ASME BPVC.XII-2025

SECTION XII

2025

ASME Boiler and Pressure Vessel Code

An International Code

Rules for Construction and Continued Service of Transport Tanks

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AN INTERNATIONAL CODE

2025 ASME Boiler & Pressure Vessel Code

2025 Edition July 1, 2025

XII

RULES FOR CONSTRUCTION AND CONTINUED SERVICE OF TRANSPORT TANKS

ASME Boiler and Pressure Vessel Committee
on Transport Tanks

The American Society of Mechanical Engineers
Two Park Avenue • New York, NY • 10016 USA

Date of Issuance: July 1, 2025

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FOREWORD*

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In 1911, The American Society of Mechanical Engineers established the Boiler and Pressure Vessel Committee to formulate standard rules for the construction of steam boilers and other pressure vessels. In 2009, the Boiler and Pressure Vessel Committee was superseded by the following committees:

(a) Committee on Power Boilers (I)
(b) Committee on Materials (II)
(c) Committee on Construction of Nuclear Facility Components (III)
(d) Committee on Heating Boilers (IV)
(e) Committee on Nondestructive Examination (V)
(f) Committee on Pressure Vessels (VIII)
(g) Committee on Welding, Brazing, and Fusing (IX)
(h) Committee on Fiber-Reinforced Plastic Pressure Vessels (X)
(i) Committee on Nuclear Inservice Inspection (XI)
(j) Committee on Transport Tanks (XII)
(k) Committee on Overpressure Protection (XIII)
(l) Technical Oversight Management Committee (TOMC)

Where reference is made to "the Committee" in this Foreword, each of these committees is included individually and collectively.

The Committee's function is to establish rules of safety relating to pressure integrity. The rules govern the construction** of boilers, pressure vessels, transport tanks, and nuclear components, and the inservice inspection of nuclear components and transport tanks. For nuclear items other than pressure-retaining components, the Committee also establishes rules of safety related to structural integrity. The Committee also interprets these rules when questions arise regarding their intent. The technical consistency of the Sections of the Code and coordination of standards development activities of the Committees is supported and guided by the Technical Oversight Management Committee. The Code does not address other safety issues relating to the construction of boilers, pressure vessels, transport tanks, or nuclear components, or the inservice inspection of nuclear components or transport tanks. Users of the Code should refer to the pertinent codes, standards, laws, regulations, or other relevant documents for safety issues other than those relating to pressure integrity and, for nuclear items other than pressure-retaining components, structural integrity. Except for Sections XI and XII, and with a few other 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. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of components addressed by the Code. The objective of the rules is to afford reasonably certain protection of life and property, and to provide a margin for deterioration in service to give a reasonably long, safe period of usefulness. Advancements in design and materials and evidence of experience have been recognized.

The Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction activities and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects that 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 engineers 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.

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

* The information contained in this Foreword is not part of this American National Standard (ANS) and has not been processed in accordance with ANSI's requirements for an ANS. Therefore, this Foreword may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary for conformance to the Code.

** *Construction*, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and overpressure protection.

responsible for all technical assumptions inherent in the programs they use and the application of these programs to their design.

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 Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code cases, and requests for interpretations. Only the Committee has the authority to provide official interpretations of the Code. Requests for revisions, new rules, Code cases, or interpretations shall be addressed to the staff secretary in writing and shall give full particulars in order to receive consideration and action (see the Correspondence With the Committee page). Proposed revisions to the Code resulting from inquiries will be presented to the Committee for appropriate action. The action of the Committee becomes effective only after confirmation by 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 (ANSI) and published at http://go.asme.org/BPVCPublicReview to invite comments from all interested persons. After public review and final approval by ASME, revisions are published at regular intervals in Editions of the Code.

The 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 Committee. ASME is to be notified should questions arise concerning improper use of the ASME Single Certification Mark.

When required by context in the Code, the singular shall be interpreted as the plural, and vice versa.

The words "shall," "should," and "may" are used in the Code as follows:

– *Shall* is used to denote a requirement.
– *Should* is used to denote a recommendation.
– *May* is used to denote permission, neither a requirement nor a recommendation.

STATEMENT OF POLICY ON THE USE OF THE ASME SINGLE CERTIFICATION MARK 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 the ASME Single Certification Mark 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 ASME Single Certification Mark for the benefit of the users, the enforcement jurisdictions, and the holders of the ASME Single Certification Mark who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the ASME Single Certification Mark, 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 the ASME Single Certification Mark 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." An ASME corporate logo shall not be used by any organization other than ASME.

The ASME Single Certification Mark 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 the ASME Single Certification Mark who may also use the facsimile in advertising to show that clearly specified items will carry the ASME Single Certification Mark.

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 ASME Single Certification Mark described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the ASME Single Certification Mark 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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ASME codes and standards are developed and maintained by committees with the intent to represent the consensus of concerned interests. Users of ASME codes and standards may correspond with the committees to propose revisions or cases, report errata, or request interpretations. Correspondence for this Section of the ASME Boiler and Pressure Vessel Code (BPVC) should be sent to the staff secretary noted on the Section's committee web page, accessible at https://go.asme.org/CSCommittees.

NOTE: See ASME BPVC Section II, Part D for guidelines on requesting approval of new materials. See Section II, Part C for guidelines on requesting approval of new welding and brazing materials ("consumables").

Revisions and Errata

The committee processes revisions to this Code on a continuous basis to incorporate changes that appear necessary or desirable as demonstrated by the experience gained from the application of the Code. Approved revisions will be published in the next edition of the Code.

In addition, the committee may post errata and Special Notices at http://go.asme.org/BPVCerrata. Errata and Special Notices become effective on the date posted. Users can register on the committee web page to receive email notifications of posted errata and Special Notices.

This Code is always open for comment, and the committee welcomes proposals for revisions. Such proposals should be as specific as possible, citing the paragraph number, the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent background information and supporting documentation.

Cases

(a) The most common applications for cases are

(1) to permit early implementation of a revision based on an urgent need

(2) to provide alternative requirements

(3) to allow users to gain experience with alternative or potential additional requirements prior to incorporation directly into the Code

(4) to permit use of a new material or process

(b) Users are cautioned that not all jurisdictions or owners automatically accept cases. Cases 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, constructors, or owners to choose any method of design or any form of construction that conforms to the Code.

(c) The committee will consider proposed cases concerning the following topics only:

(1) equipment to be marked with the ASME Single Certification Mark, or

(2) equipment to be constructed as a repair/replacement activity under the requirements of Section XI

(d) A proposed case shall be written as a question and reply in the same format as existing cases. The proposal shall also include the following information:

(1) a statement of need and background information

(2) the urgency of the case (e.g., the case concerns a project that is underway or imminent)

(3) the Code Section and the paragraph, figure, or table number to which the proposed case applies

(4) the editions of the Code to which the proposed case applies

(e) A case is effective for use when the public review process has been completed and it is approved by the cognizant supervisory board. Cases that have been approved will appear in the next edition or supplement of the Code Cases books, "Boilers and Pressure Vessels" or "Nuclear Components." Each Code Cases book is updated with seven Supplements.

Supplements will be sent or made available automatically to the purchasers of the Code Cases books until the next edition of the Code. Annulments of Code Cases become effective six months after the first announcement of the annulment in a Code Case Supplement or Edition of the appropriate Code Case book. The status of any case is available at http://go.asme.org/BPVCCDatabase. An index of the complete list of Boiler and Pressure Vessel Code Cases and Nuclear Code Cases is available at http://go.asme.org/BPVCC.

Interpretations

(a) Interpretations clarify existing Code requirements and are written as a question and reply. Interpretations do not introduce new requirements. If a revision to resolve conflicting or incorrect wording is required to support the interpretation, the committee will issue an intent interpretation in parallel with a revision to the Code.

(b) Upon request, the committee will render an interpretation of any requirement of the Code. An interpretation can be rendered only in response to a request submitted through the online Inquiry Submittal Form at http://go.asme.org/InterpretationRequest. Upon submitting the form, the inquirer will receive an automatic email confirming receipt.

(c) ASME does not act as a consultant for specific engineering problems or for the general application or understanding of the Code requirements. If, based on the information submitted, it is the opinion of the committee that the inquirer should seek assistance, the request will be returned with the recommendation that such assistance be obtained. Inquirers may track the status of their requests at http://go.asme.org/Interpretations.

(d) ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME committee or subcommittee. ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

(e) Interpretations are published in the ASME Interpretations Database at http://go.asme.org/Interpretations as they are issued.

Committee Meetings

The ASME BPVC committees regularly hold meetings that are open to the public. Persons wishing to attend any meeting should contact the secretary of the applicable committee. Information on future committee meetings can be found at http://go.asme.org/BCW.

SUMMARY OF CHANGES

Changes listed below are identified on the pages by a margin note, **(25)**, placed next to the affected area.

Page	***Location***	***Change***
xviii	List of Sections	Title of Section XI, Division 1 revised
xix	Foreword	Third, fourth, seventh, tenth, and eleventh paragraphs editorially revised
xxii	Personnel	Updated
3	TG-140	First and third paragraphs revised
7	TG-310	First sentence revised
8	TG-330	Revised
9	TG-420	Last sentence revised
16	TM-130.2	Subparagraph (b) revised
16	TM-140.1	Subparagraphs (a)(3)(-b), (e), and (f) revised
17	Table TM-130.2-1	Under “Bolting,” SA-194 deleted
20	Table TM-130.2-2	Revised
29	Table TM-130.2-5	Revised
32	Table TM-130.2-7	Revised
34	TM-140.2	First sentence revised
39	Figure TM-220.1	Revised
59	TD-130	Subparagraph (a) revised
63	TD-300.2	In subpara. (b), equation revised
64	TD-310.2	Revised in its entirety
68	Table TD-310.2-3	Added
65	TD-310.3	Revised in its entirety
68	Table TD-310.3-1	Added
70	TD-400.4	Revised
104	TW-130.4	First paragraph revised
105	Table TW-130.4	Type No. “(12)” corrected by errata to “(1)”
124	TF-110.2	In subpara. (a), last paragraph revised
128	TF-200	Subparagraph (f) revised
128	TF-210	Subparagraph (e) revised
128	TF-210.1	Subparagraphs (b) and (i)(2) revised
131	TF-220.7	Subparagraph (a) revised
143	TF-710	Subparagraph (f)(1) revised
155	TE-110.2	Subparagraph (a)(2) revised
157	TE-230.1	Subparagraph (b)(3)(-c) revised
166	TT-300	Subparagraph (e) revised
171	TOP-120	Subparagraph (a) revised
175	TS-100	Subparagraphs (c) and (g) revised
175	Figure TS-100	Revised
176	TS-100.1	Added and subsequent paragraphs redesignated
177	TS-110	Revised in its entirety
177	TS-130	Revised in its entirety
178	TS-200.7	Revised
180	TS-310	Subparagraph (c) revised
189	1-1.2	Definition of *dump body* added
192	1-1.4	Redesignated as 1-1.4.1 and 1-1.4.2 added
200	1-1.5	Subparagraph (c) added
217	1-4.4	First sentence added and subpara. (d) revised

Page	*Location*	*Change*
221	1-4.7	Revised in its entirety
226	3-1.5	First sentence revised
229	3-1.8	Revised in its entirety
236	I-1	Second paragraph revised
237	I-11	Second sentence revised
237	I-16	Subparagraph (d) revised
239	III-2	Definition of *Material Test Report* revised
249	V-2	Revised
251	VI-2	Revised
260	X-2	Subparagraphs (c)(1) and (c)(2) revised
269	XV-4	Subparagraph (c)(10) revised
283	XX-5	Subparagraph (d) revised
287	XX-6	Paragraph following eq. (6) revised
307	Table C-1	Instruction/description for (54) revised
310	Form T-1A	"Certificate of Shop Inspection" revised
311	Form T-1B	"Certificate of Shop Inspection" revised
312	Form T-1C	"Certificate of Shop Inspection" revised
313	Form T-2A	"Certificate of Shop Inspection" revised
314	Form T-2B	"Certificate of Shop Inspection" revised
315	Form T-2C	"Certificate of Shop Inspection" revised
321	E-2	Subparagraph (b) revised
323	E-4	Subparagraph (a) revised and subpara. (a)(3) added
326	E-6	Subparagraph (o) revised
328	E-9	Subparagraph (e) deleted
329	E-12	Added
337	H-5.3	Subparagraph (c) revised

CROSS-REFERENCING IN THE ASME BPVC

Paragraphs within the ASME BPVC may include subparagraph breakdowns, i.e., nested lists. The following is a guide to the designation and cross-referencing of subparagraph breakdowns:

(a) *Hierarchy of Subparagraph Breakdowns*

(1) First-level breakdowns are designated as (a), (b), (c), etc.

(2) Second-level breakdowns are designated as (1), (2), (3), etc.

(3) Third-level breakdowns are designated as (-a), (-b), (-c), etc.

(4) Fourth-level breakdowns are designated as (-1), (-2), (-3), etc.

(5) Fifth-level breakdowns are designated as (+a), (+b), (+c), etc.

(6) Sixth-level breakdowns are designated as (+1), (+2), etc.

(b) *Cross-References to Subparagraph Breakdowns.* Cross-references within an alphanumerically designated paragraph (e.g., PG-1, UIG-56.1, NCD-3223) do not include the alphanumerical designator of that paragraph. The cross-references to subparagraph breakdowns follow the hierarchy of the designators under which the breakdown appears. The following examples show the format:

(1) If X.1(c)(1)(-a) is referenced in X.1(c)(1), it will be referenced as (-a).

(2) If X.1(c)(1)(-a) is referenced in X.1(c)(2), it will be referenced as (1)(-a).

(3) If X.1(c)(1)(-a) is referenced in X.1(e)(1), it will be referenced as (c)(1)(-a).

(4) If X.1(c)(1)(-a) is referenced in X.2(c)(2), it will be referenced as X.1(c)(1)(-a).

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PART TG
GENERAL REQUIREMENTS

ARTICLE TG-1
SCOPE AND JURISDICTION

TG-100 INTRODUCTION

TG-100.1 INTENT

The rules of this Section constitute requirements for construction and continued service of pressure vessels for the transportation of dangerous goods via highway, rail, air, or water. *Construction* is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and over-pressure protection. *Continued service* is an all-inclusive term referring to inspection, testing, repair, alteration, and recertification of a transport tank that has been in service. The term *pressure vessel* refers to the pressure boundary defined by the geometric scope of this Section and includes, but is not limited to, the shell, heads, and openings. The term *tank* refers to the pressure vessel, appurtenances, and additional components that are covered by the Modal Appendices (see TG-210.1).

The general requirements given in Part TG shall be met for all vessels within the scope of this Section. In addition, all the applicable requirements of Modal Appendices, which address unique service conditions of the vessel, shall be met.

TG-100.2 APPLICABILITY

(a) The rules of this Section apply specifically to pressure vessels intended for transporting dangerous goods (see Mandatory Appendix III) with design pressures appropriate for the transportation mode and volumes greater than 450 L (120 gal).

(b) Pressures normally incident to transportation, including loading and unloading operations, are to be considered.

(c) This Section does not contain rules to cover all details of design and construction, and those aspects that are not addressed shall not be considered prohibited. Where complete details are not given, the Manufacturer, subject to the acceptance of the Inspector, shall provide details of design and construction that will be as safe as those provided by the rules of this Section. In the case of Class 3 vessels, the Design Certifying Engineer shall perform this function. (For definition of *Inspector*, see TG-410.)

TG-100.3 LAWS OR REGULATIONS

The laws or regulations issued by the competent authority covering the construction and continued service of pressure vessels intended for transporting dangerous goods shall be reviewed to determine if the requirements are more restrictive than the rules of this Section. Applicable laws and regulations may contain additional requirements for pressure vessels used in the transportation of dangerous goods, which are not addressed in this Section, such as Code of Federal Regulation, Title 49, Parts 100 through 185, Transportation.

TG-110 SCOPE

TG-110.1 GEOMETRIC SCOPE OF THE PRESSURE VESSEL

(a) The geometric scope of this Section shall, as a minimum, include the pressure-containing parts of pressure vessels up to and including the following:

(1) the first threaded joint for threaded connections.

(2) the face of the first flange for flanged connections.

(3) the first sealing surface for proprietary connections or fittings for which rules are not provided in this Section.

(4) the welding end connection for the first circumferential joint for welded connections to attached piping, valves, and instruments, etc.

(5) the welding pad for attachment of any external nonpressure attachments such as shipping frames and handling points. Parts welded to these pads need not comply with (b).

(6) pressure-retaining permanent covers and closures, including seals, bolting, and other mechanical retainers at openings.

(b) Where nonpressure parts are directly welded to the pressure-retaining surface of a pressure vessel, this scope shall include the material, design, fabrication, and testing requirements established for nonpressure attachments by the applicable paragraphs of this Section.

(c) Items in addition to the *pressure vessel* transform the vessel into a *tank*. These items are addressed in the applicable Modal Appendix.

TG-110.2 PHYSICAL SCOPE OF THE PRESSURE VESSEL

(a) Internal pressure shall be in the range from full vacuum to 138 bar (2,000 psig).

(b) The temperature range shall be from −269°C to 343°C (−452°F to 650°F).

(c) Thickness of shells and heads shall not exceed 38 mm ($1\frac{1}{2}$ in.).

TG-120 VESSEL CLASSIFICATIONS

TG-120.1 CLASSIFICATIONS OUTSIDE THE SCOPE OF THIS SECTION

The following classes of pressure-containing equipment are not within the scope of this Section:

(a) those items that are within the scope of other Sections of the Code

(b) pressure-containing equipment that is an integral part or component of a rotating or reciprocating mechanical device mounted in a common setting with the vessel, where the primary design considerations and/or design stresses are derived from the functional requirements of the device

(c) piping, valves, and other components beyond the geometric scope described in TG-110.1 for the loading, transport, and unloading of the vessel contents

(d) cylinders and multiple element gas containers and the attachment of same to trailers, commonly referred to as "tube trailers"

TG-120.2 STAMPING OF VESSELS WITHIN THE SCOPE OF THIS SECTION

(a) Any vessel that meets all applicable requirements of this Section may be stamped with the Certification Mark with T Designator.

(b) Vessels manufactured and stamped under this Section are not precluded from using parts stamped to Section VIII, Division 1, as long as all requirements of Section XII are met, except for marking and reporting. (See TM-110.10.)

TG-120.3 VESSEL CLASS

For the purposes of obtaining Certificates of Authorization, Inspections, and Stamping, vessels that meet all applicable requirements of this Section shall be designated as meeting one of three Classes. Vessel Class is defined in the applicable Modal Appendix. It is determined by the hazard class of the dangerous goods, pressure and mode of transport, as required by the competent authority (see, e.g., Code of Federal Regulations, Title 49, Part 173, Subpart F). Additional requirements are provided in TG-430.

TG-130 DOCUMENTS REFERENCED BY THIS SECTION

TG-130.1 NORMATIVE REFERENCES

The latest edition of the following documents shall be used, unless a specific edition is listed below. Items in compliance with one of the Product Standards listed in Table TG-130 are acceptable for use in construction, unless specifically prohibited elsewhere in this Section.

ANSI/NB-23. National Board Inspection Code. National Board of Boiler and Pressure Vessel Inspectors.

ASME Boiler and Pressure Vessel Code, Section VIII. Rules for Construction of Pressure Vessels — Division 1. The American Society of Mechanical Engineers.

ASME Boiler and Pressure Vessel Code, Section VIII. Rules for Construction of Pressure Vessels — Division 2, Alternative Rules (for fatigue analysis only). The American Society of Mechanical Engineers.

ASME CA-1. Conformity Assessment Requirements. The American Society of Mechanical Engineers.

ASME QAI-1. Qualifications for Authorized Inspection. The American Society of Mechanical Engineers.

ASNT ACCP 1997, Rev. 3. ASNT Central Certification Program (for Nondestructive Testing Personnel). American Society for Nondestructive Testing.

ASNT CP-189-2006. ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel. American Society for Nondestructive Testing.

ASNT Recommended Practice No. SNT-TC-1A–2006. Guidelines for Personnel Qualification and Certification in Nondestructive Testing. American Society for Nondestructive Testing.

Code of Federal Regulations, Title 49, Parts 100 through 185, Transportation. U.S. Government Publishing Office.

ISO 1496-3:1995. Series 1 freight containers — Specification and testing — Part 3: Tank containers for liquids, gases and pressurized dry bulk. International Organization for Standardization.

ISO 21010:2017. Cryogenic vessels — Gas/materials compatibility. International Organization for Standardization.

ISO 21013-3:2016. Cryogenic vessels — Pressure relief accessories for cryogenic service — Part 3: Sizing and capacity determination. International Organization for Standardization.

Table TG-130
Product Standards Referenced by This Section

Title	Number	Year
Unified Inch Screw Threads (UN and UNR Thread Form)	ASME B1.1	2018
Pipe Threads, General Purpose (Inch)	ASME B1.20.1	2018
Gray Iron Pipe Flanges and Flanged Fittings: Classes 25, 125, and 250	ASME B16.1	2015
Pipe Flanges and Flanged Fittings: NPS ½ Through NPS 24 Metric/Inch Standard	ASME B16.5	2017
Factory-Made Wrought Buttwelding Fittings	ASME B16.9	2018
Forged Fittings, Socket-Welding and Threaded	ASME B16.11	2016
Cast Copper Alloy Threaded Fittings: Classes 125 and 250	ASME B16.15	2018
Metallic Gaskets for Pipe Flanges: Ring-Joint, Spiral Wound, and Jacketed	ASME B16.20	2017
Cast Copper Alloy Pipe Flanges and Flanged Fittings and Valves: Classes 150, 300, 600, 900, 1500, and 2500	ASME B16.24	2016
Ductile Iron Pipe Flanges and Flanged Fittings: Classes 150 and 300	ASME B16.42	2016
Large Diameter Steel Flanges: NPS 26 Through NPS 60 Metric/Inch Standard	ASME B16.47	2017
Nuts for General Applications: Machine Screw Nuts, Hex, Square, Hex Flange, and Coupling Nuts	ASME B18.2.2	2015
Welded and Seamless Wrought Steel Pipe	ASME B36.10M	2018

ISO 21014:2019. Cryogenic vessels — Cryogenic insulation performance. International Organization for Standardization.

TG-130.2 INFORMATIVE REFERENCES

ADR 2003. European Agreement Concerning the International Carriage of Dangerous Goods by Road. United Nations Economic Commission for Europe.
API RP-579. Fitness for Service. American Petroleum Institute.
ASME B31.3–2018. Process Piping. The American Society of Mechanical Engineers.
ASME B31.12–2019. Hydrogen Piping and Pipelines. The American Society of Mechanical Engineers.
ASME PCC-2–2018. Repair of Pressure Equipment and Piping. The American Society of Mechanical Engineers.
ASTM E399. Standard Test Method for Plane-Strain Fracture Toughness of Metallic Materials. ASTM International.
ASTM E1820. Standard Test Method for Measurement of Fracture Toughness. ASTM International.
CGA G-4.1. Cleaning Equipment for Oxygen Service. Compressed Gas Association.
CGA S-1.2. Pressure Relief Device Standards, Part 2: Cargo and Portable Tanks for Compressed Gases. Compressed Gas Association.
IMDG Code 2018. International Maritime Dangerous Goods Code (including Amendment 31-02). International Maritime Organization.
RID 2003. Carriage of Dangerous Goods. Intergovernmental Organisation for International Carriage by Rail.
United Nations Recommendations on the Transport of Dangerous Goods — Model Regulations. United Nations Publications.
UL-969. Marking and Labeling Systems. Underwriters Laboratories, Inc.

TG-140 UNITS OF MEASUREMENT (25)

Either U.S. Customary, SI, or any local customary units may be used to demonstrate compliance with all requirements of this Section (e.g., materials, design, fabrication, examination, inspection, testing, certification, and overpressure protection).

In general, it is expected that a single system of units shall be used for all aspects of design except where unfeasible or impractical. When components are manufactured at different locations where local customary units are different than those used for the general design, the local units may be used for the design and documentation of that component. Similarly, for proprietary components or those uniquely associated with a system of units different than that used for the general design, the alternate units may be used for the design and documentation of that component.

For any single equation, all variables shall be expressed in a single system of units. Calculations using any material data published in Section XII or Section II, Part D shall be carried out in one system of standard units listed in Mandatory Appendix XII. When separate equations are provided for U.S. Customary and SI units, those equations must be executed using variables in the units associated with the specific equation. Data expressed in other units shall be converted to U.S. Customary or SI units for use in these equations. The result obtained from execution of these equations may be converted to other units.

Production, measurement and test equipment, drawings, welding procedure specifications, welding procedure and performance qualifications, and other fabrication documents may be in U.S. Customary, SI, or local customary units in accordance with the fabricator's practice. When values shown in calculations and analysis, fabrication documents or measurement and test equipment are in different units, any conversions necessary for verification of Code compliance, and to ensure that dimensional consistency is maintained, shall be in accordance with the following:

(a) Conversion factors shall be accurate to at least four significant figures.

(b) The results of conversions of units shall be expressed to a minimum of three significant figures.

Conversion of units, using the precision specified above shall be performed to ensure that dimensional consistency is maintained. Conversion factors between U.S. Customary and SI units may be found in the Nonmandatory Appendix G. Whenever local customary units are used, the Manufacturer shall provide the source of the conversion factors that shall be subject to verification and acceptance by the Authorized Inspector or Certified Individual.

Material that has been manufactured and certified to either the U.S. Customary or SI material specification (e.g., SA-516 or SA-516M) may be used regardless of the unit system used in design. Standard fittings (e.g., flanges, elbows, etc.) that have been certified to either U.S. Customary or SI units may be used regardless of the units system used in design.

All entries on a Manufacturer's Data Report and data for Code-required nameplate marking shall be in units consistent with the fabrication drawings for the component using U.S. Customary, SI, or local customary units. It is acceptable to show alternate units parenthetically. Users of this Code are cautioned that the competent authority at the receiving location should be contacted to ensure the units are acceptable.

It has been customary for transport tanks to express pressure in bars (1 bar = 14.5 psi). The bar is not a standard SI unit, but its use is encouraged where appropriate.

The User may specify a duplicate nameplate (per Article TS-1) and duplicate certified documents translated into the language and units of measurement appropriate for the modal service application.

TG-150 EQUATIONS

The equations in this Section may be used with any consistent set of units. When constants in the equations depend on units, the equations for both sets of units are provided. Either SI units or U.S. Customary units may be used for compliance with this Section, but one system shall be used consistently throughout for all phases of construction.

TG-160 TOLERANCES

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.

ARTICLE TG-2
ORGANIZATION OF SECTION XII

TG-200 PARTS

This Section is divided into ten parts.

(a) Part TG contains general requirements.

(b) Part TM contains the material requirements.

(c) Part TD contains the design requirements.

(d) Part TW contains the requirements for welded construction.

(e) Part TF contains the fabrication requirements.

(f) Part TE contains requirements for nondestructive examination.

(g) Part TT contains the testing requirements.

(h) Part TOP contains rules for overpressure protection.

(i) Part TS contains the stamping and certification requirements. It also provides requirements for Manufacturer's Data Reports and other records.

(j) Part TP contains the requirements for continued service, repair, and alterations.

TG-210 APPENDICES

TG-210.1 MODAL APPENDICES

The Modal Appendices contain rules for vessels used in specific transport modes and service applications. The Modal Appendices take precedence over the requirements of other parts of this Section.

TG-210.2 MANDATORY APPENDICES

The Mandatory Appendices contain specific rules that are not covered elsewhere in this Section. Their requirements are mandatory when applicable.

TG-210.3 NONMANDATORY APPENDICES

The Nonmandatory Appendices provide information and suggested good practices. The information provided is not mandatory; however, if a nonmandatory appendix is used, it shall be used in its entirety, to the extent applicable.

TG-220 ARTICLES AND PARAGRAPHS

TG-220.1 ARTICLES

The main divisions of the Parts of this Section are designated as Articles. These are given numbers and titles such as Article TG-1, Scope and Jurisdiction.

TG-220.2 PARAGRAPHS AND SUBPARAGRAPHS

The Articles are divided into paragraphs and subparagraphs, which are given three-digit numbers, the first of which corresponds to the Article number. Each such paragraph or subparagraph number is prefixed with letters that, with the first digit (hundreds), indicate the Part and Article of this Section in which it is found, such as TD-140, which is a subparagraph of TD-100 in Article TD-1 of Part TD.

(a) Major subdivisions of paragraphs, or subparagraphs, are indicated by the basic paragraph number, followed by a decimal point and one or two digits. Each of these subdivisions is titled.

(b) Minor subdivisions of paragraphs are designated (a), (b), etc.

(c) Where further subdivisions are needed, they are designated by numbers in parentheses [e.g., TG-230.2 (b)(1)].

TG-220.3 TABLES, CHARTS, AND FIGURES

Tables, charts, and figures providing relevant illustrations or supporting information for text passages have been designated with numbers corresponding to the paragraph they illustrate or support. Multiple tables, charts, and figures referenced by the same paragraph shall be designated with the paragraph number with a hyphen, and sufficient additional numbers reflecting the order of reference.

TG-230 REFERENCES

When a Part, Article, or paragraph is referenced in this Section, the reference shall be taken to include all subdivisions under that Part, Article, or paragraph (including all subparagraphs) and any tables, charts, or figures referenced by that paragraph.

TG-240 TERMS AND DEFINITIONS

Terms and definitions used in this Section are defined where they first appear or are of primary interest. Some of these terms and definitions are also included in Mandatory Appendix III.

ARTICLE TG-3
RESPONSIBILITIES AND DUTIES

TG-300 GENERAL

The Owner, Manufacturer, and Inspector involved in the construction of vessels and vessel parts to the rules of this Section and the Party responsible for continued service have definite responsibilities and duties in meeting the requirements of this Section. The responsibilities and duties set forth in the following paragraphs relate only to compliance with the rules of this Section, and are not to be construed as involving contractual relations or legal liabilities. Whenever *Owner* appears in this document, it may be considered to apply also to an Agent or User acting in the Owner's behalf. When the Owner is not identified before the vessel is manufactured, the responsibilities assigned to the Owner in TG-310 apply to the Manufacturer.

(25) TG-310 OWNER'S RESPONSIBILITY

It is the responsibility of the Owner or the Owner's designated agent to provide the Manufacturer with the necessary information regarding modal application and service conditions, including the hazardous material to be transported, design pressure and temperatures, design loads, corrosion allowance, and other pertinent information needed to determine the design and construction requirements of the vessel.

TG-310.1 USER'S RESPONSIBILITIES

In addition to the responsibilities agreed upon between the Owner and the User, the User is responsible for meeting the requirements for continued service; see Part TP.

TG-320 MANUFACTURER'S RESPONSIBILITY

The Manufacturer has the responsibility of ensuring that the quality control, the detailed examinations and tests required by this Section are performed. The Manufacturer shall perform duties as specified by the rules of this Section.

Some, but not all, of these duties that are defined elsewhere within the applicable rules of this Section are summarized as follows:

(a) Prepare a Quality Control System and obtain the Certificate of Authorization in accordance with CA-1 authorizing the construction and stamping of a specific class of vessel.

(b) Prepare or obtain the drawings and design calculations for the vessel or part.

(c) Provide for identification for all materials used in the fabrication of the vessel or part.

(d) Obtain any Partial Data Reports (see TS-310) and attach to the vessel data report.

(e) Provide access for the Inspector.

(f) Examine all materials before fabrication to make certain they meet the required thickness, to detect defects, to make certain the materials are permitted by this Section, and to ensure that the traceability to the material identification has been maintained.

(g) Document any impact tests and any tests in addition to those in the material specification.

(h) Obtain concurrence of the Inspector, prior to any repair.

(i) Examine the shell and head sections to confirm they have been properly formed to the specified shapes within the permissible tolerances.

(j) Qualify the welding procedures before they are used in fabrication.

(k) Qualify welders and welding operators.

(l) Examine all parts, prior to joining, to make sure they have been properly fitted for welding and that the surfaces to be joined have been cleaned and the alignment tolerances are maintained.

(m) Examine parts as fabrication progresses, for material marking, for detection of flaws, and to ensure that dimensional tolerances are maintained.

(n) Provide controls to ensure that all required heat treatments are performed.

(o) Record all nondestructive examinations performed on the vessel or vessel parts. This shall include retaining the radiographic film.

(p) Perform the required hydrostatic or pneumatic test and maintain a record of such test.

(q) Apply the required stamping and or nameplate to the vessel and make certain that it is applied to the proper vessel.

(r) Prepare the required Manufacturer's Data Report and have it certified by the Inspector.

(s) Provide for retention of Manufacturer's Data Reports.

TG-320.1 STRUCTURAL AND PRESSURE-RETAINING INTEGRITY

The Manufacturer is responsible for the structural and pressure-retaining integrity of the vessel or vessel part and for compliance with the requirements specified by the Owner and the rules of this Section.

TG-320.2 CODE COMPLIANCE

(a) The Manufacturer has the responsibility to comply with all the applicable requirements of this Section and, through proper certification, to ensure that any work performed by others also complies with all the requirements of this Section.

(b) The Manufacturer shall certify compliance with these requirements by the completion of the appropriate Manufacturer's Data Report, as prescribed in Article TS-3.

(25) TG-330 INSPECTOR'S DUTIES

It is the duty of the Inspector to verify that the inspections and tests specified by the rules of this Section are performed, ensuring that materials are in accordance with the requirements of the material specifications, that the construction is in accordance with the Manufacturer's design calculations and drawings, and that the requirements of this Section are met. This includes monitoring the Manufacturer's Quality Control System to ensure that the proper controls for materials, design, drawings, and fabrication are properly implemented. The Inspector shall certify the above to be true to the best of the Inspector's knowledge by signing the Manufacturer's Data Report. The Inspector does not have the duty of determining the completeness or correctness of the design calculations; however, the Inspector does have the duty of establishing that the Manufacturer of the completed vessel has prepared design calculations that address the requirements of this Section.

The Inspector shall make other inspections as in the Inspector's judgment are necessary to verify that all vessels to be stamped with the Certification Mark have been designed and constructed in accordance with the requirements of this Section. Some, but not all, of the required inspections and verifications that are defined elsewhere within the applicable rules of this Section are summarized as follows:

(a) verifying that the Manufacturer has a valid Certificate of Authorization and is working to a Quality Control System

(b) verifying that the applicable design calculations are available

(c) verifying that the materials used in the construction of the vessel comply with the requirements of this Section

(d) verifying that all welding procedures have been qualified

(e) verifying that all welders, welding operators have been qualified

(f) verifying that the heat treatments, including PWHT, have been performed

(g) verifying that material imperfections repaired by welding were repaired properly

(h) verifying that weld defects were acceptably repaired

(i) verifying that required nondestructive examinations, impact tests, and other tests have been performed and that results are acceptable

(j) making a visual inspection of the vessel to confirm that there are no surface defects or deviations from Code-required dimensions

(k) performing internal and external inspections and witnessing the hydrostatic or pneumatic tests

(l) verifying that the required marking is provided and that proper nameplate has been attached to the vessel

(m) signing the Certificate of Inspection on the Manufacturer's Data Report and Certificate of Conformance Form that serves as the acceptance document for the vessel when, to the best of the Inspector's knowledge and belief, the vessel is in compliance with all provisions of this Section

ARTICLE TG-4
GENERAL RULES FOR INSPECTION

TG-400 GENERAL REQUIREMENTS FOR INSPECTION AND EXAMINATION

The inspection and examination of vessels to be stamped with the Certification Mark shall conform to the general requirements for inspection and examination in this Article, and to the specific requirements for inspection and examination given in the applicable Parts and Modal Appendices of this Section.

TG-410 THE INSPECTOR

All references to Inspectors throughout this Section mean the Inspector or Certified Individual, as defined in this paragraph, responsible for verification of the inspection and testing of pressure vessels or parts thereof. All Inspections required by this Section shall be performed by the type of Inspector identified in TG-430 for the specific Class of vessel to be constructed or repaired.

ASME Qualified Inspection Organization (QIO): an organization that is qualified by ASME to criteria specified in the appropriate code or standard to provide designated oversight through the use of Qualified Inspectors (QI); not an Authorized Inspection Agency and not an entity authorized by ASME to use its marks.

Authorized Inspector (AI): an inspector regularly employed by an ASME-accredited Authorized Inspection Agency (AIA), who has been qualified to ASME developed criteria, to perform inspections under the rules of any jurisdiction that has adopted the ASME Code.

The Authorized Inspector shall not be in the employ of the Manufacturer. The AIA and supervisor's duties and qualifications and AI qualifications are as required in the latest edition and addenda of ASME QAI-1, Qualifications for Authorized Inspection.

Certified Individual (CI): an individual employee of the Certificate Holder who is authorized by ASME under a Certificate of Authorization to apply the ASME Certification Mark on items that are in compliance with the governing standard, and who may serve as the Certificate Holder's authorized representative responsible for signing data reports or certificates of conformance.

The CI shall be qualified and certified by the Certificate Holder to criteria specified in the governing standard. The qualification and certification are subject to evaluation by ASME Designees. The CI is neither an AI nor a Qualified Inspector providing inspections as an employee of a Qualified Inspection Organization. The quality management system shall establish measures to designate, train, qualify, and certify an individual(s) to perform the duties of a CI.

