committee members with regard to the inquiry. Attendance at a Committee meeting shall be at the expense of the inquirer. The inquirer's attendance or lack of attendance at a meeting shall not be a basis for acceptance or rejection of the inquiry by the Committee.

21-300 CODE REVISIONS OR ADDITIONS

Requests for Code revisions or additions shall provide the following.

(a) Proposed Revision(s) or Addition(s). For revisions, identify the rules of the Code that require revision and submit a copy of the appropriate rules as they appear in the Code, marked up with the proposed revision. For additions, provide the recommended wording referenced to the existing Code rules.

(b) Statement of Need. Provide a brief explanation of the need for the revision(s) or addition(s).

(c) Background Information. Provide background information to support the revision(s) or addition(s) including any data or changes in technology that form

the basis for the request that will allow the Committee to adequately evaluate the proposed revision(s) or addition(s). Sketches, tables, figures, and graphs should be submitted as appropriate. When applicable, identify any pertinent paragraph in the Code that would be affected by the revision(s) or addition(s), and identify paragraphs in the Code that reference the paragraphs that are to be revised or added.

21-400 CODE CASES

Requests for Code Cases shall provide a *Statement of Need* and *Background Information* similar to that defined in 21-300(b) and (c), respectively, for Code revisions or additions. The proposed Code Case should identify the Code Section and Division and be written as a *Question* and a *Reply* in the same format as existing Code Cases. Requests for Code Cases should also indicate the applicable Code Edition(s) and Addenda to which the proposed Code Case applies.

21-500 CODE INTERPRETATIONS

Requests for Code interpretations shall provide the following.

(a) Inquiry. Provide a condensed and precise question, omitting superfluous background information and, when possible, composed in such a way that a "yes" or a "no" *Reply,* possibly with brief provisos, is acceptable. The question should be technically and editorially correct.

(b) Reply. Provide a proposed *Reply* that will clearly and concisely answer the *Inquiry* question. Preferably, the *Reply* should be "yes" or "no," possibly with brief provisos.

(c) Background Information. Provide any background information that will assist the Committee in understanding the proposed *Inquiry* and *Reply.*

21-600 SUBMITTALS

Submittals to and responses from the Committee shall meet the following.

(a) Submittal. Inquiries from Code users shall preferably be submitted in typewritten form; however, legible handwritten inquiries will also be considered. They shall include the name, address, telephone number, and fax number, if available, of the inquirer and be mailed to the following address:

Secretary
ASME Boiler and Pressure Vessel Committee
Three Park Avenue
New York, NY 10016-5990

(b) Response. The Secretary of the ASME Boiler and Pressure Vessel Committee or of the appropriate Subcommittee shall acknowledge receipt of each properly prepared inquiry and shall provide a written response to the inquirer upon completion of the requested action by the Code Committee.

MANDATORY APPENDIX 22
ACCEPTANCE OF TESTING LABORATORIES AND AUTHORIZED OBSERVERS FOR CAPACITY CERTIFICATION OF PRESSURE RELIEF VALVES

22-100 SCOPE

These rules cover the requirements for ASME acceptance of testing laboratories and Authorized Observers for conducting capacity certification tests of pressure relief valves.

22-200 TEST FACILITIES AND SUPERVISION

The tests shall be conducted at a place where the testing facilities, methods, procedures, and person supervising the tests (Authorized Observer) meet the applicable requirements of ASME PTC 25, Pressure Relief Devices. The tests shall be made under the supervision of and certified by an Authorized Observer. The testing facilities, methods, procedures, and the qualifications of the Authorized Observer shall be subject to the acceptance of ASME on recommendation from a representative from an ASME Designated Organization. Acceptance of the testing facility is subject to review within each 5 year period. The testing laboratory shall have available for reference a copy of ASME PTC 25 and this Division.

22-300 ACCEPTANCE OF TESTING FACILITY

Before a recommendation is made to the ASME Boiler and Pressure Vessel Committee on the acceptability of a testing facility, a representative from an ASME Designated Organization shall review the applicant's Quality Control System and testing facility and shall witness test runs. Before a favorable recommendation can be made to ASME, the testing facility must meet all applicable requirements of ASME PTC 25. Uncertainty in final flow measurement results shall not exceed ±2%. To determine the uncertainty in final flow measurements, the results of flow tests on an object tested at the applicant's testing laboratory will be compared to flow test results on the same object tested at a designated ASME accepted testing laboratory.

22-400 QUALITY CONTROL SYSTEM

The applicant shall prepare a Quality Control Manual describing his Quality Control System which will clearly establish the authority and responsibility of those in charge of the Quality Control System. The manual shall include a description of the testing facility, testing arrangements, pressure, size and capacity limitations, and the testing medium used. An organization chart showing the relationship among the laboratory personnel is required to reflect the actual organization.

The Quality Control Manual shall include as a minimum the applicable requirements of this Division and ASME PTC 25, including but not limited to a description of the Quality Control Manual and document control, the procedure to be followed when conducting tests, the methods by which test results are to be calculated, how test instruments and gages are to be calibrated and the frequency of their calibration, and methods of identifying and resolving nonconformities. Sample forms shall be included. If testing procedure specifications or other similar documents are referenced, the Quality Control Manual shall describe the methods of their approval and control.

22-500 TESTING PROCEDURES

(a) Flow tests shall be conducted at the applicant's facility, including the testing of one or more valves and other flow devices (nozzle orifice or other object with a fixed flow path) in accordance with the methods specified

by this Division and ASME PTC 25. The capacity of the devices to be tested shall fall within the testing capability of the laboratory being evaluated and a designated ASME-accepted testing laboratory. The representative from an ASME Designated Organization will observe the procedures and methods of tests, and the recording of results.

(b) The devices tested at the applicant's facility will then be tested at a designated ASME-accepted testing laboratory to confirm the test results obtained. Agreement between the results of the two laboratories shall be within ±2%.

The purpose of comparing test results at the two laboratories is to check not only procedures, but also all test instruments and equipment of the applicant's facility over the capacity and pressure range proposed. Since the capabilities of each laboratory are different, a specific number of tests cannot be predetermined. The number will be in accordance with the flow capability and measurement techniques available at the laboratory being evaluated.

Provided the above tests and comparisons are found acceptable, a representative from an ASME Designated Organization will submit a report to the Society recommending the laboratory be accepted for the purpose of conducting capacity certification tests. If a favorable recommendation cannot be given, the ASME Designee will provide, in writing to the Society, the reasons for such a decision.

22-600 AUTHORIZED OBSERVERS

A representative from an ASME Designated Organization shall review and evaluate the experience and qualifications of persons who wish to be designated as Authorized Observers. Following such review and evaluation, a representative from an ASME Designated Organization shall make a report to the Society. If a favorable recommendation is not made, full details shall be provided in the report.

Persons designated as Authorized Observers by the ASME Boiler and Pressure Vessel Committee shall supervise capacity certification tests only at testing facilities specified by ASME.

MANDATORY APPENDIX 23
ADHESIVE ATTACHMENT OF NAMEPLATES

23-100 SCOPE

The rules in this Appendix cover minimum requirements for the use of adhesive systems for the attachment of nameplates, limited to:

(a) the use of pressure-sensitive acrylic adhesives which have been preapplied by the nameplate manufacturer to a nominal thickness of at least 0.005 in. (0.13 mm) and which are protected with a moisture-stable liner;

(b) use for vessels with design temperatures within the range of −40°F to 300°F (−40°C to 150°C), inclusive;

(c) application to clean, bare metal surfaces, with attention being given to removal of antiweld spatter compound which may contain silicone;

(d) use of prequalified application procedures as outlined in 23-200;

(e) use of the preapplied adhesive within an interval of 2 years after adhesive application.

23-200 NAMEPLATE APPLICATION PROCEDURE QUALIFICATION

(a) The Manufacturer's Quality Control System shall define that written procedures, acceptable to the Inspector, for the application of adhesive-backed nameplates shall be prepared and qualified.

(b) The application procedure qualification shall include the following essential variables, using the adhesive and nameplate manufacturers' recommendations where applicable:

(1) description of the pressure-sensitive acrylic adhesive system employed, including generic composition;

(2) the qualified temperature range [the cold box test temperature shall be −40°F (−40°C) for all applications];

(3) materials of nameplate and substrate when the mean coefficient of expansion at design temperature of one material is less than 85% of that for the other material;

(4) finish of the nameplate and substrate surfaces;

(5) the nominal thickness and modulus of elasticity at application temperature of the nameplate when nameplate preforming is employed. A change of more than 25% in the quantity "[(nameplate nominal thickness)^2 × nameplate modulus of elasticity at application temperature]" will require requalification.

(6) the qualified range of preformed nameplate and companion substrate contour combinations when preforming is employed;

(7) cleaning requirements for the substrate;

(8) application temperature range and application pressure technique;

(9) application steps and safeguards.

(c) Each procedure used for nameplate attachment by pressure-sensitive acrylic adhesive systems shall be qualified for outdoor exposure in accordance with Standard UL-969, Marking and Labeling Systems, with the following additional requirements.

(1) Width of nameplate test strip shall not be less than 1 in. (25 mm).

(2) Nameplates shall have an average adhesion of not less than 8 lb/in. (36 N/mm) of width after all exposure conditions, including low temperature.

(d) Any change in (b) above shall require requalification.

(e) Each lot or package of nameplates shall be identified with the adhesive application date.

MANDATORY APPENDIX 24 DELETED **04**

MANDATORY APPENDIX 25
RULES FOR DRILLED HOLES NOT PENETRATING THROUGH VESSEL WALL

25-100 SCOPE

Partially drilled radial holes in cylindrical and spherical shells may be used provided they are 2.0 in. (50 mm) or less in diameter and the shell diameter-to-thickness ratio D/t is ≥ 10. The acceptance criterion for the depth of the hole is that the plot of the ratio t_{min}/t versus d/D is on or above the curve in Fig. 25-100.1.

25-200 SUPPLEMENTARY REQUIREMENTS

In addition to the above, the following conditions shall be met.

(a) The minimum remaining wall thickness t_{min} shall not be less than 0.25 in. (6 mm).

(b) The calculated average shear stress, $\tau = Pd/\,4t_{min}$, in the remaining wall shall not exceed 0.8S.

(c) The centerline distance between any two such drilled holes or between a partially drilled hole and an unreinforced opening shall satisfy the requirements of AD-510(b). Partially drilled holes shall not be placed within the limits of reinforcement of a reinforced opening.

(d) The outside edge of the hole shall be chamfered; for flat bottom holes the inside bottom corner of the hole shall have a minimum radius of the lesser of $\frac{1}{4}$ in. (6 mm) or $d/4$.

(e) These rules are not applicable to studded connections (see AD-630).

25-300 NOMENCLATURE

In this Appendix, the nomenclature used is as follows:

D = vessel inside diameter
P = design pressure (see AD-200.1)
S = maximum allowable stress value
d = diameter of drilled hole
t = nominal thickness in corroded condition
t_{min} = minimum remaining wall thickness

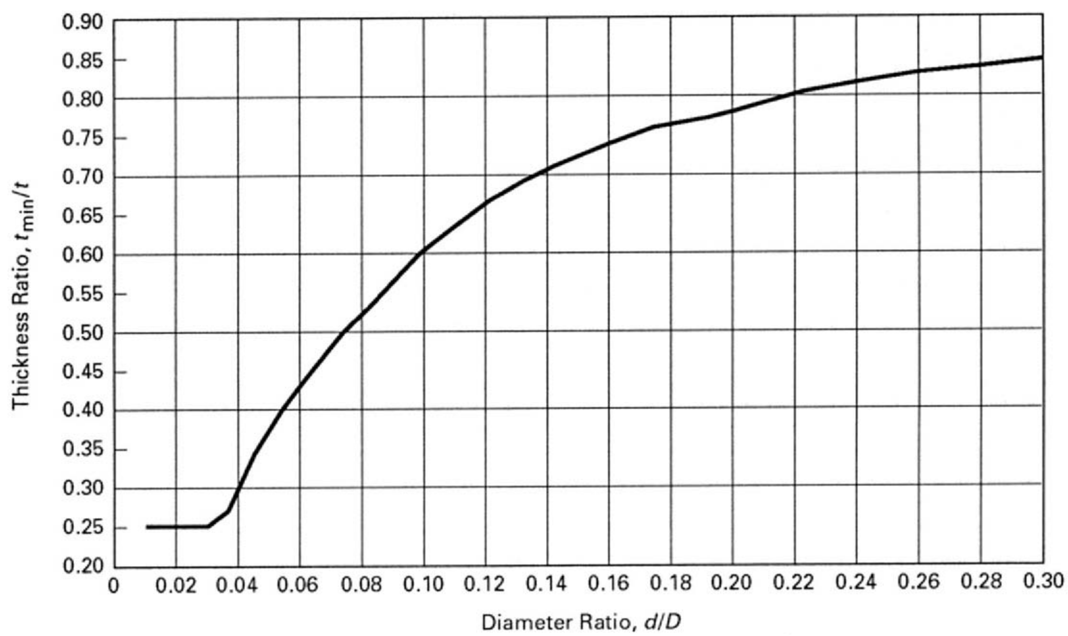


FIG. 25-100.1 THICKNESS RATIO VERSUS DIAMETER RATIO

MANDATORY APPENDIX 26
RULES FOR Cr–Mo STEELS WITH ADDITIONAL REQUIREMENTS FOR WELDING AND HEAT TREATMENT

26-100 SCOPE

This Appendix covers special fabrication and testing rules for a group of materials for which tightly controlled welding and heat treatment procedures are of particular importance. The materials and appropriate specifications covered by this Appendix are listed in Table 26-100.1.

The requirements of this Appendix are in addition to the rules in other parts of this Division for carbon and low alloy steels. In cases of conflicts, the rules in this Appendix shall govern.

This Appendix number shall be shown on the Manufacturer's Data Report Form.

26-200 POSTWELD HEAT TREATMENT

(a) $2^1/_4$Cr–1Mo–$^1/_4$V and 3Cr–1Mo–$^1/_4$V–Ti–B Materials. The final postweld heat treatment shall be in accordance with the requirements of this Division for P-No. 5C materials.

(b) $2^1/_4$Cr–1Mo Materials. The final postweld heat treatment temperature shall be in accordance with the requirements of this Division for P-No. 5A materials, except that the permissible minimum normal holding temperature is 1,200°F (650°C) and the holding time shall be 1 hr/in. (1 hr/25 mm) up to a nominal thickness of 5 in. (125 mm). For thicknesses over 5 in. (125 mm), the holding time shall be 5 hr plus 15 min for each additional inch over 5 in. (125 mm).

26-300 TEST SPECIMEN HEAT TREATMENT

(a) In fulfilling the requirements of Articles T-1 and T-2, two sets of tension specimens and one set of Charpy impact specimens shall be tested. One set each of the tension specimens shall be exposed to heat treatment Condition A. The second set of tension specimens and the set of Charpy impact specimens shall be exposed to heat treatment Condition B.

Condition A. Temperature shall be no lower than the actual maximum vessel-portion temperature, less 25°F (14°C). Time at temperature shall be no less than 80% of the actual hold time of the vessel portion exposed to the maximum vessel-portion temperature.

Condition B. Temperature shall be no higher than the actual minimum vessel-portion temperature, plus 25°F (14°C). Time at temperature shall be no more than 120% of the actual hold time of the vessel portion exposed to the minimum vessel-portion temperature.

(b) Suggested procedure for establishing test specimen heat treatment parameters:

(1) establish maximum and minimum temperatures and hold times for the vessel/component heat treatment based on experience/equipment;

(2) determine Conditions A and B for the test specimen heat treatments;

(3) see Fig. 26-300.1 (shaded area) for vessel heat treatment temperature and hold time limitations, and test specimen Conditions A and B.

26-400 WELD PROCEDURE QUALIFICATIONS AND WELD CONSUMABLES TESTING

(a) Welding procedure qualifications using a production weld consumable shall be made for material welded to itself or to other materials. The qualifications shall conform to the requirements of Section IX, and the maximum tensile strength at room temperature shall be 110 ksi (760 MPa) (for heat treatment Conditions A and B). Welding shall be limited to the submerged-arc (SAW) and shielded metal-arc (SMAW) processes for 3Cr–1Mo–$^1/_4$V–Ti–B material only.

(b) Weld metal from each heat or lot of electrodes and filler wire–flux combination shall be tested. The minimum

TABLE 26-100.1
MATERIAL SPECIFICATIONS

Nominal Composition	Type/ Grade	Specification No.	Product Form
$2^1/_4$Cr–1Mo	Grade 22, Cl. 3	SA-508	Forgings
	Grade 22, Cl. 3	SA-541	Forgings
	Type B, Cl. 4	SA-542	Plates
$2^1/_4$Cr–1Mo–$^1/_4$V	Grade F22V	SA-182	Forgings
	Grade F22V	SA-336	Forgings
	Grade 22V	SA-541	Forgings
	Type D, Cl. 4a	SA-542	Plates
	Grade 22V	SA-832	Plates
3Cr–1Mo–$^1/_4$V–Ti–B	Grade F3V	SA-182	Forgings
	Grade F3V	SA-336	Forgings
	Grade 3V	SA-508	Forgings
	Grade 3V	SA-541	Forgings
	Type C, Cl. 4a	SA-542	Plates
	Grade 21V	SA-832	Plates

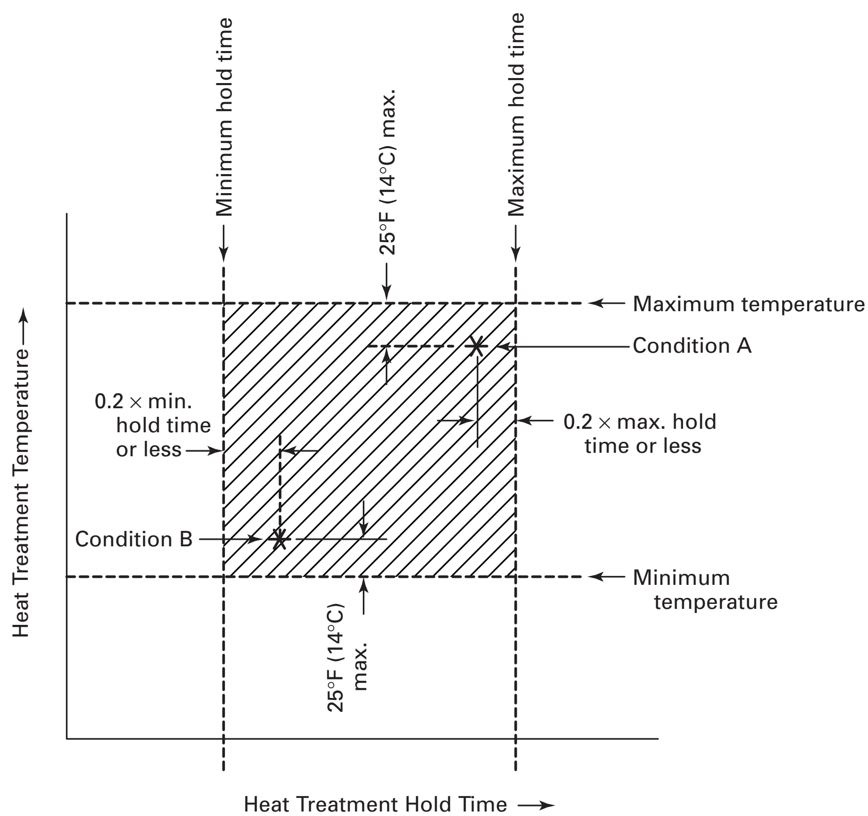


FIG. 26-300.1

TABLE 26-400.1
COMPOSITION REQUIREMENTS FOR $2^1/_4$Cr–1Mo–$^1/_4$V WELD METAL

Welding Process	C	Mn	Si	Cr	Mo	P	S	V	Cb
SAW	0.05–0.15	0.50–1.30	0.05–0.35	2.00–2.60	0.90–1.20	0.015 max.	0.015 max.	0.20–0.40	0.010–0.040
SMAW	0.05–0.15	0.50–1.30	0.20–0.50	2.00–2.60	0.90–1.20	0.015 max.	0.015 max.	0.20–0.40	0.010–0.040
GTAW	0.05–0.15	0.30–1.10	0.05–0.35	2.00–2.60	0.90–1.20	0.015 max.	0.015 max.	0.20–0.40	0.010–0.040
GMAW	0.05–0.15	0.30–1.10	0.20–0.50	2.00–2.60	0.90–1.20	0.015 max.	0.015 max.	0.20–0.40	0.010–0.040

and maximum tensile properties shall be met in PWHT Conditions A and B. The minimum CVN impact properties shall be met in PWHT Condition B. Testing shall be in general conformance with SFA-5.5 for covered electrodes and SFA-5.23 for filler wire–flux combinations.