Qualifications shall include as a minimum:

(a) knowledge of the requirements of this Section of the Code for application of the Certification Mark with the appropriate Designator

(b) knowledge of the Manufacturer's Quality System Program

(c) training commensurate with the scope, complexity, or special nature of the activities to which oversight is to be provided

(d) a record, maintained, and certified by the Manufacturer, containing objective evidence of the qualifications of the CI and training provided

The CI's qualifications and duties are as required in the latest edition and addenda of ASME QAI-1, Qualifications for Authorized Inspection. The CI shall be qualified in accordance with ASME CA-1.

Qualified Inspector (QI): an inspector regularly employed by an ASME Qualified Inspection Organization (QIO) who has been qualified to ASME-developed criteria by a written examination, to perform inspections under the rules of any jurisdiction that has adopted the ASME Code. The QI shall not be in the employ of the Manufacturer.

The QIO's and supervisor's duties and qualifications and the QI's qualifications are as required in the latest edition and addenda of ASME QAI-1, Qualifications for Authorized Inspection.

TG-420 ACCESS FOR THE INSPECTOR (25)

The Manufacturer of the pressure 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 or part, 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 during the period of its assembly and testing. The Manufacturer shall keep the Inspector informed of the progress of the work and shall notify the Inspector reasonably in advance when the vessel or materials will be ready for any required tests or inspections.

TG-430 THE MANUFACTURER

(a) Manufacturers of Class 1 vessels constructed in accordance with the rules of this Section shall have in force, at all times, a valid inspection contract or agreement with an accredited Authorized Inspection Agency, employing Authorized Inspectors as defined in this Article.

(b) Manufacturers of Class 2 vessels constructed in accordance with the rules of this Section shall have in force, at all times, a valid inspection contract or agreement with an accredited QIO, employing Qualified Inspectors as defined in this Article.

(c) Manufacturers of Class 3 vessels constructed in accordance with the rules of this Section shall employ a Certified Individual as defined in this Article.

(d) Vessel Classes are designated in the applicable Modal Appendix.

(e) Authorized Inspection Agencies may provide inspection services for Manufacturers of Class 2 and Class 3 vessels. Qualified Inspection Organizations may provide inspection services for Manufacturers of Class 3 vessels.

TG-440 CONTINUED SERVICE

(a) Personnel performing inspections during the course of repair, alteration, or continued service of these pressure vessels shall meet the requirements of TG-430.

(b) Users may perform continued service inspections and tests if no rerating, repairs, or alterations requiring welding are performed, except see TG-100.3.

(c) Users may perform continued service inspections, including repairs and alterations, if the User possesses a valid Owner/User Certificate of Authorization issued by The National Board of Boiler and Pressure Vessel Inspectors or the equivalent recognized by the competent authority, and the Inspectors possess a National Board Owner/User commission or the equivalent recognized by the competent authority and are in the employ of the Owner/User.

PART TM
MATERIAL REQUIREMENTS

ARTICLE TM-1
MATERIAL REQUIREMENTS

TM-100 GENERAL

The requirements of Part TM are applicable to all pressure parts in pressure vessels and attachments to pressure parts, except as permitted by the applicable Modal Appendix, and shall be used in conjunction with the specific requirements given elsewhere in this Section that pertain to the method of fabrication, the material used, and the commodities being transported. See the applicable Modal Appendix for materials for other parts of transport tanks.

TM-110 GENERAL REQUIREMENTS FOR ALL PRODUCTS

(a) Material subject to stress due to pressure, and attachments that are essential to structural integrity of the pressure vessel when welded to pressure-retaining components, shall conform to one of the specifications given in Tables TM-130.2-1 through TM-130.2-7 and listed in Section II, Parts A and B, except as otherwise permitted in TM-110.5, TM-110.10, TM-120, and TM-130.1. Material may be identified as meeting more than one material specification or grade, provided the material meets all requirements of the identified material specification(s) or grade(s).

(b) Except as limited by TM-180.2, material for nonpressure parts, such as baffles, extended heat transfer surfaces, insulation supports, and minor attachments[1] (such as clips, locating lugs, nameplates) need not conform to the specifications for the material to which they are attached or to a material specification permitted in this Section; but if attached to the vessel by welding, it shall be of weldable quality. The allowable stress values for material not identified in accordance with Tables TM-130.2-1 through TM-130.2-7 shall not exceed 80% of the maximum allowable stress value permitted for similar material in Tables TM-130.2-1 through TM-130.2-7.

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

(d) Materials outside the limits of size and/or thickness listed in the title or scope clause of the specifications listed in Tables TM-130.2-1 through TM-130.2-7, and permitted elsewhere in this Section, 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 the stress tables. 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.

(e) All material used for construction of vessels and appurtenances must be suitable for the modal application and conditions specified by the User (see TG-310) and shall comply with the additional requirements in the applicable Modal Appendices.

TM-110.1 PLATES

Plates used in the construction of vessels shall conform to one of the specifications in Tables TM-130.2-1 through TM-130.2-7 for which allowable stress values are given in Section II, Part D, except as otherwise provided in TM-110(a) through TM-110(e), TM-110.10, TM-120, and TM-130.1.

TM-110.2 FORGINGS

Forged material may be used in vessel construction, provided the material has been worked sufficiently to remove the coarse ingot structure. Specifications for acceptable forging materials are given in Tables TM-130.2-1 through TM-130.2-7 and maximum allowable stress values in Section II, Part D.

TM-110.3 CASTINGS

Cast material may be used in the construction of vessels and vessel parts. Specifications for acceptable casting materials are listed in Tables TM-130.2-1 through TM-130.2-7 and the maximum allowable stress values in Section II, Part D. Castings shall comply with the additional requirements in TM-190. The allowable stress values shall be multiplied by the applicable casting quality factor given in TM-190.

TM-110.4 PIPE AND TUBES

Pipe and tubes of seamless or welded construction conforming to one of the specifications given in Tables TM-130.2-1 through TM-130.2-7 may be used for shells and other parts of transport tanks. Allowable stress values for the materials used in pipe and tubes are given in Section II, Part D.

TM-110.5 WELDING MATERIALS

Welding materials shall comply with the requirements of this Section, Section IX, and the applicable qualified welding procedure specification. When the welding materials comply with one of the specifications in Section II, Part C, the marking or tagging of the material, containers, or packages as required by the applicable Section II specification may be accepted for identification in lieu of a Material Test Report or a Certificate of Compliance. When the welding materials do not comply with one of the specifications of Section II, the marking or tagging shall be identifiable with the welding materials set forth in the welding procedure specification and may be accepted in lieu of a Material Test Report or a Certificate of Compliance.

TM-110.6 BOLTS AND STUDS

(a) Bolts and studs may be used for the attachment of removable parts. Permissible specifications are listed in Tables TM-130.2-1 through TM-130.2-7. Nuts and bolts shall conform to the requirements of TM-110.6 and the additional rules in TM-150.1, TM-150.5, or TM-160.1, as applicable. The allowable stresses for bolting materials are given in Section II, Part D, Subpart 1, Table 3.

(b) 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 eight diameters in length may have an unthreaded portion that has the nominal diameter of the thread, provided the following requirements are met:

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

(2) 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

(3) a suitable transition shall be provided between the root diameter and the unthreaded portion

(4) particular consideration shall be given to any dynamic loadings

TM-110.7 NUTS AND WASHERS

(a) Nuts shall conform to the requirements in the applicable paragraph elsewhere in this Code (see TM-150.1, TM-150.2, and TM-160.2). They shall engage the threads for the full depth of the nut.

(b) The use of washers is optional. When used, they shall be of wrought materials.

TM-110.8 RODS AND BARS

Rod and bar stock may be used in the vessel construction for pressure parts such as flange rings, stiffening rings, frames for reinforced openings, stays and staybolts, and similar parts. Rod and bar materials shall conform to the requirements for bars or bolting in the applicable section elsewhere in this Code (see TM-150.4).

TM-110.9 FERRITIC STEELS WITH TENSILE PROPERTIES ENHANCED BY HEAT TREATMENT

Except when specifically prohibited by Part TM (see TM-180.2 and TW-130.7), steels listed in Table TM-130.2-6 may be used for the entire vessel or for individual components that are joined to other Grades listed in that Table or to other steels conforming to the specifications in Table TM-130.2-1 or Table TM-130.2-2. The maximum allowable stress values for the materials listed in Table TM-130.2-6 are given in Section II, Part D.

TM-110.10 PREFABRICATED OR PREFORMED PRESSURE PARTS FURNISHED WITHOUT A CERTIFICATION MARK

(a) Prefabricated or preformed pressure parts for pressure vessels that are subject to stresses due to pressure and that are furnished by others instead of the Manufacturer of the completed vessel shall conform to all applicable requirements of this Section except as permitted in (b) through (e). When the prefabricated or preformed parts are furnished with a nameplate that contains product-identifying marks 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 tank Manufacturer's Data Report. The nameplate shall be destroyed. The rules of (b) through (e) shall not be applied to welded shells or heads or to quick-actuating closures. Parts furnished under the provisions of (b), (c), and (d) need not be manufactured by a Certificate of Authorization Holder. However, the Manufacturer of the completed

vessel or Certification Mark-stamped part shall ensure that parts furnished under the provisions of (b), (c), (d), and (e) meet all of the applicable Code requirements such as TF-310.1(c), TF-410.4, TF-510.1, and TF-610.1. Prefabricated or preformed pressure parts may be supplied as follows:

(1) cast, forged, rolled or die-formed nonstandard pressure parts

(2) cast, forged, rolled or die-formed standard pressure parts that comply with an ASME product standard, welded or nonwelded

(3) cast, forged, rolled or die-formed standard pressure parts that comply with a standard other than an ASME product standard, welded or nonwelded

(b) Cast, Forged, Rolled, or Die-Formed Nonstandard Pressure Parts. 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 Section, and the Manufacturer of the part shall furnish identification in accordance with TM-140.2. Such parts shall be marked with the name or trademark of the parts manufacturer and with such other markings to identify the particular parts with accompanying material identification. The Manufacturer of the completed tank shall be satisfied that the part is suitable for the design conditions specified for the completed tank in accordance with the rules of this Section.

(c) Cast, Forged, Rolled, or Die-Formed Standard Pressure Parts That Comply with an ASME Product Standard, Welded or Nonwelded

(1) These are pressure parts that comply with an ASME product standard accepted by reference in TG-130. The ASME product standard establishes the basis for the pressure–temperature rating and marking unless modified in TM-110.5.

(2) Flanges and flanged fittings may be used at the pressure–temperature ratings specified in the appropriate standard listed in this Section.

(3) Materials for standard pressure parts shall be as follows:

(-a) as permitted by this Section

(-b) as specifically listed in the ASME product standard (see TG-130)

(4) When welding is performed, it shall meet the following:

(-a) the requirements of Article TF-2

(-b) the welding requirements of SA-234

(5) Pressure parts, such as welded standard pipe fittings, welding caps, and flanges that are fabricated by one of the welding processes recognized by this Section do not require inspection, identification in accordance with TM-140.1(a) or TM-140.1(b), or Partial Data Reports, provided the requirements in (c) are met.

(6) If postweld heat treatment is required by the rules of this Section, it may be performed either in the location of the parts manufacturer or in the location of the Manufacturer of the tank to be marked with the Certification Mark.

(7) If radiography or other volumetric examination is required by the rules of this Section, it may be performed at one of the following locations:

(-a) Manufacturer of the completed tank

(-b) pressure parts manufacturer

(-c) examination provider

(8) Parts made to an ASME product standard shall be marked as required by the ASME product standard.

(9) The Manufacturer of the completed tank shall have the following responsibilities when using standard pressure parts that comply with an ASME product standard:

(-a) Ensure that all standard pressure parts comply with the applicable rules of this Section.

(-b) Ensure that all standard pressure parts are suitable for the design conditions of the completed tank.

(10) The Manufacturer shall fulfill these responsibilities by obtaining, when necessary, documentation as follows, provide for retention of this documentation, and have such documentation available for examination by the Inspector when requested. The documentation shall contain at a minimum:

(-a) material used

(-b) pressure–temperature rating of the part

(-c) basis for establishing the pressure–temperature rating

(d) Cast, Forged, Rolled, or Die-Formed Standard Pressure Parts That Comply With a Standard Other Than an ASME Product Standard, Welded or Nonwelded

(1) Standard pressure parts that are welded or nonwelded and comply with a manufacturer's proprietary standard or a standard other than an ASME product standard may be supplied by:

(-a) a Certificate of Authorization Holder

(-b) a pressure parts manufacturer

(2) Parts of small size falling within this category for which it is impossible to obtain identified material or which may be stocked and for which identification in accordance with TM-140.2 cannot be obtained and are not customarily furnished, may be used for parts as described in (b).

(3) Materials for these parts shall be as permitted by this Section only.

(4) When welding is performed, it shall meet the requirements of Article TF-2.

(5) Pressure parts, such as welded standard pipe fittings, welding caps, and flanges that are fabricated by one of the welding processes recognized by this Section do not require inspection, identification in accordance with TM-140.1 or Partial Data Reports, provided the requirements of TM-140.1(a) or TM-140.1(b) are met.

(6) If postweld heat treatment is required by the rules of this Section, it may be performed at the location of the parts manufacturer, the Manufacturer of the completed tank, or a heat-treatment facility.

(7) If radiography or other volumetric examination is required by the rules of this Section, it may be performed at one of the following locations:

(-a) Manufacturer of the completed tank

(-b) parts Manufacturer

(-c) pressure parts manufacturer

(-d) the examination provider

(8) Marking for these parts shall be as follows:

(-a) with the name or trademark of the Certificate Holder or the pressure part manufacturer and any other markings as required by the proprietary standard or other standard used for the pressure part

(-b) with a permanent or temporary marking that will identify the part with the Certificate Holder or the pressure parts manufacturer's written documentation of the particular items, and which defines the pressure–temperature rating of the part

(9) The Manufacturer of the completed tanks shall have the following responsibilities when using standard pressure parts:

(-a) Ensure that all standard pressure parts comply with applicable rules of this Section

(-b) Ensure that all standard pressure parts are suitable for the design conditions of the completed tank.

(-c) When volumetric examination is required by the rules of this Section, obtain the completed radiographs, properly identified, with a radiographic inspection report, and any other applicable volumetric examination report.

(10) The Manufacturer of the completed tank shall fulfill these responsibilities by one of the following methods:

(-a) Obtain when necessary, documentation as provided below, provide for retention of this documentation, and have such documentation available for examination by the Inspector when requested.

(-b) Perform an analysis of the pressure part in accordance with the rules of this Division. See also TG-100.2(c). This analysis shall be included in the documentation and shall be made available for examination by the Inspector when requested.

(11) The documentation shall contain at a minimum:

(-a) material used

(-b) pressure–temperature rating of the part

(-c) basis for establishing the pressure–temperature rating

(-d) written certification by the pressure parts manufacturer that all welding complies with Code requirements

(e) The Code recognizes that a Certificate of Authorization Holder may fabricate parts in accordance with (d), and that are marked in accordance with (d)(8). In lieu of the requirement in (d)(4), the Certificate of Authorization Holder may subcontract to an individual or organization not holding an ASME Certificate of Authorization standard pressure parts that are fabricated to a standard other than an ASME product standard provided all the following conditions are met:

(1) The activities to be performed by the subcontractor are included within the Certificate Holder's Quality Control System.

(2) The Certificate Holder's Quality Control System provides for the following activities associated with subcontracting of welding operations, and these provisions shall be acceptable to the Manufacturer's Authorized Inspection Agency.

(-a) welding processes permitted by this Section that are permitted to be subcontracted

(-b) welding operations

(-c) Authorized Inspection activities

(-d) placement of the Certificate of Authorization Holder's marking in accordance with (d)(8)

(3) The Certificate Holder's Quality Control System provides for the requirements of TG-420 to be met at the subcontractor's facility.

(4) The Certificate Holder shall be responsible for reviewing and accepting the Quality Control Systems of the subcontractor.

(5) The Certificate Holder shall ensure that the subcontractor uses written procedures and welding operations that have been qualified as required by this Section.

(6) The Certificate Holder shall ensure that the subcontractor uses personnel that have been qualified as required by this Section.

(7) The Certificate Holder and the subcontractor shall describe in their Quality Control Systems the operational control of procedure and personnel qualifications of the subcontracted welding operations.

(8) The Certificate Holder shall be responsible for controlling the quality and ensuring that all materials and parts that are welded by subcontractors and submitted to the Inspector for acceptance conform to all applicable requirements of this Section.

(9) The Certificate Holder shall describe in their Quality Control Systems the operational control for maintaining traceability of materials received from the subcontractor.

(10) The Certificate Holder shall receive approval for subcontracting from the Authorized Inspection Agency prior to commencing of activities.

TM-120 MATERIAL IDENTIFIED WITH OR PRODUCED TO A SPECIFICATION NOT PERMITTED BY THIS SECTION, AND MATERIAL NOT FULLY IDENTIFIED

(a) Identified Material With Complete Certification From the Material Manufacturer. Material identified with a specification not permitted by this Section and identified to a single production lot as required by a permitted specification may be accepted as satisfying the requirements of a specification permitted by this Section, provided the conditions set forth in (1) or (2) are satisfied.

(1) Recertification by an Organization Other Than the Vessel or Part Manufacturer. Not permitted

(2) Recertification by the Vessel or Part Manufacturer

(-a) Documentation is provided to the Certificate Holder demonstrating that all applicable requirements (including, but not limited to, melting method, melting practice, deoxidation, chemical analysis, mechanical properties, quality, and heat treatment) of the specification permitted by this Section, to which the material is to be recertified, have been met.

(-b) The material has marking, acceptable to the Inspector, for identification to the documentation.

(-c) When the conformance of the material with the permitted specification has been established, the material shall be marked as required by the permitted specification.

(b) Material Identified With a Specification Not Permitted by This Section and Identified to a Particular Production Lot as Required by a Specification Permitted by This Section but Which Cannot Be Qualified Under (a). Any material for which the documentation required in (a) is not available may be accepted as satisfying the requirements of the specification permitted by this Section, provided that the conditions set forth below are satisfied.

(1) Recertification by an Organization Other Than the Vessel or Part Manufacturer. Not permitted.

(2) Recertification by the Vessel or Part Manufacturer

(-a) When documentation demonstrating complete conformance to the chemical requirements is not available, chemical analyses are made on different pieces from the lot to establish a mean analysis that is to be accepted as representative of the lot. The pieces chosen for analysis shall be selected at random from the lot. The number of pieces selected shall be at least 10% of the number of pieces in the lot, but not less than three. For lots of three pieces or less, each piece shall be analyzed. Each individual analysis for an element shall conform to the limits for product analysis in the permitted specification, and the mean for each element shall conform to the heat analysis limits of that specification. Analyses need only be made for those elements required by the permitted specification (including its general specification); only those elements for which documentation is not available must be tested.

(-b) When documentation demonstrating complete conformance to the mechanical property requirements is not available, mechanical property tests are made in accordance with the requirements of the permitted specification, and the results of the tests conform to the specified requirements; only those properties for which documentation is not available must be tested.

(-c) When documentation demonstrating complete conformance to the heat treatment requirements is not available, the material is heat treated in accordance with those requirements, either prior to or during fabrication. (See also TM-140.2.)

(-d) All other applicable requirements (including, but not limited to, melting method, melting practice, deoxidation, chemical analysis, mechanical properties, grain size, and quality) of the specification permitted by this Section, to which the material is to be recertified, have been demonstrated to have been met.

(-e) The material has marking, acceptable to the Inspector, for identification to the documentation.

(-f) When the conformance of the material with the permitted specification has been established, the material has been marked as required by the permitted specification.

(c) Material Not Fully Identified. Material that cannot be qualified under the provisions of either (a) or (b), such as material not fully identified as required by the permitted specification or unidentified material, may be accepted as satisfying the requirements of a specification permitted by this Section, provided that the conditions set forth below are satisfied.

(1) Qualification by an Organization Other Than the Vessel or Part Manufacturer. Not permitted.

(2) Qualification by the Vessel or Part Manufacturer

(-a) Each piece is tested to show that it meets the chemical composition for product analysis and the mechanical property requirements of the permitted specification. Chemical analyses need only be made for those elements required by the permitted specification (including its general specification). When the direction of final rolling or major work (as required by the material specification) is not known, tension test specimens shall be taken in each appropriate direction from each sampling location designated in the permitted specification. The results of both tests shall conform to the minimum requirements of the specification, but the tensile strength of only one of the two specimens need conform to the maximum requirement.

(-b) The provisions of (b)(2)(-c), above shall be met.

(-c) All other applicable requirements (including, but not limited to, melting method, melting practice, deoxidation, chemical analysis, mechanical properties, grain

size, and quality) of the specification permitted by this Section, to which the material is to be recertified, have been demonstrated to have been met. If such verifiable evidence cannot be provided, recertification is not permitted.

(-d) When the identity of the material with the permitted specification has been established in accordance with (-a), (-b), and (-c) above, each piece (or bundle, etc., if permitted in the specification) shall be marked with a marking giving the permitted specification number and grade, type, or class, as applicable and a serial number identifying the particular lot of material. A suitable report, clearly marked as being a "Report on Tests of Nonidentified Material," shall be completed and certified by the tank or part Manufacturer. This report, when accepted by the Inspector, shall constitute authority to use the material in lieu of material procured to the requirements of the permitted specification.

TM-130 MATERIAL SPECIFICATIONS

TM-130.1 PRODUCT SPECIFICATION

When there is no material specification listed in Tables TM-130.2-1 through TM-130.2-7 covering a particular product of a grade, but there is an approved specification listed in Tables TM-130.2-1 through TM-130.2-7 covering some other product of that grade, the product for which there is no specification may be used, provided:

(a) the chemical and mechanical properties, heat treating requirements, and requirements for deoxidation, or grain size requirements conform to the approved specification listed in Tables TM-130.2-1 through TM-130.2-7. The stress values for that specification given in the tables referenced in TM-130.2 shall be used.

(b) the manufacturing procedures, tolerances, tests, and marking are in accordance with a specification listed in Tables TM-130.2-1 through TM-130.2-7 covering the same product form of a similar material.

(c) for the case of welded tubing made of plate, sheet, or strip, without the addition of filler metal, the appropriate stress values are multiplied by a factor of 0.85.

(d) the product is not pipe or tubing fabricated by fusion welding with the addition of filler metal unless it is fabricated in accordance with the rules of this Section as a pressure part.

(e) mill test reports reference the specifications used in producing the material and make reference to this paragraph.

(25) TM-130.2 APPROVED MATERIAL SPECIFICATIONS

(a) Approved material specifications are listed in the following Tables:

Table TM-130.2-1	Carbon and Low Alloy Steel
Table TM-130.2-2	High Alloy Steel
Table TM-130.2-3	Aluminum and Aluminum Alloy Products
Table TM-130.2-4	Copper and Copper Alloys
Table TM-130.2-5	Nickel and High Nickel Alloys
Table TM-130.2-6	Ferritic Steels With Tensile Properties Enhanced by Heat Treatment
Table TM-130.2-7	Titanium and Titanium Alloys

(b) The maximum allowable tensile stress values for the materials listed in Tables TM-130.2-1 through TM-130.2-7 are the values given in Section II, Part D, for Section XII construction, except where otherwise specified or limited by Table TM-130.2-1, Note (1); Table TM-130.2-2, Notes (1) and (2); Table TM-130.2-5, Note (1); and Table TM-130.2-7.

TM-130.3 MATERIAL PROPERTIES

When the rules of this Section require the use of material physical properties, these properties shall be taken from the applicable tables in Section II, Part D, Subpart 2. If the applicable tables in Section II, Part D, Subpart 2 do not contain these properties for a permitted material or do not list them within the required temperature range, the Manufacturer may use other authoritative sources for the needed information. The Manufacturer's Data Report shall note under "Remarks" the property values obtained and their source.

NOTE: If material physical properties are not listed, the Manufacturer is encouraged to bring the information to the attention of the ASME Committee on Materials (BPVC Section II) so that the data can be added in Section II, Part D, Subpart 2.

TM-140 INSPECTION AND MARKING OF MATERIALS

TM-140.1 INSPECTION OF MATERIALS (25)

(a) Except as provided in TM-110(a) through TM-110(e), TM-110.10, TM-120, and TM-130.1, requirements for acceptance of materials furnished by the material Manufacturer or material supplier shall be in complete compliance with a material specification of Section II and the following requirements:

(1) For plates, the tank Manufacturer shall obtain the material test report or certificate of compliance as provided for in the material specification and the Inspector shall examine the Material Test Report or Certificate of Compliance and shall determine if it represents the material and meets the requirements of the material specification.

Table TM-130.2-1
Carbon and Low Alloy Steels

(25)

Specification Number	Type/Grade	ASME P-No.	Group No.
Plates, Sheet, and Strip			
SA-36	...	1	1
SA-203	A, B	9A	1
	D, E, F	9B	1
SA-204	A	3	1
	B, C	3	2
SA-225	C	10A	1
SA-283	C, D	1	1
SA-285	A, B, C	1	1
SA-299	A	1	2
	B	1	3
SA-302	A	3	2
	B, C, D	3	3
SA-387	2, Cl. 1	3	1
	2, Cl. 2	3	2
SA-414	A, B, C, D, E	1	1
	F, G	1	2
SA-455	...	1	2
SA-515	60, 65	1	1
	70	1	2
SA-516	55, 60, 65	1	1
	70	1	2
SA-537	Cl. 1	1	2
	Cl. 2 and 3	1	3
SA-572	42, 50	1	1
	55, 60	1	2
	65	1	3
SA-612	...	10C	1
SA-656	T3 50, T7 50	1	1
	T3 60, T7 60	1	2
	T3 70, T7 70	1	3
	T3 80, T7 80	1	4
SA-662	A, B	1	1
	C	1	2
SA-737	B	1	2
	C	1	3
SA-738	A	1	2
	B, C	1	3
SA-1008	CS-A and CS-B	1	1
SA-1011	HSLAS 45 Cl. 1 and 2	1	1
	HSLAS 50 Cl. 1 and 2	1	1
	HSLAS 60 Cl. 1 and 2	1	2
	SS 45, SS 50	1	1
SA/CSA-G40.21	38W	1	1
SA/EN 10028-2	P295GH	1	1
SA/EN 10028-3	P275NH	1	1
Forgings			
SA-266	1	1	1
	2, 4	1	2

Table TM-130.2-1
Carbon and Low Alloy Steels (Cont'd)

Specification Number	Type/Grade	ASME P-No.	Group No.
Forgings (Cont'd)			
SA-336	F1	3	2
SA-372	A	1	1
	B	1	2
	C, D	...	...
	E Cl. 65 and 70	...	...
	F Cl. 70, G Cl. 70	...	...
	H Cl. 70, J Cl. 65	...	...
	J Cl. 70 and 110, L	...	...
	M Cl. A and B	...	...
SA-508	1, 1A	1	2
	2 Cl. 1, 3 Cl. 1, 4N Cl. 3	3	3
SA-541	1, 1A	1	2
	2 Cl. 1, 3 Cl. 1	3	3
SA-765	I	1	1
	II	1	2
	III	9B	1
SA-836	...	1	1
Flanges, Fittings, and Valves			
SA-105	...	1	2
SA-181	Cl. 60	1	1
	Cl. 70	1	2
SA-182	F1, F2	3	2
	FR	9A	1
SA-234	WPB	1	1
	WPC	1	2
	WP1	3	1
SA-350	LF1	1	1
	LF2	1	2
	LF5 Cl. 1 and 2, LF9	9A	1
	LF3	9B	1
SA-420	WPL6	1	1
	WPL9	9A	1
	WPL3	9B	1
SA-727	...	1	1
Pipe			
SA-53	S Gr. A and B, E Gr. A and B	1	1
SA-106	A, B	1	1
	C	1	2
SA-135	A, B	1	1
SA-333	1, 6	1	1
	7, 9	9A	1
	3	9B	1
SA-335	P1, P2, P15	3	1
SA-369	FP1, FP2	3	1
SA-524	I, II	1	1
SA-587	...	1	1

Table TM-130.2-1
Carbon and Low Alloy Steels (Cont'd)

Specification Number	Type/Grade	ASME P-No.	Group No.
Tubes			
SA-178	A, C	1	1
SA-179	...	1	1
SA-192	...	1	1
SA-209	T1, T1a, T1b	3	1
SA-210	A-1	1	1
	C	1	2
SA-213	T2	3	1
	T17	10B	1
SA-214	...	1	1
SA-250	T1, T1a, T1b	3	1
SA-334	1, 6	1	1
	7, 9	9A	1
	3	9B	1
SA-556	A2, B2	1	1
	C2	1	2
SA-557	A2, B2	1	1
	C2	1	2
Castings			
SA-216	WCA	1	1
	WCB, WCC	1	2
SA-217	WC1	3	1
SA-352	LCB	1	1
	LC1	3	1
	LC2	9A	1
	LC3	9B	1
SA-487	1 Cl. A and B	10A	1
	2 Cl. A and B, 4 Cl. A	3	3
Bar			
SA-675	45, 50, 55, 60, 65	1	1
	70	1	2
Bolting			
SA-193	B5, B7, B7M, B16	...	...
SA-307	B	...	...
SA-320	L7, L7A, L7M, L43	...	...
SA-325	1	...	...
SA-354	BC, BD	...	...
SA-437	B4B, B4C	...	...
SA-449	...	...	...
SA-540	B21 Cl. 1, 2, 3 and 4	...	...
	B22 Cl. 3	...	...
	B23 Cl. 1, 2, 3, 4, and 5	...	...
	B24 Cl. 1, 2, 3, 4, and 5	...	...
	B24V	...	...
SA-574 (screws)	...	...	...
Nuts			
SA-540	B23, B24	...	...

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Table TM-130.2-2
High Alloy Steels

Specification Number	UNS No.	Type/Grade	ASME P-No.	Group No.
Plates, Sheet, and Strip				
SA-240	S41000	410	6	1
	S42900	429	6	2
	S40500	405	7	1
	S41008	410S	7	1
	S43000	430	7	2
	S44400	...	7	2
	S30200	302	8	1
	S30400	304	8	1
	S30403	304L	8	1
	S30451	304N	8	1
	S30453	304LN [Note (1)]	8	1
	S31600	316	8	1
	S31603	316L	8	1
	S31635	316Ti	8	1
	S31640	316Cb	8	1
	S31651	316N	8	1
	S31653	316LN [Note (2)]	8	1
	S31700	317	8	1
	S31703	317L	8	1
	S32100	321	8	1
	S34700	347	8	1
	S34800	348	8	1
	S38100	XM-15	8	1
	S30815	...	8	2
	S30908	309S	8	2
	S30940	309Cb	8	2
	S31008	310S	8	2
	S31040	310Cb	8	2
	S31050	310MoLN	8	2
	S20100	201-1, 201-2	8	3
	S20153	201LN	8	3
	S20400	204	8	3
	S20910	XM-19	8	3
	S24000	XM-29	8	3
	S31254	...	8	4
	S31725	...	8	4
	S31200	...	10H	1
	S31260	...	10H	1
	S31803	...	10H	1
	S32304	...	...	...
	S32550	...	10H	1
	S32900	329	10H	1
	S32950	...	10H	1
	S44626	XM-33	10I	1
	S44627	XM-27	10I	1
	S44635	25-4-4	10I	1
	S44700	29-4	10J	1
	S44660	26-3-3	10K	1

Table TM-130.2-2
High Alloy Steels (Cont'd)

Specification Number	UNS No.	Type/Grade	ASME P-No.	Group No.
Plates, Sheet, and Strip (Cont'd)				
	S44800	29-4-2	10K	1
	N08940	...	45	...
SA-666	S20100	201-1, 201-2	8	3
	S21904	XM-11	8	3
Forgings				
SA-965	S30400	F304	8	1
	S30403	F304L	8	1
	S30451	F304N	8	1
	S30453	304LN [Note (1)]	8	1
	S31600	F316	8	1
	S31603	F316L	8	1
	S31651	F316N	8	1
	S31653	316LN [Note (2)]	8	1
	S32100	F321	8	1
	S34700	F347	8	1
	S34800	F348	8	1
	S31000	F310	8	2
	S21904	FXM-11	8	3
Flanges, Fittings, and Valves				
SA-182	S41000	F6a Cl. 1	6	1
	S41000	F6a Cl. 2	6	3
	S30400	F304	8	1
	S30403	F304L	8	1
	S30453	304LN9	8	1
	S31600	F316	8	1
	S31603	F316L	8	1
	S31700	F317	8	1
	S31703	F317L	8	1
	S32100	F321	8	1
	S34700	F347	8	1
	S34800	F348	8	1
	S30815	F45	8	2
	S31000	F310	8	2
	S20910	FXM-19	8	3
	S21904	FXM-11	8	3
	S31254	F44	8	4
	S31803	F51	10H	1
	S44627	FXM-27Cb	10I	1
	N08940	...	45	...
SA-403	S30400	WP304	8	1
	S30403	WP304L	8	1
	S30451	WP304N	8	1
	S31600	WP316	8	1
	S31603	WP316L	8	1
	S31651	WP316N	8	1
	S31700	WP317	8	1

Table TM-130.2-2
High Alloy Steels (Cont'd)

Specification Number	UNS No.	Type/Grade	ASME P-No.	Group No.
Flanges, Fittings, and Valves (Cont'd)				
	S31703	WP317L	8	1
	S32100	WP321	8	1
	S34700	WP347	8	1
	S34800	WP348	8	1
	S30900	WP309	8	2
	S31000	WP310	8	2
	S20910	WPXM-19	8	3
SA-815	S31803	...	10H	1
Pipe				
SA-312	S30400	TP304	8	1
	S30403	TP304L	8	1
	S30451	TP304N	8	1
	S30453	304LN [Note (1)]	8	1
	S31600	TP316	8	1
	S31603	TP316L	8	1
	S31651	TP316N	8	1
	S31700	TP317	8	1
	S31703	TP317L	8	1
	S32100	TP321	8	1
	S34700	TP347	8	1
	S34800	TP348	8	1
	S38100	TPXM-15	8	1
	S30815	...	8	2
	S30908	TP309S	8	2
	S30940	TP309Cb	8	2
	S31008	TP310S	8	2
	S31040	TP310Cb	8	2
	S31050	TP310MoLN	8	2
	S20910	TPXM-19	8	3
	S21904	TPXM-11	8	3
	S24000	TPXM-29	8	3
	N08940	...	45	...
SA-358	S31254	...	8	4
	S31725	...	8	4
SA-376	S30400	TP304	8	1
	S30451	TP304N	8	1
	S30453	304LN [Note (1)]	8	1
	S31600	TP316	8	1
	S31651	TP316N	8	1
	S31653	316LN [Note (2)]	8	1
	S32100	TP321	8	1
	S34700	TP347	8	1
	S34800	TP348	8	1
	S31725	...	8	4
SA-409	S31725	...	8	4
SA-731	S44626	TPXM-33	10I	1
	S44627	TPXM-27	10I	1

Table TM-130.2-2
High Alloy Steels (Cont'd)

Specification Number	UNS No.	Type/Grade	ASME P-No.	Group No.
Pipe (Cont'd)				
SA-790	S31260	...	10H	1
	S31500	...	10H	1
	S31803	...	10H	1
	S32304	...	10H	1
	S32550	...	10H	1
	S32750	...	10H	1
	S32900	...	10H	1
	S32950	...	10H	1
SA-813	S30908	TP309S	8	2
	S30940	TP309Cb	8	2
	S31008	TP310S	8	2
	S31040	TP310Cb	8	2
SA-814	S30908	TP309S	8	2
	S30940	TP309Cb	8	2
	S31008	TP310S	8	2
	S31040	TP310Cb	8	2
Tubes				
SA-213	S30400	TP304	8	1
	S30403	TP304L	8	1
	S30451	TP304N	8	1
	S30453	304LN [Note (1)]	8	1
	S31600	TP316	8	1
	S31603	TP316L	8	1
	S31651	TP316N	8	1
	S32100	TP321	8	1
	S34700	TP347	8	1
	S34800	TP348	8	1
	S38100	TPXM-15	8	1
	S30815	...	8	2
	S30908	TP309S	8	2
	S30940	TP309Cb	8	2
	S31008	TP310S	8	2
	S31040	TP310Cb	8	2
	S31050	TP310MoLN	8	2
	S31725	...	8	4
SA-249	S30400	TP304	8	1
	S30403	TP304L	8	1
	S30451	TP304N	8	1
	S31600	TP316	8	1
	S31603	TP316L	8	1
	S31651	TP316N	8	1
	S31700	TP317	8	1
	S31703	TP317L	8	1
	S32100	TP321	8	1
	S34700	TP347	8	1
	S34800	TP348	8	1
	S38100	TPXM-15	8	1

Table TM-130.2-2
High Alloy Steels (Cont'd)

Specification Number	UNS No.	Type/Grade	ASME P-No.	Group No.
Tubes (Cont'd)				
	S30815	...	8	2
	S30908	TP309S	8	2
	S30940	TP309Cb	8	2
	S31008	TP310S	8	2
	S31040	TP310Cb	8	2
	S31050	TP310MoLN	8	2
	S20910	TPXM-19	8	3
	S24000	TPXM-29	8	3
	S31254	...	8	4
	S31725	...	8	4
	N08940	...	45	...
SA-268	S41000	TP410	6	1
	S42900	TP429	6	2
	S40500	TP405	7	1
	S40800	...	7	1
	S40900	TP409	7	1
	S43000	TP430	7	2
	S43035	TP439	7	2
	S44400	...	7	2
	S44600	TP446-1	10I	1
	S44626	TPXM-33	10I	1
	S44627	TPXM-27	10I	1
	S44635	...	10I	1
	S44700	29-4	10J	1
	S44735	29-4C	10J	1
	S44660	26-3-3	10K	1
	S44800	29-4-2	10K	1
SA-688	S30400	TP304	8	1
	S30403	TP304L	8	1
	S30451	TP304N	8	1
	S31600	TP316	8	1
	S31603	TP316L	8	1
	S24000	TPXM-29	8	3
SA-789	S31260	...	10H	1
	S31500	...	10H	1
	S31803	...	10H	1
	S32304	...	10H	1
	S32550	...	10H	1
	S32750	...	10H	1
	S32900	...	10H	1
	S32950	...	10H	1
SA-803	S43035	TP439	7	2
	S44660	26-3-3	10K	1
Castings				
SA-217	J91150	CA15	6	3
SA-351	J92500	CF3, CF3A	8	1
	J92590	CF10	8	1

Table TM-130.2-2
High Alloy Steels (Cont'd)

Specification Number	UNS No.	Type/Grade	ASME P-No.	Group No.
Castings (Cont'd)				
	J92600	CF8, CF8A	8	1
	J92710	CF8C	8	1
	J92800	CF3M	8	1
	J92900	CF8M	8	1
	J93000	CG8M	8	1
	J93400	CH8	8	2
	J93402	CH20	8	2
	J94202	CK20	8	2
	J93790	CG6MMN	8	3
	J93254	CK3MCuN	8	4
	N08151	CT15C	45	...
SA-995	J93345	CE8MN	10H	1
Bar and Shapes				
SA-479	S41000	410	6	1
	S40500	405	7	1
	S43000	430	7	2
	S43035	439	7	2
	S30200	302	8	1
	S30400	304	8	1
	S30403	304L	8	1
	S30453	304LN [Note (1)]	8	1
	S31600	316	8	1
	S31603	316L	8	1
	S31653	316LN [Note (2)]	8	1
	S32100	321	8	1
	S34700	347	8	1
	S34800	348	8	1
	S30815	...	8	2
	S30908	309S	8	2
	S30940	309Cb	8	2
	S31008	310S	8	2
	S31040	310Cb	8	2
	S20910	XM-19	8	3
	S24000	XM-29	8	3
	S31725	...	8	4
	S32550	...	10H	1
	S44627	XM-27	10I	1
	S44700	29-4	10J	1
	S44800	29-4-2	10K	1
	N08904	904L	45	...
Bolting				
SA-193	S21800	B8S, B8SA	...	...
	S30400	B8 Cl. 1 and 2	...	...
	S30451	B8NA Cl. 1A	...	...
	S30500	B8P Cl. 1 and 2	...	...
	S31600	B8M Cl. 1 and 2, B8M2 Cl. 2	...	...