(c) Duplicate testing in PWHT Condition A and PWHT Condition B (see 26-300) is required. The minimum tensiles and CVN impact properties for the base material shall be met. CVN impact testing is only required for Condition B.

For $2^1/_4$Cr–1Mo–$^1/_4$V material, the weld metal shall meet the compositional requirements listed in Table 26-400.1. For all other materials, the minimum carbon content of the weld metal shall be 0.05%.

(d) In addition, for $2^1/_4$Cr–1Mo material, category A welds intended for design temperatures above 825°F (441°C), and for $2^1/_4$Cr–1Mo–$^1/_4$V material, category A welds intended for design temperatures above 875°F (468°C), each heat of filler wire and flux combination used in production shall also be qualified by a weld metal stress-rupture test on specimens machined parallel (all weld metal specimens) and transverse to the weld axis (one specimen each) in accordance with the following:

(1) The specimen diameter within the gage length shall be 0.5 in. (13 mm) or greater. The specimen centerline shall be located at the $^1/_4$ thickness (or closer to the center) location for material $^3/_4$ in. (19 mm) and greater in thickness.

(2) The gage length for the transverse specimen shall include the weld and at least 0.75 in. (19 mm) of base metal adjacent to the fusion line.

(3) The test material shall be postweld heat treated to Condition A.

(4) For $2^1/_4$Cr–1Mo material, the condition of the stress-rupture test shall be 30.0 ksi at 950°F (207 MPa at 510°C). The time of failure shall exceed 650 hr.

(5) For $2^1/_4$Cr–1Mo–$^1/_4$V material, the condition of the stress-rupture test shall be 30.0 ksi at 1,000°F (207 MPa at 538°C). The time of failure shall exceed 900 hr.

26-500 TOUGHNESS REQUIREMENTS

The minimum toughness requirements for base metal, weld metal, and heat affected zone, after exposure to the simulated postweld heat treatment Condition B, shall be as follows:

Number of Specimens	Impact Energy, ft-lb (J)
Average of 3	40 (54)
Only one in set	35 min. (48 min.)

NOTE: Full-size Charpy V-notch, transverse, tested at the MDMT.

If the material specification or other parts of this Section have more demanding toughness requirements, they shall be met.

MANDATORY APPENDIX 27 STANDARD UNITS FOR USE IN EQUATIONS

04

TABLE 27-100.1
STANDARD UNITS FOR USE IN EQUATIONS

Quantity	U.S. Customary Units	SI Units
Linear dimensions (e.g., length, height, thickness, radius, diameter)	inches (in.)	millimeters (mm)
Area	square inches (in.^{2})	square millimeters (mm^2)
Volume	cubic inches (in.^{3})	cubic millimeters (mm^3)
Section modulus	cubic inches (in.^{3})	cubic millimeters (mm^3)
Moment of inertia of section	inches^4 (in.^{4})	millimeters^4 (mm^4)
Mass (weight)	pounds mass (lbm)	kilograms (kg)
Force (load)	pounds force (lbf)	newtons (N)
Bending moment	inch-pounds (in.-lb)	newton-millimeters (N·mm)
Pressure, stress, stress intensity, and modulus of elasticity	pounds per square inch (psi)	megapascals (MPa)
Energy (e.g., Charpy impact values)	foot-pounds (ft-lb)	joules (J)
Temperature	degrees Fahrenheit (°F)	degrees Celsius (°C)
Absolute temperature	Rankine (R)	kelvin (K)
Fracture toughness	ksi square root inches (ksi$\sqrt{\text{in.}}$)	MPa square root meters (MPa$\sqrt{\text{m}}$)
Angle	degrees or radians	degrees or radians
Boiler capacity	Btu/hr	watts (W)

Nonmandatory Appendices

NONMANDATORY APPENDIX A
INSTALLATION AND OPERATION

A-100 INTRODUCTION

(a) The rules in this Appendix are for general information only, because they pertain to the installation and operation of pressure vessels which are the prerogative and responsibility of the law enforcement authorities in those states and municipalities which have made provision for the enforcement of this Division.

(b) It is permissible to use any departures, suggested herein, from provisions in the mandatory parts of this Division when granted by the authority having legal jurisdiction over the installation of pressure vessels.

A-101 CORROSION

(a) Vessels subject to external corrosion shall be so installed that there is sufficient access to all parts of the exterior to permit proper inspection of the exterior, unless adequate protection against corrosion is provided or unless the vessel is of such size and is so connected that it may readily be removed from its permanent location for inspection.

(b) Vessels having manholes, handholes, or cover plates to permit inspection of the interior shall be so installed that these openings are accessible.

(c) In vertical cylindrical vessels subject to corrosion, to insure complete drainage, the bottom head, if dished, should preferably be concave to pressure.

A-102 MARKING OF THE VESSEL

The marking required by this Division shall be so located that it will be accessible after installation and when installed shall not be covered with insulation or other material that is not readily removable (see AS-130).

A-103 PRESSURE RELIEVING SAFETY DEVICES

The general provisions for the installation of pressure relieving devices are fully covered in Article R-6. The following paragraphs contain details in arrangement of stop valves for shutoff control of safety pressure relief devices, which are sometimes necessary to the continuous operation of processing equipment of such a complex nature that the shutdown of any part of it is not feasible. There are also rules in regard to the design of inlet and discharge piping to and from safety and relief valves which can only be general in nature, because the design engineer must fit the arrangement and proportions of such a system to the particular requirements in the operation of the equipment involved.

A-104 STOP VALVES BETWEEN PRESSURE RELIEVING DEVICE AND VESSEL

(a) A vessel, in which pressure can be generated because of service conditions, may have a full-area stop valve between it and its pressure relieving device for inspection and repair purposes only. When such a stop valve is provided, it shall be so arranged that it can be locked or sealed open and it shall not be closed, except by an authorized person who shall remain stationed there during that period of the vessel's operation within which the valve remains closed and who shall again lock or seal the stop valve in the open position before leaving the station.

(b) A vessel or system for which the pressure originates from an outside source exclusively may have individual pressure relieving devices on each vessel or connected to any point on the connecting piping or on

any one of the vessels to be protected. Under such an arrangement, there may be a stop valve between any vessel and the pressure relieving devices and this stop valve need not be locked open, provided it also closes off that vessel from the source of pressure.

A-105 STOP VALVES ON THE DISCHARGE SIDE OF A PRESSURE RELIEVING DEVICE (SEE AR-615)

A full-area stop valve may be placed on the discharge side of a pressure relieving device when its discharge is connected to a common header with other discharge lines from other pressure relieving devices on nearby vessels that are in operation, so that this stop valve when closed will prevent a discharge from any connected operating vessels from backing up beyond the valve so closed. Such a stop valve shall be so arranged that it can be locked or sealed in either the open or closed position and it shall be locked or sealed in either position only by an authorized person. When it is to be closed while the vessel is in operation, an authorized person shall be present, and he shall remain stationed there; he shall again lock or seal the stop valve in the open position before leaving the station. Under no condition should this valve be closed while the vessel is in operation, except when a stop valve on the inlet side of the safety relieving device is installed and is first closed.

A-106 INLET PRESSURE DROP FOR HIGH LIFT, TOP GUIDED SAFETY, SAFETY RELIEF, AND PILOT OPERATED PRESSURE RELIEF VALVES IN COMPRESSIBLE FLUID SERVICE

(a) The nominal pipe size of all piping, valves, and fittings, and vessel components between a pressure vessel and its safety, safety relief, or pilot operated pressure relief valves, shall be at least as large as the nominal size of the device inlet, and the flow characteristics of the upstream system shall be such that the cumulative total of all nonrecoverable inlet losses shall not exceed 3% of the valve set pressure. The inlet pressure losses will be based on the valve nameplate capacity, corrected for the characteristics of the flowing fluid.

(b) When two or more required safety, safety relief, or pilot operated pressure relief valves are placed on one connection, the internal cross-sectional area of the inlet of this connection shall be at least equal to the combined areas of the nominal pipe size inlets of the valves connected to it, and the flow characteristics of the upstream system shall meet the requirements of (a) above with all valves relieving simultaneously.

A-107 DISCHARGE LINES FROM SAFETY DEVICES

(a) When it is feasible, the use of a short discharge pipe or vertical riser, connected through long-radius elbows from each individual device blowing directly to the atmosphere, is recommended. Such discharge pipes shall be at least of the same size as the valve outlet. Where the nature of the discharge permits, telescopic (sometimes called "broken") discharge lines, whereby condensed vapor in the discharge line or rain is collected in a drip pan and piped to a drain, are recommended.[1]

(b) When discharge lines are long or where outlets of two or more valves having set pressures within a comparable range are connected into a common line, the effect of the back pressure that may be developed therein, when certain valves operate, must be considered. The sizing of any section of a common discharge header downstream from each of the two or more pressure relieving devices that may reasonably be expected to discharge simultaneously shall be based on the total of their outlet areas, with due allowance for the pressure drop in all downstream sections. Use of specially designed valves suitable for use on high or variable back pressure service should be considered.

(c) The flow characteristics of the discharge system of high lift, top guided safety, safety relief, or pilot operated pressure relief valves in compressible fluid service shall be such that the static pressure developed at the discharge flange of a conventional direct spring loaded valve will not exceed 10% of the set pressure when flowing at stamp capacity. Other valve types exhibit various degrees of tolerance to back pressure, and the Manufacturer's recommendation should be followed.

(d) All discharge lines shall be run as directly as is practicable to the point of final release for disposal. For the longer lines, due consideration shall be given to the advantage of long-radius elbows, avoidance of closeup fittings, and the minimizing of excessive line strains by expansion joints and well-known means of support to minimize line sway and vibration under operating conditions.

(e) Provisions should be made in all cases for adequate drainage of discharge lines.

[1] This construction has the further advantage of not transmitting discharge pipe strains to the valve. In these types of installation, the back pressure effect will be negligible, and no undue influence upon normal valve operation can result.

NOTE: It is recognized that no simple rule can be applied generally to fit the many installation requirements, which vary from simple short lines that discharge directly to the atmosphere to the extensive manifold discharge piping systems, where the quantity and rate of the product to be disposed of requires piping to a distant safe place.

A-108 PRESSURE DROP, NONRECLOSING PRESSURE RELIEF DEVICES

Piping, valves, and fittings, and vessel components comprising part of a nonreclosing device pressure relieving system, shall be sized to prevent the vessel pressure from rising above the allowable overpressure.

A-109 GENERAL ADVISORY INFORMATION ON THE CHARACTERISTICS OF SAFETY RELIEF VALVES DISCHARGING INTO A COMMON HEADER

Because of the wide variety of types and kinds of safety relief valves, it is not considered advisable to attempt a description in this Appendix of the effects produced by discharging them into a common header. Several different types of valves may conceivably be connected into the same discharge header and the effect of back pressure on each type may be radically different. Data compiled by the Manufacturers of each type of valve used should be consulted for information relative to its performance under the conditions anticipated.

A-110 PRESSURE DIFFERENTIALS FOR PRESSURE RELIEF VALVES

Due to the variety of service conditions and the various designs of safety and safety relief valves, only general guidance can be given regarding the differential between the set pressure of the valve (see AR-140) and the operating pressure of the vessel. Operating difficulty will be minimized by providing an adequate differential for the application. The following is general advisory information on the characteristics of the intended service and of the safety or safety relief valves that may bear on the proper pressure differential selection for a given application. These considerations should be reviewed early in the system design, since they may dictate the MAWP of the system.

(a) Consideration of the Process Characteristics in the Establishment of the Operating Margin to Be Provided. To minimize operational problems, it is imperative that the user consider not only normal operating conditions of fluids, pressures, and temperatures, but also startup and shutdown conditions, process upsets, anticipated ambient conditions, instrument response times, pressure surges due to quick closing valves, etc. When such conditions are not considered, the pressure relieving device may become, in effect, a pressure controller, a duty for which it is not designed.

Additional consideration should be given to hazard and pollution associated with the release of the fluid. Larger differential may be appropriate for fluids which are toxic, corrosive, or exceptionally valuable.

(b) Consideration of Safety Relief Valve Characteristics. The blowdown characteristic and capability is the first consideration in selecting a compatible valve and operating margin. After a self-actuated release of pressure, the valve must be capable of reclosing above the normal operating pressure. For example, if the valve is set at 100 psig (690 kPa) with a 7% blowdown, it will close at 93 psig (640 kPa). The operating pressure must be maintained below 93 psig (640 kPa) in order to prevent leakage or flow from a partially open valve. Users should exercise caution regarding the blowdown adjustment of large spring loaded valves. Test facilities, whether owned by Manufacturers, repair houses, or users, may not have sufficient capacity to accurately verify the blowdown setting. The settings cannot be considered accurate unless made in the field on the actual installation.

Pilot operated valves represent a special case from the standpoints of both blowdown and tightness. The pilot portion of some pilot operated valves can be set at blowdowns as short as 2%. This characteristic is not, however, reflected in the operation of the main valve in all cases. The main valve can vary considerably from the pilot, depending on the location of the two components in the system. If the pilot is installed remotely from the main valve, significant time and pressure lags can occur, but reseating of the pilot assures reseating of the main valve. The pressure drop in the connecting piping between the pilot and the main valve must not be excessive; otherwise, the operation of the main valve will be adversely affected.

The tightness of the main valve portion of these combinations is considerably improved above that of conventional valves by pressure loading the main disc, or by the use of soft seats, or both.

Despite the apparent advantages of pilot operated valves, users should be aware that they should not be employed in abrasive or dirty service or in applications where coking, polymerization, or corrosion of the wetted pilot parts can occur, or where freezing or condensation of the lading fluid at ambient temperatures is possible. For all applications, the valve Manufacturer should be consulted prior to selecting a valve of this type.

Tightness capability is another factor affecting valve selection, whether spring loaded or pilot operated. It varies somewhat depending on whether metal or resilient seats are specified, and also on such factors as corrosion or temperature. The required tightness and test method should be specified to comply at a pressure no lower than the normal operating pressure of the process. A recommended procedure and acceptance standard is given in API Standard 527. It should also be remembered that any degree of tightness obtained should not be considered permanent. Service operation of a valve almost invariably reduces the degree of tightness.

Application of special designs such as O-rings or resilient seats should be reviewed with the valve Manufacturer.

The anticipated behavior of the valves includes allowance for a plus or minus tolerance on set pressure which varies with the pressure level. Installation conditions such as back pressure variations and vibrations influence selection of special types and an increase in differential pressure.

(c) General Recommendations. The following pressure differentials are recommended, unless the safety or safety relief valve has been designed or tested in a specific or similar service and a smaller differential has been recommended by the Manufacturer.

A minimum differential of 5 psi (35 kPa) is recommended for set pressures to 70 psi (480 kPa). In this category, the set pressure tolerance is ±2 psi (±14 kPa) [AR-120(d)], and the differential to the leak test pressure is 10% or 5 psi (35 kPa), whichever is greater.

A minimum differential of 10% is recommended for set pressures from 71 psi to 1,000 psi (490 kPa to 6.9 MPa). In this category, the set pressure tolerance is ±3% and the differential to the leak test pressure is 10%.

A minimum differential of 7% is recommended for set pressures above 1,000 psi (6.9 MPa). In this category, the set pressure tolerance is ±3% and the differential to the leak test pressure should be 5%. Valves having small seat sizes will require additional maintenance when the pressure differential approaches these recommendations.

A-111 INSTALLATION OF SAFETY AND SAFETY RELIEF VALVES

Spring loaded safety and safety relief valves normally should be installed in the upright position with the spindle vertical. Where space or piping configuration preclude such an installation, the valve may be installed in other than the vertical position, provided that:

(a) the valve design is satisfactory for such position;

(b) the media is such that material will not accumulate at the inlet of the valve;

(c) drainage of the discharge side of the valve body and discharge piping is adequate.

A-112 REACTION FORCES AND EXTERNALLY APPLIED LOADS

(a) Reaction Thrust. The discharge of a pressure relief valve imposes reactive flow forces on the valve and associated piping. The design of the installation may require computation of the bending moments and stresses in the piping and vessel nozzle. There are momentum effects and pressure effects at steady state flow as well as transient dynamic loads caused by opening.

(b) External Loads. Mechanical forces may be applied to the valve by discharge piping as a result of thermal expansion, movement away from, and weight of any unsupported piping. The resultant bending moments on a closed pressure relief valve may cause valve leakage and excessive stress in inlet piping. The design of the installation should consider these possibilities.

A-113 SIZING OF PRESSURE RELIEF DEVICES FOR FIRE CONDITIONS

(a) Excessive pressure may develop in pressure vessels by vaporization of the liquid contents and/or expansion of vapor content due to heat influx from the surroundings, particularly from a fire. Pressure relief systems for fire conditions are usually intended to release only the quantity of product necessary to lower the pressure to a predetermined safe level, without releasing an excessive quantity. This control is especially important in situations where release of the contents generates a hazard because of flammability or toxicity. Under fire conditions, consideration must also be given to the possibility that the safe pressure level for the vessel will be reduced due to heating of the vessel material with a corresponding loss of strength.

(b) Several formulas have evolved over the years for calculating the pressure relief capacity required under fire conditions. The major differences involve heat flux rates. There is no single formula yet developed which takes into account all of the many factors which could be considered in making this determination. When fire conditions are a consideration in the design of a pressure vessel, the following references which provide recommendations for specific installations may be used.

API RP 520, Recommended Practice for the Design and Installation of Pressure-Relieving Systems in Refineries, Part I — Design, 1976, American Petroleum Institute, Washington, DC

API Standard 2000, Venting Atmospheric and Low-Pressure Storage Tanks (nonrefrigerated and refrigerated), 1973, American Petroleum Institute, Washington, DC

AAR Standard M-1002, Specifications for Tank Cars, 1978, Association of American Railroads, Washington, DC

Safety Relief Device Standards: S-1.1, Cylinders for Compressed Gases; S-1.2, Cargo and Portable Tanks; and S-1.3, Compressed Gas Storage Containers; Compressed Gas Association, Arlington, VA

NFPA Code Nos. 30, 59, and 59A, National Fire Protection Association, Quincy, MA

Pressure-Relieving Systems for Marine Cargo Bulk Liquid Containers, 1973, National Academy of Sciences, Washington, DC

Bulletin E-2, *How to Size Safety Relief Devices,* Phillips Petroleum Company, Bartlesville, OK

A Study of Available Fire Test Data as Related to Tank Car Safety Device Relieving Capacity Formulas, 1971, Phillips Petroleum Company, Bartlesville, OK

NONMANDATORY APPENDIX B TEMPERATURE PROTECTION

B-100 TEMPERATURE PROTECTION

(a) Any pressure vessel, in a service where it can be damaged by overheating, should be provided with means by which the metal temperature can be controlled within safe limits or a safe shutdown can be effected.

(b) It is recognized that it is impractical to specify detailed requirements to cover the multiplicity of means to prevent the operation of pressure vessels at overtemperature. Any means which in principle will provide compliance with (a) will meet the intent of this Division.

NONMANDATORY APPENDIX C SUGGESTED METHODS FOR OBTAINING THE OPERATING TEMPERATURE OF VESSEL WALLS IN SERVICE

C-100

At least three thermocouples shall be installed on vessels that are to have contents at temperatures above that at which the allowable stress value of the material is less than its allowable stress value at 100°F (40°C). One of the thermocouples shall be on the head that will be subject to the higher temperature, and the other two shall be on the shell in the zone of maximum temperature. For a number of vessels in similar service in the same plant, thermocouples need be attached to one vessel only of each group or battery, provided that each vessel has a suitable temperature measuring device to show the temperature of the entering fluid, in order that a comparison of the operation of the different vessels can be made and any abnormal operation immediately detected. Thermocouples shall be attached to the outside surface of the vessel by inserting the terminals separately in two small holes drilled into the shell approximately $\frac{1}{2}$ in. (13 mm) center-to-center and firmly securing them therein, or by some other equally satisfactory method.

C-200

In lieu of the provisions in the preceding paragraph, it shall be optional to provide a thermocouple or other temperature measuring device for obtaining the temperature of the fluid in the zone of the vessel having the highest temperature. In this case, the metal temperature shall be assumed to be the same as the maximum fluid temperature.

NONMANDATORY APPENDIX D
PREHEATING

D-100 CONSIDERATIONS DETERMINING NEED TO PREHEAT

Preheating may be employed during welding to assist in completion of the welded joint. The need for and temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of parts being joined, elevated physical properties, and heavy thickness. Mandatory rules for preheating are, therefore, not given in this Division, except as required in the Notes that provide for exemptions to postweld heat treatment in Table AF-402.1.

D-110 SOME SUGGESTED PRACTICES

(a) Some practices used for preheating are given below as a general guide for the materials listed by P-Numbers and Group numbers in Section IX. It is cautioned that the preheating temperatures listed below do not necessarily insure satisfactory completion of the welded joint, and requirements for individual materials within the P-Number and Group numbers listing may have preheating more or less restrictive than this general guide. The procedure specification for the material being welded specifies the minimum preheating requirements of the welding procedure qualification requirements of Section IX.

(b) The heat of welding may assist in maintaining preheat temperatures after the start of welding and, for inspection purposes, temperature checks can be made near the weld. The method or extent of application of preheat is not, therefore, specifically given. Normally, when materials of two different P-Number groups are joined by welding, the preheat used will be that of the material with the higher preheat specified in the procedure specification.

D-120 SUGGESTED PREHEAT TEMPERATURES

D-120.1 Suggested Temperatures for P-No. 1

(a) 175°F (80°C) for material which has both a specified maximum carbon content in excess of 0.30% and a thickness at the joint in excess of 1 in. (25 mm). This does not apply to fillet welds $\frac{1}{2}$ in. (13 mm) and under in size used to attach insulation clips, vessel internals, and other parts not carrying loadings due to internal pressure.

(b) 50°F (10°C) for all other materials in this P-Number.

D-120.3 Suggested Temperatures for P-No. 3

(a) 175°F (80°C) for material which has either a specified minimum tensile strength in excess of 70,000 psi (483 MPa) or a thickness at the joint in excess of $\frac{5}{8}$ in. (16 mm).

(b) 50°F (10°C) for all other materials in this P-Number.

D-120.4 Suggested Temperatures for P-No. 4

(a) 250°F (120°C) for material which has either a specified minimum tensile strength in excess of 60,000 psi (410 MPa) or a thickness at the joint in excess of $\frac{1}{2}$ in. (13 mm).

(b) 50°F (10°C) for all other materials in this P-Number.

D-120.5 Suggested Temperatures for P-Nos. 5A, 5B, and 5C

(a) 400°F (205°C) for material which has either a specified minimum tensile strength in excess of 60,000 psi (414 MPa) or has both a specified minimum chromium content above 6.0% and a thickness at the joint in excess of $\frac{1}{2}$ in. (13 mm).

(b) 300°F (150°C) for all other materials in these P-Numbers.

D-120.6 Suggested Temperatures for P-No. 6. 400°F (205°C).

D-120.7 Suggested Temperatures for P-No. 7. None.

D-120.8 Suggested Temperatures for P-No. 8. None.

D-120.9 Suggested Temperatures for P-Nos. 9A and 9B. 300°F (150°C).

D-120.10 Suggested Temperatures for P-No. 10

(a) For P-No. 10A, 300°F (150°C) with interpass temperature maintained between 350°F and 450°F (175°C and 230°C).

(b) For P-No. 10F, 250°F (120°C).

D-120.11 Suggested Temperatures for P-No. 11

(a) For P-No. 11A Gr. No. 1: for 9% nickel steel preheat is neither required nor prohibited.[1]

(b) For P-No. 11B Gr. Nos. 1–6: same as for P-No. 3.[1]

D-120.21 Suggested Temperatures for P-Nos. 21 to 24, Inclusive. None.

D-120.31 Suggested Temperatures for P-Nos. 31 to 35, Inclusive. None.

D-120.41 Suggested Temperatures for P-Nos. 41 to 44, Inclusive. None.

[1] Consideration shall be given to the limitation of interpass temperature for various thicknesses to avoid detrimental effects on the mechanical properties of heat treated materials.

NONMANDATORY APPENDIX E LIMITING SERVICE TEMPERATURES FOR NONFERROUS MATERIALS

04

See Appendix A, Table A-152, of Section II, Part D.

NONMANDATORY APPENDIX G EXAMPLES ILLUSTRATING THE APPLICATION OF CODE FORMULAS AND RULES

G-101 EXAMPLE NO. 1: AD-201

Determine the minimum wall thickness of a cylindrical shell subjected to internal pressure given the following:

inside radius $R = 10$ in.
internal design pressure $P = 10{,}000$ psi
design temperature = 250°F
material: SA-266, Cl. 3
corrosion allowance: none
$S_m = 22.5$ ksi

Internal pressure is the only applicable loading of those listed in AD-110. Also, under the rules of AD-160, a fatigue evaluation is not required. Therefore, from AD-201(a) and Table 2A of Section II, Part D,

$$t = PR/(S - 0.5P)$$

$$= 10{,}000(10)/(22{,}500 - 5{,}000)$$

$$= 5.714 \text{ in.}$$

For the alternative calculation, check for $P > 0.4S$:

$$0.4S = 0.4(22{,}500)$$

$$= 9{,}000 \text{ psig}$$

$P > 9{,}000$ psig; therefore

$$P/S = \ln{(R + t)/R} = \ln x$$

$$\ln x = 10{,}000/22{,}500 = 0.4444$$

from which $x = 1.560$. But

$$x = (R + t)/R$$

$$= (10 + t)/10$$

$$= 1.560$$

and solving gives $t = 5.600$ in.

The minimum thickness of the shell may therefore be taken as 5.600 in.

G-102 EXAMPLE NO. 2: AD-202

Determine the minimum wall thickness of a spherical shell subjected to internal pressure, given the following:

inside radius $R = 10$ in.
internal design pressure $P = 10{,}000$ psi
design temperature = 250°F
material: SA-266, Cl. 3
corrosion allowance: none
$S_m = 22.5$ ksi

Internal pressure is the only applicable loading of those listed in AD-110. Also, under the rules of AD-160, a fatigue evaluation is not required. Therefore, from AD-202(a) and Table 2A of Section II, Part D,

$$t = 0.5PR/(S - 0.25P)$$

$$= (0.5 \times 10{,}000 \times 10)/(22{,}500 - 2{,}500)$$

$$= 2.500 \text{ in.}$$

For the alternative calculation, check for $P > 0.4S$:

$$0.4S = 0.4(22{,}500)$$

$$= 9{,}000 \text{ psig}$$

$P > 9{,}000$ psig; therefore

$$0.5P/S = \ln(R + t)/R = \ln x$$

$$\ln x = 5{,}000/22{,}500 = 0.2222$$

from which $x = 1.249$. But

$$x = (R + t)/R$$

$$1.249 = (10 + t)/10$$

and solving gives $t = 2.490$.

The minimum thickness of the shell can therefore be taken as 2.490 in.

G-104 EXAMPLE NO. 4: AD-201, AD-340

Determine the minimum wall thickness of a cylindrical shell subject to internal pressure and wind loading given the following:

- inside radius $R = 24$ in.
- internal design pressure $P = 250$ psi
- design temperature = 300°F
- bending moment due to wind load $M_B = 6 \times 10^6$ in.-lb
- weight of vessel and contents effective in causing axial compressive stress $W = 5{,}000$ lb
- material: SA-515, Grade 70
- corrosion allowance: none
- $S_m = 22.5$ ksi

Internal pressure, wind load, and static weight are the applicable loadings given in AD-110. The minimum thickness must be established using the worst combination of loading per AD-140. Also, under the rules of AD-160, a fatigue evaluation is not required. Therefore, per AD-201(a) and Table 2A of Section II, Part D ($P < 0.4S$):

$$t = \frac{PR}{S - 0.5P} = \frac{250\ (24)}{22{,}500 - 125} = 0.268 \text{ in.}$$

The effective weight of the vessel is 5,000 lb = W; therefore, per AD-201(b),

$$F = \pm [M_B / \pi R_m{}^2] - \frac{W}{2\pi R_m} \left(\frac{\text{lb}}{\text{in.}}\right)$$

where R_m is the midwall radius.

$$F = \pm \frac{(6 \times 10^6)}{\pi R_m{}^2} - \frac{W}{2\pi R_m}$$

$$= \pm \frac{6 \times 10^6}{\pi (24.134)^2} - \frac{(5{,}000)}{2\pi (24.134)}$$

$$= \pm 3{,}279 - 33.0$$

$$= 3{,}246 \text{ or } -3{,}312$$

But $0.5PR = 0.5(250)(24) = 3{,}000$ lb/in. Since F is induced by dead weight and bending, it can be both positive and negative; also, F exceeds $0.5PR$ so that a new value of t must be computed per AD-201(b) and Table AD-150.1 for the most severe load combination B for tensile loading.

$$t = \frac{0.5PR + F}{1.2S_m - 0.5P} = \frac{3{,}000 + 3{,}246}{26{,}875}$$

from which $t = 0.232$ in. This value is less than that found in AD-201(a).

Per AD-201(c), since F is also negative for loading combination B, the structural stability must be evaluated per AD-340. The axial compressive stress is:

$$S = \frac{F}{t} = \frac{-3{,}312}{t}$$

from which, using $t = 0.268$ in.,

$$S = 12{,}360 \text{ psi}$$

which compares with 1.2 times the allowable stress value from Table 2A of Section II, Part D of 22,500 psi (negative), or

$$1.2(22{,}500) = 27{,}000 \text{ psi}$$

From AD-340(b) and Fig. CS-2 in Subpart 3 of Section II, Part D:

$$t = 0.268 \text{ in.}$$

$$R = 24 \text{ in.}$$

$$B = 13{,}500$$

The allowable stress intensity is 1.2(13,500) which is 16,200 psi. This is greater than the above value of 12,360 psi; therefore, the selected thickness is satisfactory.

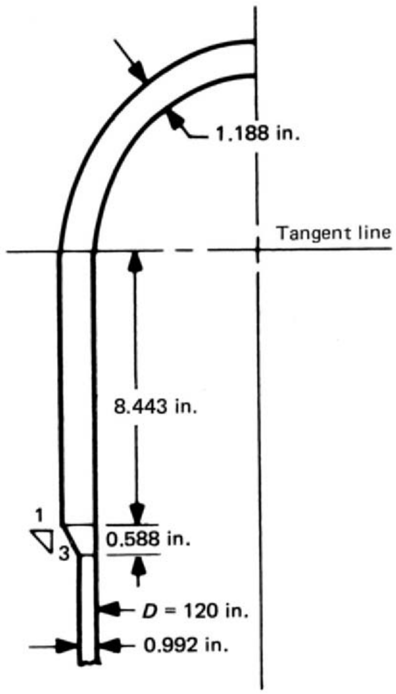


FIG. G-105.1

G-105 EXAMPLE NO. 5: AD-204.3

Determine the minimum wall thickness and attachment details for a cylinder and a 2:1 ellipsoidal head subjected to internal pressure as shown in Fig. G-105.1, given the following:

inside diameter $D = 120$ in.
internal design pressure $P = 300$ psi
design temperature = 100°F
material: SA-285, Gr. C
corrosion allowance: none
$S_m = 18.3$ ksi

Internal pressure is the only applicable loading of those listed in AD-110. Also, under the rules of AD-160 a fatigue evaluation is not required. Therefore, from AD-201(a) and Table 2A of Section II, Part D, for the cylinder

$$t = \frac{PR}{S - 0.5P} = \frac{300(60)}{18{,}300 - 150} = 0.992$$

For the head, per AD-204.3 and Table 2A of Section II, Part D:

$$\frac{P}{S} = \frac{300}{18{,}300} = 0.0164$$

For this value of P/S, from Fig. AD-204.1 read right to the intersection of the diagonal line marked 2:1 Ellipsoidal head. From this point, read down to the value of $t/L = 0.011$. As noted on Fig. AD-204.1, for a 2:1 ellipsoidal head $L = 0.9D$. Therefore:

$$t = 0.011(0.9)D$$
$$= 0.011(0.9)(120)$$
$$= 1.188 \text{ in.}$$

The attached shell must be at least 1.188 in. thick for a distance

$$\sqrt{Rt} = \sqrt{(60)(1.188)} = 8.443 \text{ in.}$$

from the tangent line.

Also, to comply with AD-420(a), the length of the transition to a shell 0.992 in. thick must be at least

$$3(1.188 - 0.992) = 0.588 \text{ in.}$$

and this transition cannot be within the distance $\sqrt{Rt}$.

If a shorter skirt is desired, the head shall be analyzed according to Appendix 4.

G-106 EXAMPLE NO. 6: AD-140, AD-160, 4-120, 4-221, 4-222, 5-110.3

Determine the adequacy of a thick cylindrical shell subjected to the following cyclic loadings:

(1) 15,000 cycles of 0 to 3,500 psi;

(2) 10,000 local pressure disturbances while at pressure down to 2,500 psi;

(3) 10 hydrostatic tests of 0 to 4,375 psi (where 4,375 psi = 1.25 × 3,500).

inside radius $R = 20$ in.
shell thickness $t = 3.375$ in.
steady state internal design pressure $P_1 = 3{,}500$ psi
design temperature = 250°F
material: SA-266, Cl. 3
corrosion allowance: none
$S_m = 22.5$ ksi
no discontinuity stresses and no stress concentrations ($K = 1.0$)

Per AD-140(b) and 4-222(a)

$$S_1 = (P_1R/t) + (P_1/2)$$
$$= [(3{,}500)(20)/3.375] + (3{,}500/2)$$
$$= 22{,}500 \text{ psi}$$

From Table 2A of Section II, Part D, $S_1 = S_m = 22{,}500$ psi and, therefore, is acceptable.

Per AD-160.2 Condition B,

$$3S_m = 3(22{,}500) = 67{,}500 \text{ psi}$$

Per Fig. 5-110.1, $S_a = 67{,}500$ psi gives $N = 1{,}750$ cycles. Therefore, a fatigue analysis *is* required.

Per 5-110.3 and 4-221, since the maximum stress intensity is on the inside shell surface,

$$Z = Y = (20 + 3.375)/20 = 1.17$$

Per 4-221, for Condition (1) where $P_1 = 3{,}500$ psi,

$$\sigma_1 = \sigma_t = P_1(1 + Z^2)/(Y^2 - 1)$$

$$= 3{,}500 \times (2.3689/0.3689)$$

$$= 22{,}480 \text{ psi}$$

$$\sigma_2 = \sigma_l = P_1(Y^2 - 1) = 3{,}500/0.3689$$

$$= 9{,}490 \text{ psi}$$

$$\sigma_3 = \sigma_r = P_1(1 - Z^2)/(Y^2 - 1)$$

$$= 3{,}500 \times (-0.3689/0.3689)$$

$$= -3{,}500 \text{ psi}$$

Calculate stress differences according to 4-120(e) and 5-110.3(a)(2):

$$S_{12} = \sigma_1 - \sigma_2 = 22{,}480 - 9{,}490 = 12{,}990 \text{ psi}$$

$$S_{23} = \sigma_2 - \sigma_3 = 9{,}490 - (-3{,}500) = 12{,}990 \text{ psi}$$

$$S_{31} = \sigma_3 - \sigma_1 = (-3{,}500) - 22{,}480 = 25{,}980 \text{ psi}$$

$$\therefore S_{1\,max} = 25{,}980 \text{ psi at } 3{,}500 \text{ psi}$$

Note that this calculation may also be made according to 4-222(b).

For Condition (2) where $P_2 = 3{,}500 - 2{,}500 = 1{,}000$ psi:

$$S_{2\,max} = S_{1\,max}\ (P_2/P_1)$$

$$= 25{,}980\ (1/3.5)$$

$$= 7{,}420 \text{ psi}$$

For Condition (3) where $P_3 = 4{,}375$ psi:

$$S_{3\,max} = S_{1\,max}\ (P_3/P_1)$$

$$= 25{,}980\ (4{,}375/3{,}500)$$

$$= 32{,}480 \text{ psi}$$

Calculate alternating stress intensity according to 5-110.3(d):

$$S_{a1} = S_{1\,max}/2 = 12{,}990 \text{ psi}$$

$$S_{a2} = S_{2\,max}/2 = 3{,}710 \text{ psi}$$

$$S_{a3} = S_{3\,max}/2 = 16{,}240 \text{ psi}$$

Correct alternating stress intensity for temperature according to 5-110.3(f):

$$S'_{a1} = (30/29.25)S_{a1} = 13{,}320 \text{ psi}$$

$$S'_{a2} = (30/29.25)S_{a2} = 3{,}810 \text{ psi}$$

$$S'_{a3} = (30/29.9)S_{a3} = 16{,}290 \text{ psi}$$

Determine cumulative damage according to 5-110.3(g):

$$N_1 \text{ at } S'_{a1} = 560{,}000$$

$$N_2 \text{ at } S'_{a2} = 1{,}000{,}000$$

$$N_3 \text{ at } S'_{a3} = 210{,}000$$

$$U_1 = n_1/N_1 = 15{,}000/560{,}000 = 0.027$$

$$U_2 = n_2/N_2 = 10{,}000/1{,}000{,}000 = 0.01$$

$$U_3 = n_3/N_3 = 10/210{,}000 = 0.000$$

$U_1 + U_2 + U_3 = 0.037 < 1.00$, and is therefore satisfactory.

G-107 EXAMPLE NO. 7: ARTICLE 4-6

Determine the design adequacy of a nozzle in the cylindrical shell of G-106. The nozzle axis is perpendicular to the cylinder surface and satisfies the requirements of 4-613 and the primary stress limits for specified design conditions. The specified operating pressure equals the design pressure. No thermal transients or nozzle loads are specified.

The general membrane stress intensity for the cylinder from G-106 was found to be $S_1 = 22{,}500$ psi for the internal design pressure of 3,500 psi.

From 4-612(b), for a nozzle in a cylindrical shell, the largest stress index factor to be applied to membrane stress intensity S is 3.3 at the inside corner of the nozzle. The maximum $P_L + P_b + Q + F$ stress intensity for the specified operating conditions is found as follows:

$$S_{max} = 3.3(22{,}500) = 74{,}250 \text{ psi}$$

Since there is no load reversal, the stress intensity range $S_R = 74{,}250$ psi and $S_a = \frac{1}{2}S_R = 37{,}125$ psi for $P =$

3,500 psi. At this point, a check is required for the most severe operating condition to ensure adequate fatigue design integrity.