Table TM-130.2-2
High Alloy Steels (Cont'd)

Specification Number	UNS No.	Type/Grade	ASME P-No.	Group No.
Bolting (Cont'd)				
	S31651	B8MNA Cl. 1A	...	...
	S32100	B8T Cl. 1 and 2	...	...
	S34700	B8C Cl. 1 and 2	...	...
	S41000	B6	...	...
SA-320	S30323	B8F Cl. 1, B8FA Cl. 1A	...	...
	S30400	B8 Cl. 1 and Cl. 2, B8A Cl. 1A	...	...
	S31600	B8M Cl. 1 and 2, B8MA Cl. 1A	...	...
	S32100	B8T Cl. 1 and 2, B8TA Cl. 1A	...	...
	S34700	B8C Cl. 1 and 2, B8CA Cl. 1A	...	...
SA-453	S63198	651 Cl. A and B	...	...
	S66286	660 Cl. A and B	...	...
SA-479	S20910	XM-19	...	...
SA-564	S17400	630 H1100 and H1150 (not welded)	...	...
SA-705	S17400	630 H1100	...	...

NOTES:

(1) The maximum allowable design stress values given in Section II, Part D, Subpart 1, Table 1A, for solution annealed Type 304 stainless steel (Alloy UNS S30400) are applicable for solution annealed Type 304LN stainless steel (Alloy UNS S30453) for maximum design metal temperature not exceeding 38°C (100°F).

(2) The maximum allowable design stress values given in Section II, Part D, Subpart 1, Table 1A, for solution annealed Type 316 stainless steel (Alloy UNS S31600) are applicable for solution annealed Type 316LN stainless steel (Alloy UNS S31653) for maximum design metal temperature not exceeding 38°C (100°F).

Table TM-130.2-3
Aluminum and Aluminum Alloy Products

Specification Number	Alloy Designation/UNS No.	ASME P-No.
Plates, Sheet, and Strip		
SB-209	Alclad 3003, A91060, A91100, A93003	21
	Alclad 3004, A93004, A95052, A95154, A95254, A95454	22
	Alclad 6061, A96061	23
	A95083, A95086, A95456, A95652	25
SB-928	A95083, A95086, A95456	...
Forgings		
SB-247	A93003	21
	A96061	23
	A95083	25
	A92014	...
Pipe and Tubes		
SB-210	Alclad 3003, A91060, A93003	21
	A95052, A95154	22
	A96061, A96063	23
SB-234	Alclad 3003, A91060, A93003	21
	A95052, A95454	22
	A96061	23
SB-241	Alclad 3003, A91060, A91100, A93003	21
	A95052, A95454	22
	A96061, A96063	23
	A95083, A95086, A95456	25
Castings		
SB-26	A02040, A03560, A24430	...
SB-108	A02040, A03560	...
Rod, Bar, Wire, Shapes		
SB-211	A92014, A92024, A96061	23
SB-221	A91060, A91100, A93003	21
	A95154, A95454	22
	A96061, A96063	23
	A95083, A95086, A95456	25
	A92024	...
SB-308 (shapes)	A96061	23
Bolting		
SB-211	A92014, A92024, A96061	...

Table TM-130.2-4
Copper and Copper Alloys

Specification Number	Alloy Designation/UNS No.	ASME P-No.
Plates, Sheet, Strip, and Rolled Bars		
SB-96	C65500	33
SB-152	C10200, C10400, C10500, C10700, C11000, C12200, C12300	31
SB-169	C61400	35
SB-171	C36500, C44300, C44400, C44500, C46400, C46500	32
	C70600, C70620, C71500, C71520	34
	C61400, C63000	35
Forgings		
SB-283	C37700	...
	C64200	...
Pipe		
SB-42	C10200, C12000, C12200	31
SB-43	C23000	32
SB-315	C65500	33
SB-467	C70600, C70620	34
Tubes		
SB-75	C10200, C12000, C12200	31
SB-111	C10200, C12000, C12200, C14200, C19200	31
	C23000, C28000, C44300, C44400, C44500, C68700	32
	C70400, C70600, C70620, C71000, C71500, C71520, C72200	34
	C60800	35
SB-135	C23000	32
SB-315	C65500	33
SB-359	C70600, C70620	34
SB-395	C10200, C12000, C12200, C14200, C19200	31
	C23000, C44300, C44400, C44500, C68700	32
	C70600, C70620, C71000, C71500, C71520	34
	C60800	35
SB-466	C70600, C70620, C71000, C71500, C71520	34
SB-543	C12200, C19400	31
	C23000, C44300, C44400, C44500, C68700	32
	C70400, C70600, C70620, C71500, C71520	34
Castings		
SB-61	C92200	...
SB-62	C83600	...
SB-148	C95200, C95400	35
SB-271	C95200	35
SB-584	C92200, C93700, C97600	...
Rod, Bar, and Shapes		
SB-98	C65100, C65500, C66100	33
SB-150	C61400, C62300, C63000, C64200	35
SB-187	C10200, C11000	31
Bolting		
SB-98	C65100, C65500, C66100	33
SB-150	C61400, C62300, C63000, C64200	35
SB-187	C10200, C11000	31

Table TM-130.2-5 Nickel and Nickel Alloys

(25)

Specification Number	UNS No.	ASME P-No.
Plates, Sheet, and Strip		
SB-127	N04400	42
SB-162	N02200, N02201	41
SB-168	N06600, N06690	43
SB-333	N10001, N10665, N10675	44
SB-424	N08825	45
SB-434	N10003	44
SB-435	N06002, N06230	43
	R30556	45
SB-443	N06625	43
SB-463	N08020	45
SB-536	N08330	46
SB-575	N06022, N06059, N06455, N10276	44
SB-582	N06007, N06030, N06975, N06985	45
SB-599	N08700	45
SB-620	N08320	45
SB-625	N08925	45
SB-688	N08366, N08367	45
SB-709	N08028	45
Forgings		
SB-564	N04400	42
	N06022, N06059, N06230, N06600, N06625, N10276	43
	N10675	44
	N08367	45
SB-637	N07718, N07750	...
Flanges, Fittings, and Valves		
SB-366	N02200, N02201	41
	N04400	42
	N06002, N06022, N06230, N06059, N06455, N06600, N06625, N10276	43
	N10001, N10003, N10665, N10675	44
	N06007, N06030, N06985, N08020, N08825	45
	N08330	46
SB-462	N08020, N08367	45
Pipe and Tube		
SB-161	N02200, N02201	41
SB-163	N02200, N02201	41
	N04400	42
	N06600	43
	N08825	45
SB-165	N04400	42
SB-167	N06600, N06690	43
SB-423	N08825	45
SB-444	N06625	43
SB-464	N08020, N08024, N08026	45
SB-468	N08020, N08024, N08026	45
SB-516	N06600	43
SB-517	N06600	43

Table TM-130.2-5
Nickel and Nickel Alloys (Cont'd)

Specification Number	UNS No.	ASME P-No.
Pipe and Tube (Cont'd)		
SB-535	N08330	46
SB-619	N06002, N06022, N06059, N06230, N06455, N10276	43
	N10001, N10665, N10675	44
	N06007, N06030, N06975, N06985, N08320, R30556	45
SB-622	N06002, N06022, N06059, N06455, N10276	43
	N10001, N10665, N10675	44
	N06007, N06030, N06975, N06985, N08320, R30556	45
SB-626	N06002, N06022, N06059, N06455, N10276	43
	N10001, N10665, N10675	44
	N06007, N06030, N06975, N06985, N08320, R30556	45
SB-668	N08028	45
SB-673	N08925	45
SB-674	N08925	45
SB-675	N08367	45
SB-676	N08367	45
SB-677	N08925	45
SB-690	N08367	45
SB-704	N06625	43
	N08825	45
SB-705	N06625	43
	N08825	45
SB-710	N08330	46
SB-729	N08020	45
SB-804	N08367	...
Castings		
SA-351	J94651 (Grade CN3MN)	45
SA-494	N26022 (Grade CX2MW), N30002 (Grade CW-12MW/C), N30012 (Grade N-12MV/B)	44
Rod, Bar, Wire, and Shapes		
SB-160	N02200, N02201	41
SB-164	N04400, N04405	42
SB-166	N06600, N06690	43
SB-335	N10001, N10665, N10675	44
SB-425	N08825	45
SB-446	N06625	43
SB-473	N08020	45
SB-511	N08330	46
SB-572	N06002, N06230	43
	R30556	45
SB-573	N10003	44
SB-574	N06022, N06059, N06455, N10276	44
SB-581	N06007, N06030, N06975, N06985	45
SB-621	N08320	45
SB-649	N08925	45
SB-672	N08700	45
SB-691	N08367	45

Table TM-130.2-5
Nickel and Nickel Alloys (Cont'd)

Specification Number	UNS No.	ASME P-No.
Bolting [Note (1)]		
SB-160	N02200, N02201	...
SB-164	N04400, N04405	...
SB-166	N06600	...
SB-335	N10001, N10665	...
SB-425	N08825	...
SB-446	N06625	...
SB-572	N06002, R30556	...
SB-573	N10003	...
SB-574	N06022, N06455, N10276	...
SB-581	N06007, N06030, N06975	...
SB-621	N08320	...
SB-637	N07718, N07750	...

NOTE: (1) Minimum design metal temperature for all bolting material listed in this table is −196°C (−320°F).

Table TM-130.2-6
Ferritic Steels With Tensile Properties Enhanced by Heat Treatment

Specification Number	Type/Grade	ASME P-No.	Group No.
Plates and Sheet			
SA-353	...	11A	1
SA-517	A	11B	1
	E	11B	2
	F	11B	3
	B	11B	4
	J	11B	6
	P	11B	8
SA-533	B Cl. 3, D Cl. 3	11A	4
SA-553	I, II	11A	1
SA-645	A	11A	2
SA-724	A, B, C	1	4
Flanges, Fittings, and Valves			
SA-420	WPL8	11A	1
SA-522	I	11A	1
SA-592	A	11B	1
	E	11B	2
	F	11B	3
Pipe			
SA-333	8	11A	1
Tubes			
SA-334	8	11A	1
Castings			
SA-487	4 Cl. B and E	11A	3
	CA6NM Cl. A	6	4

(25)

Table TM-130.2-7 Titanium and Titanium Alloys

Specification Number	UNS No.	Grade	ASME P-No.
Plates, Sheet, and Strip			
SB-265	R50400	2	51
	R52400	7	51
	R52402	16	51
	R50550	3	52
	R53400	12	52
	R56320	9	53
Forgings			
SB-381	R50400	F-2	51
	R52400	F-7	51
	R52402	F-16	51
	R50550	F-3	52
	R53400	F-12	52
	R56320	F-9	53
Fittings			
SB-363	R50400	WPT2	51
	R52400	WPT7	51
	R50550	WPT3	52
	R53400	WPT12	52
Pipe			
SB-861 (seamless)	R50400	2	51
	R52400	7	51
	R50550	3	52
	R53400	12	52
	R56320	9	53
SB-862 (welded)	R50400	2	51
	R52400	7	51
	R50550	3	52
	R53400	12	52
	R56320	9	53
Tubing			
SB-338	R50400	2	51
	R52400	7	51
	R52402	16	51
	R50550	3	52
	R53400	12	52
	R56320	9	53
Bars and Billet			
SB-348	R50400	2	51
	R52400	7	51
	R52402	16	51
	R50550	3	52
	R53400	12	52

Table TM-130.2-7
Titanium and Titanium Alloys (Cont'd)

Specification Number	UNS No.	Grade	ASME P-No.
Castings			
SB-367	R50400	C-2	51
	R52400	C-7	51
	R50550	C-3	52

(2) For all other product forms, the material shall be accepted as complying with the material specification if the material specification provides for the marking of each piece with the specification designation, including the grade, type, and class if applicable, and each piece is so marked.

(3) If the material specification does not include for the marking of each piece as indicated in (2), the material shall be accepted as complying with the material specification, provided the following requirements are met:

(-a) Each bundle lift, or shipping container is marked with the specification designation, including the grade, type, and class if applicable by the material Manufacturer or supplier.

(-b) The handling and storage of the material by the vessel Manufacturer shall be documented in the Manufacturer's Quality Control System such that the Inspector can determine that it is the material identified in (-a). Traceability to specific lot, order, or heat is not required. Traceability is required only to material specification and grade and type and class, if applicable.

(4) For pipe or tube where the length is not adequate for the complete marking in accordance with the material specification or not provided in accordance with (3), the material shall be acceptable as complying with the material specification, provided the following are met:

(-a) A coded marking is applied to each piece of pipe or tube by the material Manufacturer or material supplier.

(-b) The coded marking applied by the material Manufacturer or material supplier is traceable to the specification designation, including the grade, type, and class, if applicable.

(b) Except as otherwise provided in TM-110(a) through TM-110(e), TM-110.10, TM-120, and TM-130.1, when some requirements of a material specification of Section II have been completed by other than the material Manufacturer (see TM-140.2 and TM-210.4), then the tank Manufacturer shall obtain supplementary material test reports or certificates of compliance, and the Inspector shall examine these documents and shall determine that they represent the material and meet the requirements of the material specification.

(c) When requirements or provisions of this Section applicable to the materials exceed or supplement the requirements of the material specification of Section II (see TM-140.2, TM-150.6, and TM-210.1), then the tank Manufacturer shall obtain supplementary material test reports or certificates of compliance and the Inspector shall examine these documents and shall determine that they represent the material and meet the requirements or provisions of Section XII.

(d) Unless otherwise specified below, all materials to be used in constructing a pressure vessel shall be visually examined before fabrication for the purpose of detecting, as far as possible, imperfections that would affect the safety of the pressure vessel.

(1) Particular attention should be given to cut edges and other parts of rolled plate that would disclose the existence of laminations, shearing cracks, and other imperfections.

(2) All materials that are to be impact-tested in accordance with the requirements of TM-200 shall be examined for surface cracks.

(3) When a pressure part is to be welded to a flat plate thicker than 13 mm ($^1\!/_2$ in.) to form a corner joint under the provisions of TW-130.5(e), the weld joint preparation in the flat plate shall be examined before welding as specified in (4) by either the magnetic particle or liquid-penetrant methods. After welding, both the peripheral edge of the flat plate and any remaining exposed surface of the weld joint preparation shall be reexamined by the magnetic particle or liquid-penetrant methods as described in (4). When the plate is nonmagnetic, only the liquid-penetrant method shall be used.

(4) For Figure TW-130.5-2, 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 weld joint preparations in the flat plate as shown in sketches (b), (c), (d), and (f)

(-b) the outside peripheral edge of the flat plate after welding as shown in sketches (a) through (d)

(-c) the outside peripheral edge of the flat plate after welding, as shown in sketches (e), (f), and (g) 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, such as defined in TD-500(b)

(-d) the inside peripheral surface of the flat plate after welding as shown in sketches (m) and (n)

(e) The Inspector shall ensure that the thickness and other dimensions of material comply with the requirements of this Section.

(f) The Inspector shall verify that the inspection and marking requirements of TM-190 have been complied with for those castings assigned a casting quality factor exceeding 80%.

TM-140.2 HEAT TREATMENT PERFORMED BY OTHER THAN MATERIAL MANUFACTURER

(25)

When plate specification heat treatments are not performed by the material Manufacturer, they shall be performed by, or be under the control of the Manufacturer who shall 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 specification have been performed. The Manufacturer shall also document in accordance with TM-140.1(b) that the specified heat treatment has been performed.

See TF-310.2, TF-610.3, and TF-610.4 for heat treatment of test specimens.

TM-140.3 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 TM-110(b), TM-110.10, TM-120, or TM-140.1. 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 TF-110.2(a). (See TM-140.2.)

TM-140.4 EXAMINATION OF SURFACES

All materials used in the construction shall be examined for imperfections that have been uncovered during fabrication as well as to determine that the work has been done properly. (See TF-110.3.)

TM-150 ADDITIONAL REQUIREMENTS FOR CARBON AND LOW ALLOY STEELS

TM-150.1 USE IN WELDED CONSTRUCTION

Carbon and 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.

TM-150.2 CARBON AND LOW ALLOY STEEL BOLT MATERIAL

(a) Approved specifications for bolt materials of carbon steel and low alloy steel are given in Table TM-130.2-1. (See TM-110.6.)

(b) High alloy steel and nonferrous bolts, studs, and nuts may be used, provided they meet the requirements of TM-160.2(a) or TM-170.1, as applicable.

TM-150.3 NUTS AND WASHERS FOR CARBON STEEL AND LOW ALLOY STEEL VESSELS

(a) Materials for nuts shall conform to SA-194, SA-563, or to the requirements for nuts in the specifications 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 Table TM-130.2-1 or Table TM-130.2-2 and shall be either: hot- or cold-forged; or machined from hot-forged, hot-rolled, or cold-drawn bars. Washers may be made from any suitable material listed in Tables TM-130.2-1 and TM-130.2-2.

(b) Nuts shall be semifinished, chamfered, and trimmed. Nuts shall be threaded to Class 2B or finer tolerances according to ASME B1.20.1. For use with flanges conforming to the standards listed in TD-100.5, nuts shall conform at least to the dimensions given in ASME B18.2.2 for Heavy Series Nuts.

(c) Nuts of special design or dimensions other than ANSI Heavy Series may be used, 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 [see TG-100.2(c)].

TM-150.4 CARBON AND LOW ALLOY STEEL BARS

(a) Carbon and low alloy steel bolt materials listed in Table TM-130.2-1 may be used as bar material. Allowable stresses at different temperatures are given in Section II, Part D.

(b) Parts made from bars, on which welding is done, shall be made of material for which a P-Number for procedure qualification is given in Section IX, Table QW/QB-422.

(c) *Use of Rod and Bar for Nozzle Neck.* In addition to the pressure parts listed in TM-110.8, rod and bar material listed in Table TM-130.2-1 may be used for nozzle necks of pressure vessels, provided the following additional requirements are met:

(1) When the nozzle neck is greater than DN 100 (NPS 4), or nozzle nominal wall thickness is less than that for standard wall pipe, or the design hoop tension stress is greater than 50% of the allowable stress value, the material shall be formed into a ring. The joints in the ring shall be welded using joints that are Type No. 1 or 2 of Table TW-130.4.

TM-150.5 STRUCTURAL QUALITY STEEL

(a) Structural quality steel plate, sheets, and shapes conforming to specifications listed in Table TM-130.2-1 may be used for nonpressure boundary materials and for attachments to pressure boundary materials not

deemed to be essential to the structural integrity of the pressure vessel.

(b) Structural quality plates, sheets, and shapes may not be used for pressure parts in transport tanks conforming to the requirements of this Section, except as permitted by Mandatory Appendix VIII or the applicable Modal Appendix.

TM-150.6 HEAT TREATMENT OF TEST SPECIMENS

(a) Heat treatment as used in this Section shall include all thermal treatments of the material during fabrication exceeding 480°C (900°F).

(b) When material is subject to heat treatment during fabrication, the test specimens required by the applicable specification shall be obtained from sample coupons that 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.

(c) The material used in the tank shall be represented by test specimens that 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 tank Manufacturer shall specify the temperature, time, and cooling rates to which the material will be subjected during fabrication, except as permitted in TF-310.2(g). Material from which the specimens are prepared shall be heated at the specified temperature within reasonable tolerances such as are normal 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 time may be applied to the test specimen blanks.

(d) Heat treatment of material is not intended to include such local heating as thermal cutting, preheating, welding, or heating below the lower transformation temperature of tubing and pipe for bending or sizing.

(e) Exemptions From Requirement of Sample Test Coupons. See TF-310.2 for exemptions from the requirement of heat treating sample test coupons.

TM-160 ADDITIONAL REQUIREMENTS FOR HIGH ALLOY STEELS

TM-160.1 HIGH ALLOY STEEL MATERIALS

The specifications in Table TM-130.2-2 do not use a uniform system for designating the Grade number of materials that have approximately the same range of chemical composition. To provide a uniform system of reference, these tables include a column of UNS (Unified Numbering System) numbers assigned to identify various alloy compositions. When these particular UNS numbers were assigned, the familiar AISI type numbers for stainless steels were incorporated in the designation. These type numbers are used in the rules of this Section whenever reference is made to materials of approximately the same chemical composition that are furnished under more than one approved specification or in more than one product form.

TM-160.2 HIGH ALLOY STEEL BOLT MATERIAL

(a) Approved specifications for bolt materials of high alloy steel are given in Table TM-130.2-2. (See TM-110.6.)

(b) Nonferrous bolts, studs, and nuts may be used, provided they meet the requirements of TM-170.1 or TM-170.2, as applicable.

TM-160.3 METALLURGICAL PHENOMENA

See Section II, Part D, Nonmandatory Appendix A, A-300.

TM-170 ADDITIONAL REQUIREMENTS FOR NONFERROUS MATERIALS

TM-170.1 BOLT MATERIAL

(a) Approved materials for nonferrous bolts are listed in Tables TM-130.2-3, TM-130.2-4, TM-130.2-5, and TM-130.2-7. (See TM-110.6.)

(b) When 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 Section II, Part D, Subpart 1, Table 3, to be used in design shall be based on the condition of the material selected.

TM-170.2 NUTS AND WASHERS

(a) Approved materials for nonferrous nuts and washers are listed in Tables TM-130.2-3, TM-130.2-4, TM-130.2-5, and TM-130.2-7.

(b) Nuts may be of any dimension or shape, provided their strength is equal to that of bolting, giving due consideration to bolt hole clearance, bearing area, thread form and class of fit, thread shear, and radial thrust from threads.

TM-170.3 METALLURGICAL PHENOMENA

See Section II, Part D, Nonmandatory Appendix A, A-400.

TM-180 ADDITIONAL REQUIREMENTS FOR FERRITIC STEELS ENHANCED BY HEAT TREATMENT

TM-180.1 HEAT TREATMENT OF TEST COUPONS

See TF-610.3 for heat treatment verification tests.

TM-180.2 STRUCTURAL ATTACHMENTS AND STIFFENING RINGS TO FERRITIC STEELS WITH PROPERTIES ENHANCED BY HEAT TREATMENT

(a) Except as permitted in (b), all structural attachments and stiffening rings that are welded directly to pressure parts shall be made of materials of specified minimum yield strength within ±20% of that of the material to which they are attached and which are listed in Table TM-130.2-6.

(b) All permanent structural attachments welded directly to shells or heads constructed of materials conforming to SA-333 Grade 8, SA-334 Grade 8, SA-353, SA-522, SA-553, and SA-645 Grade A shall be of the material covered by these specifications or austenitic stainless steel of the type that cannot be hardened by heat treatment. If suitable austenitic stainless steel is used for permanent attachments, consideration should be given to the greater coefficient of expansion of the austenitic stainless steel.

TM-190 ADDITIONAL REQUIREMENTS FOR CASTINGS

(a) Quality Factors. A casting quality factor as specified below shall be applied to the allowable stress values for carbon and low alloy steel castings. At a welded joint in a casting, only the lesser of the casting quality factor or the weld joint efficiency specified in TW-130.4 applies, but not both. NDE methods and the acceptance standards are given in Mandatory Appendix X.

(1) A casting quality factor not to exceed 80% shall be applied to static castings, which are examined in accordance with the minimum requirements of the material specification. 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 6.35 μm (250 μin.) arithmetical mean deviation, and a factor not to exceed 85% shall be applied.

(2) For nonferrous materials, a factor not to exceed 90% shall be applied if in addition to the minimum requirements of (1).

(-a) Each casting is subjected to a thorough examination of all surfaces, particularly such as are exposed to machining or drilling, without revealing any defects.

(-b) At least three pilot castings[2] representing the first lot of five castings made from a new or altered design are sectioned or radiographed at all critical sections[3] without revealing any defects.

(-c) One additional casting taken at random from every subsequent lot of five is sectioned or radiographed at all critical sections without revealing any defects.

(-d) All castings other than those that have been radiographed are examined at all critical sections[3] by the magnetic particle or liquid-penetrant methods in accordance with the requirements of Mandatory Appendix X.

(3) For nonferrous materials, a factor not to exceed 90% may be used for a single casting that has been radiographed at all critical sections and found free of defects.

(4) For nonferrous materials, a factor not to exceed 90% may be used for a casting that has been machined to the extent that all critical sections[3] are exposed for examination for the full wall thickness. The examination afforded may be taken in lieu of destructive or radiographic testing required in (2)(-b).

(5) For carbon, low alloy, or high alloy steels, higher quality factors may be applied if, in addition to the minimum requirements of (2)(-a), additional examinations are made as follows:

(-a) For centrifugal castings, a factor not to exceed 90% may be applied if the castings are examined by the magnetic particle or liquid-penetrant methods in accordance with the requirements of Mandatory Appendix X.

(-b) For static and centrifugal castings, a factor not to exceed 100% may be applied if the castings are examined with all the requirements of Mandatory Appendix X.

(6) The following additional requirements apply when castings (including those permitted in TM-110.10) are to be used in vessels containing hazardous fluids [see TW-100.1(a)].

(-a) Casings of cast iron and cast ductile iron are prohibited.

(-b) Each casting of nonferrous material permitted by this Section shall be radiographed at all critical sections[3] without revealing any defects. The quality factor for nonferrous castings shall not exceed 90%.

(-c) Each casting of steel material permitted by Section XII shall be examined per Mandatory Appendix X for severe service applications [see Mandatory Appendix X, X-3(b)]. The quality factor shall not exceed 100%.

(b) Defects. Imperfections found as unacceptable by either the material specification or by Mandatory Appendix X, X-3, whichever is more restrictive, are considered to be defects and shall be the basis for rejection of the casting. Where defects may have been repaired by welding, the completed repair shall be subject to reexamination and, when required by either the rules of this Section or the requirements of the casting specification, the repaired casting shall be examined as required by (a)(2), (a)(3), (a)(4), (a)(5), or (a)(6). Repairs shall be made using the procedures and Welders qualified in accordance with Section IX.

(c) Identification and Marking. Each casting to which a quality factor greater than 80% is applied shall be marked with the name, trademark, or other traceable identification of the Manufacturer and the casting identification, including the casting quality factor and the material designation.

ARTICLE TM-2
NOTCH TOUGHNESS REQUIREMENTS

TM-200 GENERAL TOUGHNESS REQUIREMENTS FOR ALL STEEL PRODUCTS

TM-210 GENERAL

(a) Unless exempted by TM-240 or TM-250, or otherwise specified in TM-250.1(c)(2) or TM-260.2(b), Charpy V-notch impact tests in accordance with Article TM-2 shall be made for steel materials used for shells, heads, nozzles, manways, reinforcing pads, flanges, backing strips that remain in place, and attachments that are essential to structural integrity of the pressure vessel when welded to pressure-retaining components.

(b) Toughness test requirements for materials listed in Table TM-130.2-1 are given in TM-240 and the acceptance criteria is in TM-220.1 and TM-220.2. Toughness requirements for materials listed in Table TM-130.2-2 are given in TM-250. Toughness requirements for materials listed in Table TM-130.2-6 are given in TM-260. For weld and heat-affected zone toughness requirements, see TM-230, TM-240.2, TM-250.1, TM-250.2, and TM-260.3, as applicable.

(c) Impact testing is not required for vessels constructed of materials listed in Tables TM-130.2-3, TM-130.2-4, TM-130.2-5, and TM-130.2-7 (see TM-270).

TM-210.1 Test Procedures

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

(b) Unless permitted by Table TM-210.1, the impact test temperature shall not be warmer than the minimum design metal temperature [see TD-140(b)].

Table TM-210.1
Impact Test Temperature Differential

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

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

TM-210.2 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 Figure TM-210.2. 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 245 J (180 ft-lbf) 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 100 J (75 ft-lbf) 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 TM-220.3(b) shall apply for Table TM-130.2-1 materials having a specified minimum tensile strength less than 655 MPa (95 ksi) 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 2.5 mm (0.099 in.), but carbon steels too thin to impact test shall not be used for design temperatures colder than −48 °C (−55°F).

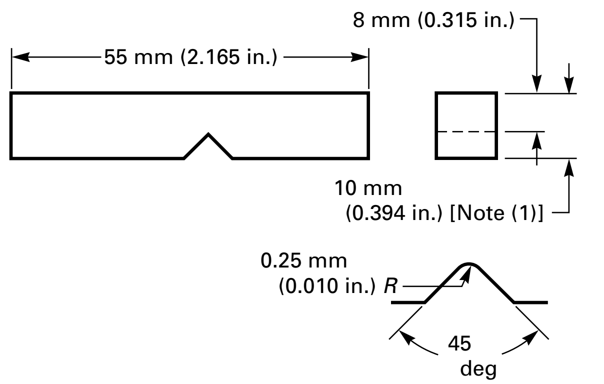
TM-210.3 Standard Product Forms

When no procedural requirements are included in the product specification for toughness testing, the following apply:

(a) 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.

(b) When the part is too small to provide the three specimens of at least minimum size indicated in TM-210.2, no impact test need be made [see TM-210.2(c)].

Figure TM-210.2
Simple Beam Impact Test Specimens (Charpy-Type Test)



NOTE: (1) See TM-210.2(c) and TM-220.3(b) for width of reduced-type specimen.

TM-210.4 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 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 TF-310.2)

(b) The Manufacturer of the vessel may have impact tests made to prove the suitability of a material that the materials Manufacturer has not impact-tested, provided that the number of tests and the method of taking the test specimens are as specified for the materials Manufacturer (see TM-140.1).

TM-220 ACCEPTANCE CRITERIA FOR IMPACT TESTS OF FERROUS MATERIALS OTHER THAN BOLTING

TM-220.1 Minimum Energy Requirements for Table TM-130.2-1 Materials With Specified Minimum Tensile Strength Less Than 655 MPa (95 ksi)

The applicable minimum energy requirement for all specimen sizes shall be that shown in Figure TM-220.1 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 TM-210.2(b). The minimum impact test energy for one specimen shall not be less than two-thirds of the minimum average energy required for three specimens.

TM-220.2 Lateral Expansion Requirements for All Other Steels

(a) Except for materials produced and impact-tested in accordance with the specifications listed in Figure TM-220.1, General Note (c), the applicable minimum lateral expansion opposite the notch for all specimen sizes for Table TM-130.2-1 materials having a specified minimum tensile strength of 655 MPa (95 ksi) or greater and for Table TM-130.2-6 materials shall be not less than the requirements shown in Table TM-220.2. The minimum values for intermediate thicknesses may be obtained by straight line interpolation.

(b) For Table TM-130.2-2 materials, the minimum lateral expansion opposite the notch shall be 0.38 mm (0.015 in.) for minimum design metal temperatures (MDMTs) of −196°C (−320°F) and warmer. For MDMTs colder than −196°C (−320°F), the testing temperature shall be −196°C (−320°F) and the lateral expansion opposite the notch shall be not less than 0.53 mm (0.021 in.). (See also Figure TM-220.2.)

TM-220.3 Impact Test Temperature Criteria

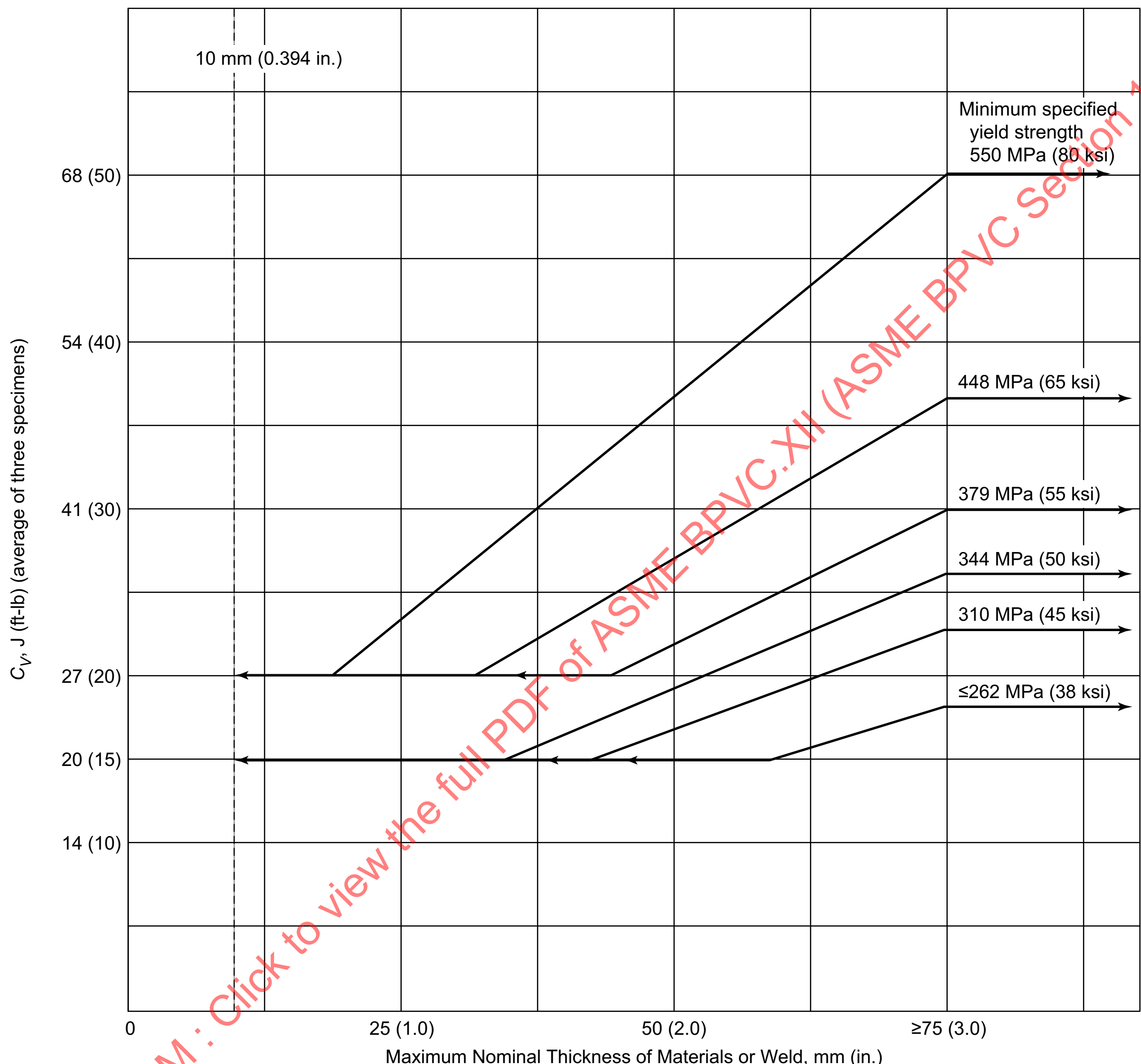
For all Charpy impact tests, the following test temperature criteria shall be observed:

(a) For Materials of Thickness Equal to or Greater Than 10 mm (0.394 in.). Where the largest obtainable Charpy V-notch specimen has a width along the notch of at least 8 mm (0.315 in.) (see Figure TM-210.2), the Charpy test of such a specimen shall be conducted at a temperature not warmer than the minimum design metal temperature. Where the largest possible test specimen has a width along the notch less than 8 mm (0.315 in.), the test shall be conducted at a temperature colder than the minimum design metal temperature by the amount shown in Table TM-220.3 for the specimen width. [This requirement does not apply when the option of TM-210.2(b) is used.]