Design conditions:

(1) 15,000 cycles from 0 to 3,500 psi at 250°F

(2) 10,000 cycles from 3,500 to 2,500 to 3,500 psi at 250°F

(3) 10 cycles of hydrotest from 0 to 4,375 psi at 250°F

By inspection, Condition (1) governs; therefore, from Fig. 5-110.1:

$$N = 10{,}000 \text{ cycles at } S_a = 37.1 \text{ ksi}$$

$$U_1 = n/N = \frac{15{,}000}{10{,}000} = 1.5$$

Since $U_1 > 1.0$, the design does not satisfy the requirements of 5-110.3(e).

The shell thickness must be increased in order to satisfy the specified operating conditions.

Since D/t should not be less than 10, a shell thickness $t_1 = 3.875$ in. at the nozzle region is assumed.

The revised general membrane stress intensity is:

$$S = \frac{PR}{t_1} + \frac{P}{2} = \frac{3{,}500 \times 20}{3.875} + \frac{3{,}500}{2}$$

$$S = 18{,}060 + 1{,}750 = 19{,}810 \text{ psi}$$

Determine S_a for each design condition:

Condition	S_a
(1)	$(3.3/2)(19{,}810) = 32{,}690$ psi
(2)	$\frac{(1{,}000)}{(3{,}500)}(32{,}690) = 9{,}340$ psi
(3)	$\frac{(4{,}375)}{(3{,}500)}(32{,}690) = 40{,}860$ psi

Correcting S_a for the design temperature in accordance with 5-110.3(f):

$$S'_{a1} = (30/29.25)S_{a1} = 33{,}530 \text{ psi}$$

$$S'_{a2} = (30/29.25)S_{a2} = 9{,}580 \text{ psi}$$

$$S'_{a3} = (30/29.9)S_{a3} = 41{,}000 \text{ psi}$$

Determine the damage factor in accordance with 5-110.3(e) and (g):

Condition	S_a, ksi	N	n	$U = n/N$
(1)	33.5	15,300	15,000	0.9804
(2)	9.58	10^6	10,000	0.0100
(3)	41.0	8,000	10	0.00125

$$U_{total} = U_1 + U_2 + U_3 = 0.9917$$

$U = 0.9917 < 1.0$; therefore the shell thickness $t_1 = 3.875$ in. at the nozzle region satisfies the specified requirements.

G-108 EXAMPLE NO. 8: AD-211.1

Determine the reinforcement requirements and minimum shell thickness for a cylinder–cone junction as shown in Fig. G-108.1 and given the following:

inside radius of cylinder $R_L = 120$ in.
internal design pressure $P = 150$ psi
design temperature = 300°F
cone angle $\alpha = 30$ deg
material: SA-515 Gr. 70; $S_m = 22.5$ ksi
corrosion allowance: none

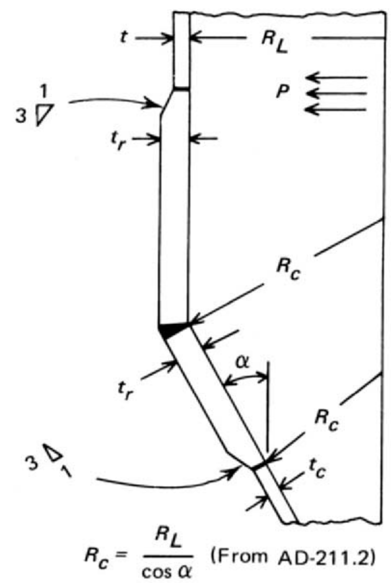


FIG. G-108.1

Internal pressure is the only applicable loading of those listed in AD-110. Also, under the rules of AD-160 a fatigue evaluation is not required. Therefore, from AD-201(a) for the cylinder and using Table 2A of Section II, Part D:

$$t = \frac{PR_L}{S - 0.5P} = \frac{150(120)}{22{,}500 - 75} = 0.803 \text{ in.}$$

For the unreinforced cone, AD-203(a):

$$t_c = \frac{PR_c}{S - 0.5P} = \frac{150(120/0.866)}{22{,}500 - 75} = 0.927 \text{ in.}$$

Per Figs. AD-211.1 and AD-211.2:

$$\frac{P}{S} = \frac{150}{22{,}500} = 0.0067$$

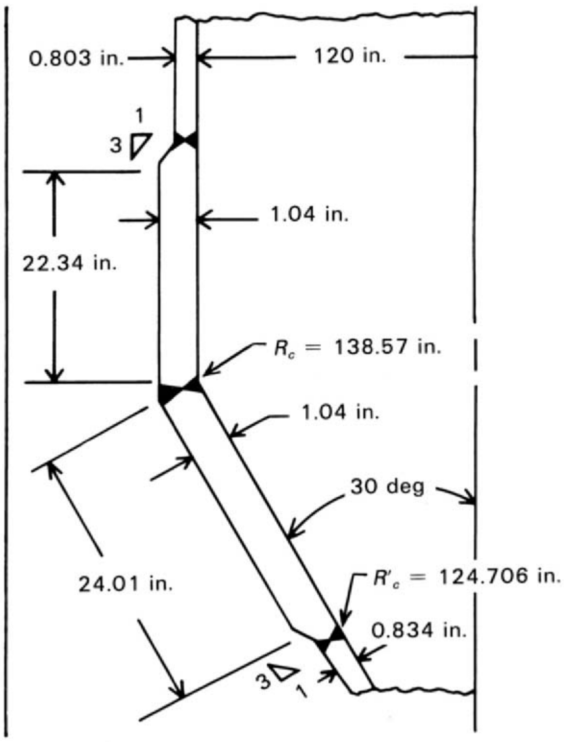


FIG. G-108.2

For this value of P/S and $\alpha = 30$ deg, Fig. AD-211.1 shows that reinforcement is required. From Fig. AD-211.2 for $P/S = 0.0067$ and $\alpha = 30$ deg, it is indicated that $Q = 1.3$; therefore,

$$t_r = Qt = 1.3(0.803) = 1.04 \text{ in.}$$

For the cylindrical part the reinforcement length is:

$$2\sqrt{R_L t_r} = 2\sqrt{120(1.04)} = 22.34 \text{ in.}$$

For the conical part, the reinforcement length is:

$$2\sqrt{\frac{R_L t_r}{\cos\alpha}} = 2\sqrt{\frac{120(1.04)}{0.866}} = 24.01 \text{ in.}$$

Per AD-203(a) for the cone based on R'_c at end of conical reinforcement length:

$$t_c = \frac{PR_c}{S - 0.5P} = \frac{150(124.706)}{22{,}500 - 75} = 0.834 \text{ in.}$$

Therefore, thicknesses are as follows:

unreinforced cylinder $t = 0.803$ in.
reinforced cylinder $t_r = 1.04$ in.
reinforced cone $t_r = 1.04$ in.
unreinforced cone $t_c = 0.834$ in.

Refer to AD-211.2.

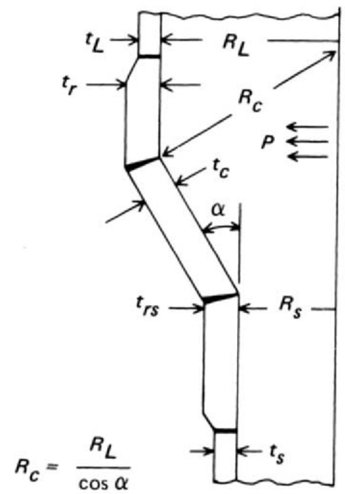


FIG. G-109.1

G-109 EXAMPLE NO. 9: AD-203, AD-211, AD-212

Determine the reinforcement requirements and minimum shell thickness for a cylinder–cone junction as shown in Fig. G-109.1 and given the following:

inside radius of cylinder $R_S = 48$ in.
inside radius of cylinder $R_L = 60$ in.
internal design pressure $P = 250$ psi
design temperature = 300°F
cone angle $\alpha = 30$ deg
material: SA-515 Gr. 70; $S_m = 22.5$ ksi
corrosion allowance: none

Internal pressure is the only applicable loading of those listed in AD-110. Also, under the rules of AD-160, a fatigue evaluation is not required. Therefore, from AD-201(a) for the cylinder and using Table 2A of Section II, Part D:

$$t_s = \frac{PR_s}{S - 0.5P} = \frac{250(48)}{22{,}500 - 125} = 0.536 \text{ in.}$$

Likewise, for the larger cylinder:

$$t_L = \frac{PR_L}{S - 0.5P} = \frac{250(60)}{22{,}500 - 125} = 0.670 \text{ in.}$$

Per AD-203(a) for the unreinforced cone:

$$t_c = \frac{PR_c}{S - 0.5P} = \frac{250(60/0.866)}{22{,}500 - 125} = 0.774 \text{ in.}$$

For the larger end of cylinder–cone junction per Fig. AD-211.1,

$$P/S = (250/22{,}500) = 0.011$$

For this value the maximum value of α for no reinforcement is 27.5 deg. However, the specified angle α is 30

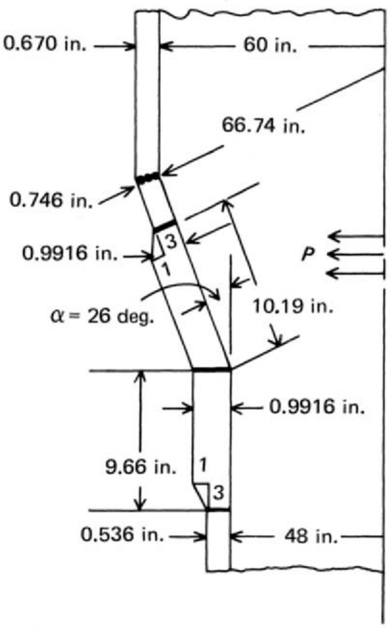


FIG. G-109.2

deg; therefore, reinforcement is required. Also, per AD-211(e), the junction must be at least $2.5\sqrt{R_L t_r}$ in. from another junction of major discontinuity.

From Fig. AD-211.2, for $P/S = 0.011$, $Q = 1.16$ for $\alpha = 30$ deg; then

$$t_{rL} = Qt_L = 1.16(0.670) = 0.777 \text{ in.}$$

Checking the cone length per AD-211(e), $2.5\sqrt{R_L t_{rL}} = 2.5\sqrt{60(0.777)} = 17.07$; for $\alpha = 30$ deg, the cone length is 12/sin 30 deg = 24 in., which is more than the minimum required distance of 17.07 in.; therefore, α may be 30 deg and no reinforcing is required at the large cylinder–cone junction. To illustrate when the cone angle α must be less than 30 deg, assume that the cone length needs to be 27 in. This requires $\sin \alpha = 12/27 = 0.444$. α may then be set at 26 deg. Per AD-203(a) with $\alpha = 26$ deg:

$$t_c = \frac{PR_c}{S - 0.5P} = \frac{250(60/0.899)}{22{,}500 - 125} = 0.746 \text{ in.}$$

For the small end of the cylinder–cone junction from Fig. AD-212.2,

$$P/S = (250/22{,}500) = 0.011$$

For this value at $\alpha = 26$ deg, it is indicated that $Q = 1.85$, from which

$$t_{rs} = Qt_s = 1.85(0.536) = 0.992 \text{ in.}$$

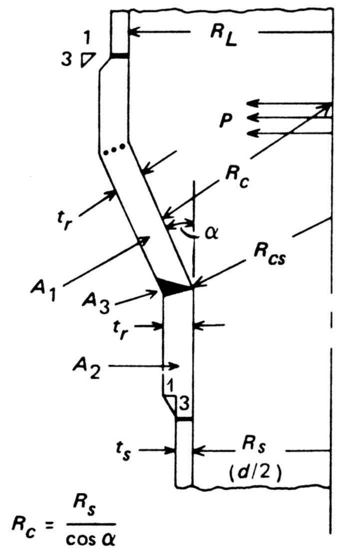


FIG. G-110.1

and, per Fig. AD-212.2, reinforcement must be confined within the limits, along the cylinder,

$$1.4\sqrt{R_s t_r} = 1.4\sqrt{48(0.992)} = 9.66 \text{ in.}$$

or along the cone,

$$1.4\sqrt{\frac{R_s t_r}{\cos \alpha}} = 1.4\sqrt{\frac{48(0.992)}{0.899}} = 10.19 \text{ in.}$$

Therefore, the required thicknesses (see Fig. G-109.2) are:

small cylinder $t_s = 0.536$ in.
reinforced small cylinder $t_{rs} = 0.992$ in.
reinforced cone $t_r = 0.992$ in.
unreinforced cone $t_c = 0.746$ in.
large cylinder $t_L = 0.670$ in.
cone angle $\alpha = 26$ deg

G-110 EXAMPLE NO. 10: AD-212.3

Determine the reinforcement requirements and minimum shell thickness for a cylinder–cone junction as shown in Fig. G-110.1 and given the following:

inside radius of large cylinder $R_L = 96$ in.
inside radius of small cylinder $R_s = 48$ in.
internal design pressure $P = 225$ psi
design temperature = 300°F
cone angle $\alpha = 33$ deg
material: SA-515 Gr. 70; $S_m = 22.5$ ksi
corrosion allowance: none

Internal pressure is the only applicable loading of those listed in AD-110. Also, under the rules of AD-160, a fatigue evaluation is not required.

NOTE: In this example only the small cylinder–cone junction is considered, per AD-212.3; it is assumed that the large end is properly reinforced.

Per AD-201(a) for a cylinder:

$$t = \frac{PR_s}{S - 0.5P} = \frac{225(48)}{22{,}500 - 112.5} = 0.482 \text{ in.}$$

Per Fig. AD-212.3, required amount of reinforcement = $A \leq (A_1 + A_2 + A_3)$, where

$$A = \frac{dt \tan \alpha}{2} = \frac{96(0.482)(0.649)}{2}$$

$$= 15.02 \text{ sq in.}$$

Per AD-212.3(c), two-thirds of A must be located within the limits:

$$0.5\sqrt{\frac{dt}{2}} = 0.5\sqrt{\frac{96(0.482)}{2}} = 2.41 \text{ in.}$$

measured along the cylinder, and

$$0.5\sqrt{\frac{dt}{2\cos^2\alpha}} = 0.5\sqrt{\frac{96(0.482)}{1.4067}} = 2.87 \text{ in.}$$

measured along the cone.

From Fig. AD-610.1, the throat thickness of the weld A_3 is the smaller of $0.7t$ or 0.25 in.

$$0.7t = 0.7(0.482) = 0.337 \text{ in.}$$

Therefore, t_c for the A_3 fillet weld can be 0.25 in. (for simplicity A_3 is considered a small isosceles triangle);

$$A_3 \approx t_c^2 \sin 57 \text{ deg} = (0.25)^2(0.839) = 0.0524 \text{ sq in.}$$

But

$$A_1 + A_2 + A_3 = 15.02 \text{ sq in.}$$

Therefore,

$$A_1 + A_2 = 15.02 - 0.0524 = 14.97 \text{ sq in.}$$

Since two-thirds of the 14.97 sq in. ($14.97 \times \frac{2}{3} = 9.98$ sq in.) must be located within

$$2.41 \text{ in.} + 2.87 \text{ in.} = 5.28 \text{ in.}$$

the required reinforcement thickness becomes

$$9.98/(2)(5.28) = 0.945 \text{ in.}$$

The total required thickness is then 0.945 in. + 0.482 in. = 1.427 in. for the small cylinder. For convenience, let 0.945 in. be the basic required thickness; then for the remaining one-third of the reinforcement, the required length is

$$14.97 \times \frac{1}{3}\Big/(2)(0.945) = 2.64 \text{ in.}$$

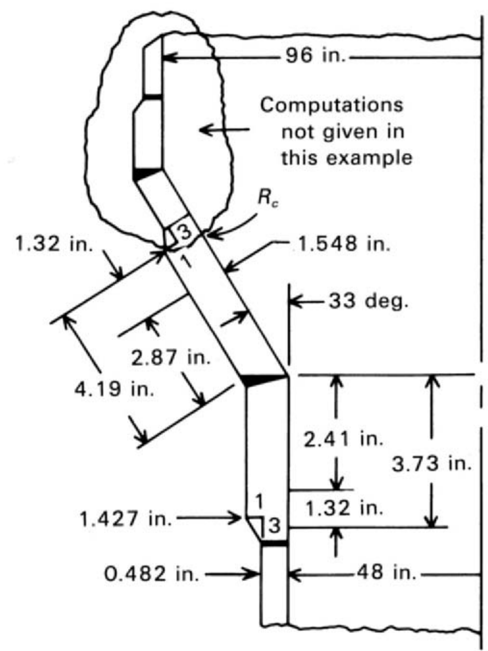


FIG. G-110.2

one-half of which will be taken along the cylinder.

Per AD-203(a) for a cone-reinforcement zone, R_c equals the cone radius at the upper end of 4.19 in. reinforcement:

$$t_c = \frac{PR_c}{S - 0.5P} = \frac{225(50.3/0.839)}{22{,}500 - 112.5} = 0.603 \text{ in.}$$

Therefore, the total required thickness is

$$t_r = 0.945 + 0.603 = 1.548 \text{ in.}$$

for the cone at the junction and within the limit of 4.19 in. along the cone.

The thickness of the cone beyond the distance of 4.19 in. and at the large cylinder junction requires separate computation. The final geometry is shown in Fig. G-110.2.

Note that the distance for the small cylinder (2.41 in.) and the cone (2.87 in.) meets the two-thirds rule.

G-112 EXAMPLE NO. 12: AD-310

Determine the minimum thickness of a cylindrical shell subjected to external pressure given the following:

inside diameter D = 168 in.
design pressure: full vacuum (15 psi external)
design temperature = 700°F
shell length L = 39 in.
material: SA-285 Gr. C
corrosion allowance: none

External pressure is the only applicable loading of those listed in AD-110. Also, under the rules of AD-160, a fatigue evaluation is not required. Per AD-310.1:

Step 1. Select a thickness $t = 0.25$ in. Then

$$\frac{L}{D_o} = \frac{39}{168.50} = 0.232$$

$$\frac{D_o}{t} = \frac{168.50}{0.25} = 674$$

Steps 2, 3. Enter Fig. G in Subpart 3 of Section II, Part D at a value $L/D_o = 0.232$ and move horizontally to intersect the line for $D_o/t = 674$. From this intersection move vertically downwards and read value of factor $V = 0.00035$.

Steps 4, 5. Using $A = 0.00035$, enter Fig. CS-2 of Section II, Part D and move vertically to the material/temperature line for 700°F. From this intersection, move horizontally to the right and read the value of $B = 4{,}250$.

Step 6. Calculate the value of the maximum allowable external working pressure P_a as follows:

$$P_a = \frac{4B}{3(D_o/t)} = \frac{4(4{,}250)}{3(674)}$$

$$= 8.41 \text{ psi}$$

Since P_a is less than the external design pressure P, it is necessary to select a shell thickness greater than 0.25 in. and to repeat the above procedure.

Step 1. Select $t = 0.3438$ in.

$$\frac{L}{D_o} = \frac{39}{168.6875} = 0.2312$$

$$\frac{D_o}{t} = \frac{168.6875}{0.3438} = 490$$

Steps 2–5

$$B = 6{,}900$$

Step 6

$$P_a = 4[(6{,}900)/(3)(490)]$$

$$= 18.78 \text{ psi}$$

Since P_a is greater than the external design pressure P, the selected shell thickness of 0.3438 in. is satisfactory.

NOTE: The procedure can be repeated until P_a is exactly equal to P, if desired.

G-113 EXAMPLE NO. 13: AD-320

Determine the minimum thickness of a spherical shell subjected to external pressure given the following:

inside radius $R = 92$ in.
design pressure: full vacuum (15 psi external)
design temperature = 700°F
material: SA-285 Gr. C
corrosion allowance: none

External design pressure is the only applicable loading of those listed in AD-110. Also, under the rules of AD-160, a fatigue evaluation is not required. Per AD-320:

Step 1. Select $t = 0.50$ in. Then

$$R_o = 92 + 0.5 = 92.5$$

and

$$A = \frac{0.125}{(R_o/t)} = \frac{0.125}{(92.5/0.5)} = 0.00068$$

Steps 2, 3. Enter Fig. CS-2 in Subpart 3 of Section II, Part D at $A = 0.00068$ and move vertically to the material/temperature line for 700°F. From this intersection, move horizontally to the right and read the value of $B = 7{,}100$.

Step 4. Compute the maximum allowable external working pressure P_a for the shell thickness of 0.50 in. as follows:

$$P_a = \frac{B}{(R_o/t)} = \frac{7{,}100}{185}$$

$$= 38.38 \text{ psi}$$

A pressure capability of 38.38 psi may be too conservative since the design pressure is full vacuum. Therefore, select a new shell thickness and repeat the above procedure.

Step 1. Select $t = 0.3125$ in. Then

$$R_o = 92 + 0.3125 = 92.3$$

and

$$A = \frac{0.125}{(R_o/t)} = \frac{0.125}{(92.3/0.3125)} = 0.00042$$

Steps 2–4

$$B = 5{,}000$$

$$P_a = 16.93 \text{ psi}$$

Since P_a is greater than the external design pressure P, the thickness of 0.3125 in. is satisfactory.

NOTE: If desired, the procedure can be repeated until P_a is exactly equal to P.

G-114 EXAMPLE NO. 14: AD-300.1, AD-331

Determine the stiffening ring requirements for a cylindrical shell subjected to external design pressure given the following:

outside diameter $D_o = 169$ in.
shell thickness $t = 0.3125$ in.
support distance $L_s = 40$ in.
design pressure: full vacuum (15 psi external)
design temperature = 700°F
material
shell: SA-285 Gr. C
ring: SA-36
corrosion allowance: none

External design pressure is the only applicable loading of those listed in AD-110. Also, under the rules of AD-160 a fatigue evaluation is not required. Per AD-300.1 and AD-331:

Step 1. To illustrate the procedure, a channel section is selected and attached to the shell by the channel legs. The channel selected is an American Standard Channel Member (C-6 × 8.2) having a value $A_s = 2.40$ sq in. The quantity of

$$1.1\sqrt{D_o t} = 1.1\sqrt{(169)(0.3125)} = 8 \text{ in.}$$

Using this value, the combined ring–shell moment of inertia is approximately 3 in.^{4}

The factor B (AD-331) is

$$B = \frac{3}{4}\left[\frac{PD_o}{t + A_s/L_s}\right]$$

$$= 0.75\left[\frac{(15)(169)}{0.3125 + \frac{2.40}{40}}\right] = 5{,}104$$

Step 2. Enter the right-hand side of Fig. CS-2 of Section II, Part D at a value $B = 5{,}104$ and move horizontally to the left to the material/temperature line for 700°F. Move vertically downwards and read value $A = 0.00042$. Then

$$I_s = \frac{D_o^2 L_s\left(t + \frac{A_s}{L_s}\right)A}{10.9}$$

$$= \frac{(169)^2(40)\left(0.3125 + \frac{2.40}{40}\right)(0.00042)}{10.9}$$

$$= 16.4 \text{ in.}^4$$

Step 3. This required value of the moment of inertia, $I_s = 16.4$ in.^{4}, is larger than the available moment of inertia of 3.728 in.^{4} of the combined channel–shell cross section. The available moment of inertia will be increased to 25.32 in.^{4} if the channel web is placed in the radial direction. This is too conservative. A new shape is recommended. For illustration purposes, a bar of rectangular cross section, 2 in. × 3.75 in., is chosen. This shape provides an $A_s = 7.50$ sq in. With the 3.75 in. dimension in the radial direction, the combined ring–shell moment of inertia is 16.57 in.^{4} Then

$$B = \frac{0.75(15)(169)}{0.3125 + \frac{7.5}{40}} = 3{,}803$$

Enter the right-hand side of Fig. CS-2 in Subpart 3 of Section II, Part D at a value $B = 3{,}803$ and move horizontally to the left to the material line for 700°F. Move vertically downwards and read value $A = 0.00031$. Then

$$I_s = \frac{(169)^2(40)\left(0.3125 + \frac{7.5}{40}\right)(0.00031)}{10.9}$$

$$= 16.25 \text{ in.}^4$$

Step 4. The required moment of inertia of 16.25 in.^{4} for the combined ring–shell section is less than the value of 16.55 in.^{4} provided by the shell–ring section with a 2 in. × 3.75 in. bar; therefore, this stiffening ring is satisfactory.

G-115 EXAMPLE NO. 15: AD-101 AND AD-520–AD-570

Determine the reinforcing requirements for the case of a 6 in. stainless steel nozzle attached to a 60 in. diameter carbon steel cylindrical shell as shown in Fig. G-115.1 and given the following:

shell inside radius $R_s = 30$ in.
nominal shell wall thickness $t_s = 0.875$ in.
internal design pressure $P = 350$ psi
design temperature = 400°F
operating temperature range: 70°F–400°F
nozzle outside diameter $d_o = 6.625$ in.
nozzle wall thickness $t_n = 0.432$ in.
internal projection of nozzle = 0.25 in.
shell material: SA-515 Gr. 60 carbon steel
nozzle material: SA-213, Type 304 stainless steel
corrosion allowance: none
$S_m = 18.3$ ksi for SA-515 Gr. 60
$S_m = 18.7$ ksi for SA-213 TP304

The material combination is permitted by AD-101(b)(3).

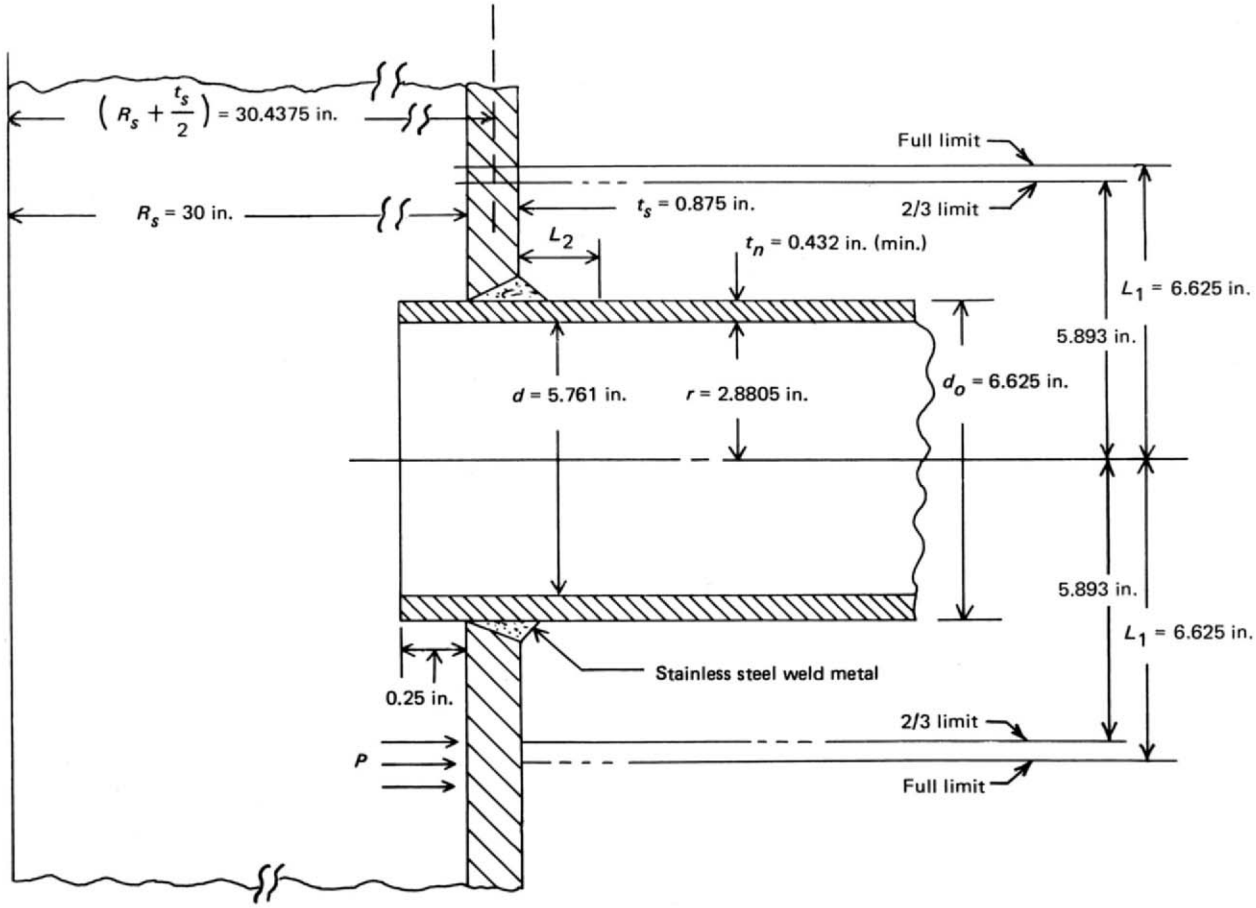


FIG. G-115.1

Per AD-520(a), the total cross-sectional area of reinforcement A required is:

$$A = dt_rF$$

where

$$d = 5.761 \text{ in.}$$

$$F = 1.0$$

and

$$t_r = \frac{PR_s}{S - 0.5P} = \frac{350(30)}{18{,}300 - 175} = 0.579 \text{ in.}$$

According to AD-550(f), calculation is required to determine if certain metal area may be considered for reinforcement

$$|(\alpha_R - \alpha_V)\Delta T| \leq 0.0008$$

$$(9.19 - 6.74)\ 10^{-6}(400 - 70) = 0.00081$$

This exceeds 0.0008; therefore, no credit can be taken for the reinforcement potentially available as excess nozzle wall thickness, nozzle projection within the shell, and stainless fillet weld metal. Thus, the only metal available for reinforcement, exclusive of added reinforcement, is that due to excess shell thickness A_1 and the area to be required shall be based on the nozzle outside diameter. Thus,

$$A = (6.625)(0.579)(1) = 3.836 \text{ sq in.}$$

Per AD-510(a)

$$0.2\sqrt{R_m t_s} = 0.2\sqrt{(30.4375)(0.875)} = 1.032 \text{ in.}$$

The opening is 6.625 in. diameter; therefore, added reinforcement may be necessary. Per AD-540.1, the limit of reinforcement L_1 on each side of the axis of the opening and parallel to the axis of the shell is 6.625 in. The limit to contain two-thirds of the required reinforcement is

$$r + 0.5\sqrt{R_m t_s} = 3.3125 + 2.58 = 5.893 \text{ in.}$$

Therefore,

$$\tfrac{2}{3}(A/2) = \tfrac{2}{3}(3.836/2) = 1.279 \text{ sq in.}$$

must be within the 5.893 in. limit.

Per AD-540.2(c), the limit of reinforcement normal to the shell is:

$$L_2 = 2.5t_n + t_e = (2.5)(0.432) + 0 = 1.08 \text{ in.}$$

The value of 1.08 in. can change if a reinforcing pad of thickness t_e is added. The available reinforcement in the shell is

$$A_1 = (L_1 - r)(t_s - t_r)$$

$$= (6.625 - 3.3125)(0.875 - 0.579)$$

$$= 0.981 \text{ sq in.}$$

The area of reinforcement available within the two-thirds rule limit of 5.893 in. is

$$A_1 = (5.893 - 3.3125)(0.875 - 0.579) = 0.764 \text{ sq in.}$$

which is deficient by

$$0.981 - 0.764 = 0.217 \text{ sq in.}$$

Therefore, the metal inherently available for reinforcement is

$$A_1 = 0.981 \text{ sq in.}$$

The required reinforcement each side of the axis of the nozzle is

$$3.836/2 = 1.918 \text{ sq in.}$$

Therefore,

$$1.918 - 0.981 = 0.937 \text{ sq in.}$$

of added reinforcement is required. This reinforcement can be achieved by:

(a) providing a local increase in shell thickness within the L_1 limitation; or

(b) adding a reinforcing pad of material conforming to the requirements of AD-551 and AD-570.

Reinforcement by a Local Increase in Shell Thickness:

Assume an insert plate with constant thickness to radius $= L_1$ and provide a 1:3 taper at the periphery per Fig. AD-420.1. Nozzle projection within the shell will not be considered since no reinforcing credit is allowed.

$$A_1 = (L_1 - r)(t_s - t_r) = 0.981 + 0.937 = 1.918 \text{ sq in.}$$

$$(6.625 - 3.3125)(t_s - 0.579) = 1.918$$

from which t_s locally equals 1.158 in. minimum. The reinforcement within the two-thirds rule limit is

$$(5.893 - 3.3125)(1.158 - 0.579) = 1.494 \text{ sq in.}$$

But, $\tfrac{2}{3}$ of 1.918 is 1.279 sq in.; therefore, this reinforcement is satisfactory.

The taper length is

$$3(1.158 - 0.579) = 1.737 \text{ in.}$$

resulting in an insert plate diameter of 15.0 in.

Reinforcement by Reinforcing Pad:

Per AD-551 and AD-570, a reinforcing pad of SA-515, Grade 60 carbon steel (same material as shell) would be satisfactory. Since no part of the nozzle is permitted for reinforcement, the L_2 calculation previously made can be disregarded and a reinforcing pad provided in accordance with Fig. G-115.2. The diameter of the pad D_p plus the distance occupied by the peripheral pad weld must be within the $2L_1$ limit and must also satisfy the two-thirds rule limit. As before, the required added area of reinforcement is 0.937 sq in., each side of the nozzle axis.

Assume that the reinforcing pad thickness will not exceed the shell thickness; then per Fig. AD-612.1, the weld throat dimension can be taken as $0.7t_e$ and the weld leg dimension is thus

$$0.7t_e/0.707 = 0.99t_e\text{; use leg} = t_e$$

The weld area is then $0.5t_e^2$.

The nozzle neck and stainless fillet weld at neck is excluded for reinforcement. Take pad inside radius = 3.3125 and outside radius $= L_1 - t_e$. Then

$$(6.625 - t_e - 3.3125)t_e + 0.5t_e^2 = 0.937 \text{ sq in. (required)}$$

$$t_e = 0.296 \text{ in. min.}$$

resulting in pad of 12.658 in. O.D. and width 3.017 in.

The pad reinforcement within the two-thirds rule is

$$(5.893 - 3.3125)(0.296) = 0.764 \text{ sq in.}$$

$$\text{reinforcement in shell} = 0.764 \text{ sq in.}$$

$$\text{total} = 1.528 \text{ sq in. (vs. 1.279 required)}$$

This reinforcement is therefore satisfactory.

A thicker pad with lesser width, such as a 0.375 in. thick by 12.0 in. O.D. pad, would also be satisfactory.

NOTE: AD-160 rules may require a fatigue analysis.

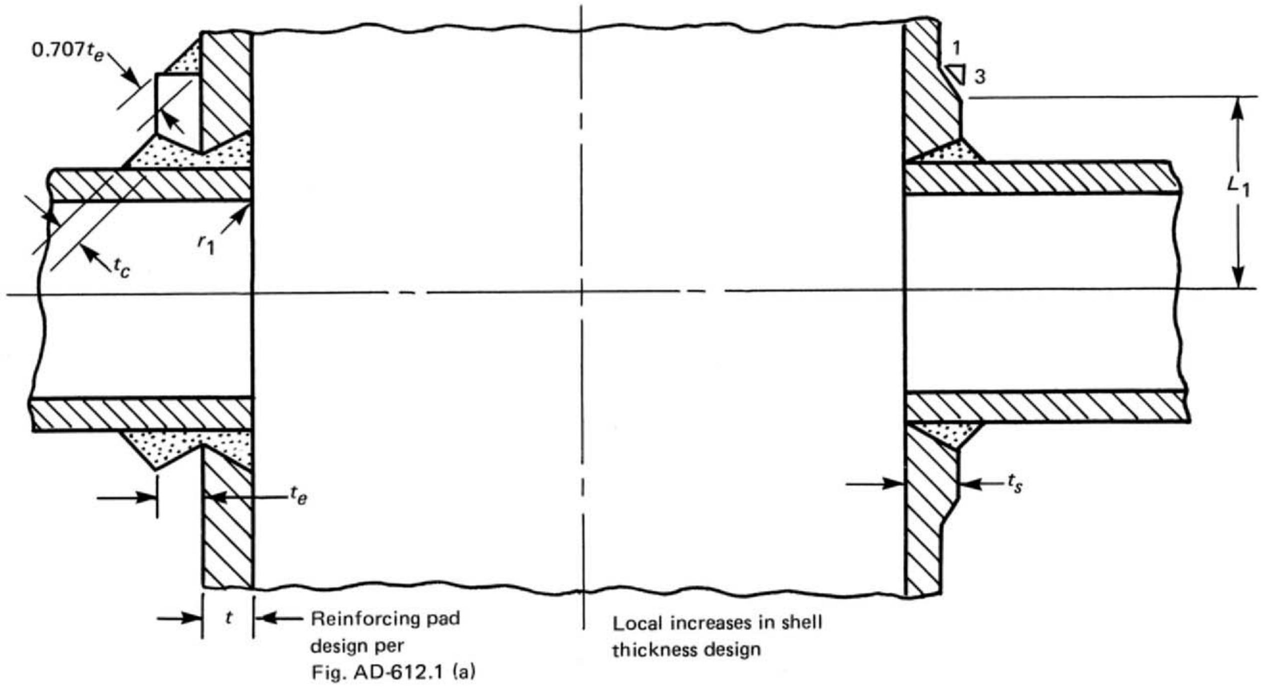


FIG. G-115.2

G-116 EXAMPLE NO. 16: AD-560

Determine the reinforcing requirements for a nozzle in a hemispherical head given the following:

internal design pressure $P = 3{,}500$ psi
pressure cycles $N = 5{,}000$
design temperature = 400°F
head inside diameter $D = 72$ in.
head thickness $t = 3.25$ in.
nozzle inside diameter $d = 10.75$ in.
nozzle wall thickness $t_n = 1.0$ in.
head material: SA-516 Gr. 70, where $S_m = 21.7$ ksi, $S_u = 70$, and $S_y = 38$
nozzle material: SA-266 Cl. 3, where $S_m = 21.4$ ksi, $S_u = 75$, and $S_y = 37.5$
corrosion allowance: none

Internal pressure is the only applicable loading of those listed in AD-110. The number of pressure cycles exceeds the maximum allowance for Condition A of AD-160.2. It will be shown below that Condition B cannot be met; and, therefore, a fatigue analysis of the nozzle is required.

The nozzle will be designed in accordance with the alternative rules of AD-560 and will resemble the configuration in Fig. AD-560.1(a).

The limitations of AD-560.1 are examined first. Limitations (a), (b), and (c) are met. Limitation (d) is also met for both materials:

For head material

$$\text{UTS/YS} = 70/38 = 1.842 > 1.5$$

For nozzle material

$$\text{UTS/YS} = 75/37.5 = 2.000 > 1.5$$

Before Limitation (e) can be tested, the minimum wall thickness of the head is determined from AD-204.1. Furthermore, since the minimum nozzle wall thickness is required to determine the reinforcing requirements, it also is determined from AD-201.

$$t_r = \frac{0.5PR}{S - 0.25p} = \frac{0.5(3{,}500)(36)}{21{,}700 - 0.25(3{,}500)} = 3.025 \text{ in.}$$

$$t_{rn} = \frac{Pr}{S - 0.5p} = \frac{3{,}500(5.375)}{21{,}400 - 0.5(3{,}500)} = 0.957 \text{ in.}$$

Limitation (e) can also be met since:

$$10 < D/t = 72/3.25 = 22.15 < 100$$

$$d/D = 10.75/72 = 0.149 < 0.5$$

$$d/\sqrt{Dt} = 10.75/\sqrt{72 \times 3.25} = 0.70 < 0.8$$

Therefore, the alternative rules can be used.