(b) For Materials With Thickness Less Than 10 mm (0.394 in.). 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.[4]

Where the largest possible test specimen has a width along the notch of less than 80% of the material thickness, the test for Table TM-130.2-1 materials having a specified minimum tensile strength of less than 655 MPa (95 ksi), shall be conducted at a temperature colder than the minimum design metal temperature by an amount equal to the difference (referring to Table TM-220.3) between the temperature reduction corresponding to the actual material thickness and the temperature reduction corresponding to the Charpy specimen width actually

Figure TM-220.1
Charpy V-Notch Impact Test Requirements for Full-Size Specimens for Carbon and Low Alloy Steels, Having Specified Minimum Tensile Strength Less Than 655 MPa (95 ksi), Listed in Table TM-130.2-1 (25)



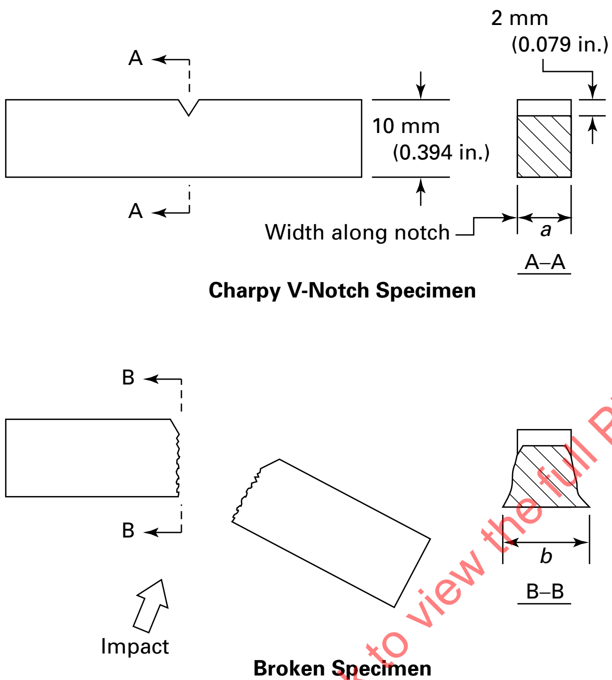
GENERAL NOTES:
(a) Interpolation between yield strengths is permitted.
(b) The minimum impact energy value for one specimen shall not be less than two-thirds of the average energy required for three specimens.
(c) Material produced and impact tested in accordance with SA-320, SA-333, SA-334, SA-350, SA-352, SA-420, SA-437, SA-540 (except for materials produced under Table 2, Note 4 in SA-540), 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 (95 ksi) or more, see TM-220.2.

Table TM-220.2 Minimum Lateral Expansion Requirements

Maximum Nominal Thickness, mm (in.)	Minimum Charpy V-Notch Lateral Expansion, mm (mils) [Note (1)]
≤32 (1$\frac{1}{4}$)	0.38 (15)
54 (2$\frac{1}{8}$)	0.51 (20)
75 (3)	0.64 (25)

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

Figure TM-220.2 Illustration of Lateral Expansion in a Broken Charpy V-Notch Specimen



tested. [This requirement does not apply when the option of TM-210.2(b) is used.] For Table TM-130.2-1 materials having a specified minimum tensile strength greater than or equal to 655 MPa (95 ksi), and for Tables TM-130.2-2 and TM-130.2-6 materials, the test shall be conducted at a temperature not warmer than the minimum design metal temperature.

TM-220.4 Retest

(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.

Table TM-220.3 Charpy Impact Test Temperature Reduction Below Minimum Design Metal Temperature (MDMT)

Actual Material Thickness [See (b)] of Charpy Impact Specimen Width Along the Notch [Note (1)]	
Thickness, mm (in.)	Temperature Reduction, °C (°F)
10.01 (full-size standard bar) (0.394)	0 (0)
8.99 (0.354)	0 (0)
8.00 (0.315)	0 (0)
7.49 ($\frac{3}{4}$ size bar) (0.295)	3 (5)
7 (0.276)	4 (8)
6.7 ($\frac{2}{3}$ size bar) (0.262)	6 (10)
5.99 (0.236)	8 (15)
5.00 ($\frac{1}{2}$ size bar) (0.197)	11 (20)
4 (0.158)	17 (30)
3.33 ($\frac{1}{3}$ size bar) (0.131)	19 (35)
3.00 (0.118)	22 (40)
2.51 ($\frac{1}{4}$ size bar) (0.099)	28 (50)

GENERAL NOTE: For Table TM-130.2-1 materials having a specified minimum tensile strength of less than 655 MPa (95 ksi), when the subsize Charpy impact width is less than 80% of the material thickness.

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

(b) For Lateral Expansion Criteria

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

(-a) for Table TM-130.2-1 materials having specified minimum tensile strengths of 655 MPa (95 ksi) or greater and for Table TM-130.2-6 materials, if the measured value of lateral expansion for one test specimen in a group of three is less than that required by Table TM-220.2

(-b) for materials of Table TM-130.2-2 for MDMTs no colder than −196°C (−320 °F) , if the measured value of lateral expansion for one test specimen in a group of three is less than 0.38 mm (0.015 in.), but not less than 0.25 mm (0.010 in.)

(-c) for materials of Table TM-130.2-2 for MDMTs colder than −196°C (−320°F), if the measured value of lateral expansion for one test specimen in a group of three is less than 0.53 mm (0.021 in.), but not less than 0.38 mm (0.015 in.)

(-d) for materials of Table TM-130.2-6, if the measured value of lateral expansion for one specimen in a group of three is less than that required in Table TM-220.2, but not less than two-thirds of the required value

(2) The retest shall consist of three additional specimens. For materials listed in Table TM-130.2-6 and for Table TM-130.2-1 materials having specified tensile

strengths of 655 MPa (95 ksi) or greater, the retest value for each specimen must equal or exceed the value listed in Table TM-220.2. For Table TM-130.2-2 materials, the retest value for each specimen must equal or exceed 0.38 mm (0.015 in.) for MDMTs no colder than −196°C (−320°F).

(3) If the required values are not obtained in the retest, or if the values in the initial test are less than minimum required for retest, the material may be reheat treated. 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 minimum required values in Table TM-220.2.

(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 TM-220.2(b) is used for the initial test and the acceptance of 100 J (75 ft-lbf) minimum is not attained, retest using full-size (10 mm × 10 mm) specimens will be allowed.

TM-230 IMPACT TEST REQUIREMENTS FOR WELDED JOINTS

TM-230.1 Impact Testing of Welds

(a) For steel vessels of welded construction, the impact toughness of welds and heat-affected zones of procedure qualification plates and vessel impact test plates (production impact test plates) shall be determined as herein required.

(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 TM-140.1, TF-310.2, TF-610.3, and TF-610.4 shall apply to the test plates, except that the provisions of TF-310.2(f) are not applicable to plates joining P-Nos. 1 and 2 materials.

TM-230.2 Location, Orientation, Temperature, and Values of Weld Impact Tests

All welded joint impact tests shall comply with the following:

(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 1.6 mm ($^1/_{16}$ in.) of the surface of the material.

(b) Each set of heat-affected zone impact test specimens shall be taken across the weld and of sufficient length to locate, after etching, the notch in the heat-affected zone. The notch shall be cut approximately normal to the material surface in such a manner as to include as much of the heat-affected zone material as possible in the resulting fracture.

(c) For welds made of solid-state welding process, such as for electric resistance-welded 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 such that the notch is normal to the surface of the material and one face of the specimen shall be within 1.6 mm ($^1/_{16}$ in.) of the surface of the material. The weld impact tests are not required if the weld and the base metal have been annealed, normalized, or quenched and tempered.

(d) The test temperature for welds and heat-affected zones shall not be higher than required for the base metal.

(e) Impact test values shall be at least as high as those required for the base metal.

TM-230.3 Impact Tests of Welding Procedure Qualifications

(a) General. For steel vessels of welded construction, the impact toughness of the welds and heat-affected zones of the procedure qualification test plates shall be determined in accordance with TM-230.2 and the requirements specified in (a) through (d).

(b) When Required. Welding procedure impact tests shall be made when required by TM-240.2, TM-250, or TM-260.3. For vessels constructed of carbon and low alloy steels in Table TM-130.2-1, the test plate material shall satisfy the following requirements relative to the material to be used in production:

(1) be of the same P-Number and Group Number for ferrous materials and the same P-Number and UNS Number for nonferrous materials

(2) meet the minimum notch toughness requirements of TM-220.1 for the thickest material of the range of base material qualified by the procedure (see Figure TM-220.1).

If impact tests are required for the weld metal, but the base metal is exempted from impact tests (as in TM-250), 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 test 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.

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 TM-210 when impact testing is a requirement.

(c) Material Over 38 mm (1$^1/_2$ in.) Thick. When procedure tests are made on material over 38 mm (1½ in.) in thickness, three sets of impact test specimens are required. One set of heat-affected zone specimens shall be taken as described in TM-230.2(b). Two sets of impact test specimens shall be taken from the weld with one set located near [within 1.6 mm ($^1/_{16}$ in.)] 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 in TM-230.2.

(d) Supplementary Essential Variables. The additional supplementary essential variables described in Section IX, QW-250, for impact testing are required.

TM-230.4 Vessel (Production) Impact Test Plates

(a) General. In addition to the requirements of TM-230.3, impact tests of welds and heat-affected zones shall be made in accordance with TM-230.2 for each qualified welding procedure used on each vessel or group of vessels as defined in (c). The vessel impact test plate shall be one of the heats of steel used for the vessel or group of vessels. For Category A joints, the test plate shall, where practicable, be welded as an extension to the end of a production joint so that the test plate weldment will represent as nearly as practicable the quality and type of welding in the vessel joint. 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.

(b) When Required. Vessel (production) impact test plates shall be made for all joints for which impact tests are required for the welding procedure by TM-240.2, TM-250, and TM-260.3 (except where production test plates are specifically exempt by these paragraphs). Tests shall be made of the weld metal and/or heat-affected zone to the extent required by the procedure test (see TM-240.2, TM-250, and TM-260.3).

(c) Number of Impact Test Plates Required

(1) 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 (2). In addition, for Categories A and B joints the following shall apply:

(-a) If automatic or semiautomatic welding is performed, a test plate shall be made in each position employed in the vessel welding.

(-b) 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). Qualifications in the vertical position shall qualify that manual process in all positions.

(2) 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 6 mm ($\frac{1}{4}$ in.) , or 25%, whichever is greater, and of the same specification and grade of material, a test plate shall be made for each 120 m (400 ft) of joints welded by the same procedure.

TM-230.5 Rejection

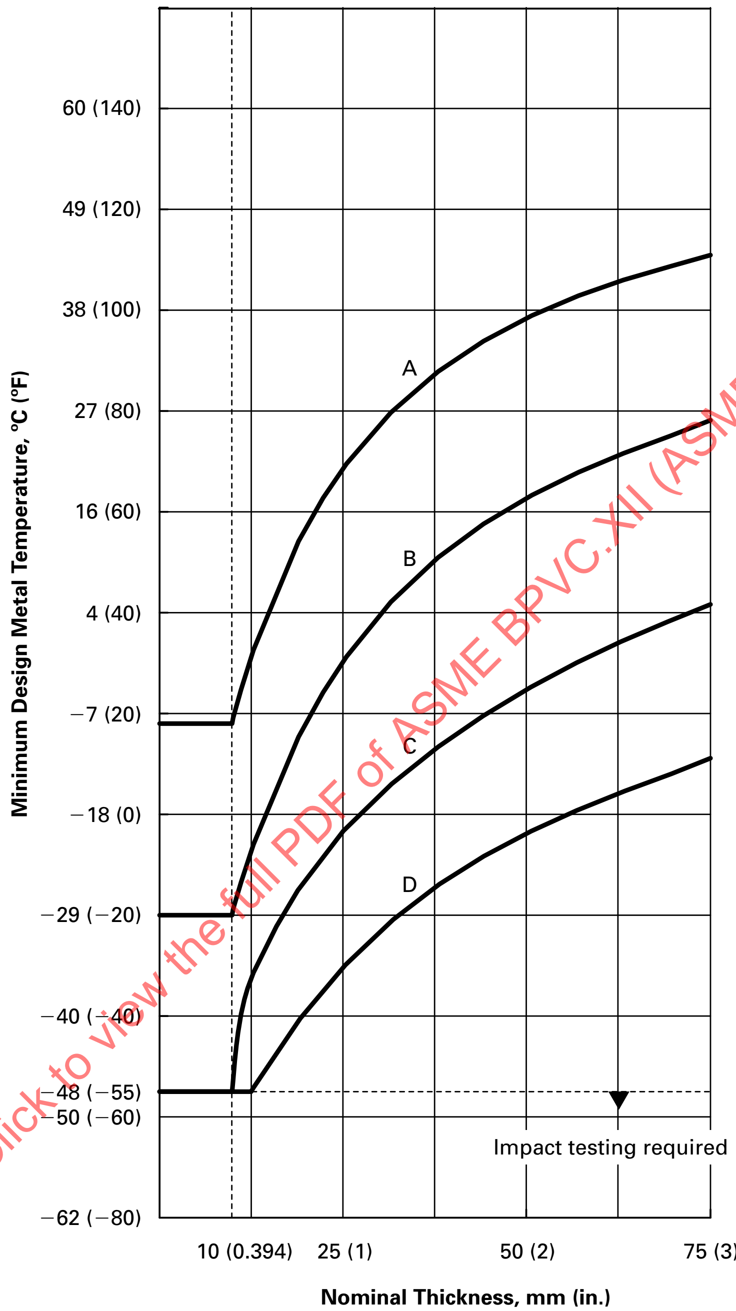
If the vessel test plate fails to meet the impact test requirements, the weld(s) represented by the plate shall be unacceptable. Reheat treatment and retesting, or retesting only, are permitted.

TM-240 IMPACT TEST REQUIREMENTS FOR CARBON AND LOW ALLOY STEELS

TM-240.1 For Carbon and Low Alloy Steels, Dependent on Design Temperature

Figure TM-240.1-1 shall be used to establish impact testing exemptions for steels listed in Table TM-130.2-1. Unless otherwise exempted by the rules of Section XII, impact testing is required for a combination of minimum design metal temperature [see TD-140(b)] 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 Section XII, except as required by TM-240.2 for weld metal and heat-affected zones. See also Table TM-240.1.

Figure TM-240.1-1
Impact Test Exemption Curves



GENERAL NOTES:

(a) Curve A applies to

(1) all carbon and all low alloy steel plates, structural shapes, and bars not listed in Curves B, C, and D below

(2) SA-216 Grades WCB and WCC if normalized and tempered or water-quenched and tempered; SA-217 Grade WC6 if normalized and tempered or water-quenched and tempered

(b) Curve B applies to

(1) SA-216 Grade WCA if normalized and tempered or water-quenched and tempered
SA-216 Grades WCB and WCC for thicknesses not exceeding 50 mm (2 in.), if produced to fine grain practice and water-quenched and tempered
SA-285 Grades A and B
SA-414 Grade A
SA-515 Grade 60

Figure TM-240.1-1
Impact Test Exemption Curves (Cont'd)

GENERAL NOTES (Cont'd)

SA-516 Grades 65 and 70 if not normalized
SA-612 if not normalized
SA-662 Grade B if not normalized
SA/EN 10028-2 P295GH as-rolled;

(2) except for cast steels, all materials of Curve A if produced to fine grain practice and normalized that are not listed in Curves C and D below;

(3) all pipe, fittings, forgings and tubing not listed for Curves C and D below;

(4) parts permitted under TM-110.10 shall be included in Curve B even when fabricated from plate that otherwise would be assigned to a different curve.

(c) Curve C

(1) SA-302 Grades C and D
SA-516 Grades 55 and 60 if not normalized
SA-662 Grade A

(2) all material of Curve B if produced to fine grain practice and normalized and not listed for Curve D below.

(d) Curve D

SA-203
SA-508 Grade 1
SA-516 if normalized
SA-524 Classes 1 and 2
SA-537 Classes 1, 2, and 3
SA-612 if normalized
SA-662 if normalized
SA-738 Grade A
SA-738 Grade A with Cb and V deliberately added in accordance with the provisions of the material specification, not colder than −29 °C (−20°F)
SA-738 Grade B not colder than −29°C (−20°F)
SA/EN 10028-2 P295GH if normalized [see Note (g)(3)]
SA/EN 10028-3 P275NH

(e) For bolting and nuts, the following impact test exemption temperature shall apply:

Bolting

Spec. No.	Grade	Diameter, mm (in.)	Impact Test Exemption Temperature, °C (°F)
SA-193	B5	Up to 100 (4), incl.	−29 (−20)
	B7	Up to 65 (2½) , incl.	−48 (−55)
		Over 65 (2½) to 180 (7)	−40 (−40)
	B7M	Up to 65 (2½) , incl.	−48 (−55)
	B16	Up to 180 (7), incl.	−29 (−20)
SA-307	B	All	−29 (−20)
SA-320	L7, L7A,	Up to 65 (2½) , incl.	See Figure TM-220.1, General Note (c)
	L7M,	Up to 65 (2½) , incl.	See Figure TM-220.1, General Note (c)
	L43	Up to 25 (1), incl.	See Figure TM-220.1, General Note (c)
SA-325	1	13 (½) to 38 (1½)	−29 (−20)
SA-354	BC	Up to 100 (4), incl.	−18 (0)
	BD	Up to 100 (4), incl.	−7 (20)
SA-437	B4B, B4C	All diameters	See Figure TM-220.1, General Note (c)
SA-449	...	Up to 75 (3), incl.	−29 (−20)
SA-540	B21 Cl. All	All	Impact test required
	B22 Cl. 3	Up to 100 (4), incl.	Impact test required
	B23 Cl. 1, 2	All	Impact test required
	B23 Cl. 3, 4	Up to 150 (6), incl.	See Figure TM-220.1, General Note (c)
	B23 Cl. 3, 4	Over 150 (6) to 240 (9½) , incl.	Impact test required
	B23 Cl. 5	Up to 200 (8), incl.	See Figure TM-220.1, General Note (c)
	B24 Cl. 5	Over 200 (8) to 240 (9½) , incl.	Impact test required
	B24 Cl. 1	Up to 150 (6), incl.	See Figure TM-220.1, General Note (c)
	B24 Cl. 1	Over 150 (6) to 200 (8), incl.	Impact test required
	B24 Cl. 2	Up to 180 (7), incl.	See Figure TM-220.1, General Note (c)
	B24 Cl. 2	Over 180 (7) to 240 (9½) , incl.	Impact test required
	B24 Cl. 3, 4	Up to 200 (8), incl.	See Figure TM-220.1, General Note (c)

Figure TM-240.1-1
Impact Test Exemption Curves (Cont'd)

GENERAL NOTES (Cont'd)

Bolting

Spec. No.	Grade	Diameter, mm (in.)	Impact Test Exemption Temperature, °C (°F)
	B24 Cl. 3, 4	Over 200 (8) to 240 ($9\frac{1}{2}$) , incl.	Impact test required
	B24 Cl. 5	Up to 240 ($9\frac{1}{2}$) , incl.	See Figure TM-220.1, General Note (c)
	B24V Cl. 3	All	See Figure TM-220.1, General Note (c)

Nuts

Spec. No.	Grade	Impact Test Exemption Temperature, °C (°F)
SA-194	2, 2H, 2HM, 3, 4, 7, 7M, and 16	−55 (−48)
SA-540	B21/B22/B23/B24/B24V	−55 (−48)

(f) When no class or grade is shown, all classes or grades are included.
(g) The following shall apply to all material assignment notes.
(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 procedure necessary to obtain a fine austenitic grain size as described in SA-20.
(3) Normalized rolling condition is not considered as being equivalent to normalizing.
(h) Tabular values for this Figure are provided in Table TM-240.1.
(i) Castings not listed in General Notes (a) and (b) shall be impact tested.

Components such as shells, heads, nozzles, manways, reinforcing pads, stiffening rings, flanges, flat cover plates, backing strips, and attachments that 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), and the minimum design metal temperature. The following thickness limitations apply when using Figure TM-240.1-1.

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

(1) for butt joints, except those in flat heads, the nominal thickness of the thickest welded joint [see Figure TM-240.1-2, 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, the larger of (2) 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 temperatures 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 (MDMT) of the welded assembly [see Figure TM-240.1-2, sketch (b)]

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

(c) The governing thickness of flat nonwelded parts, such as bolted flanges 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.

Examples of the governing thickness for some typical vessel details are shown in Figure TM-240.1-2.

TM-240.2 Impact Tests of Welding Procedures

Except as exempted by TM-240.4(a), the Welding Procedure Qualification for welded construction shall include impact tests of welds and heat-affected zones made in accordance with TM-230 when required by the following provisions. The MDMT used below shall be the MDMT stamped on the nameplate, or the exemption temperature of the welded component before applying the temperature reduction permitted by TM-240.3(a) or TM-240.4(g):

(a) Welds made with filler metal shall be impact-tested in accordance with TM-210 and TM-230 when any of the following apply:

(1) when either base metal is required to be impact-tested by the rules of this Section, or

(2) when joining base metals from Figure TM-240.1-1 Curves C or D, or metals exempted from impact testing by TM-240.4(f), and the minimum design metal temperature is colder than −29°C (−20°F) but not colder than −48°C (−55°F), unless welding consumables that have been classified by impact tests

Table TM-240.1
Tabular Values for Figure TM-240.1-1

Thickness, in.	Curve A, °F	Curve B, °F	Curve C, °F	Curve D, °F
0.25	18	−20	−55	−55
0.3125	18	−20	−55	−55
0.375	18	−20	−55	−55
0.4375	25	−13	−40	−55
0.5	32	−7	−32	−55
0.5625	37	−1	−26	−51
0.625	43	5	−22	−48
0.6875	48	10	−18	−45
0.75	53	15	−15	−42
0.8125	57	19	−12	−38
0.875	61	23	−9	−36
0.9375	65	27	−6	−33
1	68	31	−3	−30
1.0625	72	34	−1	−28
1.125	75	37	2	−26
1.1875	77	40	4	−23
1.25	80	43	6	−21
1.3125	82	45	8	−19
1.375	84	47	10	−18
1.4375	86	49	12	−16
1.5	88	51	14	−14
1.5625	90	53	16	−13
1.625	92	55	17	−11
1.6875	93	57	19	−10
1.75	94	58	20	−8
1.8125	96	59	22	−7
1.875	97	61	23	−6
1.9375	98	62	24	−5
2	99	63	26	−4
2.0625	100	64	27	−3
2.125	101	65	28	−2
2.1875	102	66	29	−1
2.25	102	67	30	0
2.3125	103	68	31	1
2.375	104	69	32	2
2.4375	105	70	33	3
2.5	105	71	34	4
2.5625	106	71	35	5
2.625	107	73	36	6
2.6875	107	73	37	7
2.75	108	74	38	8
2.8125	108	75	39	8
2.875	109	76	40	9
2.9375	109	77	40	10
3	110	77	41	11

GENERAL NOTE: See Figure TM-240.1-1 for SI values.

at a temperature not warmer than the MDMT by the applicable SFA specification are used

(3) when joining base metals exempt from impact testing by TM-240.4(f) when the design metal temperature is colder than −48 °C (−55°F).

(b) Welds in materials listed in Table TM-130.2-1 made without the use of filler metal shall be impact-tested when the thickness of the weld exceeds 13 mm ($^1/_2$ in.) for all minimum design metal temperatures or when the thickness at the weld exceeds 8 mm ($^5/_{16}$ in.) and the minimum design metal temperature is colder than 10°C (50°F).

(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 Section

(2) when the welds have any individual weld pass exceeding 13 mm ($^1/_2$ in.) in thickness, and the minimum design metal temperature is colder than 21°C (70°F)

(3) when joining base metals exempt from testing by TM-240.4(f) when the minimum design metal temperature is colder than −48°C (−55°F)

(d) Vessel (production) impact tests in accordance with TM-230.4 may be waived for any of the following:

(1) weld metals joining steels exempted from impact testing by TM-240.1 or TM-240.4 for minimum design metal temperatures of −29 °C (−20°F) or warmer

(2) weld metals defined in (a)(2) and (a)(3)

(3) heat-affected zones in steels exempted from impact testing by TM-240.1 or TM-240.4, except when (c)(3) applies

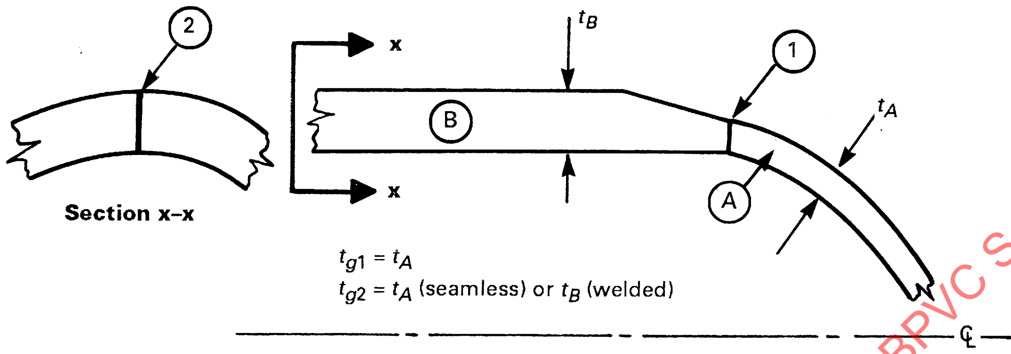
TM-240.3 For Carbon and Low Alloy Steels, Dependent on Design Stress Values

(a) When the coincident ratio defined in Figure TM-240.3-1 is less than one, Figure TM-240.3-1 provides a basis for the use of components made of Table TM-130.2-1 materials without impact testing at MDMT colder than that derived from TM-240.1.

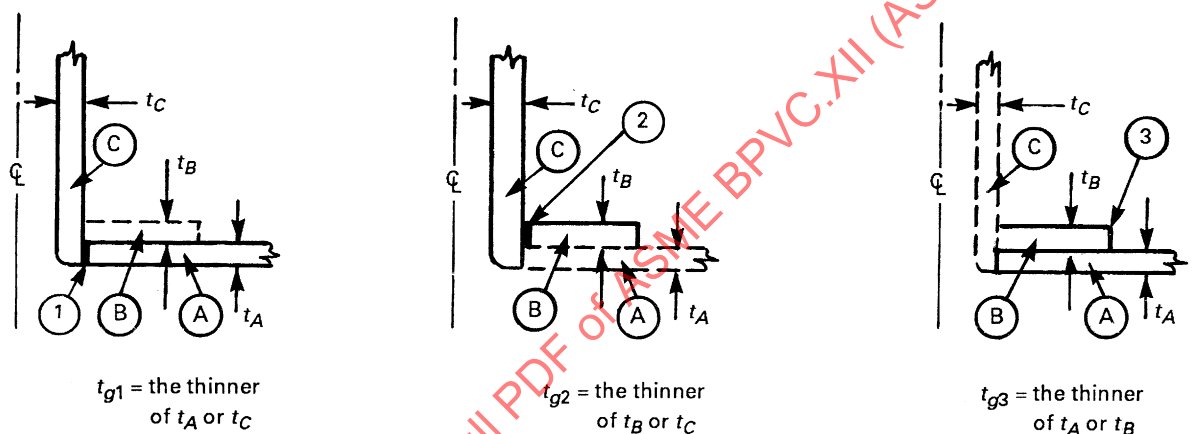
(1) For such components, and for MDMT of −48°C (−55°F) and warmer, the MDMT without impact testing as determined in TM-240.1 for the given material and thickness may be reduced as determined from Figure TM-240.3-1. If the resulting temperature is colder than the required MDMT, impact testing of the material is not required.

(2) Figure TM-240.3-1 may also be used for components not stressed in general primary membrane tensile stress, such as flat heads, covers, and flanges (including bolts and nuts). The MDMT of these components without impact testing as determined in TM-240.1 or TM-240.4(b) may be reduced as determined from Figure TM-240.3-2. The ratio used in Step 3 of Figure TM-240.3-2 shall be the ratio of maximum design pressure at the MDMT to the maximum allowable pressure (MAP) of the component

Figure TM-240.1-2
Some Typical Tank Details Showing the Governing Thicknesses as Defined in TM-240.1

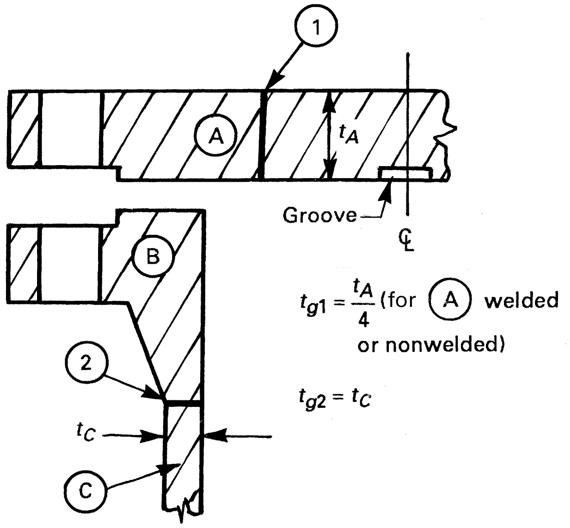


(a) Butt-Welded Components

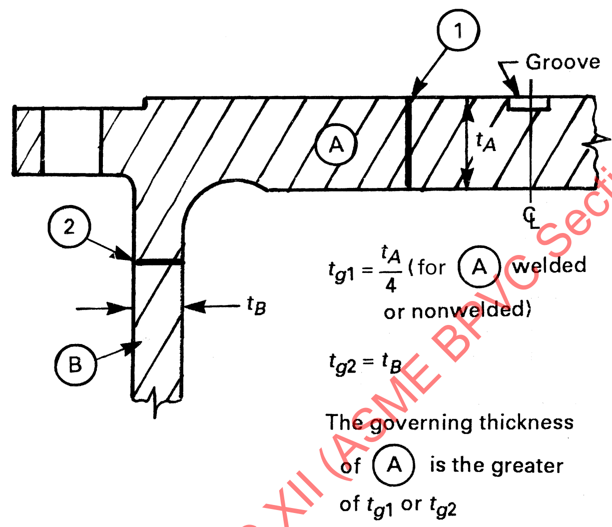


(b) Welded Connection With Reinforcement Plate Added [Note (1)]

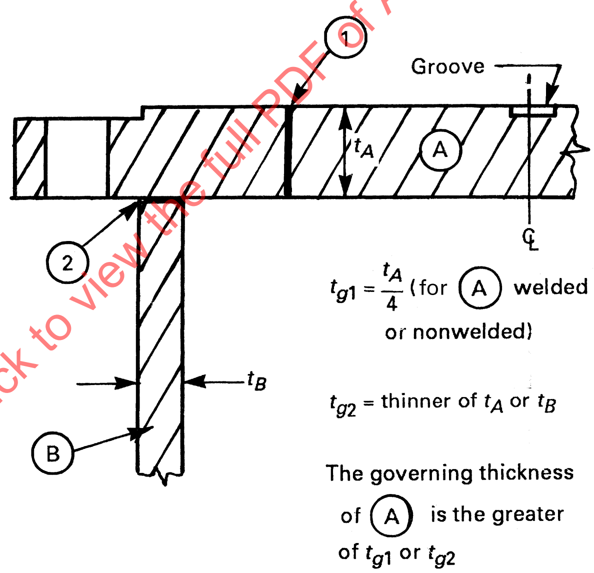
Figure TM-240.1-2
Some Typical Tank Details Showing the Governing Thicknesses as Defined in TM-240.1 (Cont'd)



(c) Bolted Flat Head or Tubesheet and Flange

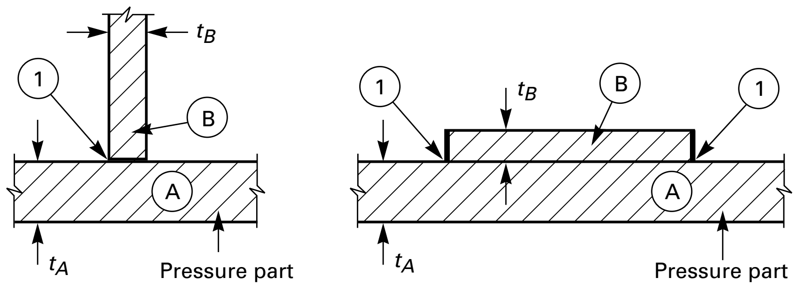


(d) Integral Flat Head or Tubesheet



(e) Flat Head or Tubesheet With a Corner Joint

Figure TM-240.1-2
Some Typical Tank Details Showing the Governing Thicknesses as Defined in TM-240.1 (Cont'd)



t_{g1} = thinner if t_A or t_B

(f) Welded Attachments as Defined in TM-240.1

GENERAL NOTE: t_g = governing thickness of the welded joint as defined in TM-240.1

NOTE: (1) Using t_{g1}, t_{g2}, and t_{g3}, determine the warmest MDMT and use that as the permissible MDT for the welded assembly.

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 −48°C (−55°F).

(3) In lieu of using (2), the MDMT determined in TM-240.1 or TM-240.4(b) may be reduced for a flange attached by welding, by the same reduction as determined in (2) 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.

(4) When the minimum design metal temperature is colder than −48°C (−55°F), impact testing is required for all materials, except as allowed in (5) and TM-240.4(g).

(5) When the minimum design metal temperature is colder than −48°C (−55°F) and not colder than −104°C (−155°F), and the coincident ratio defined in Figure TM-240.3-1 is less than or equal to 0.35, impact testing is not required.

(b) The exemptions in (a) apply to those vessels in which the pressure is dependent on the vapor pressure of the contents (e.g., vessels 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 on or above the line in Figure TM-240.1-1 for the applicable group of materials, using the appropriate design stress values in Section II, Part D. Thickness calculations then will be made for the maximum coincident pressure expected below the line in Figure TM-240.1-1 for the applicable group of materials using the reduced design stress value(s). The greater of the thickness so calculated shall be used. Comparison of pressure ratios or stress ratios may suffice when loadings not caused by pressure are insignificant.

TM-240.4 Other Requirements and Exemptions for Carbon and Low Alloy Steels

(a) Impact testing in accordance with Article TM-2 is not mandatory for tank materials, which satisfy all of the following:

(1) The material shall be limited to P-No. 1, Gr. No. 1 or 2, and the thickness as defined in TM-240.1 shall not exceed that given in (-a) and (-b):

(-a) 6 mm ($^1\!/_4$ in.) for materials listed in Curve A of Figure TM-240.1-1

(-b) 13 mm ($^1\!/_2$ in.) for materials listed in Curve B, C, or D of Figure TM-240.1-1

(2) The completed vessel shall be hydrostatically tested in accordance with Article TT-2.

(3) The design temperature is neither warmer than 343°C (650°F) nor colder than −29°C (−20°F).