The required reinforcement area is found from AD-560.3. Since

$$d/\sqrt{Rt_r} = [10.75/\sqrt{36(3.025)}] = 1.030$$

then

$$A_r = dt_r \cos \phi$$

$$\phi = \sin (d/D) = \sin (0.149) = 8.569 \text{ deg}$$

and

$$A_r = 10.75(3.025) \cos 8.569 \text{ deg} = 32.156 \text{ sq in.}$$

The limit of the reinforcing zone is determined from Fig. AD-560.4.

$$L_n = 1.26\ (t_r/R)^{2/3}\ [R(r/R + 0.5)]$$

$$= 1.26\ (3.025/36)^{2/3}\ [(36)\ (5.375/36 + 0.5)]$$

$$= 5.650 \text{ in.}$$

Assuming the reinforcement is provided in the nozzle forging, since the allowable stresses are different for the two materials, the rules of AD-560.5 must be followed, which increases the required reinforcement area to:

$$A_r = 32.156\ (21{,}700/21{,}400) = 32.607 \text{ sq in.}$$

The transition details are determined from AD-560.6 and Fig. AD-560.1.

$$t/8 \le r_1 \le t/2$$

$$0.406 \text{ in.} \le r_1 \le 1.63 \text{ in.}$$

The minimum r_1 is chosen so as to reduce the material removed and thereby decrease reinforcement requirements; $r_2 \ge$ the larger of $1.41\sqrt{rt_{rn}}$ or $t/2$:

$$1.41\ \sqrt{5.375(0.957)} \text{ or } 3.25/2$$

$$3.198 \text{ in.; say } 3.500 \text{ in.}$$

$\theta = 45$ deg; $r_3 \ge$ the larger of $\sqrt{(\theta/45)(rt_{rn})}$ or $(\theta/90)t_n$:

$$2.268 \text{ or } 0.500 = \text{use } 2.268 \text{ in.}$$

Since the geometric requirements are established, it is now possible to determine the available area of reinforcement. To simplify the analysis, the area added by r_3 is ignored. A summary of the geometric data is given.

$D = 72$ in.	$d = 10.75$ in.	
$R = 36$ in.	$r = 5.375$ in.	
$t_r = 3.025$ in.	$t_{rn} = 0.957$ in.	
$t = 3.25$ in.	$t_n = 1.00$ in.	
$A_r = 32.607$ sq in.		
$r_1 = 0.406$ in.	$r_2 = 3.50$ in.	$r_3 = 2.268$ in.
$L_n = 5.650$ in.	$\theta = 45$ deg	

The nozzle is shown in Fig. G-116.1 with reinforcement areas labeled.

The available reinforcement area is:

$$A_a = A_1 + A_2 + A_3 + A_4 + A_5$$

where

$$A_1 = t_2\ [\sqrt{(R + t_r)^2 - (r + t_{rn})^2} + L_n - \sqrt{(R + t)^2 - (t_2/2 + t_n + r)^2} - t_2/2]$$

$$A_2 = {r_2}^2 \left(\tan \frac{\alpha}{2} - \frac{\pi\alpha}{360}\right)$$

$$A_3 = (l_1 - t + t_r)(t_n - t_{rn})$$

$$A_4 = L_n(t - t_r)$$

$$A_5 = \frac{R^2}{2}\ (\sin \beta - \sin \phi)(\cos \phi - \cos \beta) - 0.2146(r_1)^2$$

and where

$$\beta = \sin^{-1} \left(\frac{r + t_n + t_2 + r_2}{R + t + r_2}\right)$$

$$\alpha = 90 - \beta$$

Assuming

$$t_2 = 2.25 \text{ in.}$$

$$l_1 = L_n = 5.65 \text{ in.}$$

$$\beta = \sin^{-1} \left(\frac{5.375 + 1.000 + 2.250 + 3.500}{36 + 3.250 + 3.500}\right)$$

$$= 16.48 \text{ deg}$$

$$\alpha = 73.52 \text{ deg}$$

The reinforcement areas are:

$$A_1 = 2.25 \left[\sqrt{(36 + 3.025)^2 - (5.375 + 0.957)^2} + 5.650 - \sqrt{(36 + 3.25)^2 - \left(\frac{2.25}{2} + 1.000 + 5.375\right)^2} - \frac{2.25}{2}\right] = 10.14 \text{ in.}^2$$

$$A_2 = (3.5)^2 \left[\tan \frac{73.52}{2} - \frac{\pi \times 73.52}{360}\right] = 1.29 \text{ in.}^2$$

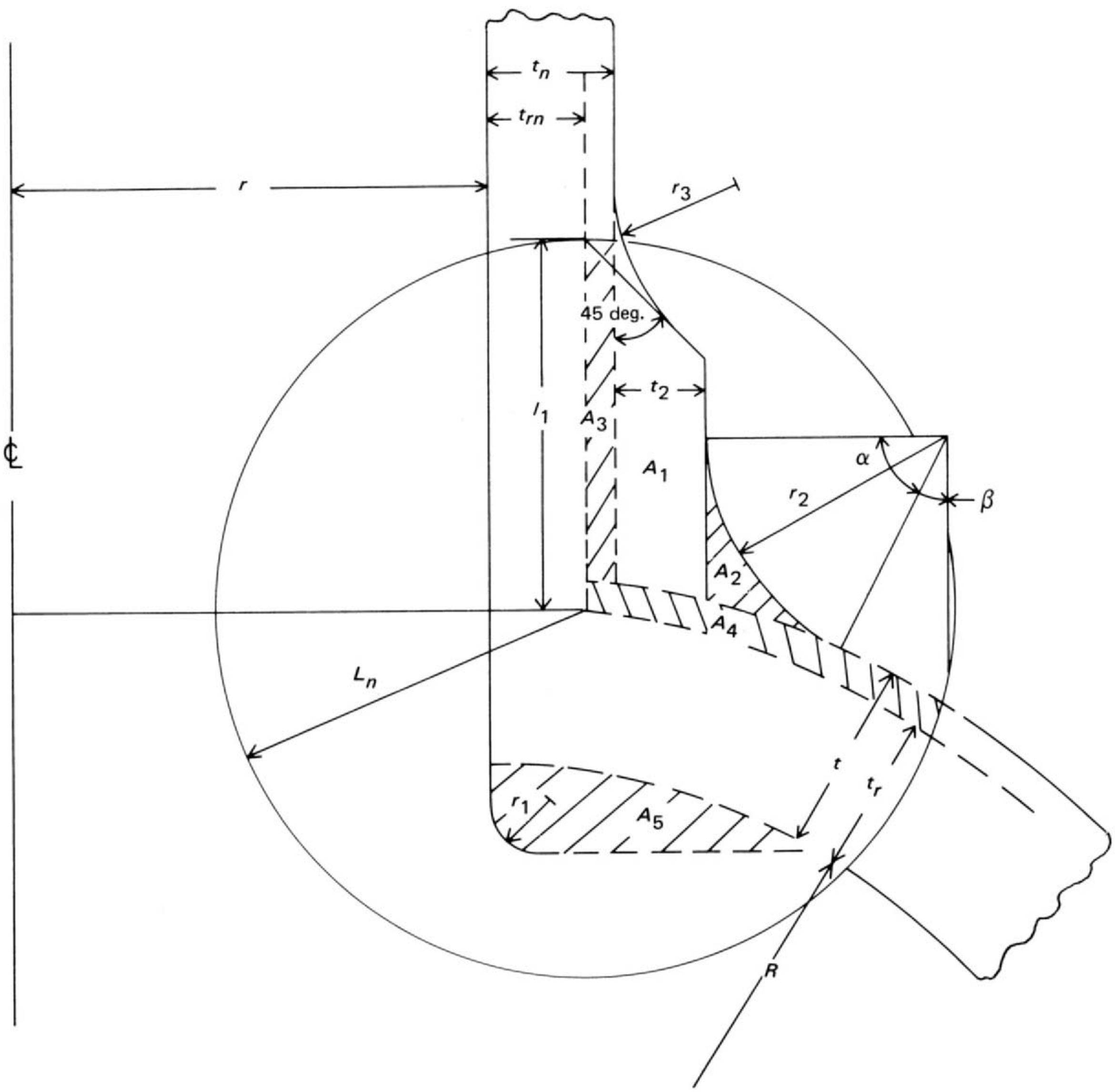


FIG. G-116.1

$$A_3 = (5.65 - 3.25 + 3.025)(1.000 - 0.957)$$

$$= 0.23 \text{ in.}^2$$

$$A_4 = 5.65\ (3.25 - 3.025) = 1.27 \text{ in.}^2$$

$$A_5 = \frac{(36)^2}{2} (\sin 16.48 \text{ deg} - \sin 8.57 \text{ deg})$$

$$\times (\cos 8.57 \text{ deg} - \cos 16.48 \text{ deg})$$

$$- 0.2146\ (0.406)^2 = 2.58 \text{ in.}^2$$

$$A_a = 10.14 + 1.29 + 0.23 + 1.27 + 2.58$$

$$= 15.51 \text{ in.}^2$$

$A_a < A_r/2$; therefore, move the work point at the 45 deg slope and r_3 outboard ½ in. and thus obtain 0.98 sq in. of additional area. Then 16.50 sq in. > 16.30 sq in. and the Code requirement has been met.

A fatigue analysis of the nozzle is required per AD-160.2 Condition A. Condition B (a) also is not satisfied since

$$S_m = 21{,}400 \text{ psi and } S_a = 63{,}900 \text{ psi}$$

which when entered in Fig. 5-110.1 gives 2,100 cycles, a smaller number than desired.

Using Table AD-560.7 to determine the peak stresses for a fatigue analysis

$$\sigma = 2.2S$$

where

$$S = \frac{P(2R + t)}{4t} = \frac{3500(72 + 3.25)}{4(3.25)} = 20{,}260 \text{ psi}$$

and

$$\sigma = 2.2(20{,}260)$$

$$= 40{,}520 \text{ psi}$$

From 5-110.3(a), σ is seen to be equivalent to maximum (S_{ij}) and therefore $S_{alt} = \sigma/2$.

However, from 5-110.3(d) and (e), and Table TM-1 in Subpart 2 of Section II, Part D:

$$S_a = \frac{40{,}520}{2} \times \frac{30 \times 10^6}{27.5 \times 10^6} = 22{,}102 \text{ psi}$$

Entering Fig. 5-110.1 at $S_a = 22{,}102$, the allowable number of cycles is approximately 70,000. Therefore, the nozzle design is adequate for the required service.

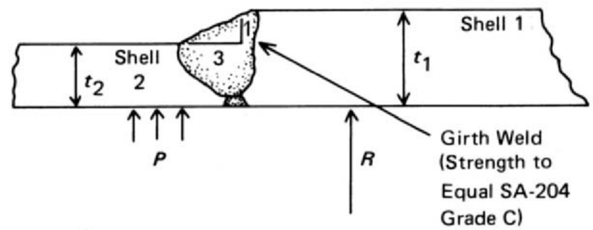


FIG. G-118.1

G-118 EXAMPLE 18: AD-101

A cylindrical vessel composed of two different materials is subject to internal pressure. Determine the suitability of construction as shown in Fig. G-118.1 and given the following:

inside shell radius $R = 30$ in.
internal design pressure $P = 630$ psi
design temperature = 700°F
corrosion allowance = 0.10 in.
material:
shell 1: SA-516 Gr. 70; $S_m = 18.3$ ksi
shell 2: SA-204 Gr. C; $S_m = 21.7$ ksi

Internal pressure is the only applicable loading of those listed in AD-110. Also, under the rules of AD-160, a fatigue evaluation is not required. Per AD-201(a):

$$t_1 = \frac{PR}{S - 0.5P} = \frac{630(30.1)}{18{,}300 - 315} = 1.054 \text{ in.}$$

$$t_1 \text{ (Actual)} = 1.054 + 0.10 = 1.154 \text{ in.}$$

$$t_2 = \frac{PR}{S - 0.5P} = \frac{630(30.1)}{21{,}700 - 315} = 0.887 \text{ in.}$$

$$t_2 \text{ (Actual)} = 0.887 + 0.10 = 0.987 \text{ in.}$$

Per AD-101(b)(1)(d):

$$S_2 \le 1.2S_1\ (E_2/E_1)$$

$$21.700 \le 1.2(18{,}300)[(25.3 \times 10^6)/(25.5 \times 10^6)]$$

$$21{,}700 \le 21{,}788$$

Therefore, the construction is acceptable and a local stress analysis is not required.

NONMANDATORY APPENDIX I
GUIDE FOR PREPARING MANUFACTURER'S DATA REPORTS

I-200 GUIDE FOR PREPARING MANUFACTURER'S DATA REPORTS

Introduction

(a) The instructions contained in the Appendix are to provide general guidance to the Manufacturer in preparing Data Reports as required in AS-300.

(b) Manufacturers' Data Reports required by this Division are not intended for pressure vessels that do not meet the provisions of the Code, including those of special design or construction that require and receive approval by jurisdictional authorities under the laws, rules, and regulations of the respective state or municipality in which the vessel is to be installed.

(c) The instructions for the Data Reports are identified by circled numbers corresponding to numbers on the sample Forms in this Appendix.

(d) Where more space than has been provided for on the Form is needed for any item, indicate in the space "See Remarks" or "See attached Form A-3," as appropriate.

FORM A-1 MANUFACTURER'S DATA REPORT FOR PRESSURE VESSELS
As Required by the Provisions of the ASME Code Rules, Section VIII, Division 2

1. Manufactured and certified by ______ (1) ______
(Name and address of manufacturer)

2. Manufactured for ______ (2) ______
(Name and address of purchaser)

3. Location of installation ______ (3) ______
(Name and address)

4. Type ___(5)___ Horiz. or vert. tank ___(7)___ Mfr.'s Serial No. ___(8)___ CRN ___(9)___ Drawing No. ___(11)___ Nat'l. Bd. No. ______ Year built

5. The chemical and physical properties of all parts meet the requirements of material specifications of the ASME BOILER AND PRESSURE VESSEL CODE. The design, construction, and workmanship conform to ASME Code, Section VIII, Division 2 ___(12)___ Year
___(12)___ Addenda date ___(13)___ Code Case No.

Items 6 to 11 incl. to be completed for single wall vessels, jackets of jacketed vessels, or shells of heat exchangers

6. Shell ___(15)___ Material (Spec. No., Grade) ___(16)___ Nom. thk. ___(17)___ Corr. allow. ___(18)___ Inside diameter ___(19)___ Length (overall)

7. Seams ___(20)___ Longitudinal ___(21)___ Heat treatment ___(22)___ Radiographic treatment
___(23)___ Girth ___(21)___ Heat treatment ___(24)___ Radiographic treatment ___(25)___ No. of courses

8. Heads: (a) Matl. ___(15) (20) (21) (22)___ Spec. No., Grade (b) Matl. ______ Spec. No., Grade

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)		(26)	(17)							
(b)										

9. If removable, bolts used (describe other fastenings): ___(27)___ Matl., Spec. No., Grade, Size, Number

10. Jacket closure ___(28)___ Describe as ogee and weld, bar, etc. If bar, give dimensions ______ If bolted, describe or sketch.

11. Design press. ___(29)___ at max. temp. ___(30)___. Charpy impact ___(31)___ at test temp. of ___(31)___. Min. design metal temp. ___(32)___ at ______. Pneu., hydro., or comb. test pressure ___(33)___.

Items 12 and 13 to be completed for tube sections

12. Tubesheets ___(15)___ Stationary matl. (Spec. No., Grade) ___(18)___ Diam. (subject to pressure) ___(16)___ Nom. thk. ___(17)___ Corr. allow. ______ Attach. (wld., bolted)
___(15)___ Floating matl. (Spec. No., Grade) ______ Diam. ___(16)___ Nom. thk. ___(17)___ Corr. allow. ______ Attach. (wld., bolted)

13. Tubes ___(15)___ Matl. (Spec. No., Grade) ______ O.D. ______ Nom. thk. ______ Number ______ Type (straight or "U")

Items 14 to 18 incl. to be completed for inner chambers of jacketed vessels, or channels of heat exchangers

14. Shell ___(15)___ Matl. (Spec. No., Grade) ___(16)___ Nom. thk. ___(17)___ Corr. allow. ___(18)___ Inside diameter ___(19)___ Length (overall)

15. Seams ___(20)___ Longitudinal (wld., dbl., sngl.) ___(21)___ Heat treatment (yes or no) ___(22)___ Radiographic treatment
___(23)___ Girth ___(21)___ Heat treatment ___(24)___ Radiographic treatment ___(25)___ No. of courses

16. Heads: (a) Matl. ______ Spec. No., Grade (b) Matl. ______ Spec. No., Grade

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)										
(b)										

17. If removable, bolts used (describe other fastenings) ______ Matl., Spec. No., Grade, Size, Number

18. Design press. ___(29)___ at max. temp. ___(30)___. Charpy impact ___(31)___ at test temp. of ___(31)___. Min. design metal temp. ___(32)___ at ______. Pneu., hydro., or comb. test pressure ___(33)___.

FORM A-1 (Back)

Items below to be completed for all vessels where applicable

19. Nozzles, inspection and safety valve openings:

Purpose (Inlet, Outlet, Drain, etc.)	D No.	iam. or Size	Type	Material	Nom. Thk.	Reinforcement Material	How Attached	Location
34 35 36		35	35 50	15 51	16 52			36

20. Supports: Skirt ___37___ (Yes or no) Lugs ______ (No.) Legs ______ (No.) Other ______ (Describe) Attached ______ (Where and how)

21. Service: Fatigue analysis required ___38___ (Yes or no) and ___39___ (Describe contents or service)

22. Remarks: Manufacturer's Partial Data Reports properly identified and signed by commissioned inspectors have been furnished for the following items of the report: ___14 21 22 24 31 33 37 40 47___ (Name of part, item number, manufacturer's name, and identifying stamp)

______

42

CERTIFICATION OF DESIGN

User's Design Specification on file at ______

Manufacturer's Design Report on file at ______

User's Design Specification certified by ______ PE State ___42 49___ Reg. No. ______

Manufacturer's Design Report certified by ______ PE State ___42 49___ Reg. No. ______

41

CERTIFICATE OF SHOP COMPLIANCE

We certify that the statements in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Code for Pressure Vessels, Section VIII, Division 2.

"U2" Certificate of Authorization No. ___41___ expires ______ .

Date ______ Co. name ___41___ (Manufacturer) Signed ___41___ (Representative)

43

CERTIFICATE OF SHOP INSPECTION

Vessel made by ______ at ______

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of ______ and employed by ______ of ______ , have inspected the pressure vessel described in this Manufacturer's Data Report on ______ , and state that, to the best of my knowledge and belief, the Manufacturer has constructed this pressure vessel in accordance with ASME Code, Section VIII, Division 2. By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in this Manufacturer's' Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date ______ Signed ___43___ (Authorized Inspector) Commissions ___44___ (Nat'l Board (incl. endorsements), State, Prov., and No.)

41

CERTIFICATE OF FIELD ASSEMBLY COMPLIANCE

We certify that the field assembly construction of all parts of this vessel conforms with the requirements of SECTION VIII, Division 2 of the ASME BOILER AND PRESSURE VESSEL CODE.

"U2" Certificate of Authorization No. ___41___ expires ______ .

Date ______ Co. name ___41___ (Assembler that certified and constructed field assembly) Signed ___41___ (Representative)

45

CERTIFICATE OF FIELD ASSEMBLY INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of ______ and employed by ______ ______ of ______ , have compared the statements in this Manufacturer's Data Report with the described pressure vessel and state that parts referred to as data items ______ , not included in the certificate of shop inspection, have been inspected by me and that, to the best of my knowledge and belief, the Manufacturer has constructed and assembled this pressure vessel in accordance with the ASME Code, Section VIII, Division 2. The described vessel was inspected and subjected to a hydrostatic test of ___45___ psi. By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in this Manufacturer's Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date ______ Signed ___45___ (Authorized Inspector) Commissions ___44___ (Nat'l Board (incl. endorsements), State, Prov., and No.)