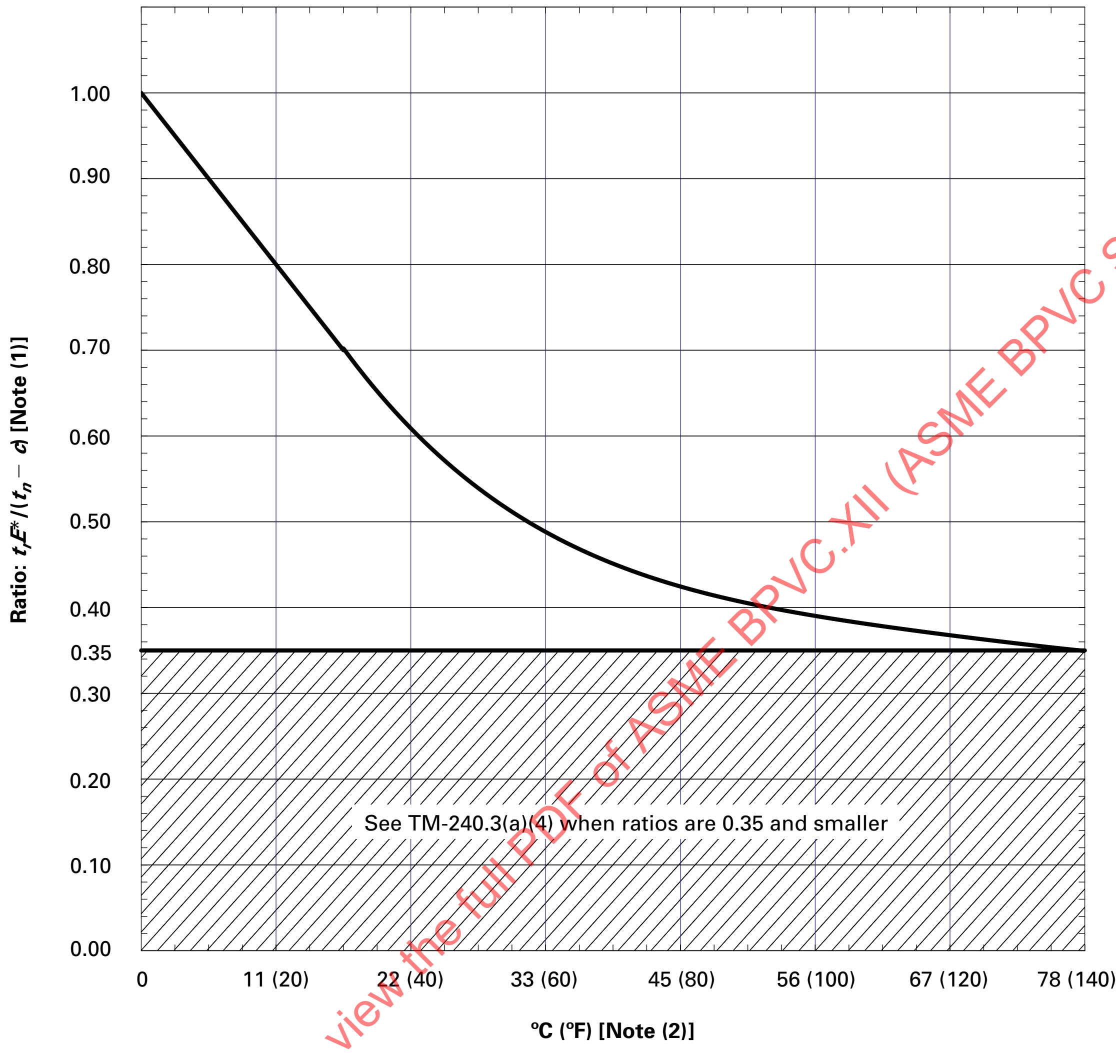
(4) Thermal or mechanical shock loadings are not a controlling design requirement (see TD-200).

(5) Cyclic loading is not a controlling design requirement (see TD-200).

(b) No impact testing is required for ASME B16.5 and ASME B16.47 ferritic steel flanges used at design metal temperatures not colder than −29°C (−20°F).

(c) No impact testing is required for Table TM-130.2-1 materials with a thickness of 2.5 mm (0.10 in.) and thinner, but such exempted Table TM-130.2-1 materials shall not be used at design metal temperatures colder than −48 °C (−55°F). For vessels or components made from DN 100 (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 −104°C (−155°F) and warmer:

Figure TM-240.3-1
Reduction in Minimum Design Metal Temperature Without Impact Testing



Legend:

c = corrosion allowance, mm (in.)

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

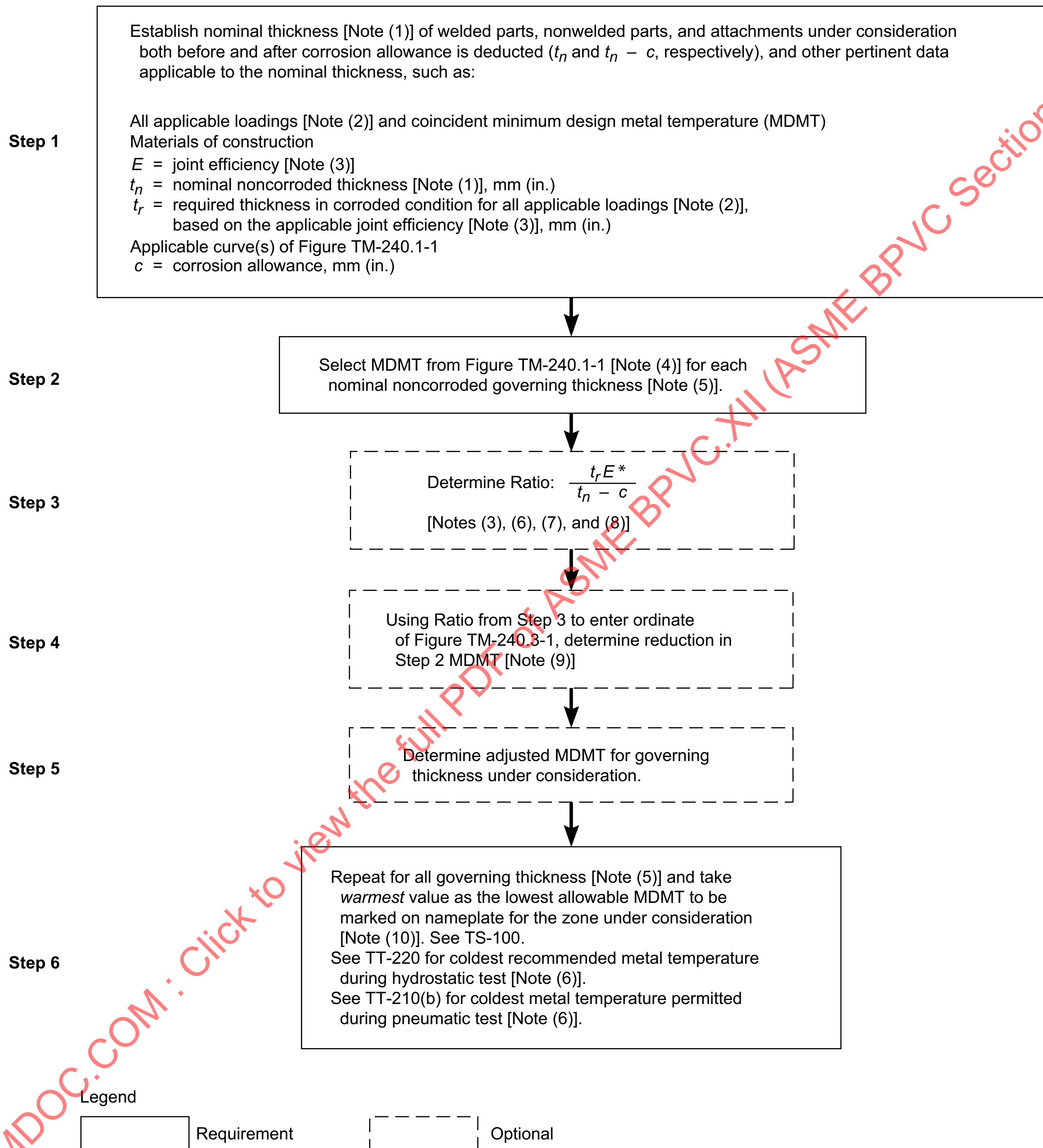
t_r = required thickness of the component under consideration in the corroded condition for all applicable loadings [see Figure TM-240.3-2, Note (2)], based on the applicable joint efficiency E [see Figure TM-240.3-2, Note (3)], mm (in.)

NOTES:

(1) Alternative Ratio = S^*E^* divided by the product of the maximum allowable stress value from Table TM-130.2-1 times E, where S^* is the applied general primary tensile stress and E and E^* are as defined in Figure TM-240.3-2, Note (3).

(2) See TM-240.4(h).

Figure TM-240.3-2
Diagram of TM-240.1 Rules for Determining Lowest Minimum Design Metal Temperature (MDMT) Without Impact Testing



NOTES:
(1) For pipe where a mill undertolerance is allowed by the material specification, the thickness after the mill undertolerance has been deducted shall be taken as the noncorroded nominal thickness, t_n, for 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 TD-200, which result in general primary membrane tensile stress at the coincident MDMT.
(3) E is the joint efficiency (see Table TW-130.4) used in the calculation of t_r; E^* has a value equal to E, except that E^* shall not be less than 0.80. For castings, use quality factor or joint efficiency E, whichever governs design.
(4) The construction of Figure TM-240.1-1 is such that the MDMT so selected is considered to occur coincidentally with the applied general primary membrane tensile stress at the maximum allowable stress value in tension from Section II Part D. Tabular values for Figure TM-240.1-1 are shown in Table TM-240.1.

Figure TM-240.3-2
Diagram of TM-240.1 Rules for Determining Lowest Minimum Design Metal Temperature (MDMT) Without Impact Testing (Cont'd)

NOTES (Cont'd)
(5) See TM-240.1(a), TM-240.1(b), and TM-240.1(c) for definitions of governing thickness.
(6) If the basis for calculated test pressure is greater than the design pressure, 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 permitted during the pneumatic test. See TT-210(a)(3) and TT-210(b)(5).
(7) Alternatively, a ratio of S^*E^* divided by the product of the maximum allowable stress value in tension from Section II, Part D, times E may be used, where S^* is the applied general membrane tensile stress and E and E^* are as defined in Note (3).
(8) For TM-240.3(b) and TM-240.4(h), a ratio of the maximum design pressure at the MDMT to the maximum allowable pressure (MAP) at the MDMT shall be used. The maximum MAP is defined as the highest permissible pressure as determined by the design equations for the component using the nominal thickness less corrosion allowance and the maximum allowable stress value from Section II, Part D at the MDMT. For ferritic steel flanges defined in TM-220.4(b), the flange rating at the warmer of the MDMT or 38°C (100°F) may be used as the MAP.
(9) For reduction in MDMT up to and including 4°C (40°F), the reduction can be determined by: reduction in MDMT = (1 − ratio) 38°C [MDMT = (1 −ratio) 100°F].
(10) A colder MDMT may be obtained by selective use of impact-tested materials as appropriate to the need (see TM-210). See also TM-240.4(g).

SMYS, MPa (ksi)	Thickness, mm (in.)
140 to 240 (20 to 35)	6.0 (0.237)
250 to 310 (36 to 45)	3.2 (0.125)
315 (46) and higher	2.5 (0.10)

(d) The material Manufacturer's identification marking die required by the material specification shall not be stamped on plate material less than 6 mm (1/4 in.) 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 5 mm (0.1875 in.) or the minimum nominal pipe wall thickness shall be 4 mm (0.154 in.).

(3) Minimum design metal temperature shall be not colder than −29°C (−20°F).

(e) Unless specifically exempted in Figure TM-240.1-1, materials having a SMYS greater than 450 MPa (65 ksi) must be impact-tested.

(f) Materials produced and impact-tested in accordance with specifications listed in Figure TM-220.1, General Note (c), are exempt from impact testing by the rules of this Section at minimum design metal temperatures not more than 3°C (5°F) colder than the test temperature required by the specification.

(g) If postweld heat treating is performed when it is not otherwise a requirement of Section XII, a 17°C (30°F) reduction in the temperature at which impact testing is required by Figure TM-240.1-1 is permitted for P-No. 1 materials (see TF-320.1).

(h) For components made of Table TM-130.2-1 materials that are impact-tested, Figure TM-240.3-1 provides a basis for the use of these components at a MDMT colder than the impact test temperature, provided the coincident ratio defined in Figure TM-240.3-1 is less than one and the MDMT is not colder than −104°C (−155°F).

(1) For such components, the MDMT shall be not colder than the impact test temperature less the allowable temperature reduction as determined from Figure TM-240.3-2.

(2) Figure TM-240.3-1 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 be not colder than the impact test temperature less the allowable temperature reduction as determined from Figure TM-240.3-2. The ratio used in Figure TM-240.3-2, Step 3 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), the MDMT for a flange attached by welding shall be not colder than the impact test temperature less the allowable temperature reduction as determined in (1) for the neck or shell to which the flange is attached.

NOTE: The bolt-up condition need not be considered when determining the temperature reduction for flanges.

(i) No impact testing is required for metal backing strips, which remain in place, made of materials assigned to Figure TM-240.1-1, Curve A in thicknesses not exceeding 6 mm (1/4 in.) when the minimum design temperature is −29°C (−20°F) or warmer.

TM-250 IMPACT TEST REQUIREMENTS FOR HIGH ALLOY STEELS

Impact tests employing the lateral expansion criterion of TM-250.1 shall be performed on materials listed in Table TM-130.2-2 for all combinations of materials and minimum design metal temperatures, except as exempted by TM-250.4, TM-250.5, TM-250.6, TM-250.7, or TM-250.8. Impact tests are not required where the maximum obtainable Charpy specimen has a width along the notch less than 2.5 mm (0.099 in.). As an alternative method to impact tests, ASTM E1820 J1c tests are allowed when the MDMT is colder than −196°C (−320°F). See Nonmandatory Appendix J for the flowchart illustration of impact testing requirements.

TM-250.1 Required Impact Testing of Base Metal, Heat-Affected Zones, and Weld Metal

(a) Impact tests shall be made from sets of three test specimens. A set shall be tested from the base metal; a set shall be tested from the heat-affected zone (HAZ); a set shall be tested from the weld metal. The specimens shall be subjected to the same heat treatments[5] as the part or vessel that the specimens represent. Test procedures, size, location, and orientation of the specimen shall be the same as required in TM-220 and TM-230.

(b) When the MDMT is −196°C (−320°F) and warmer, impact tests shall be performed at the MDMT or colder, and the following requirements shall be met:

(1) Each of the three specimens tested in each set shall have a lateral expansion opposite the notch not less than 0.38 mm (0.015 in.) for MDMTs of −196°C (−320°F) and warmer.

(2) When MDMT is −196°C (−320°F) and warmer, and the average value of lateral expansion of the three specimens in a set equals or exceeds 0.38 mm (0.015 in.), but the value of lateral expansion for one specimen of that set is less than 0.38 mm (0.015 in.), but not less than 0.25 mm (0.010 in.), a retest of three additional specimens may be made in accordance with TM-220.4(b).

(c) When MDMT is colder than −196°C (−320°F), production welding processes shall be limited to shielded metal arc welding (SMAW), gas metal arc welding (GMAW), submerged arc welding (SAW), plasma arc welding (PAW), and gas tungsten arc welding (GTAW). Notch toughness testing shall be performed as specified in (1) and (2), as appropriate.

(1) If using Type 316L weld filler metal, or Type 308L filler metal welded with the GTAW or GMAW process

(-a) a weld metal deposited from each heat of Type 316L filler metal shall have a Ferrite Number (FN) not greater than 10, and a weld metal deposited from each heat of Type 308L filler metal shall have a FN in the range of 4 to 14, as measured by a ferritescope or magna gauge calibrated in accordance with AWS A4.2, or as determined by applying the chemical composition from the test weld to Figure TM-250.1.

(-b) impact tests shall be conducted at −196°C (−320°F) on three sets of three specimens: one set from the base metal, one set from the weld metal, one set from the HAZ.

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

(2) When the qualifying conditions of (1) cannot be met

(-a) a weld metal deposited from each heat or lot of austenitic stainless steel filler metal used in production shall have a FN not greater than the FN determined for the test weld.

(-b) impact tests shall be conducted at −196°C (−320°F) on a set of three specimens from the base metal. Each of three specimens shall have a lateral expansion opposite the notch not less than 0.53 mm (0.021 in.).

(-c) ASTM E1820 J_{IC} tests shall be conducted on two sets of two specimens: one set from the HAZ, one set from the weld metal, at a test temperature no warmer than MDMT. The HAZ specimen orientation shall be T−L as defined in ASTM E399. A K_{IC} (J) value not less than 132 $\text{MPa}\sqrt{\text{m}}$ (120 $\text{ksi}\sqrt{\text{in.}}$) is required for all specimens tested.

(3) When the required Charpy impact test specimens do not meet the lateral expansion requirements in (1)(-c) or (2)(-b), ASTM E1820 J_{IC} tests shall be conducted on an additional set of two specimens representing the failed set of impact test specimens at a test temperature no warmer than MDMT. The specimen orientation for the base metal and HAZ shall be T−L. A K_{IC} (J) value not less than 132 $\text{MPa}\sqrt{\text{m}}$ (120 $\text{ksi}\sqrt{\text{in.}}$) is required for all specimens tested.

TM-250.2 Required Impact Testing for Welding Procedure Qualifications

For welded construction, the Welding Procedure Qualification shall include impact tests of welds and heat-affected zones (HAZs) made in accordance with TM-230.3 and with the requirements of TM-250.1, when any of the components[6] of the welded joint are required to be impact-tested by the rules of Section XII.

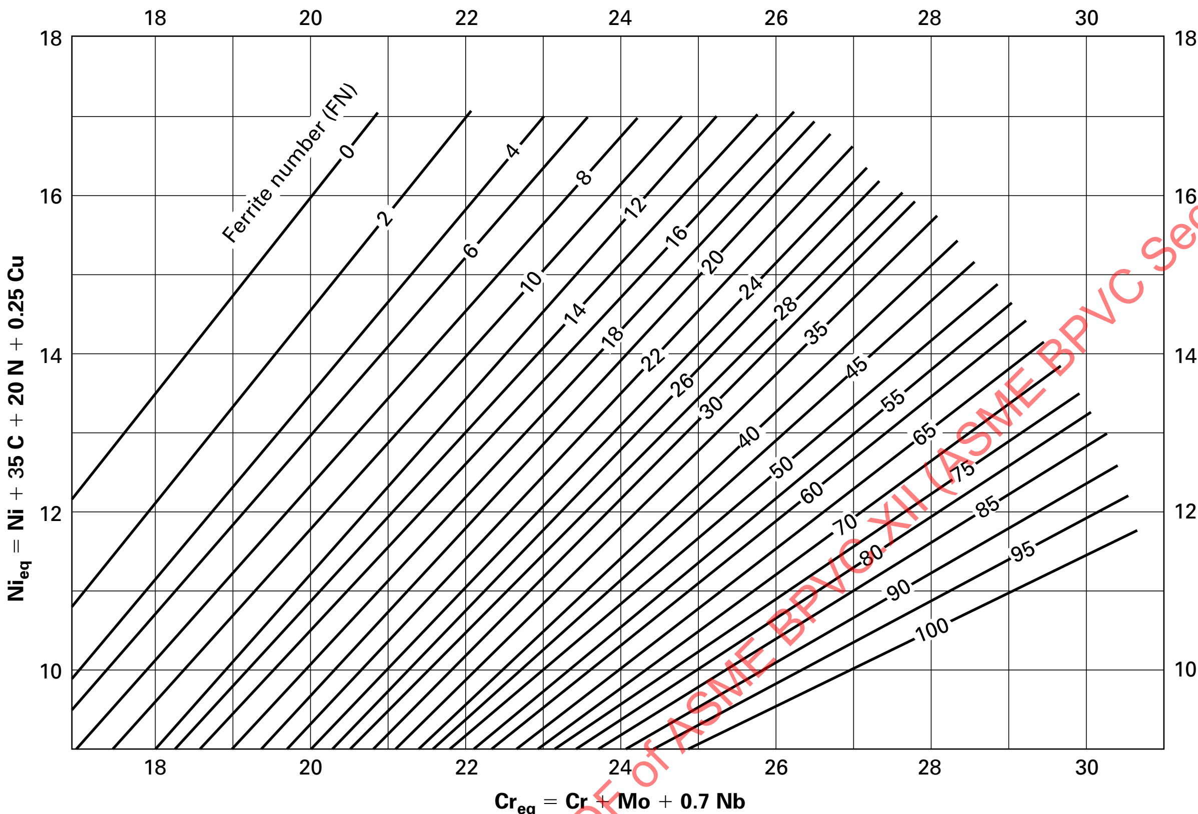
TM-250.3 Required Impact Tests When Thermal Treatments Are Performed

Impact tests are required at the test temperature in accordance with TM-250.1, but not warmer than 20°C (70°F), whenever thermal treatments within the temperature ranges listed for the following materials are applied:

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

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

Figure TM-250.1
Weld Metal Delta Ferrite Content



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.

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

TM-250.4 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 TM-250.3.

(a) For austenitic chromium-nickel stainless steels as follows:

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

(2) having a carbon content exceeding 0.10% at MDMTs of −48°C (−55°F) and warmer

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

(b) For austenitic chromium-manganese-nickel stainless steels (200 series) as follows:

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

(2) having a carbon content exceeding 0.10% at MDMTs of −48°C (−55°F) and warmer

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

(c) For the following cast and wrought steels at MDMTs of −29°C (−20°F) and warmer:

(1) austenitic-ferritic duplex steels with a nominal thickness of 10 mm (3/8 in.) and thinner

(2) ferritic chromium stainless steels with a nominal thickness of 3.2 mm (1/8 in.) and thinner

(3) martensitic chromium stainless steels with a nominal thickness of 6 mm (1/4 in.) and thinner

Carbon content as used in (a) and (b) is as specified by the purchaser and must be within the limits of the material specification.

TM-250.5 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 MDMTs, except as modified in TM-250.3:

(a) 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 −104°C (−155°F) and warmer

(b) for austenitic weld metal

(1) 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 −104°C (−155°F) and warmer

(2) 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 −48°C (−55°F) and warmer

(c) for the following weld metal, when the base metal of similar chemistry is exempt as stated in TM-250.4(c), then the weld metal shall also be exempt at MDMTs of −29°C (−20°F) and warmer:

(1) austenitic-ferritic duplex steels

(2) ferritic chromium stainless steels

(3) martensitic chromium stainless steels

Carbon content as used in (b) is for weld metal produced with the addition of filler metal.

TM-250.6 Pre-Use Test Requirements for Austenitic Stainless Steel Welding Consumables

For austenitic stainless steel production welds at MDMTs colder than −104°C (−155°F), all of the following conditions shall be satisfied:

(a) The welding processes are limited to SMAW, SAW, GMAW, GTAW, and PAW.

(b) The applicable Welding Procedure Specifications (WPSs) are supported by Procedure Qualification Records (PQRs) with impact testing in accordance with the requirements of TM-210 (using the acceptance criteria of TM-250.1) or when the applicable PQR is exempted from impact testing by other provisions of Section XII.

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

(d) 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.

(1) Each heat and/or lot of welding consumables to be used in production welding with the SMAW and GMAW processes shall be pre-use tested by conducting impact tests in accordance with the requirements of TM-250.1. Test coupons shall be prepared in accordance with Section II, Part C, SFA-5.4, A9.3.5 using the WPS to be used in production welding.

(2) Each heat of filler metal and batch of flux combination to be used in production welding with the SAW process shall be pre-use tested by conducting impact tests in accordance with the requirements of TM-250.1. Test coupons shall be prepared in accordance with Section II, Part C, SFA-5.4, A9.3.5 using the WPS to be used in production welding.

(3) 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. Pre-use testing in accordance with the requirements of TM-250.1 may be conducted by the welding consumable manufacturer, provided certified mill test reports are furnished with the consumables.

(4) The following filler metals may be used without pre-use testing of each heat, lot, and/or batch, provided that procedure qualification impact testing in accordance with TM-230.3 at the MDMT 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.

(5) The following filler metals may be used without pre-use testing of each heat and/or lot, provided that procedure qualification impact testing in accordance with TM-230.3 at the MDMT or colder is performed: ER308L, ER316L, and ER310 used with the GTAW or PAW processes.

TM-250.7 Exemption From Impact Testing Because of Low Stress

Impact testing of materials listed in Table TM-130.2-2 is not required, except as modified by TM-250.3, when the coincident ratio of design stress[7] in tension to allowable tensile stress is less than 0.35. This exemption also applies to the welding procedures and production welds for the component.

TM-250.8 Vessel (Production) Impact Tests

(a) For welded construction of duplex stainless steels, ferritic stainless steels, and martensitic stainless steels, vessel (production) impact tests in accordance with TM-230.4 are required if the Weld Procedure Qualification requires impact testing, unless otherwise exempted by the rules of Section XII.

(b) For welded construction of austenitic stainless steels, vessel (production) impact tests in accordance with TM-230.4 are required unless exempted in (1) and (2) below.

(1) At MDMTs of −104°C (−155°F) and warmer, vessel (production) impact tests are exempted, provided the impact test exemption requirements for the applicable Weld Procedure Qualification in TM-250.5 are satisfied.

(2) At MDMTs colder than −104°C (−155°F) but not colder than −196°C (−320°F), vessel (production) impact tests are exempted, provided the pre-use test requirements in TM-250.6 are satisfied.

(3) At MDMTs colder than −196°C (−320°F), vessel (production) impact tests or ASTM E1820 J_{Ic} tests shall be conducted in accordance with TM-250.1(c).

(c) For autogenous welds (welded without filler metal), vessel (production) impact tests are not required when the following conditions are satisfied:

(1) The MDMT is −196°C (−320°F) and warmer.

(2) The material is solution annealed after welding.

TM-260 IMPACT TEST REQUIREMENTS FOR FERRITIC STEELS WITH TENSILE PROPERTIES ENHANCED BY HEAT TREATMENT

TM-260.1 General

(a) All steels listed in Table TM-130.2-6 shall be tested for notch ductility, as required by TM-260.2. These tests shall be conducted at a temperature not warmer than the minimum design metal temperature [see TD-140(b)], but not warmer than 0°C (32°F). Materials may be used at temperatures colder than the minimum design metal temperature as limited in (1) and (2).

(1) When the coincident ratio defined in Figure TM-240.3-1 is 0.35 or less, the corresponding minimum design metal temperature shall be not colder than −104°C (−155°F).

(2) When the coincident ratio defined in Figure TM-240.3-1 is greater than 0.35, the corresponding minimum design metal temperature shall not be colder than the impact test temperature less the allowable temperature reduction permitted in Figure TM-240.3-1 and shall in no case be colder than −104°C (−155°F).

(b) All test specimens shall be prepared from the material in its final heat-treated condition or from full-thickness samples of the same heat similarly and simultaneously treated. Test samples shall be of such size that the prepared test specimens are free from any change in properties due to edge effects.

(c) Where the vessel or vessel parts are to be hot-formed or postweld heat treated (stress relieved), this identical heat treatment shall be applied to the test specimens required by the material specifications including the cooling rate specified by the fabricator, which shall in no case be slower than that specified in the applicable material specifications.

TM-260.2 Impact Test Requirements

(a) Test Specimen and Test Procedures

(1) One Charpy V-notch test (three specimens) shall be made from each plate as heat treated, and from each heat of bars, pipe, tube, rolled sections, forged parts, or castings included in any one heat treatment lot.

(2) The test procedures, and size, location, and orientation of the specimens shall be the same as required by TM-210.1, except that for plates, the specimens shall be oriented transverse to the final direction of rolling and for circular forgings, the specimens shall be oriented tangential to the circumference.

(3) Each of the three specimens tested shall have a lateral expansion opposite the notch not less than the requirements in Table TM-220.2.

(4) If the value of lateral expansion for one specimen is less than that required in Table TM-220.2 but not less than two-thirds of the required value, a retest of three additional specimens may be made, each of which must be equal to or greater than the required value in Table TM-220.2. Such a retest shall be permitted only when the average value of the three specimens is equal to or greater than the required value in Table TM-220.2. If the values required are not obtained in the retest or if the values in the initial test are less than the values required for retest, the material may be reheat treated. After reheat treatment, a set of three specimens shall be made, each of which must be equal to or greater than the required value in Table TM-220.2.

(b) Materials conforming to SA-353 and SA-553 for use at minimum design metal temperatures colder than −196°C (−320°F), materials conforming to SA-517, SA-543, and SA-592 for use at minimum design metal temperatures colder than −29°C (−20°F), and materials conforming to SA-645 Grade A for use at minimum design metal temperatures colder than −171°C (−275°F) shall have, in addition to the Charpy tests required under (a), drop-weight tests as defined by ASTM E208, Conducting Drop-Weight Tests to Determine Nil Ductility Transition Temperatures of Ferritic Steels, made as follows:

(1) For plates 16 mm ($^5/_8$ in.) thick and over, one drop-weight test (two specimens) shall be made for each plate as heat treated.

(2) 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 using the procedure in SA-350 for forgings and in SA-352 for castings.

(3) Each of the two test specimens shall meet the "no-break" criterion, as defined by ASTM E208, at the test temperature.

TM-260.3 Welded Joints

(a) For welded vessels, the deposited weld metal and the heat-affected zone shall meet the impact test requirements of TM-210.1 and TM-230, except that the Charpy V-notch tests and requirements of TM-260.2(a) shall apply.

(b) The following materials are exempt from production impact tests of the weld metal in accordance with TM-210.1 and TM-230 under the conditions given in (1) through (5):

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	K41583	11A/1
SA-645 Grade A	K41583	11A/2

(1) One of the following high nickel alloy filler metals is used:

Specification No.	Classification	F-No.
SFA-5.11	ENiCrMo-3	43
SFA-5.11	ENiCrMo-6	43
SFA-5.11	ENiCrFe-2	43
SFA-5.11	ENiCrFe-3	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 TM-230.

(3) Production impact tests of the heat-affected zone are performed in accordance with TM-230.4.

(4) The welding processes are limited to gas metal arc, shielded metal arc, and gas tungsten arc.

(5) The minimum allowable temperature of the tank shall be not less than −196°C (−320°F).

TM-270 USE OF NONFERROUS MATERIALS AT LOW TEMPERATURES

The materials in Tables TM-130.2-3, TM-130.2-4, TM-130.2-5, and TM-130.2-7, together with deposited weld metal within the range of composition for materials in those tables, do not undergo a marked drop in impact resistance at subzero temperatures. Therefore, no additional requirements are specified for wrought aluminum alloys when they are used at temperatures down to −269°C (−452°F); for copper and copper alloys, nickel and nickel alloys, and cast aluminum alloys when they are used at temperatures down to −196°C (−320°F); and for titanium and titanium alloys used at temperatures down to −59°C (−75°F). The materials listed in Tables TM-130.2-3, TM-130.2-4, TM-130.2-5, and TM-130.2-7 may be used at lower temperatures than those specified herein 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.

PART TD
DESIGN REQUIREMENTS

ARTICLE TD-1
GENERAL DESIGN RULES

TD-100 GENERAL

The design of all pressure vessels and vessel parts shall conform to the general design requirements in the following paragraphs. For vessels in a specific service, the additional requirements of the applicable Modal Appendix shall also be met.

TD-100.1 MINIMUM THICKNESS OF SHELLS AND HEADS

Unless otherwise specified in the applicable Modal Appendices, the minimum thickness permitted for vessel shells and heads, after forming and regardless of product form and material, shall be 1.6 mm ($^1/_{16}$ in.) exclusive of any corrosion allowance.

TD-100.2 MILL UNDER-TOLERANCE

Plate material ordered shall be not thinner than the minimum required design thickness. Vessels made of plate furnished with an under-tolerance of not more than the smaller value of 0.25 mm (0.01 in.) or 6% of the ordered thickness may be used at the full design pressure for the thickness ordered. If the specification to which the plate is ordered allows a greater under-tolerance, the ordered thickness of the materials shall be sufficiently greater than the design thickness so that the thickness of the material furnished is not more than the smaller of 0.25 mm (0.01 in.) or 6% under the minimum required design thickness.

TD-100.3 PIPE UNDER-TOLERANCE

If pipe or tube is ordered by its nominal wall thickness, the manufacturing under-tolerance on wall thickness shall be taken into account, except for nozzle wall reinforcement area requirements in accordance with TD-610. The next heavier commercial wall thickness may then be used. The manufacturing under-tolerances are given in the pipe and tube specifications listed in Table TG-130. After the minimum required design thickness is determined, it shall be increased by an amount sufficient to provide the manufacturing under-tolerance allowed in the pipe or tube specification.

TD-100.4 CORROSION ALLOWANCE IN DESIGN FORMULAS

The dimensional symbols used in all design equations throughout this Section represent dimensions in the corroded condition.

TD-100.5 FLANGES AND PIPE FITTINGS

The following standards covering flanges and pipe fittings are acceptable for use under this Section in accordance with the requirements of TM-110.10. Pressure–temperature ratings shall be in accordance with the appropriate standard, except that the pressure–temperature ratings for ASME B16.9 and ASME B16.11 fittings shall be calculated for straight seamless pipes in accordance with the rules of this Section, including the maximum allowable stress for the material. The thickness tolerances of the ASME standards listed in TG-130 shall be met.

TD-110 METHODS OF FABRICATION IN COMBINATION

A vessel may be designed and constructed by a combination of the methods of fabrication given in this Section, provided the rules applying to the respective methods of fabrication are followed and the vessel is limited to the service permitted by the method of fabrication having the most restrictive requirements.

TD-120 MATERIALS IN COMBINATION

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

NOTE: Because of the different coefficients of thermal expansion of dissimilar materials, caution should be exercised in design and construction under the provisions of this paragraph, in order to avoid difficulties in service. Galvanic corrosion, if a possibility, shall also be considered.

(25) TD-130 CORROSION

(a) The User or the User's designated agent shall specify corrosion allowances other than those required by the rules of this Section. Where corrosion allowances are not provided, this fact shall be indicated on the Data Report.

(b) Vessels or parts of vessels subject to thinning by corrosion, erosion, or mechanical abrasion shall have provisions made for the desired life of the vessel by a suitable increase in the minimum required design thickness of the material.

(c) 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.

(d) Vessels subject to corrosion shall be supplied with a suitable drain opening at the lowest point practicable in the vessel.

(e) Corrosion-resistant or abrasion-resistant linings, whether or not attached to the wall of a vessel, shall not be considered as contributing to the strength of the wall.

TD-140 DESIGN TEMPERATURE

(a) The maximum temperature used in design shall be not less than the mean metal temperature (through the thickness) expected under operating conditions for the part considered. If necessary, the metal temperature shall be determined by computation or by measurement from equipment in service under equivalent operating conditions.

(b) The minimum metal temperature specified for design shall be the lowest expected in service. The minimum specified metal temperature shall be determined by the principles described in (a). Consideration shall include the lowest operating temperature, operational upsets, autorefrigeration, atmospheric temperature, and any other sources of cooling. More than one set of minimum metal temperature and corresponding design pressures may be specified.

(c) Design temperatures listed in excess of the maximum temperatures listed in the stress allowable tables for Section XII construction are not permitted (see TD-210 and the applicable Modal Appendices). In addition, design temperatures for vessels under external pressure shall not exceed the maximum temperatures given on the external pressure charts.

(d) The design of zones with different metal temperatures may be based on their determined temperatures.

TD-150 DESIGN PRESSURES

Vessels shall be designed for at least the most severe condition of coincident pressure and temperature expected in normal operation. For this condition and for test conditions, the maximum difference in pressure between the inside and outside of a vessel shall be considered. More than one set of design pressure and corresponding design temperature may be specified.

TD-160 MAWP

(a) The Maximum Allowable Working Pressure (MAWP) for a vessel is the maximum pressure permissible at the top of the vessel in its normal operating position at the designated coincident temperature. It is the least of the values of MAWP calculated for any of the essential parts of the vessel by the principles given in (b), and adjusted for any difference in static and dynamic head that may exist between the part considered and the top of vessel.

(b) The MAWP for a vessel part is the maximum internal or external pressure, including the coincident static and dynamic head, as determined by the rules and equations in this Section, together with the effect of any combination of loadings listed in TD-200, for the designated coincident temperature (excluding corrosion allowance, see TD-130).

(c) MAWP may need to be determined for more than one designated combination of pressure and temperature.

(d) See the applicable Modal Appendix for additional requirements on MAWP.

ARTICLE TD-2
LOADINGS AND STRESS ALLOWABLES

TD-200 LOADINGS

Vessels that are constructed under the rules of this Section shall be designed to withstand the loadings that are expected from the vessel's use as both a stationary vessel and as a vessel subjected to inertial forces (including vibratory forces) specified in the applicable Modal Appendices.

(a) Primary Design Loads. The loadings for which a vessel shall be designed shall include those from

(1) internal or external design pressure (as defined in TD-150), including the additional pressure due to static head of liquids

(2) weight of the vessel and normal contents under operating or test conditions

(3) superimposed static reactions from the weight of attached equipment, such as motors, machinery, other vessels, piping, linings, and insulation

(4) the attachment of

(-a) internals (see Nonmandatory Appendix B)

(-b) vessel supports, such as lugs, rings, skirts, saddles, support rails, and legs (see Nonmandatory Appendix A)

(5) cyclic and dynamic reactions due to pressure or thermal variations, or to equipment mounted on a vessel and/or motor vehicle, and mechanical loadings

(6) liquid surge reactions

(7) temperature gradients and differential thermal expansion

(8) additional loads as defined in the applicable Modal Appendices

(b) Additional Dynamic Loads. Inertial forces acting on vessels while being transported in service shall be evaluated as equivalent static loads as required for each mode where

C_i, C_j, C_k = factors that shall be multiplied by the weight of the fully loaded vessel, W_v, to determine the corresponding inertial static equivalent vector loadings in the indicated directions. These factors shall be determined in combination or individually as required by the applicable Modal Appendix.

C_N = surge vector reduction factor corresponding to number of baffles or other surge restraining devices, N. This factor shall be determined according to the most stringent of the User's requirements or the minimum requirements of the competent authority. (See Mandatory Appendix III.)

C_s = factor that shall be multiplied by weight of the liquid contents of the vessel, W_c, to determine the static equivalent surge vector, F_s. This factor shall be determined from the appropriate Modal Appendix to the transportation mode for which the vessel is designed.