FORM A-2 MANUFACTURER'S PARTIAL DATA REPORT
A Part of a Pressure Vessel Fabricated by One Manufacturer for Another Manufacturer
As Required by the Provisions of the ASME Code Rules, Section VIII, Division 2

1. Manufactured and certified by ______ (1) (Name and address of manufacturer)
2. Manufactured for ______ (4) (Name and address of purchaser)
3. Location of installation ______ (3) (48) (Name and address)
4. Type ______ (5) Horiz. or vert. tank ______ (7) Mfr.'s Serial No. ______ (8) CRN ______ (9) Drawing No. ______ (11) Nat'l. Bd. No. ______ Year built
5. The chemical and physical properties of all parts meet the requirements of material specifications of the ASME BOILER AND PRESSURE VESSEL CODE. The design, construction, and workmanship conform to ASME Code, Section VIII, Division 2 ______ (12) Year

   ______ (12) Addenda date ______ (13) Code Case No. ______ (5) (39) (48) Service
6. Constructed to: ______ (9) Drawing No. ______ (10) Drawing prepared by ______ (6) Description of part inspected

Items 7 to 12 incl. to be completed for single wall vessels, jackets of jacketed vessels, or shells of heat exchangers

7. Shell ______ (15) Material (Spec. No., Grade) ______ (16) Nom. thk. ______ (17) (48) Corr. allow. ______ (18) Inside diameter ______ (19) Length (overall)
8. Seams ______ (20) Longitudinal ______ (21) Heat treatment ______ (22) Radiographic treatment

   ______ (23) Girth ______ (21) Heat treatment ______ (24) Radiographic treatment ______ (25) No. of courses
9. Heads: (a) Matl. ______ (15) (20) Spec. No., Grade (b) Matl. ______ Spec. No., Grade

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)	(26)	(17) (48)								
(b)										

10. If removable, bolts used (describe other fastenings): ______ (27) Matl., Spec. No., Grade, Size, Number
11. Jacket closure ______ (28) Describe as ogee and weld, bar, etc. . If bar, give dimensions ______ . If bolted, describe or sketch.
12. Design press. ______ (29) (48) at max. temp. ______ (30) . Charpy impact ______ (31) at test temp. of ______ (31) . Min. design metal temp. ______ (32) at ______ . Fatigue analysis required ______ (38) (48) Yes or no. Pneu., hydro., or comb. test pressure ______ (33) .

Items 13 and 14 to be completed for tube sections

13. Tubesheets ______ (15) Stationary matl. (Spec. No., Grade) ______ (18) Diam. (subject to pressure) ______ (16) Nom. thk. ______ (17) (48) Corr. allow. ______ Attach. (wld., bolted)

    ______ (15) Floating matl. (Spec. No., Grade) ______ Diam. ______ (16) Nom. thk. ______ (17) (48) Corr. allow. ______ Attach. (wld., bolted)
14. Tubes ______ (15) Matl. (Spec. No., Grade) ______ O.D. ______ Nom. thk. ______ Number ______ Type (straight or "U")

Items 15 to 18 incl. to be completed for inner chambers of jacketed vessels or channels of heat exchangers

15. Shell ______ (15) Matl. (Spec. No., Grade) ______ (16) Nom. thk. ______ (17) (48) Corr. allow. ______ (18) Inside diameter ______ (19) Length (overall)
16. Seams ______ (20) Longitudinal (wld., dbl., singl.) ______ (21) Heat treatment (yes or no) ______ (22) Radiographic treatment

    ______ (23) Girth ______ (21) Heat treatment ______ (24) Radiographic treatment ______ (25) No. of courses
17. Heads: (a) Matl. ______ Spec. No., Grade (b) Matl. ______ Spec. No., Grade

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)										
(b)										

18. If removable, bolts used (describe other fastenings) ______ Matl., Spec. No., Grade, Size, Number
19. Design press. ______ (29) (48) at max. temp. ______ (30) . Charpy impact ______ (31) at test temp. of ______ (31) . Min. design metal temp. ______ (32) at ______ . Pneu., hydro., or comb. test pressure ______ (33) .

FORM A-2 (Back)

Items below to be completed for all vessels where applicable

20. Nozzles, inspection and safety valve openings:

Purpose (Inlet, Outlet, Drain, etc.)	No.	Diam. or Size	Type	Material	Nom. Thk.	Reinforcement Material	How Attached	Location
(34)		(35)	(35)	(15)	(16)			(36)
(35)			(50)	(51)	(52)			
(36)								
(48)								

21. Supports: Skirt ___(37)___ (Yes or no) Lugs ______ (No.) Legs ______ (No.) Other ______ (Describe) Attached ______ (Where and how)

22. Remarks ___(21) (22) (24) (31) (33) (37) (40) (47)___

---

(42)

CERTIFICATION OF DESIGN

User's Design Specification on file at ______

Manufacturer's Design Report on file at ______

User's Design Specification certified by ______ PE State ___(42) (49)___ Reg. No. ______

Manufacturer's Design Report certified by ______ PE State ___(42) (49)___ Reg. No. ______

(41)

CERTIFICATE OF SHOP COMPLIANCE

We certify that the statements made in this report are correct and that all details of material, construction, and workmanship of this vessel conform to the ASME Code for Pressure Vessels, Section VIII, Division 2.

"U2" Certificate of Authorization No. ___(41)___ expires ______ .

Date ______ Co. name ___(41)___ (Manufacturer) Signed ___(41)___ (Representative)

(43)

CERTIFICATE OF SHOP INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of ______ , and employed by ______ of ______ , have inspected the part of a pressure vessel described in this Manufacturer's Data Report on ______ and state that, to the best of my knowledge and belief, the Manufacturer has constructed this part in accordance with the ASME Code, Section VIII, Division 2. By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the part described in the Manufacturer's Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date ______ Signed ___(43)___ (Authorized Inspector) Commissions ___(44)___ (Nat'l Board (incl. endorsements), State, Prov., and No.)

FORM A-3 MANUFACTURER'S DATA REPORT SUPPLEMENTARY SHEET
As Required by the Provisions of the ASME Code Rules, Section VIII, Division 2

1. Manufactured and certified by ______ (1) (46) ______
(Name and address of manufacturer)

2. Manufactured for ______ (2) (46) ______
(Name and address of purchaser)

3. Location of installation ______ (3) (46) ______
(Name and address)

4. Type

(5) (46)	(7) (46)	(8) (46)	(9) (46)	(11) (46)	
Horiz., vert., tank, etc.	Serial No.	CRN	Dwg.	N at'l. Bd. No.	Year built

Data Report Item Number	Remarks
(46)	(47)

Date ______ Co. name ______ (43) (46) ______ Signed ______ (43) (46) ______
Manufacturer — Representative

Date ______ Signed ______ (43) (46) ______ Commissions ______ (44) (46) ______
Authorized Inspector — Nat'l Board (incl. endorsements), State, Prov., and No.

FORM A-3 MANUFACTURER'S DATA REPORT SUPPLEMENTARY SHEET
As Required by the Provisions of the ASME Code Rules, Section VIII, Division 2

1. Manufactured and certified by ____________ (Name and address of manufacturer)

2. Manufactured for ____________ (Name and address of purchaser)

3. Location of installation ____________ (Name and address)

4. Type ________ (Horiz. vert., tank, etc.) ________ (Mfgr's. serial No.) ________ (CRN) ________ (Dwg) ________ (Nat'l Bd. No.) ________ (Year built)

Data Report
(46) Item Number (A) (B) (47) Remarks

Item 6 or 7
(Shell)

(a) Layered Construction Type: *(Concentric Wrapped, Spiral Wrapped, Coil Wound, Shrink Fit, etc.)*

Location	Matl.	Layer Thk.	Nom. Thk. Tot.	No. Courses	Nom. Layer NDE
(b) Inner Shell:					
(c) Dummy Layer:	(15)	(F)	(16)	(25)	(C)
(d) Layers:					
(e) Overwraps:					

Item 8
(Heads)
(D)

(a) Layered Construction Type: *(Formed, Machined, Segmental, etc.)*

Location	Matl.	Layer Thk.	Nom. Thk. Tot.	Smls./Welded	NDE
(1) Inner Head:					
(2) Dummy Layer:	(15)	(F)	(16)	(E) (20)	(C)
(3) Layers:					

(b) Layered Construction Type:

(1) Inner Head:					
(2) Dummy Layer:					
(3) Layers:					

Item 21
(Vent Holes in Layers)

	Diam. Hole	Staggered Layers or Radial Through
(a) Layered Shell:		
(b) Layered Head:	(G)	(H)

Item 24
(Remarks)

Gaps Have Been Controlled According to the Provisions of Paragraph:
(See AF-815, AF-815.1, and AF-815.2)

(I) (J)

(B)

Date ____________ Co. name ____________ (Manufacturer) Signed ____________ (Representative)

Date ____________ Signed ____________ (Authorized Inspector) Commissions ____________ (Natl. Board (incl. endorsements), State, Prov., and No.)

FIG. I-221 EXAMPLE OF USE OF FORM A-3

TABLE I-220
INSTRUCTIONS FOR THE PREPARATION OF MANUFACTURER'S DATA REPORTS

Applies to Form			Note	
A-1	A-2	A-3	No.	Instruction
X	X	X	1	Name and street address of Manufacturer.
X	. . .	X	2	Name and address of purchaser.
X	. . .	X	3	Name of user, and address where vessel is to be installed.
. . .	X	. . .	4	Name and address of Manufacturer who will use the vessel part in making the complete vessel.
X	X	. . .	5	Type of vessel, such as horizontal or vertical, tank, separator, heat exchanger, reactor.
. . .	X	. . .	6	Brief description of vessel part (i.e., shell, two-piece head, tube, bundle).
X	X	X	7	An identifying Manufacturer's serial number marked on the vessel (or vessel part) (see Article S-1).
X	X	X	8	Canadian registration number where applicable.
X	X	. . .	9	Indicate drawing numbers, including revision numbers, that cover general assembly and list materials. For Canadian registration, the number of the drawing approved by Provincial authorities.
. . .	X	. . .	10	Organization that prepared drawing.
X	X	X	11	Where applicable, National Board Number from Manufacturer's Series of National Board Numbers. National Board Number shall not be used for owner-inspected vessels.
X	X	. . .	12	Issue date of Section VIII, Division 2 and Addenda under which vessel was manufactured.
X	X	. . .	13	All Code Case numbers when vessel is manufactured according to any Cases.
X	. . .	. . .	14	To be completed when one or more parts of the vessel are furnished by others and certified on Data Report Form A-2 as required by AS-310. The part manufacturer's name and serial number should be indicated.
X	X	. . .	15	Show the complete ASME Specification number and grade of the actual material used in the vessel part. Material is to be as designated in Section VIII, Division 2 (e.g., "SA-285 C"). Exceptions: A specification number for a material not identical to an ASME Specification may be shown *only* if such material meets the criteria in the Foreword of this Section. When material is accepted through a Code Case, the applicable Case Number shall be shown.
X	X	. . .	16	Thickness (specify inches or millimeters) is the nominal thickness of the material used in the fabrication of the vessel. It includes corrosion allowance.
X	X	. . .	17	State corrosion allowance on thickness [see AG-301.1(b) and AD-115] in inches or millimeters.
X	X	. . .	18	Indicate whether the diameter (in inches or millimeters) is inside diameter or outside diameter.
X	X	. . .	19	The shell length (in inches, millimeters, or meters) shall be shown as the overall length between closure or transition section welds, for a shell of a single diameter. In other cases, define length, as appropriate.
X	X	. . .	20	Type of longitudinal joint in cylindrical section, or any joint in a sphere (e.g., type No. 1 butt, or seamless) per AD-410, AF-220, and Table AF-241.1.
X	X	. . .	21	When heat treatment is performed by the Manufacturer, such as postweld heat treatment, annealing, or normalizing, give temperature and time. Explain any special cooling procedure under "Remarks."
X	X	. . .	22	Indicate radiographic examination applied to longitudinal seams (see AF-220 and Table AF-241.1). Any additional examinations should be included under "Remarks."
X	X	. . .	23	Type of welding used in girth joints in the cylindrical section (see 20).

TABLE I-220
INSTRUCTIONS FOR THE PREPARATION OF MANUFACTURER'S DATA REPORTS (CONT'D)

Applies to Form			Note	
A-1	A-2	A-3	No.	Instruction
X	X	. . .	(24)	Indicate radiographic examination applied to girth joints (see (22)).
X	X	. . .	(25)	Number of cylindrical courses, or belts, required to make one shell.
X	X	. . .	(26)	Show specified minimum thickness of head after forming (see AD-204). State dimensions that define the head shape.
X	X	. . .	(27)	Bolts used to secure removable head or heads of vessel.
X	X	. . .	(28)	For jacketed vessels, explain type of jacket closures used.
X	X	. . .	(29)	Show design pressure (in psi or kPa) for which vessel is constructed (see AD-120). Other internal or external pressures with coincident temperatures shall be listed where applicable.
X	X	. . .	(30)	Show maximum coincident metal temperature (in °F or °C) permitted for vessel at the design pressure.
X	X	. . .	(31)	Show minimum Charpy V-notch impact value required (in ft-lb or J) and impact test temperature (in °F or °C) (see AM-204, AM-211, AM-213, and AM-310). If exempted, indicate under "Remarks" paragraph under which exemption was taken.
X	X	. . .	(32)	Show minimum design metal temperature (see AD-155) in °F or °C.
X	X	. . .	(33)	Show hydrostatic or other tests made with specified test pressure at top of vessel in the test position. Cross out words (pneumatic, hydrostatic, or combination test pressure) that do not apply. Indicate under "Remarks" if vessel was tested in the vertical position. See AT-310.4 for special requirements for combination units.
X	X	. . .	(34)	Indicate nozzle or other opening which is designated for pressure relief (see Article R-6).
X	X	. . .	(35)	Show other nozzles and openings by size and type. See (50).
X	X	. . .	(36)	Show opening designated for inspection. Show location.
X	X	. . .	(37)	Indicate provisions for support of the vessel and any attachments for superimposed equipment.
X	X	. . .	(38)	Indicate whether fatigue analysis is required per AG-301 (also see AD-160).
X	X	. . .	(39)	Describe contents or service of the vessel.
X	X	. . .	(40)	Space for additional comments, including any Code restrictions on the vessel or any unusual Code requirements that have been met, such as those noted in (21), (22), (24), (31), and (33), or in AG-100, AG-110, and 6-100. Indicate stiffening rings, if used.
X	X	. . .	(41)	Certificate of compliance block is to show the name of the Manufacturer as shown on his ASME Code Certificate of Authorization. This should be signed in accordance with organizational authority defined in the Quality Control System (see 18-112).
X	X	. . .	(42)	This certificate is to be completed by the Manufacturer to show the disposition of the User's Design Specification and the Manufacturer's Design Report, and to identify the registered Professional Engineers who certify them (see AG-301.2 and AG-302.3). See (49).
X	X	X	(43)	This certificate is to be completed by the Manufacturer and signed by the Authorized Inspector who performs the shop inspection.
X	X	X	(44)	This Inspector's National Board Commission Number must be shown when the vessel is stamped "National Board." Otherwise, show only his state or province Commission Number.

TABLE I-220
INSTRUCTIONS FOR THE PREPARATION OF MANUFACTURER'S DATA REPORTS (CONT'D)

Applies to Form			Note	
A-1	A-2	A-3	No.	Instruction
X	. . .	. . .	(45)	This certificate is for the Authorized Inspector to sign for any field construction or assembly work (see (44) for National Board Commission Number requirements). Indicate the method used to pressure test the vessel.
. . .	. . .	X	(46)	Fill in information identical to that shown on the Data Report to which this sheet is supplementary.
. . .	. . .	X	(47)	Fill in information for which there was insufficient space for a specific item on the Data Report Form as identified by the notation "See attached Form A-3" on the Data Report. Identify the information by the applicable Data Report Item Number.
. . .	X	. . .	(48)	Indicate data, if known.
X	X	. . .	(49)	State of the U.S.A.; or province of Canada, if applicable.
X	X	. . .	(50)	Data entries with descriptions acceptable to Inspector. Abbreviations, coded identification, or reference to Code Figure and sketch number may be used to define any generic name. For ASME B16.5 flanges, the class should be identified. Flange facing and attachment to neck is not required. Some typical abbreviations: Flanged fabricated nozzle — Cl. 300 flg or PN 50 flg Long weld neck flange — Cl. 300 lwn or PN 50 lwn Weld end fabricated nozzle — w.e.
X	X	. . .	(51)	Material for nozzle neck. Flange material not necessary.
X	X	. . .	(52)	Nominal nozzle neck thickness. For ASME B16.11 and similar parts, class designation may be substituted for thickness.

TABLE I-221
SUPPLEMENTARY INSTRUCTIONS FOR THE PREPARATION OF MANUFACTURER'S DATA REPORTS FOR LAYERED VESSELS

Note Letter	Instruction
(A)	Letter symbols indicate instructions that supplement the instructions of Table I-220.
(B)	The Form, Fig. I-221, is not available preprinted as shown. It is intended as an example of suggested use of Form A-3 for reporting data for a vessel of layered construction. It is intended that the Manufacturer develop his own arrangement to provide supplementary data that describes his vessel.
(C)	Note the NDE performed (RT, PT, MT, UT).
(D)	Applies only when heads are of layered construction.
(E)	Indicates if seamless or welded.
(F)	When more than one layer thickness is used, add lines as needed.
(G)	Indicate diameter of vent holes in the layers.
(H)	Indicate whether vent holes are in random locations in each layer, or are drilled through all layers.
(I)	Indicate locations of nozzles and openings; layered shell; layered head.
(J)	Indicate method of attachment and reinforcement of nozzles and openings in layered shells and layered heads. Refer to figure number if applicable.

FORM A-4 MANUFACTURER'S OR ASSEMBLER'S CERTIFICATE OF CONFORMANCE FOR PRESSURE RELIEF VALVES

As Required by the Provisions of the ASME Code Rules, Section VIII, Division 2

1. Manufactured (or assembled) by ______ (1) ______

2. Table of Code symbol stamped items:

I.D. #	Date	Cert. #	Qty.	Type	Size (NPS)	Set Pressure	Capacity	Test Fluid	Date Code	CI Name	CI Signature
(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)

3. Remarks ______ (14) ______

______

______

______

______

______

______

CERTIFICATE OF SHOP COMPLIANCE

By the signature of the Certified Individual (CI) noted above, we certify that the statements made in this report are correct and that all details for design, material, construction, and workmanship of the pressure relief valves conform with the requirements of Section VIII, Division 2 of the ASME Boiler and Pressure Vessel Code.

UV Certificate of Authorization No. ______ (15) ______ Expires ______ (16) ______

Date ______ (17) ______ Signed ______ (18) ______ Name ______ (18) ______

(responsible representative) (Manufacturer or Assembler)

TABLE I-222
SUPPLEMENTARY INSTRUCTIONS FOR THE PREPARATION OF MANUFACTURER'S OR ASSEMBLER'S CERTIFICATE OF CONFORMANCE FORM A-4

Note No.	Instruction
(1)	Name and address of Manufacturer or Assembler.
(2)	Pressure relief device Manufacturer's or Assembler's unique number, such as serial number, work order number, or lot number.
(3)	The date of completion of production of the pressure relief device.
(4)	The NB Certification Number.
(5)	The quantity of identical valves for this line item.
(6)	The Manufacturer's Design or Type Number as marked on the nameplate.
(7)	The inlet size of the pressure relief valve (NPS).
(8)	The nameplate set pressure of the pressure relief valve.
(9)	The nameplate capacity of the pressure relief valve.
(10)	The fluid used for testing the pressure relief valve.
(11)	The year built or the pressure relief valve Manufacturer's date code.
(12)	The name of the Certified Individual.
(13)	The signature of the Certified Individual. Required for each line item.
(14)	Include any applicable remarks (referencing the identification number) that may pertain, such as identification of a Code Case that requires marking on the device.
(15)	The number of the pressure relief valve Manufacturer's Certificate of Authorization.
(16)	Expiration date of the pressure relief valve Manufacturer's Certificate of Authorization.
(17)	Date signed by the pressure relief valve Manufacturer or Assembler's authorized representative.
(18)	The Certificate of Compliance block is to show the name of the Manufacturer or Assembler as shown on his/her ASME Code Certificate of Authorization. This shall be signed in accordance with organizational authority defined in the Quality Control System (see 18-112).