F_i = static equivalent vector force directed along the direction of travel

F_j = static equivalent net vector force in the vertical direction

F_k = static equivalent vector force directed horizontally normal to the expected direction of travel

F_s = static equivalent vector force directed against the vessel wall due to forward surge of liquid contents in relation to the vessel

i = subscript denoting horizontal loads and static equivalent inertial force vectors directed parallel to expected direction of forward travel

j = subscript denoting loads and static equivalent inertial force and weight vectors directed vertically

k = subscript denoting horizontal loads and static equivalent inertial force vectors directed normal (lateral) to expected direction of travel in the horizontal plane

N = the surge retardation number used to determine C_N, equal to the number of baffles or other surge-restraining devices that are considered to effectively retard the movement of liquid contents of the vessel relative to the vessel wall in the expected direction of forward travel

W_c = weight of the liquid contents of the vessel

W_v = weight of the vessel, its contents and the weight of all equipment, structures or other items listed in (a)(2), (a)(3), and (a)(4) that are supported by the vessel during operation

(1) requirements for application of static equivalent inertial load vectors in relation to orientation of the principal axes of a vessel in motion are:

(-a) horizontal vectors directed parallel to expected direction of travel

$$F_i = C_i W_v$$

(-b) static equivalent inertial vectors directed vertically

$$F_j = C_j W_v$$

(-c) horizontal vectors directed normal (lateral) to expected direction of travel

$$F_k = C_k W_v$$

(-d) static equivalent vector force directed against the vessel wall due to surge of liquid contents in relation to the vessel

$$F_s = C_N W_c$$

(2) Vessels constructed for portable or intermodal service or for service wherein the direction of travel with relation to one or more of the vessel's principal axes is unknown shall be designed to withstand static equivalent inertial vector loads in directions normal and parallel to the direction of the meridional or longitudinal axis of the vessel that are determined as follows:

$$F_i = F_k = C_i W_v$$

(3) Reaction force vectors resulting from application of all combinations of loads to the vessel [including static equivalent inertial loadings according to the requirements of (1) and (2)], shall be determined for each location of structural attachment to the vessel. The loading effect of these reactions on the vessel shall be evaluated and combined as required by the applicable Modal Appendix.

TD-210 MAXIMUM ALLOWABLE STRESS VALUES

(a) The maximum allowable tensile stress values permitted for different materials are given in Section II, Part D, Subpart 1. (For the basis on which the tabulated stress values have been established, see Section II, Part D, Mandatory Appendix 1.) The allowable stress values given in Section II, Part D, Subpart 1 for Section XII shall be used in the design of tanks for this Section. A listing of materials allowed for construction under this Section is provided in Part TM.

(b) The maximum allowable stress values for the additional loads in TD-200(a)(8) are defined in the applicable Modal Appendices.

(c) The maximum allowable longitudinal compressive stress to be used in the design of cylindrical shells or tubes, either seamless or butt welded, subjected to loadings that produce longitudinal compression in the shell or tube shall be the smaller of the following values:

(1) the maximum allowable tensile stress value permitted in (a)

(2) the value of the factor B determined by the following procedure where

E = modulus of elasticity of material at design temperature. The modulus of elasticity to be used shall be taken from the applicable materials chart in Section II, Part D, Subpart 2. (Interpolation may be made between lines for intermediate temperatures.)

R_o = outside radius of cylindrical shell or tube

t = the minimum required thickness of the cylindrical shell or tube

The joint efficiency for butt-welded joints shall be taken as unity.

The value of B shall be determined as follows:

Step 1. Using the selected values of t and R, calculate the value of factor A using the following equation:

$$A = \frac{0.125}{(R_o/t)}$$

Step 2. Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature. Interpolation may be made between lines for intermediate temperatures. 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. 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 2.

Step 4. For values of A falling to the left of the applicable material/temperature line, the value of B shall be calculated using the following equation:

$$B = \frac{AE}{2}$$

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. 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.

(d) The wall thickness of a vessel calculated by these rules shall be determined such that, for any combination of loadings listed in TD-200 that induce primary stress and are expected to occur simultaneously during normal

operation of the vessel, the induced maximum general primary membrane stress does not exceed the maximum allowable stress value in tension [see (a)]. The above loads shall not induce a combined maximum primary membrane stress plus primary bending stress across the thickness, which exceeds $1^1/_2$ times the maximum allowable stress value in tension. It is recognized that high localized discontinuity stresses may exist in vessels designed and fabricated in accordance with these rules. Insofar as practical, design rules for details have been written to limit such stresses to a safe level consistent with experience.

The maximum allowable stress values that are to be used in the thickness calculations are to be taken from the tables at the temperature that is expected to be maintained in the metal under the conditions of loading being considered. Maximum allowable stress values may be interpolated for intermediate temperatures.

(e) Maximum shear stress, in restricted shear such as dowel bolts or similar construction in which the shearing member is so restricted that the section under consideration would fail without reduction of area, shall be limited to 0.80 times the values in Section II, Part D, Subpart 1, Table 1A, Table 1B, or Table 3.

(f) Maximum bearing stress shall be limited to 1.60 times the values in Section II, Part D, Subpart 1, Table 1A, Table 1B, or Table 3.

ARTICLE TD-3
DESIGN FOR INTERNAL PRESSURE

TD-300 THICKNESS OF SHELLS UNDER INTERNAL PRESSURE

The thickness of shells under internal pressure shall be not less than that computed by the equations in TD-300.2 through TD-300.5. In addition, provisions shall be made for any of the other loadings listed in TD-200, when such loadings are expected.

TD-300.1 NOMENCLATURE

The symbols defined below are used in the equations of TD-300.2 through TD-300.5.

E = joint efficiency for, or the efficiency of, appropriate joint in cylindrical or spherical shells. (For welded vessels, use the joint efficiencies specified in TW-130.4.)

P = internal design pressure (see TD-150)

R = inside radius of the shell course under consideration. For pipe, the inside radius R is determined by the nominal outside radius minus the nominal wall thickness. For conical shells with half apex angle not exceeding 7 deg, the conical radius at the large end of each section shall be used.

R_o = outside radius of the shell course under consideration. For conical shells with half apex angle not exceeding 7 deg, the conical radius at the large end of each section shall be used.

S = maximum allowable stress value (see TD-210)

t = minimum required thickness of shell

(25) TD-300.2 CYLINDRICAL SHELLS

The minimum required design thickness or maximum allowable working pressure of cylindrical shells and conical shells with half apex angle not exceeding 7 deg shall be the greater thickness or lesser pressure as given by (a) or (b).

(a) Circumferential Stress (Longitudinal Joints). When the thickness does not exceed one-half of the inside radius, or P does not exceed 0.385SE, the following equations shall apply:

$$t = \frac{PR}{SE - 0.6P} \quad \text{or} \quad P = \frac{SEt}{R + 0.6t}$$

(b) Longitudinal Stress (Circumferential Joints). When the thickness does not exceed one-half of the inside radius, or P does not exceed 1.25SE, the following equations shall apply:

$$t = \frac{PR}{2SE + 0.4P} \quad \text{or} \quad P = \frac{2SEt}{R - 0.4t}$$

TD-300.3 SPHERICAL SHELLS

When the thickness of the shell of a wholly spherical vessel does not exceed 0.356R, or P does not exceed 0.665SE, the following equations shall apply:

$$t = \frac{PR}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{R + 0.2t}$$

TD-300.4 LOCAL LOADINGS

When necessary, vessels shall be provided with stiffeners or other additional means of support to prevent overstress or large distortions under the external loadings listed in TD-200 other than pressure and temperature.

TD-300.5 EQUATIONS IN TERMS OF OUTSIDE RADIUS

The following equations in terms of outside radius may be used:

(a) for cylindrical shells (circumferential stress)

$$t = \frac{PR_o}{SE + 0.4P} \quad \text{or} \quad P = \frac{SEt}{R_o - 0.8t}$$

(b) for spherical shells

$$t = \frac{PR_o}{2SE + 0.8P} \quad \text{or} \quad P = \frac{2SEt}{R_o - 0.8t}$$

TD-310 FORMED HEADS AND SECTIONS, PRESSURE ON CONCAVE SIDE

The required thickness at the thinnest point after forming of ellipsoidal, torispherical, and hemispherical heads under pressure on the concave side (plus heads) shall be computed by the appropriate equations in this paragraph. In addition, provision shall be made for any of the other loadings given in TD-200.

The thickness of an unstayed ellipsoidal or torispherical head shall in no case be less than the required thickness of a seamless hemispherical head divided by the efficiency of the head-to-shell joint.

TD-310.1 NOMENCLATURE

The symbols defined below are used in equations in TD-310.1 through TD-310.4. Figure TD-310.1 shows principal dimensions of typical heads.

D = inside diameter of the head skirt, or inside length of the major axis of an ellipsoidal head
E = lowest efficiency of any joint in the head; for hemispherical heads, this includes head-to-shell joint; for welded vessels, use the joint efficiencies specified in TW-130.4
E_{RT} = modulus of elasticity at 20°C (70°F)
E_{ST} = modulus of elasticity of steel at 20°C (70°F)
E_T = modulus of elasticity at maximum design temperature
h = one-half of the length of the minor axis of the ellipsoidal head or the inside depth of the ellipsoidal head measured from the tangent line
L = inside spherical or crown radius
P = internal design pressure (see TD-150)
r = inside knuckle radius
S = maximum allowable stress value in tension as given in the tables referenced in TD-210
t = minimum required design thickness of head after forming

(25) TD-310.2 TORISPHERICAL HEADS

(a) Design of Torispherical Heads Conforming to 0.002 ≤ t/L ≤ 0.06. The minimum required thickness of a torispherical head having $0.002 \le t/L \le 0.06$ shall be the larger of the thicknesses calculated by eqs. (1) and (2). These equations are based on the assumption that the number of full pressurization cycles does not exceed 400. Any pressure cycle exceeding 20% of the range of full pressure cycle shall be considered as an equivalent full pressure cycle. [If the number of equivalent pressure cycles exceeds 400, see TG-100.2(c) and Section VIII, Divisions 1 and 2.]

$$t = \frac{PLM}{2SE - 0.2P} \tag{1}$$

$$t = \frac{3PLKE_{RT}}{4S_aE_T} \tag{2}$$

The value of S_a shall be 115,000 psi for all materials except for aluminum, aluminum alloys, copper, copper alloys, titanium, and zirconium, for which the value of S_a shall be calculated by eq. (3).

$$S_a = \frac{115,000E_{RT}}{E_{ST}} \tag{3}$$

The value of M shall be obtained from Table TD-310.2-1. Interpolation may be used for r/D values that fall within the range of the tabulated values. No extrapolation of the values is permitted.

The value of K shall be obtained from Table TD-310.2-2. Interpolation may be used for r/D values that fall within the range of the tabulated values. No extrapolation of the values is permitted.

(b) Torispherical Heads Conforming to 0.0005 ≤ t /L < 0.002. When the maximum design temperature is less than or equal to the temperature limit given in Table TD-310.2-3, the minimum required thickness of a torispherical head having $0.0005 \le t/L < 0.002$ shall be the larger of the thicknesses calculated by the equations in (1) or (2).

(1) Burst Evaluation

$$t = \frac{PLN}{2SE - 0.2P}$$

where

N = factor in the equations for torispherical heads depending on the head proportion L/r
$= \frac{1}{4}\left(3 + \sqrt{\frac{L}{r}}\right)$

(2) Buckling Evaluation

(-a) Calculate a coefficient, C_1.

(-1) For $r/D \le 0.08$, $C_1 = 9.31r/D - 0.086$.

(-2) For $r/D > 0.08$, $C_1 = 0.692r/D + 0.605$.

(-b) Calculate the elastic buckling stress, S_e.

$$S_e = C_1E_T(t/r)$$

(-c) Calculate a coefficient, C_2.

(-1) For $r/D \le 0.08$, $C_2 = 1.25$.

(-2) For $r/D > 0.08$, $C_2 = 1.46 - 2.6r/D$.

(-d) Calculate values of constants a, b, β, and ϕ.

a = $0.5D - r$
b = $L - r$
β = arc cos (a/b), rad
ϕ = $(\sqrt{Lt})/r$, rad

(-e) Calculate the value of c.

(-1) If $\phi < \beta$, then $c = a/[\cos(\beta - \phi)]$.

(-2) If $\phi \ge \beta$, then $c = a$.

Determine the value of R_e.

$$R_e = c + r$$

(-f) Calculate the value of internal pressure expected to produce elastic buckling, P_e.

$$P_e = \frac{S_e t}{C_2 R_e\left[(0.5R_e/r) - 1\right]}$$

(-g) Calculate the value of internal pressure expected to result in yield stress at the point of maximum stress, P_y.

$$P_y = \frac{S_y t}{C_2 R_e\left[(0.5R_e/r) - 1\right]}$$

(-h) Calculate the value of internal pressure expected to result in knuckle failure, P_{ck}.

(-1) For $P_e/P_y \leq 1.0$, $P_{ck} = 0.6P_e$.

(-2) For $1.0 < P_e/P_y \leq 8.29$, $P_{ck} = 0.408P_y + 0.192P_e$.

(-3) For $P_e/P_y > 8.29$, $P_{ck} = 2.0P_y$.

(-i) Calculate the value $P_{ck}/1.5$. If $P_{ck}/1.5$ is equal to or greater than the required internal design pressure, P, then the design is complete. If $P_{ck}/1.5$ is less than the required internal design pressure, P, then increase the thickness and repeat the calculations until $P_{ck}/1.5$ is equal to or greater than the required internal design pressure, P.

(25) TD-310.3 ELLIPSOIDAL HEADS

The minimum required thickness of an ellipsoidal head shall be established as an equivalent torispherical head using the rules given in TD-310.2. In using the equations in TD-310.2, the values of L and r shall be obtained from Table TD-310.3-1.

TD-310.4 HEMISPHERICAL HEADS

When the thickness of a hemispherical head does not exceed $0.356L$, or P does not exceed $0.665SE$, the following equations shall apply:

$$t = \frac{PL}{2SE - 0.2P} \text{ or } P = \frac{2SEt}{L + 0.2t}$$

TD-310.5 CROWN AND KNUCKLE RADII

The inside crown radius to which an unstayed head is dished shall not be greater than the outside diameter of the skirt of the head. The inside knuckle radius of a torispherical head shall be not less than 6% of the outside diameter of the skirt of the head but in no case less than three times the head thickness.

TD-310.6 THICKNESS TRANSITION AND TAPERS

All formed heads, thicker than the shell and concave to pressure, intended for butt-welded attachment, shall have a skirt length sufficient to meet the requirements of Figure TW-130.5-1, when a tapered transition is required. All formed heads concave to pressure and intended for butt-welded attachment need not have an integral skirt when the thickness of the head is equal to or less than the thickness of the shell. When a skirt is provided, its thickness shall be at least that required for a seamless shell of the same diameter.

Any taper at a welded joint within a formed head shall be in accordance with TW-130.5. The taper at a circumferential welded joint connecting a formed head to a main shell shall meet the requirements of TW-130.5 for the respective type of joint shown therein.

TD-310.7 FLAT SPOTS

If a torispherical, ellipsoidal, or hemispherical head is formed with a flattened spot or surface, the diameter of the flat spot shall not exceed that permitted for flat heads as given by TD-500(c)(2), eq. (1), using C = 0.25.

TD-320 OTHER TYPES OF CLOSURES

TD 320.1

Dished heads with bolting flanges usually used as full-opening rear doors of category 400 series specification tanks in vacuum truck or trailers shall be designed to the requirements of TG-100.2(c).

TD 320.2 QUICK-ACTUATING CLOSURES

Openings in pressure vessels used for the purposes other than fluid flow, fluid level detection, temperature measurement, quantity determination, pressure measurement, etc., and which are fitted with quick-opening and quick-actuating closures shall comply with the requirements specified in TD-320.2 and TD-320.3.

(a) *Definitions*. For transport tanks, the following rules shall apply for the design of full-opening rear doors and manhole covers that do not meet the definition outlets:

(1) Quick-actuating closures are closures that are operated by an action that releases all holding elements.

(2) Holding elements are parts of the closure used to hold the cover to the vessel, and/or to provide the load required to seal the closure. Hinge pins or bolts may be used as holding elements.

(3) Locking elements are parts of the closure that prevent a reduction in the load on a holding element or prevent the release of a holding element. Locking elements may also be used as holding elements.

(4) The locking mechanism or locking device may consist of a combination of locking elements.

(b) *General.* Quick-actuating closures shall be designed to meet the following general conditions:

(1) Closures shall be designed such that the locking elements will be engaged prior to loading and subsequent application of pressure and will not disengage until the pressure is released and the tank is completely unloaded.

(2) Closures shall be designed such that the failure of a single locking element or locking component while the vessel is pressurized (or contains a static head of liquid

acting at the closure or contains dynamic pressure while the tank is moving on the road due to longitudinal acceleration) will not

(-a) cause or allow the closure to be opened or leak

(-b) result in the failure of any other locking element or locking component or holding element

(-c) increase the stress in any other locking element or locking component or holding element by more than 50% above the allowable stress of the component or holding element

(3) Quick-actuating closures shall be designed and installed such that it may be determined by visual external observation followed by a low pressure leak test (20% of the design pressure of the tank) that the holding elements are in satisfactory condition before loading the tank.

(4) Quick-actuating closures shall also be designed such that all locking components can be verified to be fully engaged by visual observation followed by a low pressure leak test (20% of the design pressure of the tank) prior to loading the tank and the application of pressure to the tank.

(5) When installed, all vessels having quick-actuating closures shall be provided with two pressure-indicating devices. One device should be installed near the operating area such that it is visible from the operating area. The second device shall be installed near the front of the tank on the driver side such that it can be read from as far away from the operating area of the closure as practical. These devices shall be capable of detecting pressure at the closure and shall be capable of detecting pressures under normal operations, as low as static head.

(6) The use of a multilink component, such as a chain, is not permitted.

(7) When a quick-actuating closure is provided as a part, it shall be provided with a Partial Data Report as meeting the applicable requirements of this Section.

(8) Nonmandatory Appendix N provides supplementary information for the Manufacturer of the pressure vessel and provides guidance on installation, operation, and maintenance for the Owner and User.

(c) Specific Design Requirements.

(1) 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 designed such that when the vessel is installed the following conditions are met (see also Nonmandatory Appendix N):

(-a) The closure and its holding elements are fully engaged in their intended operating position before loading and then pressure can be applied in the vessel.

(-b) Prior to the access of the closure, the tank shall be depressurized first without any evidence of discharge of the internal contents and then unloaded safely without evidence of leakage.

(-c) The designer shall consider the MAWP of the tank, static loading, and the dynamic pressure due to the contents inside the tank when the tank is in transportation (because of longitudinal acceleration). The quick-actuating closure shall be designed to the total pressure adding all the above. For the tanks designed for vacuum loading, the designer shall consider external pressure also.

(2) The designer shall consider the effects of cyclic loading, other loadings (see TD-200) and mechanical wear, corrosion, and other environmental effects acting on the quick-actuating closure.

(3) It is recognized that it is impractical to write requirements to cover the multiplicity of quick-actuating closures, or to prevent negligent operation or the circumventing of safety devices. Any device or devices that will provide the safeguards described above shall meet the intent of these rules.

(4) The Manufacturer of a pressure vessel with a quick-actuating closure shall supply the User with an installation, operation, and maintenance manual that shall address the maintenance and operation of the closure. The manual should address the topics discussed in Nonmandatory Appendix N. The intent is for this manual to stay with the Owner or operator of the tank.

TD-320.3 QUICK-OPENING CLOSURES

(a) Definitions. For transport tanks that carry dangerous goods, these quick-opening closures shall meet the requirements of tank outlets.

(1) Outlet. An outlet is any opening in the shell or head of a tank, including the opening's closure, except the following:

(-a) a threaded opening securely closed during transportation with a threaded plug or a threaded cap

(-b) a flanged opening securely closed during transportation with a bolted or welded blank flange

(-c) a manhole

(-d) a full opening head on a tank designed to be loaded by vacuum

(-e) a gauging device

(-f) a thermometer well

(-g) a safety relief device

(-h) any opening specifically exempted in this Section

(2) Quick-opening closures are closures that are capable of fully opening within a specific time as set forth by the competent authority and in no case more than 30 sec of their activation.

(3) Each outlet shall be provided with a self-closing system that

(-a) closes all the outlets in an emergency within 30 sec of actuation

(-b) includes a remotely actuated means of closure located

(-1) more than 3 m (10 ft) from the outlet or, if vehicle length does not allow this distance, on the end of the tank furthest from the outlet

(-2) outside the cab on the tank, its supporting structure, or skirting in a clearly visible location and readily accessible to a person standing on the ground

(-c) consists of an actuated mechanism that

(-1) is corrosion resistant

(-2) operates in all climatic conditions

(-d) ensures that each outlet remains securely closed and capable of retaining lading if the actuating system is accidentally damaged or sheared off during transportation, unless the valve and actuator are protected by bottom damage protection and any piping extending beyond the accident damage protection is protected

(-e) includes a means of thermal activation that

(-1) is located as close to the outlet as is practical

(-2) closes the outlet at a temperature of 122°C (250°F) or less

(b) General

(1) Quick-opening closures shall be designed and installed such that it can be determined the closure is in satisfactory condition prior to loading the tank; satisfactory condition of the closure is determined by both a visual external observation and a leak test at 20% of the design Pressure of the tank.

(2) When a quick-opening closure is provided as a part, it shall be provided with a Partial Data Report and shall meet the applicable requirements of this Section.

(3) Nonmandatory Appendix N provides supplementary design information for the Manufacturer and provides guidance on installation, operation, and maintenance for the owner and user.

(c) Specific Design Requirements. The Manufacturer of a pressure vessel with a quick-opening closure shall supply the User with an installation, operation, and maintenance manual that shall address the maintenance and operation of the closure. The manual should address the topics discussed in Nonmandatory Appendix N. The intent is for this manual to stay with the Owner or operator of the tank.

Figure TD-310.1
Principal Dimensions of Typical Heads

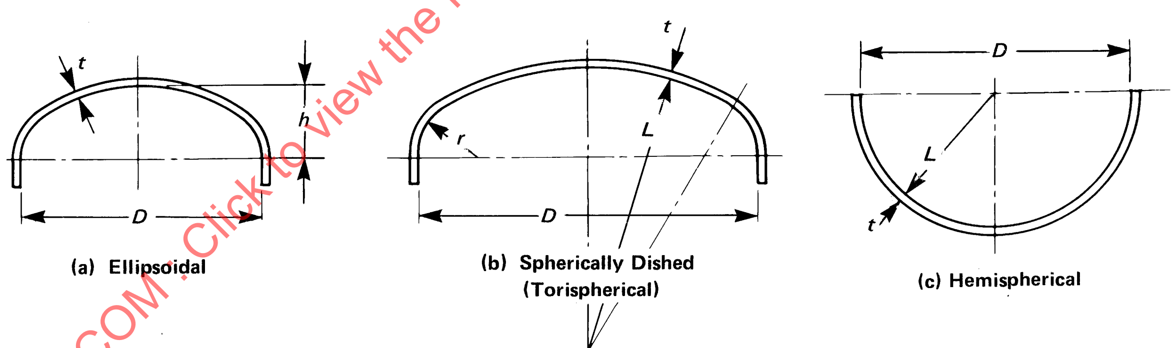


Table TD-310.2-1
Values for M

t/L	M for $r/D = 0.06$	M for $r/D = 0.07$	M for $r/D = 0.08$	M for $0.08 < r/D \le 0.2$
0.002	1.00	1.00	1.00	1.00
0.004	1.00	1.00	1.00	1.00
0.006	1.28	1.00	1.00	1.00
0.008	1.41	1.20	1.00	1.00
0.010	1.41	1.26	1.10	1.00
0.012	1.38	1.25	1.13	1.00
0.016	1.31	1.21	1.12	1.00
0.020	1.25	1.17	1.08	1.00
0.030	1.14	1.08	1.01	1.00
0.040	1.07	1.01	1.00	1.00
0.060	1.00	1.00	1.00	1.00

Table TD-310.2-2
Values for K

t/L	K for $r/D = 0.06$	K for $r/D = 0.08$	K for $r/D = 0.10$	K for $r/D = 0.14$	K for $r/D = 0.17$	K for $r/D = 0.20$
0.002	7.87	6.29	5.24	3.95	3.31	2.81
0.004	6.77	5.60	4.69	3.49	2.93	2.50
0.006	6.04	5.14	4.38	3.27	2.73	2.33
0.008	5.51	4.78	4.14	3.13	2.60	2.21
0.010	5.11	4.49	3.93	3.02	2.51	2.13
0.012	4.79	4.25	3.76	2.93	2.44	2.06
0.016	4.31	3.87	3.47	2.77	2.33	1.97
0.020	3.96	3.58	3.24	2.63	2.24	1.91
0.030	3.48	3.10	2.84	2.37	2.07	1.79
0.040	3.32	2.97	2.69	2.23	1.95	1.72
0.060	3.12	2.80	2.56	2.17	1.92	1.71

(25)
Table TD-310.2-3
Maximum Metal Temperature

Temperature Table in Which Material Is Listed	Maximum Metal Temperature, °C (°F)
Table TM-130.2-1	343 (650)
Table TM-130.2-2	316 (600)
Table TM-130.2-3	149 (300)
Table TM-130.2-4	66 (150)
Table TM-130.2-5	343 (650)
Table TM-130.2-6	343 (650)

Table TD-310.3-1
Values of Spherical Radius Factor, K_1, and Knuckle Radius, r (25)

$D/2h$ [Note (1)]	K_1	r/D
3.0	1.36	0.10
2.8	1.27	0.11
2.6	1.18	0.12
2.4	1.08	0.13
2.2	0.99	0.15
2.0	0.90	0.17
1.8	0.81	0.20
1.6	0.73	0.24
1.4	0.65	0.29
1.2	0.57	0.37
1.0	0.50	0.50

GENERAL NOTES:
(a) Equivalent spherical radius: $L = K_1D$.
(b) Equivalent knuckle radius: $r = (r/D)D$.
(c) Interpolation is permitted for intermediate values.

NOTE: (1) $D/2h$ = axis ratio.

ARTICLE TD-4
DESIGN FOR EXTERNAL PRESSURE

TD-400 THICKNESS OF SHELLS UNDER EXTERNAL PRESSURE

Rules for the design of shells under external pressure given in this Section are limited to cylindrical shells, with or without stiffening rings, and spherical shells. Three typical forms of cylindrical shells are shown in Figure TD-400.1. Charts used in determining minimum required thickness of these components are given in Section II, Part D, Subpart 3.

TD-400.1 NOMENCLATURE

The symbols defined below are used in the procedures of this paragraph (see Figure TD-400.1):

A = factor determined from Section II, Part D, Subpart 3, Figure G and used to enter the applicable material chart in Section II, Part D, Subpart 3
B = factor determined from the applicable material chart in Section II, Part D, Subpart 3 for maximum design metal temperature
D_o = outside diameter of cylindrical shell course
E = modulus of elasticity of material at design temperature. For external pressure design in accordance with this Section, the modulus of elasticity to be used shall be taken from the applicable materials chart in Section II, Part D, Subpart 3. (Interpolation may be made between lines for intermediate temperatures.)
L = design length of a vessel section between lines of support. A line of support is a:

(a) circumferential line on a head (excluding conical heads) at one-third the depth of the head from the head tangent line as shown on Figure TD-400.1

(b) stiffening ring that meets the requirements of TD-410.1

P = external design pressure (see TD-150)
P_a = calculated value of maximum allowable external working pressure for the assumed value of t
R_o = outside radius of spherical shell
t = minimum required thickness of cylindrical shell or tube or spherical shell
t_s = nominal thickness of cylindrical shell or tube

TD-400.2 CYLINDRICAL SHELLS

The required minimum thickness of a cylindrical shell having D_o/t values not less than 10, under external pressure, shall be determined by the following procedure. Alternative methods of determining allowable circumferential and longitudinal bending compressive stresses for cylindrical shells are given in TD-440.

Step 1. Assume a value for t and determine the ratios L/D_o and D/t.

Step 2. Enter Section II, Part D, Subpart 3, Figure G 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 = 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 point of intersection, move vertically downward to determine the value of factor A.

Step 4. Using the value of A calculated in Step 3, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature. 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.

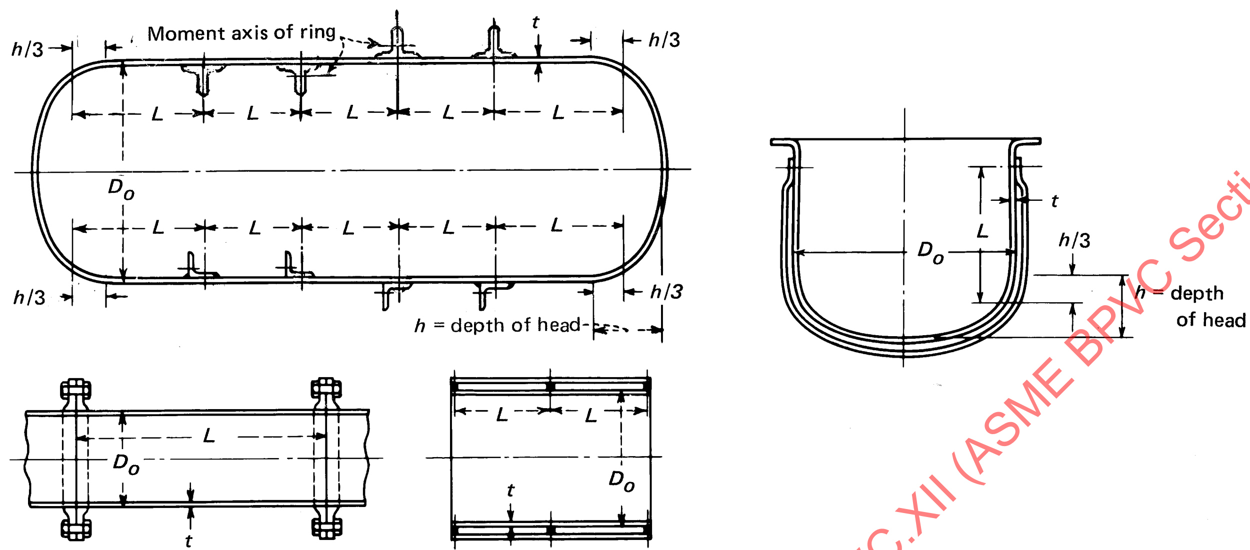
Step 6. Using this value of B, calculate the value of the maximum allowable external working pressure, P_a, using the following equation:

$$P_a = \frac{4B}{3(D_o/t)}$$

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 equation:

$$P_a = \frac{2AE}{3(D_o/t)}$$

Figure TD-400.1
Diagrammatic Representation of Variables for Design of Cylindrical Vessels Subjected to External Pressure



Step 8. Compare the calculated value of P_a obtained in Step 6 or Step 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.

TD-400.3 SPHERICAL SHELLS

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 equation:

$$A = \frac{0.125}{(R_o/t)}$$

Step 2. Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature (see TD-140). Interpolation may be made between lines for intermediate temperatures. 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. 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 equation:

$$P_a = \frac{B}{(R_o/t)}$$

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 equation:

$$P_a = \frac{0.0625E}{(R_o/t)^2}$$

Step 6. Compare P_a, obtained in Step 4 or Step 5 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.

TD-400.4 STAMPING FOR VACUUM SERVICE (25)

Vessels intended for service under external working pressures of 103 kPa (15 psi) and less may be stamped with the Certification Mark denoting compliance with the rules for external pressure, provided all the applicable rules of this Section are satisfied. When the Certification Mark is to be applied, the User or the User's designated agent shall specify the required maximum allowable external working pressure. The vessel shall be designed and stamped with the maximum allowable external working pressure.

TD-400.5 LONGITUDINAL LAP JOINTS

When there is a longitudinal lap joint in a cylindrical shell or any lap joint in a spherical shell under external pressure, the thickness of the shell shall be determined by the rules in this paragraph, except that 2P shall be used instead of P in the calculations for the required thickness.

TD-400.6 CIRCUMFERENTIAL JOINTS

Circumferential joints in cylindrical shells, unless otherwise prohibited by the rules of this Section, may be of any type permitted by the Code and shall be designed for the imposed loads.

TD-400.7 EXTERNAL LOADINGS

When necessary, vessels shall be provided with stiffeners or other additional means of support to prevent overstress or large distortions under the external loadings listed in TD-200 other than pressure and temperature.

TD-400.8 EXTERNAL PRESSURE

The external design pressure or maximum allowable external working pressure shall be not less than the maximum expected difference in operating pressure that may exist between the outside and the inside of the vessel at any time.

TD-410 STIFFENING RINGS FOR CYLINDRICAL SHELLS UNDER EXTERNAL PRESSURE

TD-410.1 REQUIRED MOMENT OF INERTIA

Except as exempted in Step 6(a), the available moment of inertia of a circumferential stiffening ring shall be not less than that determined by one of the following two equations:

$$I_s = \left[D_o^2 L_s(t + A_s/L_s)A\right]/14$$

$$I_s' = \left[D_o^2 L_s(t + A_s/L_s)A\right]/10.9$$

where

I = available moment of inertia of the stiffening ring cross section about its neutral axis parallel to the axis of the shell

I_s = required moment of inertia of the stiffening ring cross section about its neutral axis parallel to the axis of the shell

I' = available moment of inertia of combined ring shell cross section about its neutral axis parallel to the axis of the shell. The nominal shell thickness, t, shall be used and the width of shell that is taken as contributing to the moment of inertia of the combined section shall be not greater than $1.10\sqrt{D_o t_s}$ and shall be taken as lying one-half on each side of the centroid of ring. Portions of the shell plate shall not be considered as contributing area to more than one stiffening ring.

I'_s = required moment of inertia of the combined ring-shell 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.

A = factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in the stiffening ring, corresponding to the factor B, below, and the design temperature for the shell under consideration

A_s = cross-sectional area of the stiffening ring

B = factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used for the stiffening ring

L_s = one-half of the distance from the center line of the stiffening ring to the next line of support on one side, plus one-half of the center line distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the cylinder. A line of support is

(a) a stiffening ring that meets the requirements of this paragraph

(b) a circumferential connection to a jacket for a jacketed section of a cylindrical shell

(c) a circumferential line on a head at one-third the depth of the head from the head tangent line as shown on Figure TD-400.1.

P, D_o, E, t, and t_s are as defined in TD-400.1.

The adequacy of 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. Then calculate factor B using the following equation:

$$B = \frac{3}{4}\left(\frac{PD_o}{t + A_s/L_s}\right)$$

Step 2. Enter the right-hand side of the applicable material chart in Section II, Part D, Subpart 3 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.

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 equation $A = 2B/E$.

Step 6. See below.

(a) In those cases where only the stiffening ring is considered, compute the required moment of inertia from the equation for I_s given in TD-410.1.

(b) In those cases where the combined ring shell is considered, compute the required moment of inertia from the equation for I_s' given in TD-410.1.

Step 7. See below.

(a) In those cases where only the stiffening ring is considered, determine the available moment of inertia I as given in the definitions.

(b) In those cases where the combined ring shell is considered, determine the available moment of inertia I' as given in the definitions.

NOTE: In those cases where the stiffening ring is not attached to the shell or where the stiffening ring is attached but the designer chooses to consider only the ring. Steps 6(a) and 7(a) are to be used. In those cases where the stiffening ring is attached to the shell and the combined moment of inertia is considered, Steps 6(b) and 7(b) are to be used.

Step 8. If the required moment of inertia is greater than the available moment of inertia for the section selected, for those cases where the stiffening ring is not attached or where the combined ring-shell stiffness was not considered, a new section with a larger moment of inertia must be selected; the ring must be attached to the shell and the combination shall be considered; or the ring-shell combination that was previously not considered together shall be considered together. If the required moment of inertia is greater than the available moment of inertia for those cases where the combined ring-shell was considered, a new ring section with a larger moment of inertia must be selected. In any case, when a new section is used, all of the calculations shall be repeated using the new section properties of the ring or ring-shell combination.

If the required moment of inertia is smaller than the available moment of inertia, whichever method is used, that ring section or combined section is satisfactory.

CAUTION: Stiffening rings may be subject to lateral buckling. This should be considered in addition to the requirements for I_s and I'_s.

TD-410.2 STIFFENING RING ARRANGEMENT

Stiffening rings shall extend completely around the circumference of the cylinder, except as permitted below. Any joints between the ends or sections of such rings, such as shown in Figure TD-410.2-1, (A) and (B), and any connection between adjacent portions of a stiffening ring lying inside or outside the shell as shown in Figure TD-410.2-1 shall be made so that the required moment of inertia of the combined ring-shell section is maintained.

Stiffening rings placed on the inside of a vessel may be arranged as shown in Figure TD-410.2-1, (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.

Any gap in that portion of a stiffening ring supporting the shell, such as shown in Figure TD-410.2-1, (E), shall not exceed the length of arc given in Figure TD-410.2-2 unless additional reinforcement is provided as shown in Figure TD-410.2-1 or unless the following conditions are met:

(a) only one unsupported shell arc is permitted per ring

(b) the length of the unsupported shell arc does not exceed 90 deg

(c) the unsupported arcs in adjacent stiffening rings are staggered 180 deg

(d) the dimension L defined in TD-400.1 is taken as the larger of the following: the distance between alternate stiffening rings, or the distance from the head tangent line to the second stiffening ring plus one-third of the head depth.