NONMANDATORY APPENDIX J
BASIS FOR ESTABLISHING EXTERNAL PRESSURE CHARTS

See Appendix 3 of Section II, Part D.

NONMANDATORY APPENDIX K
SELECTION AND TREATMENT OF HIGH ALLOY STEELS

04 K-100 885°F EMBRITTLEMENT

See Appendix A, A-360, of Section II, Part D.

NONMANDATORY APPENDIX L
GUIDE TO INFORMATION APPEARING ON CERTIFICATE OF AUTHORIZATION (SEE FIG. L-1)

ITEM	DESCRIPTION
①	a. The name of the Manufacturer or Assembler; this description could include "doing business as" (DBA) or an abbreviation of the name. b. The full street address, city, state or province, country, and zip code.
②	This entry describes the scope and limitations, if any, on use of the Code symbol stamps, as illustrated below. **U2 Code Symbol Stamp** 1. Manufacture of pressure vessels at the above location only. 2. Manufacture of pressure vessels at the above location only. (This authorization does not cover welding or brazing.) 3. Manufacture of pressure vessels at the above location and field sites controlled by that location. 4. Manufacture of pressure vessels at the above location and field sites controlled by that location. (This authorization does not cover welding or brazing.) 5. Manufacture of pressure vessels at field sites controlled by the above location. 6. Manufacture of pressure vessels at field sites controlled by the above location. (This authorization does not cover welding or brazing.) **UV Code Symbol Stamp** 1. Manufacture of pressure vessel pressure relief valves at the above location only. 2. Manufacture of pressure vessel pressure relief valves at the above location only. (This authorization does not cover welding or brazing.) 3. Assembly of pressure vessel pressure relief valves at the above location. (This authorization does not cover welding or brazing.)
③	The date authorization was granted by the Society to use the indicated Code symbol stamp.
④	The date authorization to use the Code symbol stamp will expire.
⑤	A unique certificate number assigned by the Society.
⑥	Code symbol granted by the Society, i.e., U2 pressure vessels, UV pressure relief valves.
⑦, ⑧	The signatures of the current chair and director.

The American Society of Mechanical Engineers

CERTIFICATE OF AUTHORIZATION

This certificate accredits the named company as authorized to use the indicated symbol of the American Society of Mechanical Engineers (ASME) for the scope of activity shown below in accordance with the applicable rules of the ASME Boiler and Pressure Vessel Code. The use of the code symbol and the authority granted by this Certificate of Authorization are subject to the provisions of the agreement set forth in the application. Any construction stamped with this symbol shall have been built strictly in accordance with the provisions of the ASME Boiler and Pressure Vessel Code.

COMPANY ①

SCOPE ②

AUTHORIZED ③

EXPIRES ④

CERTIFICATE NUMBER ⑤

SYMBOL ⑥

⑦

CHAIRMAN OF THE BOILER
AND PRESSURE VESSEL COMMITTEE

⑧

DIRECTOR, ASME ACCREDITATION

FIG. L-1 SAMPLE CERTIFICATE OF AUTHORIZATION

NONMANDATORY APPENDIX M
FLANGE RIGIDITY

M-100 INTRODUCTION

Flanges which have been designed based on allowable stress limits alone may not be sufficiently rigid to control leakage. This Appendix provides a method of checking flange flexibility.

The flexibility factors covered in M-300 have been proven through extensive user experience for a wide variety of joint designs and service conditions; however, their use alone does not guarantee a leakage rate within established limits, and accordingly their use must be considered as only part of the system of joint design and assembly requirements to ensure leak tightness.

M-200 NOMENCLATURE USED IN FORMULAS

E = modulus of elasticity for the material of the flange at the design temperature (operating condition) or atmospheric temperature (gasket seating), as may apply

J = rigidity index $\leq$ 1.0. If the value of J, when calculated by the appropriate formula in M-400, is greater than 1.0, the thickness of the flange t should be increased and J recalculated until it is within the above limit.

K_I = rigidity factor for integral-type flanges (see M-300)

K_L = rigidity factor for loose-type flanges (see M-300)

All other nomenclature used in this Appendix is defined in 3-301.1.

M-300 RIGIDITY FACTORS

Experience has indicated that a K_L value of 0.2 for loose-type flanges and K_I of 0.3 for integral flange types are sufficient for most services. Other values may be used with the User's agreement.

M-400 FORMULAS

Integral-type flanges:

$$J = \frac{52.14 M_O V}{L E g_o^2 h_o K_I} \quad (1)$$

Loose-type flanges with hubs:

$$J = \frac{52.14 M_O V_L}{L E g_o^2 h_o K_L} \quad (2)$$

Loose-type flanges without hubs:

$$J = \frac{109.4 M_O}{E t^3 \ln(K) K_L} \quad (3)$$

NONMANDATORY APPENDIX N GUIDANCE FOR THE USE OF U.S. CUSTOMARY AND SI UNITS IN THE ASME BOILER AND PRESSURE VESSEL CODE

04

N-100 USE OF UNITS IN EQUATIONS

The equations in this Nonmandatory Appendix are suitable for use only with either the U.S. Customary or the SI units provided in Mandatory Appendix 27, or with the units provided in the nomenclature associated with that equation. It is the responsibility of the individual and organization performing the calculations to ensure that appropriate units are used. Either U.S. Customary or SI units may be used as a consistent set. When SI units are selected, U.S. Customary values in referenced specifications may be converted to SI values to at least three significant figures for use in calculations and other aspects of construction.

N-200 GUIDELINES USED TO DEVELOP SI EQUIVALENTS

The following guidelines were used to develop SI equivalents:

(a) SI units are placed in parentheses after the U.S. Customary units in the text.

(b) In general, separate SI tables are provided if interpolation is expected. The table designation (e.g., table number) is the same for both the U.S. Customary and SI tables, with the addition of suffix "M" to the designator for the SI table, if a separate table is provided. In the text, references to a table use only the primary table number (i.e., without the "M"). For some small tables, where interpolation is not required, SI units are placed in parentheses after the U.S. Customary unit.

(c) Separate SI versions of graphical information (charts) are provided, except that if both axes are dimensionless, a single figure (chart) is used.

(d) In most cases, conversions of units in the text were done using hard SI conversion practices, with some soft conversions on a case-by-case basis, as appropriate. This was implemented by rounding the SI values to the number of significant figures of implied precision in the existing U.S. Customary units. For example, 3,000 psi has an implied precision of one significant figure. Therefore, the conversion to SI units would typically be to 20 000 kPa. This is a difference of about 3% from the "exact" or soft conversion of 20 684.27 kPa. However, the precision of the conversion was determined by the Committee on a case-by-case basis. More significant digits were included in the SI equivalent if there was any question. The values of allowable stress in Section II, Part D generally include three significant figures.

(e) Minimum thickness and radius values that are expressed in fractions of an inch were generally converted according to the following table:

Fraction, in.	Proposed SI Conversion, mm	Difference, %
1/32	0.8	−0.8
3/64	1.2	−0.8
1/16	1.5	5.5
3/32	2.5	−5.0
1/8	3	5.5
5/32	4	−0.8
3/16	5	−5.0
7/32	5.5	1.0
1/4	6	5.5
5/16	8	−0.8
3/8	10	−5.0
7/16	11	1.0
1/2	13	−2.4
9/16	14	2.0
5/8	16	−0.8
11/16	17	2.6
3/4	19	0.3
7/8	22	1.0
1	25	1.6

(f) For nominal sizes that are in even increments of inches, even multiples of 25 mm were generally used. Intermediate values were interpolated rather than converting and rounding to the nearest mm. See examples in the following table. [Note that this table does not apply

to nominal pipe sizes (NPS), which are covered below.]

Size, in.	Size, mm
1	25
1⅛	29
1¼	32
1½	38
2	50
2¼	57
2½	64
3	75
3½	89
4	100
4½	114
5	125
6	150
8	200
12	300
18	450
20	500
24	600
36	900
40	1 000
54	1 350
60	1 500
72	1 800

Size or Length, ft	Size or Length, m
3	1
5	1.5
200	60

(g) For nominal pipe sizes, the following relationships were used:

U.S. Customary Practice	SI Practice	U.S. Customary Practice	SI Practice
NPS ⅛	DN 6	NPS 20	DN 500
NPS ¼	DN 8	NPS 22	DN 550
NPS ⅜	DN 10	NPS 24	DN 600
NPS ½	DN 15	NPS 26	DN 650
NPS ¾	DN 20	NPS 28	DN 700
NPS 1	DN 25	NPS 30	DN 750
NPS 1¼	DN 32	NPS 32	DN 800
NPS 1½	DN 40	NPS 34	DN 850
NPS 2	DN 50	NPS 36	DN 900
NPS 2½	DN 65	NPS 38	DN 950
NPS 3	DN 80	NPS 40	DN 1000
NPS 3½	DN 90	NPS 42	DN 1050
NPS 4	DN 100	NPS 44	DN 1100
NPS 5	DN 125	NPS 46	DN 1150
NPS 6	DN 150	NPS 48	DN 1200
NPS 8	DN 200	NPS 50	DN 1250
NPS 10	DN 250	NPS 52	DN 1300
NPS 12	DN 300	NPS 54	DN 1350
NPS 14	DN 350	NPS 56	DN 1400
NPS 16	DN 400	NPS 58	DN 1450
NPS 18	DN 450	NPS 60	DN 1500

(h) Areas in square inches (in.^{2}) were converted to square mm (mm^2) and areas in square feet (ft^2) were converted to square meters (m^2). See examples in the following table:

Area (U.S. Customary)	Area (SI)
1 in.^{2}	650 mm^2
6 in.^{2}	4 000 mm^2
10 in.^{2}	6 500 mm^2
5 ft^2	0.5 m^2

(i) Volumes in cubic inches (in.^{3}) were converted to cubic mm (mm^3) and volumes in cubic feet (ft^3) were converted to cubic meters (m^3). See examples in the following table:

Volume (U.S. Customary)	Volume (SI)
1 in.^{3}	16 000 mm^3
6 in.^{3}	100 000 mm^3
10 in.^{3}	160 000 mm^3
5 ft^3	0.14 m^3

(j) Although the pressure should always be in MPa for calculations, there are cases where other units are used in the text. For example, kPa is used for small pressures. Also, rounding was to one significant figure (two at the most) in most cases. See examples in the following table. (Note that 14.7 psi converts to 101 kPa, while 15 psi converts to 100 kPa. While this may seem at first glance to be an anomaly, it is consistent with the rounding philosophy.)

Pressure (U.S. Customary)	Pressure (SI)
0.5 psi	3 kPa
2 psi	15 kPa
3 psi	20 kPa
10 psi	70 kPa
14.7 psi	101 kPa
15 psi	100 kPa
30 psi	200 kPa
50 psi	350 kPa
100 psi	700 kPa
150 psi	1 MPa
200 psi	1.5 MPa
250 psi	1.7 MPa
300 psi	2 MPa
350 psi	2.5 MPa
400 psi	3 MPa
500 psi	3.5 MPa
600 psi	4 MPa
1,200 psi	8 MPa
1,500 psi	10 MPa

(k) Material properties that are expressed in psi or ksi (e.g., allowable stress, yield and tensile strength, elastic modulus) were generally converted to MPa to three significant figures. See example in the following table:

Strength (U.S. Customary)	Strength (SI)
95,000 psi	655 MPa

(l) In most cases, temperatures (e.g., for PWHT) were

rounded to the nearest 5°C. Depending on the implied precision of the temperature, some were rounded to the nearest 1°C or 10°C or even 25°C. Temperatures colder than 0°F (negative values) were generally rounded to the nearest 1°C. The examples in the table below were created by rounding to the nearest 5°C, with one exception:

Temperature, °F	Temperature, °C
70	20
100	38
120	50
150	65
200	95
250	120
300	150
350	175
400	205
450	230
500	260
550	290
600	315
650	345
700	370
750	400
800	425
850	455
900	480
925	495
950	510
1,000	540
1,050	565
1,100	595
1,150	620
1,200	650
1,250	675
1,800	980
1,900	1 040
2,000	1 095
2,050	1 120

N-300 CHECKING EQUATIONS

When a single equation is provided, it has been checked using dimensional analysis to verify that the results obtained by using either the U.S. Customary or SI units provided are equivalent. When constants used in these equations are not dimensionless, different constants are provided for each system of units. Otherwise, a U.S. Customary and an SI version of the equation are provided. However, in all cases, the Code user should check the equation for dimensional consistency.

N-400 EXAMPLES OF DIMENSIONAL ANALYSIS

(a) This example illustrates the concept of dimensional analysis.

(1) Equation and Nomenclature

$$S = \frac{Pr}{t}$$

where

S = stress, psi (MPa)
P = pressure, psi (MPa)
r = radius, inches (mm)
t = thickness, inches (mm)

(2) Dimensional Analysis

$$S\left[\frac{\text{pounds}}{(\text{inches})(\text{inches})}\right] = \frac{P\left[\frac{\text{pounds}}{(\text{inches})(\text{inches})}\right] r(\text{inches})}{t(\text{inches})}$$

(b) Note that in the above equation, it is necessary that the dimensions of the radius, r, and the thickness, t, be the same, since they must cancel out. The dimensions of the pressure, P, and the stress, S, must also be the same. For this particular equation, r and t could be in U.S. Customary units and P and S in SI units, and the result would still be acceptable. Further, any consistent units could be used for the radius and the thickness (e.g., feet, miles, meters, light years) and the result would be the same. Similarly, the units of pressure and stress can be any legitimate pressure or stress unit (e.g., psi, ksi, kPa, MPa), as long as they are the same.

(c) When the equation is converted to SI units,

$$S(\text{MPa}) = \frac{P(\text{MPa})\,r(\text{mm})}{t(\text{mm})}$$

(d) However, more complex equations present special challenges, e.g., if it is necessary to add the stress from an axial load acting on a cylinder to the stress that results from pressure.

(1) Equation and Nomenclature

$$S_t = \frac{Pr}{2t} + \frac{L}{2\pi rt}$$

where

S_t = total stress, psi (MPa)
P = pressure, psi (MPa)
L = load, pounds (N)
r = radius, inches (mm)
t = thickness, inches (mm)

(2) Dimensional Analysis

$$S_t\left[\frac{\text{pounds}}{(\text{inches})(\text{inches})}\right] = \frac{P\left[\frac{\text{pounds}}{(\text{inches})(\text{inches})}\right] r(\text{inches})}{2t(\text{inches})} + \frac{L(\text{pounds})}{2\pi r(\text{inches})\,t(\text{inches})}$$

(e) Note that in the above equation, it is necessary that the pressure, load, and length dimensions be consistent, because quantities cannot be added unless they have the same units. Although the first part of the equation is similar to the first example, where the length and pressure units could be in different systems, the second example requires that if the pressure and stress units are in pounds per square inch, the load must be in pounds and the radius and thickness must be in inches. Note that the load could be in kips and the pressure in ksi. This is why we should permit any consistent system of units to be used. However, the equations should be checked only for the "standard" units.

(f) When the equation is converted to SI units,

$$S_t(\text{MPa}) = \frac{P(\text{MPa})r(\text{mm})}{2t(\text{mm})} + \frac{L(\text{N})}{2\pi r(\text{mm})t(\text{mm})}$$

Note that 1 MPa = 1 N/mm^2, so

$$S_t\left[\frac{\text{N}}{(\text{mm})(\text{mm})}\right] = \frac{P\left[\frac{\text{N}}{(\text{mm})(\text{mm})}\right]r(\text{mm})}{2t(\text{mm})} + \frac{L(\text{N})}{2\pi r(\text{mm})t(\text{mm})}$$

which reduces to

$$S_t\left[\frac{\text{N}}{(\text{mm})(\text{mm})}\right] = \frac{P(\text{N})r(\text{mm})}{(\text{mm})(\text{mm})2t(\text{mm})} + \frac{L(\text{N})}{2\pi r(\text{mm})t(\text{mm})}$$

(g) Therefore, the units in the above equation are consistent. However, this is not always the case. For example, the bolted joint design rules define an effective gasket seating width as a function of the actual width using an equation of the form below.

(1) Equation and Nomenclature

$$b_e = \sqrt{b_a}$$

where

b_e = effective gasket seating width
b_a = actual gasket seating width

(2) Dimensional Analysis

$$b_e(\text{inches}) = \sqrt{b_a(\text{inches})}$$

(h) Obviously, the equation above is not dimensionally consistent; therefore, a constant is needed if it is to be used with SI units. The constant can be calculated by converting the SI unit (mm) to the U.S. Customary unit (in.) for the calculation, then converting back to get the result in mm as follows:

$$b_e(\text{mm}) = 25.4(\text{mm/inch})\sqrt{\frac{b_a(\text{mm})}{25.4(\text{mm/inch})}}$$

which can be reduced to

$$b_e(\text{mm}) = 5.04\sqrt{b_a(\text{mm})}$$

N-500 SOFT CONVERSION FACTORS

The following table of "soft" conversion factors is provided for convenience. Multiply the U.S. Customary value by the factor given to obtain the SI value. Similarly, divide the SI value by the factor given to obtain the U.S. Customary value. In most cases it is appropriate to round the answer to three significant figures.

U.S. Customary	SI	Factor	Notes
in.	mm	25.4	. . .
ft	m	0.3048	. . .
in.^{2}	mm^2	645.16	. . .
ft^2	m^2	0.09290304	. . .
in.^{3}	mm^3	16,387.064	. . .
ft^3	m^3	0.02831685	. . .
U.S. gal	m^3	0.003785412	. . .
U.S. gal	liters	3.785412	. . .
psi	MPa	0.0068948	Used exclusively in equations
psi	kPa	6.894757	Used only in text and for nameplate
ft-lb	J	1.355818	. . .
°F	°C	$\frac{5}{9}$ × (°F − 32)	Not for temperature difference
°F	°C	$\frac{5}{9}$ × °F	For temperature differences only
R	K	$\frac{5}{9}$	Absolute temperature
lbm	kg	0.4535924	. . .
lbf	N	4.448222	. . .
in.-lb	N·mm	112.98484	Use exclusively in equations
ft-lb	N·m	1.3558181	Use only in text
ksi$\sqrt{\text{in.}}$	MPa$\sqrt{\text{m}}$	1.0988434	. . .
Btu/hr	W	0.2928104	Use for boiler rating and heat transfer
lb/ft^3	kg/m^3	16.018463	. . .

N-600 SPECIAL REQUIREMENTS FOR POSTWELD HEAT TREAT TIMES

In general, PWHT times in hours per inch of thickness were converted to minutes per millimeter of thickness as follows:

(a) 1 hr/in. = 2 min/mm. Although this results in heat treatment for only 51 min for a 25.4 mm thick section, this is considered to be within the range of intended precision of the U.S. Customary requirement.

(b) 15 min/in. = 0.5 min/mm. Although converting and rounding would give 0.6 min/mm, it was necessary to use 0.5 to be consistent with the rounding for 1 hr/in.

N-700 NOTES ON CONVERSIONS IN SECTION II, PARTS A, B, AND C

The conversions provided by ASTM and AWS were used for consistency with those documents.

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