TD-410.3 INTERNAL STRUCTURES AS STIFFENERS AND SUPPORTS

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.

Any internal stays or supports used as stiffeners of the shell shall bear against the shell of the vessel through the medium of a substantially continuous ring.

TD-420 ATTACHMENT OF STIFFENING RINGS FOR EXTERNAL PRESSURE

(a) Stiffening rings may be placed on the inside or outside of a vessel, and shall be attached to the shell by welding. The ring shall be essentially in contact with the shell. Welding of stiffening rings shall comply with the requirements of this Section for the type of vessel under construction.

(b) Stiffening rings may be attached to the shell by continuous, intermittent, or a combination of continuous and intermittent welds. Some acceptable methods of attaching stiffener rings are illustrated in Figure TD-420.

(c) Intermittent welding shall be placed on both sides of the stiffener and may be either staggered or in-line. Length of individual fillet weld segments shall be not less than 50 mm (2 in.) and shall have a maximum clear spacing between toes of adjacent weld segments of $8t$ for external rings and $12t$ for internal rings where t is the shell thickness at the attachment. The total length of weld on each side of the stiffening ring shall be

Figure TD-410.2-1
Various Arrangements of Stiffening Rings for Cylindrical Vessels Subjected to External Pressure

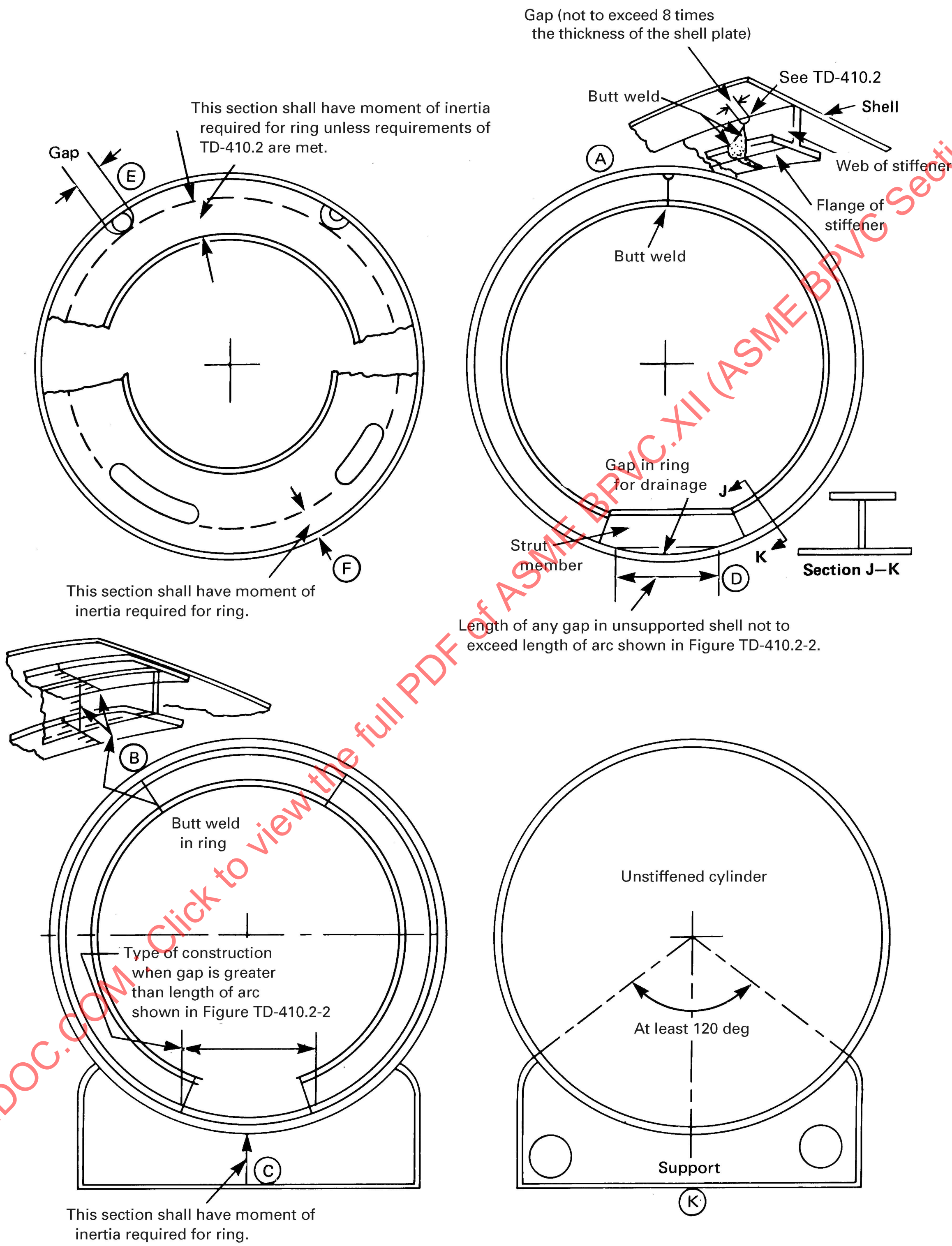
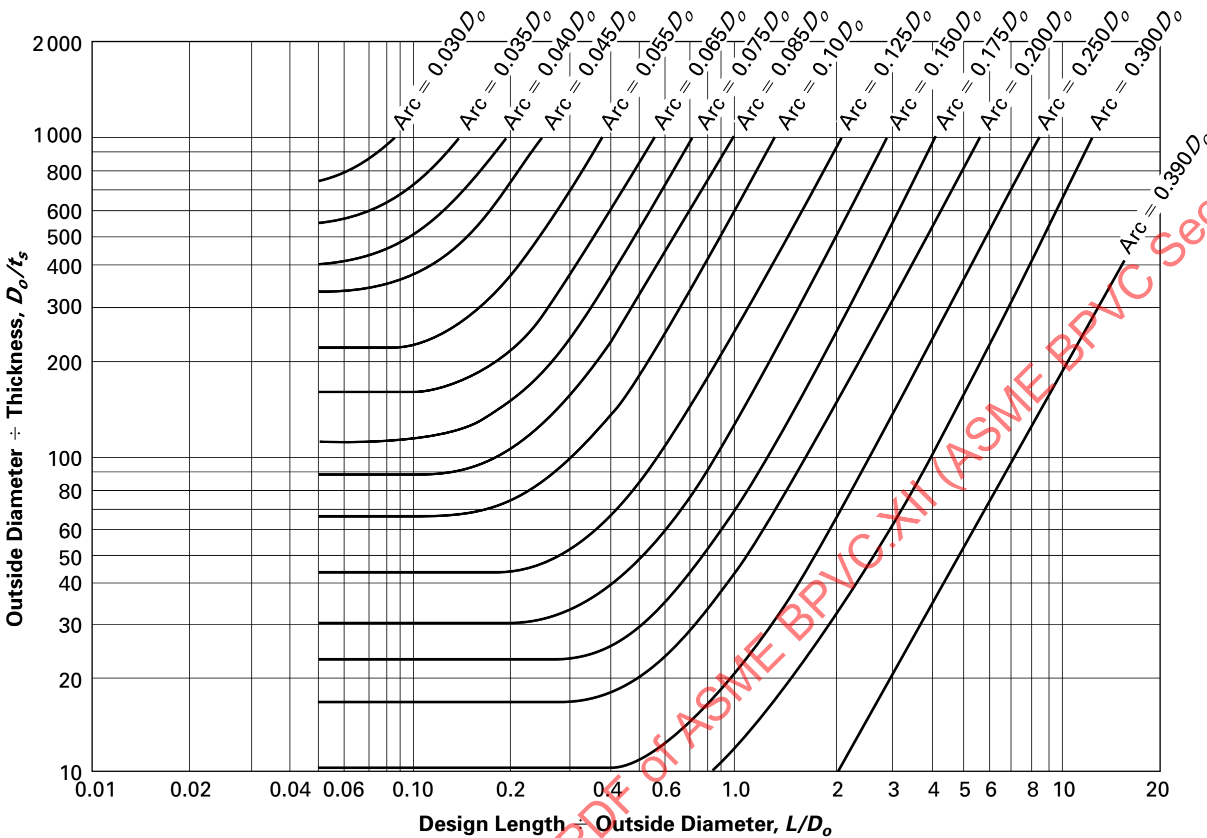


Figure TD-410.2-2
Minimum Arc of Shell Left Unsupported Because of Gap in Stiffening Ring of Cylindrical Shell Under External Pressure



(1) not less than one-half the outside circumference of the vessel for rings on the outside, and

(2) not less than one-third the circumference of the vessel for rings on the inside

(d) A continuous full-penetration weld is permitted as shown in sketch (e) of Figure TD-420. Continuous fillet welding on one side of the stiffener with intermittent welding on the other side is permitted for sketches (a) through (d) of Figure TD-420 when the thickness t_w of the outstanding stiffener element [sketches (a) and (c)] or width w of the stiffener element mating to the shell [sketches (b) and (d)] is not more than 25 mm (1 in.). The weld segments shall be not less than 50 mm (2 in.) long and shall have a maximum clear spacing between toes of adjacent weld segments of 24t.

(e) Strength of Attachment Welds. Stiffener ring attachment welds shall be sized to resist the full radial pressure load from the shell between stiffeners, and shear loads acting radially across the stiffener caused by external design loads carried by the stiffener (if any) and a computed radial shear equal to 2% of the stiffener ring's compressive load.

(1) The radial pressure load from shell is equal to PL_s.

(2) The radial shear load is equal to 0.01$PL_s\ D_o$.

(3) P, L_s, and D_o are defined in TD-400.1 (see TD-410.1 for definitions).

(f) Minimum Size of Attachment Welds. The fillet weld leg size shall be not less than the smallest of the following:

(1) 6 mm ($^1\!/_4$ in.)

(2) vessel thickness at weld location

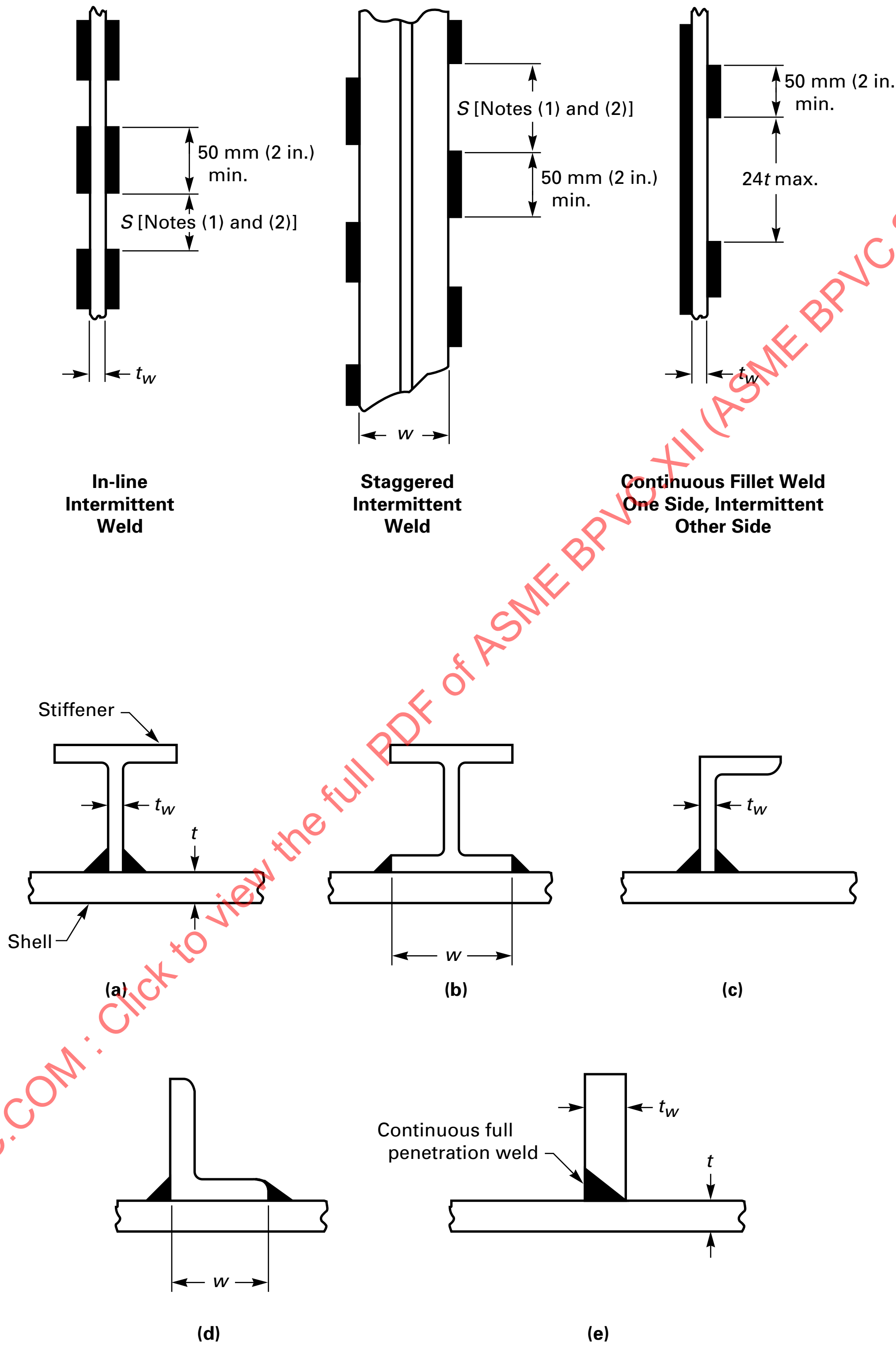
(3) stiffener thickness at weld location

TD-430 FORMED HEADS, PRESSURE ON CONVEX SIDE

(a) General. The required thickness at the thinnest point after forming of ellipsoidal, torispherical, and hemispherical heads under pressure on the convex side (minus heads) shall be computed by the appropriate equations given in this paragraph. In addition, provisions shall be made for any other loading referenced in TD-200. The required thickness for heads due to pressure on the convex side shall be determined as follows:

(1) For ellipsoidal and torispherical heads, the required thickness shall be the greater of the following:

Figure TD-420
Some Acceptable Methods of Attaching Stiffening Rings



NOTES:
(1) For external stiffeners, $S \le 8t$.
(2) For internal stiffeners, $S \le 12t$.

Table TD-430
Values of Spherical Radius Factor K_o for Ellipsoidal Head With Pressure on Convex Side

$D_o/2h_o$	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0
K_o	1.36	1.27	1.18	1.08	0.99	0.90	0.81	0.73	0.65	0.57	0.50

GENERAL NOTE: Interpolation permitted for intermediate values.

(-a) the thickness computed by the procedure given in TD-310 for heads with pressure on the concave side (plus heads) using a design pressure 1.67 times the design pressure on the convex side, assuming a joint efficiency E = 1.00 for all cases

(-b) the thickness as computed by the appropriate procedure given in (d) or (e)

(2) For hemispherical heads, the required thickness shall be determined by the rules given in (c).

(b) Nomenclature. The nomenclature defined below is used in this paragraph. See Figure TD-310.1.

A, B, E, and *P* are as defined in TD-400.1.

D_o = outside diameter of the head skirt

$D_o/2h_o$ = 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 TD-430)

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)

K_o = factor depending on the ellipsoidal head proportions, $D_o/2h_o$, (see Table TD-430)

R_o = for hemispherical heads, the outside radius
= for ellipsoidal heads, the equivalent outside spherical radius taken as K_oD_o
= for torispherical heads, the outside radius of the crown portion of the head

T = minimum required thickness of head after forming

(c) Hemispherical Heads. The required thickness of a hemispherical head having pressure on the convex side shall be determined in the same manner as outlined in TD-400.3 for determining the thickness for a spherical shell.

(d) Ellipsoidal Heads. The required thickness of an ellipsoidal head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall be not less than that determined by the following procedure.

Step 1. Assume a value for t and calculate the value of factor A using the following equation:

$$A = \frac{0.125}{R_o/t}$$

Step 2. Using the value of A calculated in Step 1, follow the same procedure as that given for spherical shells in TD-400.3, Steps 2 through 6.

(e) Torispherical Heads. The required thickness of a torispherical head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall be not less than that determined by the same design procedure as is used for ellipsoidal heads given in (d), using the appropriate value for R_0.

TD-440 ALTERNATIVE ALLOWABLE COMPRESSIVE STRESSES IN CYLINDRICAL SHELLS AND FORMED HEADS

TD-440.1 NOMENCLATURE

The symbols defined below, in addition to those of TD-400.1, are used in the procedures of this paragraph.

C_h = coefficient in equation for circumferential compressive stress

D_i = inside diameter of cylindrical shell course

D_o = outside diameter of cylindrical shell course

E = modulus of elasticity at design temperature from Section II of the ASME Boiler and Pressure Vessel Code

e = maximum deviation from a straight line, measured along a meridian over a gauge length of $L_x = 4(R_oT)^{1/2}$ or across a circumferential weld at a gauge length of $25T$

F_{ba} = allowable axial compressive membrane stress of a cylinder due to bending moment in the absence of other loads

F_{ha} = allowable circumferential compressive stress in a cylindrical shell under external pressure alone

F_{se} = allowable elastic axial compressive membrane failure (local buckling) stress of a cylinder in the absence of other loads

F_y = greater of the Section II, Part D material minimum yield strength or, if permitted by a modal appendix, a higher yield strength based on the Manufacturer's certified mill test reported minimum yield strength

FS = stress reduction factor or design factor

L_s = stiffener spacing

L_x = gauge length for measuring straightness tolerance of shells

$M_x = L_s/(R_oT)^{1/2}$
R_g = radius of gyration of cylinder
$= 0.25(D_o^2 + D_i^2)^{1/2}$
R_o = outside radius of shell
T = wall thickness

TD-440.2 STRESS REDUCTION FACTOR

Allowable compressive stresses for design and test conditions shall be as determined by applying a stress reduction factor, FS, to the predicted buckling stresses according to the equations noted in this Article unless otherwise specified in an applicable modal appendix.

$$\begin{aligned} FS &= 2.0 \text{ if } F_{ic} \leq 0.55F_y \\ &= 2.407 - 0.741\, F_{ic}/F_y \text{ if } 0.55F_y < F_{ic} < F_y \\ &= 1.667 \text{ if } F_{ic} \geq F_y \end{aligned}$$

F_{ic} is the predicted buckling stress, which is determined by letting FS = 1 in the allowable compressive stress equations given in TD-440.3(a) and TD-440.3(b).

TD-440.3 DESIGN PROCEDURES

(a) Allowable Circumferential Compressive Stresses. The allowable circumferential compressive stress for a cylindrical shell is given by

$$\begin{aligned} F_{ha} &= F_y/FS \text{ for } F_{he}/F_y \geq 2.439 \\ &= 0.7\, F_y(F_{he}/F_y)^{0.4}/FS \text{ for } 0.552 < F_{he}/F_y < 2.439 \\ &= F_{he}/FS \text{ for } F_{he}/F_y \leq 0.552 \end{aligned}$$

where

$$\begin{aligned} C_h &= 0.55T/D_o \text{ for } M_x \geq 2(D_o/T)^{0.94} \\ &= 1.12M_x^{-1.058} \text{ for } 13 < M_x < 2(D_o/T)^{0.94} \\ &= 0.92/(M_x - 0.579) \text{ for } 1.5 \leq M_x \leq 13 \\ &= 1.0 \text{ for } M_x \leq 1.5 \\ F_{he} &= 1.6C_hET/D_o \end{aligned}$$

The allowable external pressure is

$$P_a = 2F_{ha}T/D_o$$

(b) Allowable Longitudinal Compressive Stresses in a Cylinder Due to Bending Moment Across a Cross Section. The allowable longitudinal compressive stress due to bending moment across a cross section is given by the lower of F_{ba} or F_{se}.

$$\begin{aligned} F_{ba} &= F_y/FS \text{ for } D_o/T \leq 135 \\ &= \frac{466F_y}{FS\left(331 + \frac{D_o}{T}\right)} \text{ for } 135 < D_o/t < 600 \\ &= \frac{0.5F_y}{FS} \text{ for } D_o/T \geq 600 \end{aligned}$$

$$F_{se} = \frac{C_oET}{FS(D_o)}$$

where

$C_o = -0.05 - 0.572 \log (e/4T)$

(c) Tolerances for Shells Subject to Axial Compression Due to Bending Moment. Cylindrical and conical shells shall meet the out-of-roundness limitations of TF-120 and shall meet the local deviations, e, from a straight line measured along a meridian over a gauge length of L_x. The out-of-roundness shall not exceed the maximum permissible deviation range for e given below.

$$0.0006D_o \leq e \leq 0.0015D_o$$

L_x equals $4(R_oT)^{1/2}$ but not greater than L_s for cylinders, or $25T$ across circumferential welds but not greater than 95% of the distance between circumferential welds.

The allowable axial compressive stress, F_{se}, shall be calculated based on the value of e within the range stated above and shall be used as the construction tolerance for the tank. A default value of $e \leq 0.001D_o$ shall be used if the actual local deviations are not monitored and satisfied as a part of the tank construction.

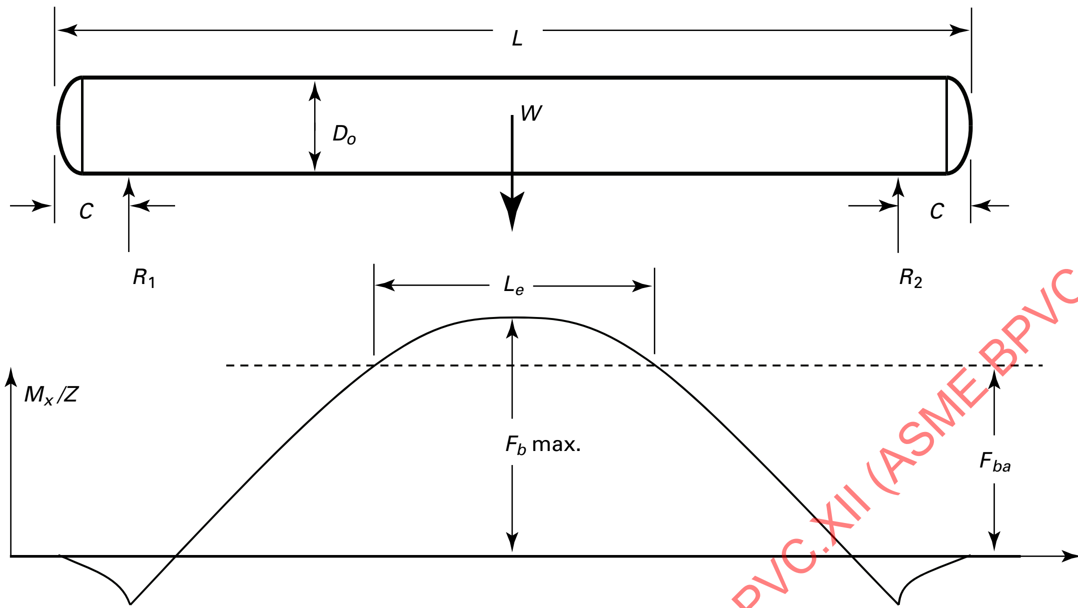
(d) Allowable Compressive Stress in a Formed Head Due to Pressure Against the Convex Side. The allowable compressive stress in a head convex to the pressure is 109.3% of that computed by the rules of TD-430, or the head design thickness can be 91.5% of that computed by the same rules.

TD-440.4 NONMANDATORY EXAMPLES OF THE TD-440 ALTERNATIVE ALLOWABLE CIRCUMFERENTIAL AND LONGITUDINAL BENDING COMPRESSIVE STRESSES IN CYLINDRICAL SHELLS

Given: A cylindrical tank with the nomenclature shown in Figure TD-440.4 is evaluated for allowable longitudinal bending stresses. The following are the design data for the tank:

– outside diameter: D_o = 64 in.
– total weight of tank and contents based on the required dynamic load conditions and allowable gross vehicle weight for highway service: W = 88,000 lb
– shell material: SA-240, Type 304
– modulus of elasticity: E = 28 × 106 psi
– F_y = greater of the Section II, Part D material minimum yield strength multiplied by 1.2 per 1-1.4
= 36,000 psi; or
– F_y = Manufacturer's certified material test report minimum yield strength multiplied by 0.9 per 1-1.4(d)(11)
= 39,000 psi
– tank overall length: L = 480 in.

Figure TD-440.4
Bending Stress Distribution in a Typical Transport Tank



GENERAL NOTE: L_e = length of tank requiring additional bending reinforcement.

– support point setback on both ends of tank: C = 30 in.

– maximum allowable tensile stress per Section II, Part D = 20,000 psi

– cylindrical tank thickness: T = 0.135 in. (10 gage) and D_o/T = 474 (Case 1)

– cylindrical tank thickness: T = 0.105 in. (12 gage) and D_o/T = 610 (Case 2)

(a) Solution for Case 1 Cylindrical Tank. The maximum bending moment at the tank center is

$$M_{\max} = \frac{WL}{4}\left(\frac{1}{2} - \frac{2C}{L}\right) = \frac{88{,}000(480)}{4}\left[\frac{1}{2} - \frac{2(30)}{480}\right] = 3{,}960{,}000\,\text{in.-lb}$$

Cylindrical section modulus

$$Z = \frac{\pi D^2 T}{4} = \frac{\pi(64)^2(0.135)}{4} = 434\,\text{in.}^3$$

Maximum longitudinal compressive stress

$$F_b = \frac{M_{\max}}{Z} = 9{,}100\text{ psi}$$

The maximum allowable longitudinal compressive stress in a cylinder due to bending from TD-440.3(b) is the lower of F_{ba} or F_{se} as follows:

From TD-440.2,

$$FS = 2.0 \text{ if } F_{ic} \le 0.55F_y$$

$$0.55F_y = 0.55(39{,}000\text{ psi}) = 21{,}450\,\text{psi}$$

$$D_o/T = 64/0.135 = 474$$

Therefore, assuming FS = 2.0,

$$F_{ba} = \frac{466F_y}{FS(331 + D_o/T)} = \frac{466(39{,}000)}{2(331 + 64/0.135)} = 11{,}300\,\text{psi}$$

To confirm the assumption that FS = 2.0,

$$F_{ic} = F_{ba}/2.0 = 5{,}700\,\text{psi} < 21{,}450$$

Therefore, the FS = 2.0 assumption is valid.

Assume $e = 0.001D_o$, the TD-440 default value. Then

$$C_o = -0.05 - 0.572\log(e/4T) = -0.05 - 0.572\log\left[\frac{0.001(64)}{4(0.135)}\right] = 0.48$$

$$F_{se} = \frac{C_oET}{FS(D_o)} = \frac{0.48(28 \times 10^6)(0.135)}{2(64)} = 14{,}200\,\text{psi}$$

Therefore, F_{ba} controls the allowable stress. The applied stress F_b (9,100 psi) is less than the allowable stress F_{ba} (11,300 psi). Therefore, the subject circular cylinder is acceptable for the applied $M_{\max}$ of 3,960,000 in.-lb.

(b) Solution for Case 2 Cylindrical Tank. Cylindrical section modulus

$$Z = \frac{\pi D^2 T}{4} = \frac{\pi (64)^2 (0.105)}{4} = 338\,\text{in.}^3$$

Maximum longitudinal compressive stress

$$F_b = \frac{M_{\max}}{Z} = 11{,}700\,\text{psi}$$

The maximum allowable longitudinal compressive stress in a cylinder due to bending from TD-440.3(b) is the lower of F_{ba} or F_{se}, as follows:

From TD-440.2,

$$FS = 2.0 \text{ if } F_{ic} \leq 0.55 F_y$$

$$0.55 F_y = 0.55(39,\,000\,\text{psi}) = 21{,}450\,\text{psi}$$

$$D_o / T = 64/0.105 = 610$$

Therefore, assuming FS = 2.0,

$$F_{ba} = \frac{0.5 F_y}{FS} = \frac{0.5(39{,}000)}{2} = 9{,}800\,\text{psi}$$

$$F_{ic} = F_{ba}/2.0 = 4{,}900\,\text{psi} < 21{,}450$$

Therefore, the FS = 2.0 assumption is valid.

Assume e = 0.001D_o, the TD-440 default value. Then

$$\begin{aligned} C_o &= -0.05 - 0.572 \log(e/4T) \\ &= -0.05 - 0.572 \log\left[\frac{0.001(64)}{4(0.105)}\right] = 0.42 \end{aligned}$$

$$F_{se} = \frac{C_o E T}{FS(D_o)} = \frac{0.42(28 \times 10^6)(0.105)}{2(64)} = 9{,}600\,\text{psi}$$

Therefore, the calculated longitudinal compressive bending stress of 11,700 psi is greater than the allowables. This can be resolved by either increasing the shell thickness or providing longitudinal stiffeners on the top of the tank (see Figure TD-440.4) that will increase the cylindrical shell section modulus and reduce the compressive bending stresses to comply with the TD-440 allowables.

ARTICLE TD-5
UNSTAYED FLAT HEADS AND COVERS

TD-500 DESIGN OF UNSTAYED FLAT HEADS AND COVERS

(a) The minimum thickness of unstayed flat heads, cover plates, and blind flanges shall conform to the requirements given in this paragraph. These requirements apply to both circular and noncircular heads and covers. Special consideration shall be given to the design of shells, nozzle necks, or flanges to which noncircular heads or covers are attached. Some acceptable types of flat heads and covers are shown in Figure TD-500. In this figure, the dimensions of the component parts and the dimensions of the welds are exclusive of extra metal required for corrosion allowance.

(b) The symbols used in this paragraph and in Figure TD-500 are defined as follows:

C = a factor depending upon the method of attachment of head, shell dimensions, and other items as listed in (d), dimensionless. The factors for welded covers also include a factor of 0.667 that effectively increases the allowable stress for such constructions to 1.5S

D = long span of noncircular heads or covers measured perpendicular to short span

d = diameter, or short span, measured as indicated in Figure TD-500

E = joint efficiency, from Table TW-130.4, of any Category A weld as defined in TW-130.3

h_G = gasket moment arm, equal to the radial distance from the centerline of the bolts to the line of the gasket reaction, as shown in Mandatory Appendix XX, Table XX-5.2

L = perimeter of noncircular bolted head measured along the centers of the bolt holes

M = the ratio t_r/t_s, dimensionless

P = internal design pressure (see TD-150)

r = inside comer radius on a head formed by flanging or forging

S = maximum allowable stress value in tension, psi, from applicable table of stress values referenced by TD-210

t = minimum required design thickness of flat head or cover

t_1 = throat dimension of the closure weld, as indicated in Figure TD-500, sketch (r)

t_f = nominal thickness of the flange on a forged head, at the large end, as indicated in Figure TD-500, sketch (b)

t_h = nominal thickness of flat head or cover

t_r = required thickness of seamless shell, for pressure

t_s = nominal thickness of shell

t_w = thickness through the weld joining the edge of a head to the inside of a vessel, as indicated in Figure TD-500, sketch (g)

W = total bolt load, given for circular heads for Mandatory Appendix XX, XX-5, eqs. (3) and (4).

Y = length of flange of flanged heads, measured from the tangent line of knuckle, as indicated in Figure TD-500, sketches (a) and (c)

Z = a factor of noncircular heads and covers that depends on the ratio of short span to long span, as given in (c), dimensionless

(c) The thickness of flat unstayed heads, covers, and blind flanges shall conform to one of the following three requirements. These equations provide adequate design margins against structural failure. However, no limit has been provided for deflection and rotation. If leakage at a threaded or gasketed joint is of concern, the thickness may have to be increased to provide adequate rotational stiffness.

(1) Circular blind flanges conforming to any of the flange standards listed in Table TG-130 and further limited in TD-100.5 shall be acceptable for the diameters and pressure–temperature ratings in the respective standard when the blind flange is of the types shown in Figure TD-500, sketches (j) and (k).

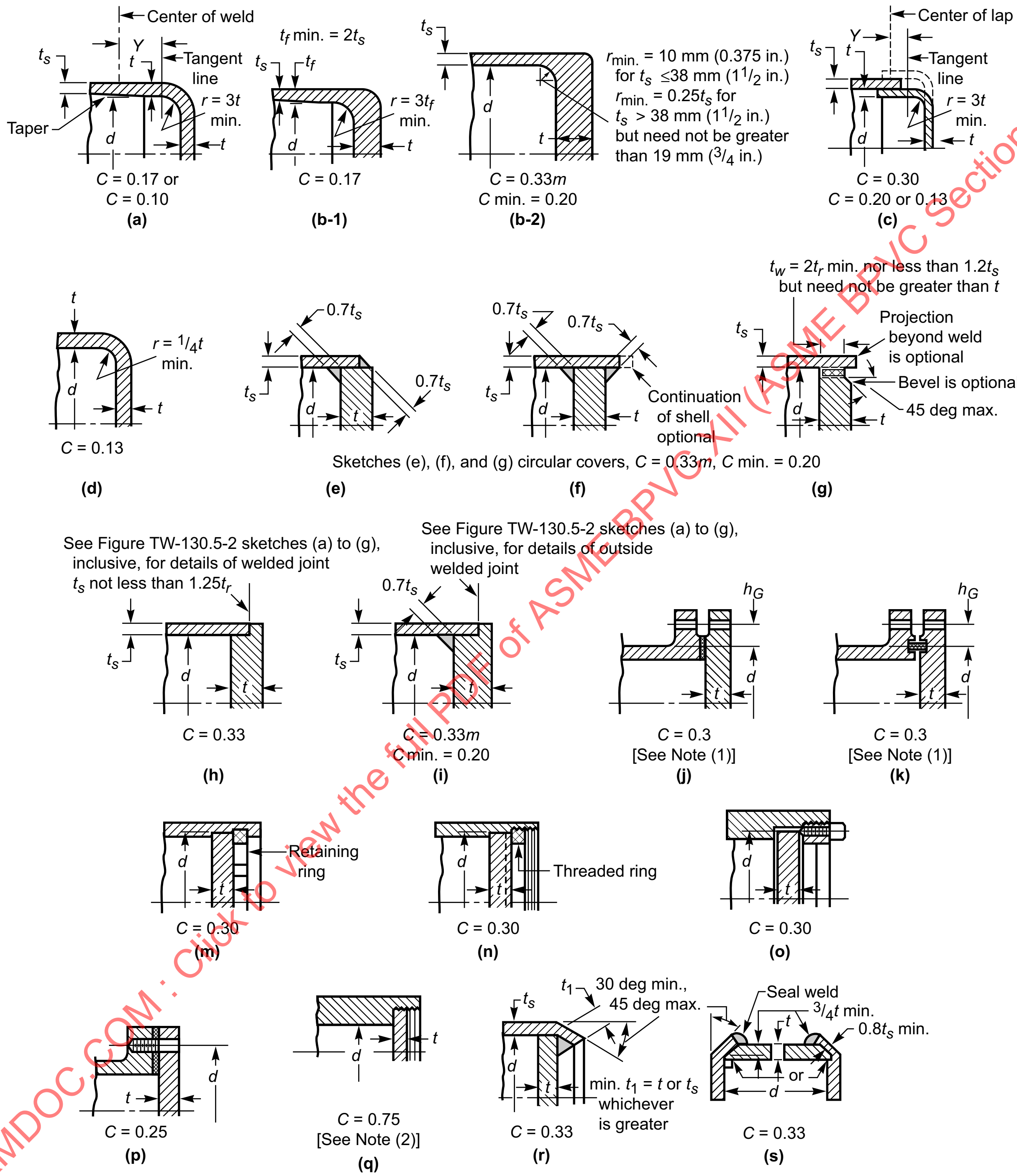
(2) The minimum required thickness of flat unstayed circular heads, covers, and blind flanges shall be calculated by the following equation:

$$t = d\sqrt{CP / SE} \tag{1}$$

except when the head, cover, or blind flange is attached by bolts causing an edge moment [sketches (j) and (k)], in which case the thickness shall be calculated by

$$t = \sqrt{\frac{CP}{SE} + \frac{1.9Wh_G}{SEd^3}} \tag{2}$$

Figure TD-500
Some Acceptable Types of Unstayed Flat Heads and Covers



GENERAL NOTE: The above sketches are diagrammatic only. Other designs that meet the requirements of TD-500 are acceptable.

NOTES:

(1) Use TD-500(c)(2), eq. (2) or TD-500(c)(3), eq. (5).

(2) When pipe threads are used, see Table TD-670.

When using eq. (2), the thickness t shall be calculated for both operating conditions and gasket seating, and the greater of the two values shall be used. For operating conditions, the value of P shall be the design pressure, and the values of S at the design temperature and W from Mandatory Appendix XX, XX-5, eq. (3) shall be used. For gasket seating, P equals zero, and the values of S at atmospheric temperature and W from and Mandatory Appendix XX, XX-5, eq. (4) shall be used.

(3) Flat unstayed heads, covers, or blind flanges may be square, rectangular, elliptical, obround, segmental, or otherwise noncircular. Their required thickness shall be calculated by the following equation:

$$t = d\sqrt{ZCP / SE} \tag{3}$$

where

$$Z = 3.4 - \frac{2.4d}{D} \tag{4}$$

with the limitation that Z need not be greater than 2.5.

Equation (3) does not apply to noncircular heads, covers, or blind flanges attached by bolts causing a bolt edge moment [sketches (j) and (k)]. For noncircular heads of this type, the required thickness shall be calculated by the following equation:

$$t = d\sqrt{\frac{ZCP}{SE} + \frac{6Wh_G}{SELd^2}} \tag{5}$$

When using eq. (5), the thickness t shall be calculated in the same way as specified above for (2), eq. (2).

(d) For the types of construction shown in Figure TD-500, the minimum values of C to be used in eqs. (1) and (2) of (c)(2), and eqs. (3) and (5) of (c)(3) are:

(1) Sketch (a)

(-a) C = 0.17 for flanged circular and noncircular heads forged integral with or butt welded to the vessel with an inside corner 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 the requirements for circumferential joints given in Part TW.

(-b) C = 0.10 for circular heads, when the flange length for heads of the above design is not less than

$$Y = \left(1.1 - 0.8\frac{t_s^2}{t_h^2}\right)\sqrt{dt_h} \tag{6}$$

(-c) C = 0.10 for circular heads, when the flange length Y is less than the requirements in (-b), eq. (6) but the shell thickness is not less than

$$t_s = 1.12t_h\sqrt{1.1 - Y / \sqrt{dt_h}} \tag{7}$$

for a length of at least $2\sqrt{dt_s}$.

When C = 0.10 is used, the taper shall be at least 1:3.

(2) Sketch (b-1). C = 0.17 for forged circular and noncircular heads integral with or butt welded to the vessel, where the flange thickness is not less than two times the shell thickness, the corner radius on the inside is not less than three times the flange thickness, and the welding meets all the requirements for circumferential joints given in Part TW.

(3) Sketch (b-2). $C = 0.33m$ but not less than 0.20 for forged circular and noncircular heads integral with or butt welded to the vessel, where the flange thickness is not less than the shell thickness, the corner radius on the inside is not less than the following:

(-a) r_{min} = 10 mm (0.375 in.) for $t_s \leq$ 38 mm (1½ in.)

(-b) $r_{min} = 0.25t$, for $t_s >$ 38 mm (1½ in.) but need not be greater than 19 mm (¾ in.)

The welding shall meet all the requirements for circumferential joints given in Part TW.

(4) Sketch (c)

(-a) C = 0.13 for circular heads lap welded to the shell with corner radius not less than $3t$ and Y not less than required by (1)(-b), eq. (6) and the requirements of TW-130.5 are met.

(-b) C = 0.20 for circular and noncircular lap-welded or brazed construction as above, but with no special requirement with regard to Y.

(-c) C = 0.30 for circular flanged plates screwed over the end of the vessel, with inside comer radius not less than $3t$, in which the design of the threaded joint against failure by shear, tension, or compression, resulting from the end force due to pressure, is based on a factor of safety of at least 3.5, and the threaded parts are at least as strong as the threads for standard piping of the same diameter. Seal welding may be used, if desired.

(5) Sketch (d). C = 0.13 for integral flat circular heads when the dimension d does not exceed 610 mm (24 in.), the ratio of thickness of the head to the dimension d is not less than 0.05 or greater than 0.25, the head thickness t_h is not less than the shell thickness t_s, the inside corner radius is not less than $0.25t$, and the construction is obtained by special techniques of upsetting and spinning the end of the shell, such as employed in closing header ends.

(6) Sketches (e), (f), and (g)

(-a) $C = 0.33m$ but not less than 0.20 for circular plates, welded to the inside of a vessel, and otherwise meeting the requirements for the respective types of welded vessels. If a value of $m < 1$ is used in calculating t, the shell thickness t_s shall be maintained along a distance inwardly from the inside face of the head equal to at least $2\sqrt{dt_s}$. The throat thickness of the fillet welds in sketches (e) and (f) shall be at least $0.7t_s$. The size of the weld t_w in sketch (g) shall be not less than two times the required thickness of a seamless shell nor less than 1.25 times the nominal shell thickness but need not be greater than the head thickness; the weld shall be deposited in a welding

groove with the root of the weld at the inner face of the head as shown in the sketch.

(-b) C = 0.33 for noncircular plates, welded to the inside of a vessel and otherwise meeting the requirements for the respective types of welded vessels. The throat thickness of the fillet welds in sketches (e) and (f) shall be at least $0.7t_s$. The size of the weld t_w in sketch (g) shall be not less than two times the required thickness of a seamless shell nor less than 1.25 times the nominal shell thickness but need not be greater than the head thickness; the weld shall be deposited in a welding groove with the root of the weld at the inner face of the head as shown in the sketch.

(7) Sketch (h). C = 0.33 for circular plates welded to the end of the shell when t_s is at least $1.25t_r$ and the weld details conform to the requirements of TW-130.5(e) and Figure TW-130.5-2, sketches (a) through (g) inclusive.

(8) Sketch (i). $C = 0.33m$ but not less than 0.20 for circular plates if an inside fillet weld with minimum throat thickness of $0.7t_s$ is used and the details of the outside weld conform to the requirements of TW-130.5(e) and Figure TW-130.5-2, sketches (a) through (g) inclusive, in which the inside weld can be considered to contribute an amount equal to t_s to the sum of the dimensions a and b.

(9) Sketches (j) and (k). C = 0.3 for circular and noncircular heads and covers bolted to the vessel as indicated in the figures. Note that (c)(2), eq. (2) or (c)(3), eq. (5) 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 sketch (k), 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

$$d\sqrt{1.9Wh_G / Sd^3}$$

for circular heads and covers, and not less than

$$d\sqrt{6Wh_G / SLd^2}$$

for noncircular heads and covers.

(10) Sketches (m), (n), and (o). C = 0.3 for a circular plate inserted into the end of a vessel and held in place by a positive mechanical locking arrangement, and when all possible means of failure (either by shear, tension, compression, or radial deformation, including flaring, resulting from pressure and differential thermal expansion) are resisted with a design margin of at least 3.5. Seal welding may be used, if desired.

(11) Sketch (p). C = 0.25 for circular and noncircular covers bolted with a full-face gasket, to shells, flanges, or side plates.

(12) Sketch (q). C = 0.75 for circular plates screwed into the end of a vessel having an inside diameter d not exceeding 305 mm (12 in.); or for heads having an integral flange screwed over the end of a vessel having an inside diameter d not exceeding 305 mm (12 in.); and when the design of the threaded joint, against failure by shear, tension, compression, or radial deformation, including flaring, resulting from pressure and differential thermal expansion, is based on a factor of safety of at least 3.5. If a tapered pipe thread is used, the requirements of Table TD-670 shall also be met. Seal welding may be used, if desired.

(13) Sketch (r). C = 0.33 for circular plates having a dimension d not exceeding 457 mm (18 in.) inserted into the vessel as shown and otherwise meeting the requirements for the respective types of welded vessels. The end of the vessel shall be crimped over at least 30 deg, but not more than 45 deg. The crimping may be done cold only when this operation will not injure the metal. The throat of the weld shall be not less than the thickness of the flat head or shell, whichever is greater.

(14) Sketch (s). C = 0.33 for circular beveled plates having a diameter d not exceeding 457 mm (18 in.), inserted into a vessel, the end of which is crimped over at least 30 deg, but not more than 45 deg, and when the undercutting for seating leaves at least 80% of the shell thickness. The beveling shall be not less than 75% of the head thickness. The crimping shall be done when the entire circumference of the cylinder is uniformly heated to the proper forging temperature for the material used. For this construction, the ratio t_s/d shall be not less than the ratio P/S nor less than 0.05. The maximum allowable pressure for this construction shall not exceed $P = S/5d$.

This construction is not permissible if machined from rolled plate.

ARTICLE TD-6
OPENINGS AND REINFORCEMENTS

TD-600 OPENINGS IN TRANSPORT TANKS

TD-600.1 SHAPE OF OPENINGS

(a) Openings in cylindrical or conical portions of vessels, or in formed heads, shall preferably be circular, elliptical, or obround. (The opening made by a pipe or circular nozzle, the axis of which is not perpendicular to the vessel wall or head, may be considered an elliptical opening for design purposes.) An obround opening is one that is formed by two parallel sides and semicircular ends.

When the long dimension of an elliptical or obround opening exceeds twice the short dimension, the reinforcement across the short dimension shall be increased as necessary to provide against excessive distortion due to twisting moment.

(b) For openings of other shapes than those given in (a), all corners shall be provided with a suitable radius. When the openings are of such proportions that their strength cannot be computed with assurance of accuracy, or when doubt exists as to the safety of a vessel with such openings, the part of the vessel affected shall be subjected to a proof hydrostatic test as prescribed in TT-210.

TD-600.2 SIZE OF OPENINGS

(a) Properly reinforced openings in cylindrical or conical shells are not limited as to size, except with the following provisions for design. The rules of TD-600.2 through TD-610.6 apply to all openings, unless exempted by other rules of this Section. For openings having a diameter exceeding the following, the supplemental rules of TD-610.7 shall also be satisfied:

(1) for vessels 1 520 mm (60 in.) inside diameter and less, one-half the vessel diameter, or 508 mm (20 in.)

(2) for vessels over 1 520 mm (60 in.) inside diameter, one-third the vessel diameter, or 1 000 mm (40 in.)

(b) Properly reinforced openings in spherical shells and formed heads are not limited in size.

TD-600.3 STRENGTH AND DESIGN OF FINISHED OPENINGS

(a) All references to dimensions in this and succeeding paragraphs apply to the finished construction after deduction has been made for material added as corrosion allowance. For design purposes, corrosion allowance shall not be considered as reinforcement. The finished opening diameter is the diameter d as defined in TD-610.1 and in Figure TD-610.3-2.

(b) Openings in cylindrical or conical shells, or formed heads shall be reinforced to satisfy the requirements in TD-610.3, except as given in (c).

Openings in flat heads shall be reinforced as required by TD-630.

(c) Openings in vessels not subject to rapid fluctuations in pressure do not require reinforcement other than that inherent in the construction under the following conditions:

(1) welded connections and flued openings attached in accordance with the applicable rules and with a finished opening not larger than:

(-a) 89 mm (3½ in.) diameter, in vessel shells or heads having a required minimum design thickness of 10 mm (⅜ in.) or less

(-b) 60 mm (2⅜ in.) diameter, in vessel shells or heads having a required minimum design thickness of over 10 mm (⅜ in.)

(2) threaded, studded, or expanded connections in which the hole cut in the shell or head is not greater than 60 mm (2⅜ in.)

(3) no two isolated unreinforced openings, in accordance with TD-600.2(a)(1) or TD-600.2(a)(2), shall have their centers closer to each other than the sum of their diameters

(4) no two unreinforced openings, in a cluster of three or more unreinforced openings in accordance with TD-600.2(a)(1) or TD-600.2(a)(2), shall have their centers closer to each other than the following:

(-a) for cylindrical or conical shells

$$(1 + 1.5 \cos \theta)(d_1 + d_2)$$

(-b) for doubly curved shells and formed or flat heads

$$2.5(d_1 + d_2)$$

where

d_1, d_2 = the finished diameters of the two adjacent openings

θ = the angle between the line connecting the center of the openings and the longitudinal axis of the shell

TD-600.4 OPENINGS THROUGH WELDED JOINTS

Additional provisions governing openings in or adjacent to welded joints are given in TW-140.1.

TD-600.5 OPENINGS IN NONCIRCULAR VESSELS

Openings in noncircular vessels are not covered by these rules, except for formed heads. See TG-100.2(c).

TD-610 REINFORCEMENT REQUIRED FOR OPENINGS IN SHELLS AND FORMED HEADS

TD-610.1 NOMENCLATURE

The symbols used in this paragraph are defined as follows (see Figure TD-610.3-2):

A = total cross-sectional area of reinforcement required in the plane under consideration
A_1 = area in excess thickness in the vessel wall available for reinforcement
A_2 = area in excess thickness in the nozzle wall available for reinforcement
A_3 = area available for reinforcement when the nozzle extends inside the vessel wall
A_5 = cross-sectional area of material added as reinforcement
A_{41}, A_{42}, A_{43} = cross-sectional area of various welds available for reinforcement
c = corrosion allowance
D = inside shell diameter
d = finished diameter of circular opening or finished dimension (chord length at midsurface of thickness excluding excess thickness available for reinforcement) of nonradial opening in the plane under consideration (see Figure TD-640)
D_p = outside diameter of reinforcing element (actual size of reinforcing element may exceed the limits of reinforcement established by TD-640; however, credit cannot be taken for any material outside these limits)
E = 1 (see definitions for t_r and t_{rn})
E_1 = 1 when the opening is in the solid plate or in the Category B butt joint, or
= joint efficiency obtained from Table TW-130.4, when any part of the opening passes through any other welded joint
F = correction factor that compensates for the variation in pressure stresses on different planes with respect to the longitudinal axis of a vessel. F = 1.0 for formed or flat heads (see Figure TD-610.3-1).
f_r = strength reduction factor, not greater than 1.0 [see TD-650(a)]
f_{r1} = S_n/S_v for nozzle wall inserted through the vessel wall
= 1.0 for nozzle wall abutting the vessel wall and for nozzles shown in Figure TD-640, sketches (j), (k), (n), and (o).
f_{r2} = S_n/S_v
f_{r3} = (lesser of S_n or S_p)/S_v
f_{r4} = S_p/S_v
h = distance nozzle projects inward from the inner surface of the vessel wall. (Extension of the nozzle beyond the inside surface of the vessel wall is not limited; however, for reinforcement calculations, credit shall not be taken from material outside the limits of reinforcement established by TD-640.)
K_1 = spherical radius factor (see definition of t_r and Table TD-610.1)
L = length of projection defining the thickened portion of integral reinforcement of a nozzle neck beyond the outside surface of the vessel wall [see Figure TD-640, sketch (e)]
P = internal design pressure (see TD-150)
R = inside radius of the shell course under consideration
R_n = inside radius of the nozzle under consideration
S = allowable stress value in tension (see TD-210)
S_n = allowable stress in nozzle (see S above)
S_p = allowable stress in reinforcing element (see S above)
S_v = allowable stress in vessel (see S above)
t = nominal thickness of the vessel wall
t_e = thickness or height of reinforcing element, (see Figure TD-640)
t_i = nominal thickness of internal projection of nozzle wall
t_n = nominal thickness of external projection of nozzle wall
t_r = required thickness of a seamless shell based on the circumferential stress, or of a formed head, computed by the rules of this Section for the designated pressure, using E = 1, except that:

(a) when the opening and its reinforcement are entirely within the spherical portion of a torispherical head, t_r is the thickness required by TD-300.3, using M = 1

Table TD-610.1
Values of Spherical Radius Factor, K_1

$D/2h$	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0
K_1	1.36	1.27	1.18	1.08	0.99	0.90	0.81	0.73	0.65	0.57	0.50

GENERAL NOTE: Equivalent spherical radius = $K_1 D$; $D/2h$ = axis ratio. For definitions, see TD-610.1. Interpolation permitted for intermediate values.

(b) 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

(c) when the opening and its reinforcement are in an ellipsoidal head and are 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 for a seamless sphere of radius $K_1 D$, where D is the shell diameter and K_1 is given by Table TD-610.1

t_{rn} = required thickness of a seamless nozzle wall

W = total load to be carried by attachment welds, lb (see TD-650)

TD-610.2 GENERAL

The rules in this paragraph apply to all openings other than:

(a) small openings covered by TD-600.3(c)

(b) openings in flat heads covered by TD-630

Reinforcement shall be provided 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. For a circular opening in a cylindrical shell, the plane containing the axis of the shell is the plane of greatest loading due to pressure. Not less than half the required reinforcement shall be on each side of the centerline of single openings.

TD-610.3 DESIGN FOR INTERNAL PRESSURE

The total cross-sectional area of reinforcement, A, required in any given plane through the opening for a shell or formed head under internal pressure shall be not less than

$$A = dt_rF + 2t_nt_rF\left(1 - f_{r1}\right)$$

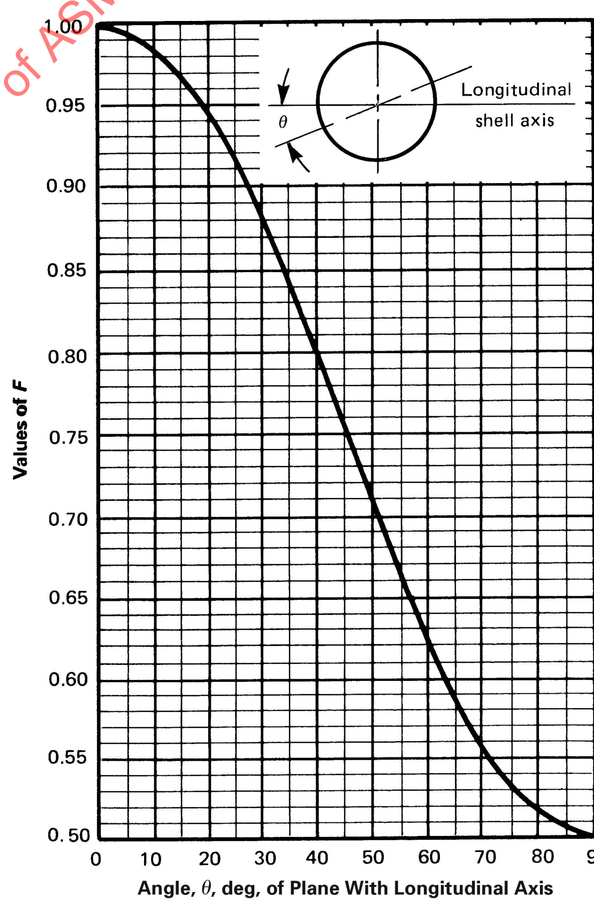
See Figure TD-610.3-1 and Figure TD-610.3-2. Where longitudinal tensile bending stresses occur at reinforcements, use F = 1.0.

TD-610.4 DESIGN FOR EXTERNAL PRESSURE

(a) The reinforcement required for openings in single-walled vessels subject to external pressure need be only 50% of that required in TD-610.3, where t_r is the wall thickness required by the rules for vessels under external pressure. The value of F shall be 1.0 in all external pressure calculations.

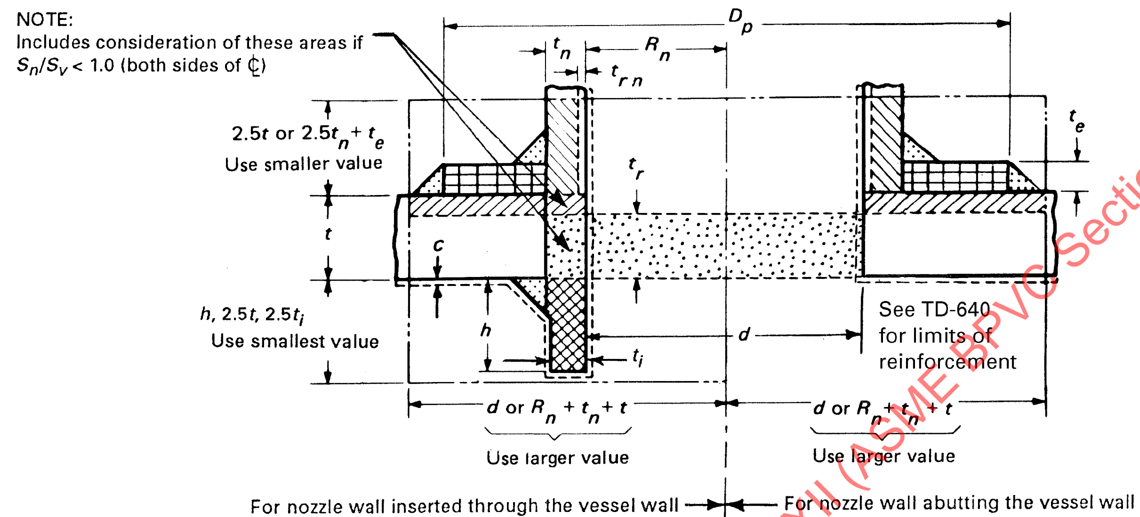
(b) The reinforcement required for openings in each shell of a multiple-walled vessel shall comply with (a) when the shell is subject to external pressure, and with TD-610.3 when the shell is subject to internal

Figure TD-610.3-1
Chart for Determining Value of F, as Required in TD-610.3



GENERAL NOTE: $F = \frac{3}{4} + \frac{1}{4}\cos(2\theta)$

Figure TD-610.3-2
Nomenclature and Equations for Reinforced Openings



Without Reinforcing Element

$A = d\,t_r\,F + 2t_n\,t_r\,F(1 - f_{r1})$	Area required
$A_1 = d(E_1\,t - Ft_r) - 2t_n\,(E_1 t - Ft_r)\,(1 - f_{r1})$ $= 2(t + t_n)(E_1 t - Ft_r) - 2t_n(E_1 t - Ft_r)(1 - f_{r1})$	Area available in shell; use larger value
$A_2 = 5(t_n - t_{rn})\,f_{r2}t$ $= 5(t_n - t_{rn})f_{r2}t_n$	Area available in nozzle projecting outward; use smaller value
$A_3 = 5t\,t_i\,f_{r2}$ $= 5t_i\,t_i\,f_{r2}$ $= 2h\,t_i\,f_{r2}$	Area available in inward nozzle; use smallest value
A_{41} = outward nozzle weld = $(\text{leg})^2 f_{r2}$	Area available in outward weld
A_{43} = inward nozzle weld = $(\text{leg})^2 f_{r2}$	Area available in inward weld
If $A_1 + A_2 + A_3 + A_{41} + A_{43} \geq A$	Opening is adequately reinforced
If $A_1 + A_2 + A_3 + A_{41} + A_{43} < A$	Opening is not adequately reinforced so reinforcing elements must be added and/or thicknesses must be increased

With Reinforcing Element Added

A = same as A, above	Area required
A_1 = same as A_1, above	Area available
$A_2 = 5(t_n - t_{rn})f_{r2}t$ $= 2(t_n - t_{rn})(2.5t_n + t_e)f_{r2}$	Area available in nozzle projecting outward; use smaller area
A_3 = same as A_3, above	Area available in inward nozzle
A_{41} = outward nozzle weld = $(\text{leg})^2 f_{r3}$	Area available in outward weld
A_{42} = outer element weld = $(\text{leg})^2 f_{r4}$	Area available in outer weld
A_{43} = inward nozzle weld = $(\text{leg})^2 f_{r2}$	Area available in inward weld
$A_5 = (D_p - d - 2t_n)\,t_e\,f_{r4}$ [Note (1)]	Area available in element
If $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5 \geq A$	Opening is adequately reinforced

GENERAL NOTE: This figure illustrates a common nozzle configuration and is not intended to prohibit other configurations permitted by the Code.

NOTE: (1) This formula is applicable for a rectangular cross-sectional element that falls within the limits of reinforcement.

pressure, regardless of whether or not there is a common nozzle secured to more than one shell by strength welds.

TD-610.5 DESIGN FOR BOTH INTERNAL AND EXTERNAL PRESSURE

Reinforcement of vessels subject to both internal and external pressures shall meet the requirements of TD-610.3 for internal pressure and TD-610.4 for external pressure.

TD-610.6 AREA REPLACEMENT

Details and equations for required area and available area are given in Figure TD-610.3-2.

TD-610.7 LARGE OPENINGS IN SHELLS

(a) Openings exceeding the dimensional limits given in TD-600.2(a)(1) shall be provided with reinforcement that complies with the following rules. Two-thirds of the required reinforcement shall be within the following limits:

(1) parallel to vessel wall: the larger of three-fourths times the limit in TD-640, or equal to the limit in TD-640(b)(2)

(2) normal to the vessel wall the smaller of the limit in TD-640(c)(1), or in TD-640(c)(2)

(b) Openings for radial nozzles in cylindrical shells that exceed the limits in TD-600.2 and that also are within the range defined by the following limits shall meet the requirements of (c), (d), and (e):

(1) vessel diameters greater than 1 500 mm (60 in.) in diameter

(2) nozzle diameters that exceed 1 000 mm (40 in.) in diameter and also exceed $3.4\sqrt{Rt}$ (The terms R and t are defined in Figure TD-610.7.)

(3) the ratio R_n/R does not exceed 0.7 [For nozzle openings with R_n/R exceeding 0.7, refer to (c) and/or TG-100.2(c).]

These rules are limited to radial nozzles in cylindrical shells that do not have internal projections, and do not have externally applied mechanical loads specified. For cases that do not meet these limitations, a recognized analytical method shall be used. see TG-100.2(c).

(c) The membrane stress, S_m, as calculated by (e)(1), eq. (1) or (e)(2), eq. (2) shall not exceed S, as defined in TD-610.1 for the applicable materials at design conditions. The maximum combined membrane stress, S_m, and bending stress, S_b, shall not exceed 1.5S at design conditions. S_b shall be calculated by (e)(3), eq. (5).

(d) Evaluation of combined stresses from internal pressure and external loads shall be made in accordance with recognized good engineering practice for such cases, such as the WRC-107/297 bulletins.

(e) For membrane stress calculations, use the limits defined in Figure TD-610.7, and comply with the strength of reinforcement requirements of TD-650. For bending stress calculation, the greater of the limits defined in Figure TD-610.7 may be used. The strength reduction ratio requirements of TD-650 need not be applied, provided that the ratio of the allowable stress of the material in the nozzle neck, nozzle forging, reinforcing plate, and/or nozzle flange to the shell material allowable stress is at least 0.80.

NOTE: The bending stress, S_b, calculated by (3), eq. (5) is valid and applicable only at the nozzle neck-shell junction. It is a primary bending stress because it is a measure of the stiffness required to maintain equilibrium at the longitudinal axis junction of the nozzle-shell intersection due to the bending moment calculated by (3), eq. (3).

(1) Case A [see Figure TD-610.7, sketches (a) and (c)]

$$S_m = P \times \left[\frac{\left[\begin{array}{l} R\,(R_n + t_n + \sqrt{R_m t}\,) \\ + R_n\,(t + t_e + \sqrt{R_{nm} t_n}\,) \end{array} \right]}{A_s} \right] \qquad (1)$$

(2) Case B [see Figure TD-610.7, sketches (b) and (d)]

$$S_m = P \times \left[\frac{\left[\begin{array}{l} R\,(R_n + t_n + \sqrt{R_m t}\,) \\ + R_n\,(t + t_e + \sqrt{R_{nm} t_n}\,) \end{array} \right]}{A_s} \right] \qquad (2)$$

(3) Cases A and B (see Figure TD-610.7)

$$M = \left(\frac{R_n^3}{6} + R R_n e \right) P \qquad (3)$$

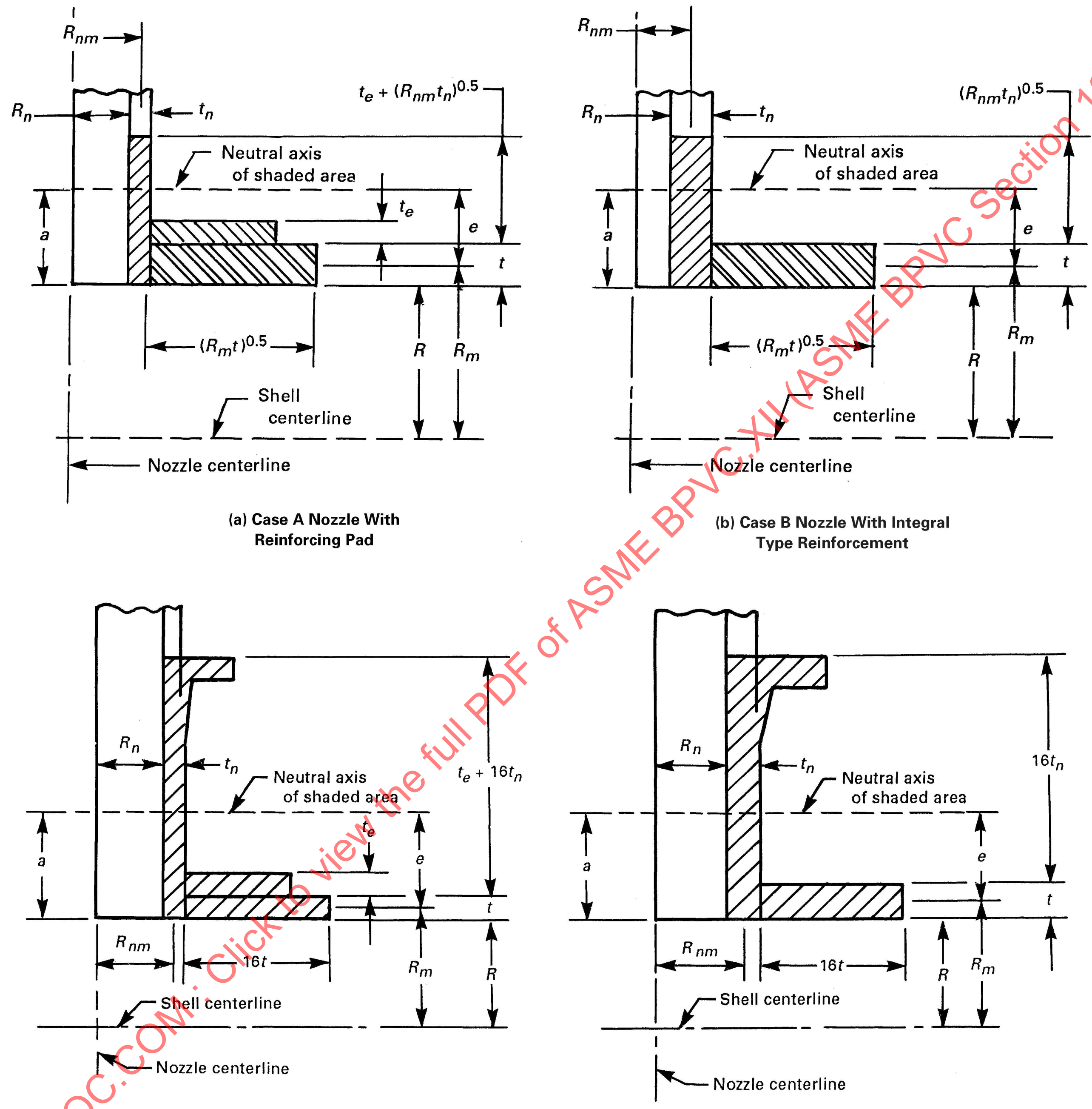
$$a = e + t/2 \qquad (4)$$

$$S_b = \frac{Ma}{I} \qquad (5)$$

(f) *Nomenclature.* Symbols used in Figure TD-610.7 are as defined in (a) and as follows:

a = distance between neutral axis of the shaded area in Figure TD-610.7 and the inside of vessel wall
A_s = shaded (cross-hatched) area in Figure TD-610.7, sketch (a) or (b)
e = distance between neutral axis of the shaded area and midwall of the shell
I = moment of inertia of the larger of the shaded areas in Figure TD-610.7 and the inside of vessel wall
R_m = mean radius of shell
R_{nm} = mean radius of nozzle neck

Figure TD-610.7
Openings for Radial Nozzles in Cylindrical Shells



(a) Case A Nozzle With Reinforcing Pad

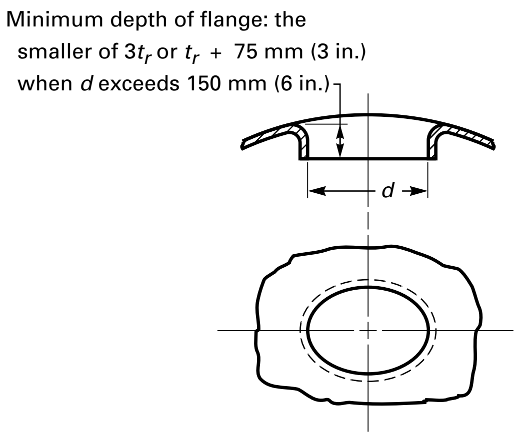
(b) Case B Nozzle With Integral Type Reinforcement

(c) Case A Nozzle With Reinforcing Pad

(d) Case B Nozzle With Integral Type Reinforcement

GENERAL NOTE: When any part of a flange is located within the greater of the $\sqrt{R_{nm}t_n} + t_e$ or $16t_n + t_e$ limit as indicated in Figure TD-610.7 sketch (a) or sketch (c), or the greater of $\sqrt{R_{nm}t_n}$ or $16t_n$ for Figure TD-610.7 sketch (b) or sketch (d), the flange may be included as part of the section that resists bending moment.

Figure TD-620
Minimum Depth for Flange of Flued in Openings



S_b = bending stress at the intersection of inside of the nozzle neck and inside of the vessel shell along the vessel shell longitudinal axis

S_m = membrane stress calculated by (e)(1), eq. (1) or (e)(2), eq. (2)

S_y = yield strength of the material at test temperature, see Section II, Part D, Subpart 1, Table Y-1

(g) It is recommended that special consideration be given to the fabrication details used and inspection employed on large openings; reinforcement often may be advantageously obtained by use of heavier shell plate for a vessel course or inserted locally around the opening; welds may be ground to concave contour and the inside corners of the opening rounded to a generous radius to reduce stress concentrations. When radiographic examination of welds is not practicable, liquid penetrant may be used with nonmagnetic materials and either liquid-penetrant or magnetic particle inspection with ferromagnetic materials. If magnetic particle inspection is employed, the prod method is preferred. The degree to which such measures should be used depends on the particular application and the severity of the intended service. Appropriate proof testing may be advisable in extreme cases of large openings approaching full vessel diameter, openings of unusual shape, etc.

TD-610.8 SPECIAL REQUIREMENTS

For additional requirements applicable to specific categories of tanks, see the applicable Modal Appendices.

TD-620 FLUED OPENINGS IN SHELLS AND FORMED HEADS

(a) Flued openings in shells and formed heads made by inward or outward forming of the head plate shall meet the requirements for reinforcement in TD-610. The thickness of the flued flange shall also meet the requirements of Article TD-3 and/or Article TD-4 as applicable, where L as used in Article TD-4 is the minimum depth of flange as shown in Figure TD-620. The minimum thickness of the flued flange on a vessel subject to both internal and external pressure shall be the larger of the two thicknesses as determined above.

(b) The minimum depth of flange of a flued in opening exceeding 152 mm (6 in.) in any inside dimension, when not stayed by an attached pipe or flue, shall equal $3t_r$ or [t_r + 75 mm (3 in.)], whichever is less, where t_r is the required shell or head thickness. The depth of flange shall be determined by placing a straight edge across the side opposite the flued opening along the major axis and measuring from the straight edge to the edge of the flanged opening (see Figure TD-620).

(c) There is no minimum depth of flange requirement for flued out openings.

(d) The minimum width of bearing surface for a gasket on a self-sealing flued opening shall be in accordance with TD-690(f).

TD-630 REINFORCEMENT REQUIRED FOR OPENINGS IN FLAT HEADS AND COVERS

(a) General. The rules in this paragraph apply to all openings in flat heads, except opening(s) that do not exceed the size and spacing limits in TD-600.3(c)(3) and do not exceed one-fourth the head diameter or shortest span.

(b) Single and multiple openings in flat heads that have diameters equal to or less than one-half the head diameter may be reinforced as follows:

(1) Flat heads that have a single opening with a diameter that does not exceed one-half the head diameter or shortest span, as defined in Article TD-5, shall have a total cross-sectional area of reinforcement for all planes through the center of the opening not less than that given by the formula

$$A = 0.5dt + tt_n\left(1 - f_{r1}\right)$$

where d, t_n, and f_{r1} are defined in Article TD-5.

(2) Multiple openings none of which have diameters exceeding one-half the head diameter and no pair having an average diameter greater than one-quarter the head diameter may be reinforced individually as required by (1) when the spacing between any pair of adjacent

openings is equal to or greater than twice the average diameter of the pair.

When spacing between adjacent openings is less than twice but equal to or more than $1^1/_4$ times the average diameter of the pair, the required reinforcement for each opening in the pair, as determined by (1), shall be summed together and then distributed such that 50% of the sum is located between the two openings. Spacings of less than $1^1/_4$ times the average diameter of adjacent openings shall be treated by rules of TG-100.2(c).

(3) Referencing Figure TD-630, sketch (a), the ligament between two adjacent openings (U_1, U_2, or U_3) shall not be less than one-quarter of the diameter of the smaller of the two openings in the pair. The radial distance between the inner edge of the opening (U_4, U_5, or U_6) and the dimension d as shown in Figure TD-500 and Figure TD-630, sketch (a) shall not be less than one quarter of the diameter of that one opening.

(c) As an alternative to (b)(1), the thickness of flat heads and covers with a single opening with a diameter that does not exceed one-half the head diameter may be increased to provide the necessary reinforcement as follows:

(1) In TD-500(c)(2), eq. (1) or TD-500(c)(3), eq. (3), use $2C$ or 0.75 in place of C, whichever is the lesser; except that, for sketches (b-1), (b-2), (e), (f), (g), and (i) of Figure TD-500, use $2C$ or 0.50, whichever is the lesser.

(2) In TD-500(c)(2), eq. (2) or TD-500(c)(3), eq. (5), double the quantity under the square root sign.

(d) Multiple openings none of which have diameters exceeding one-half the head diameter and no pair having an average diameter greater than one-quarter the head diameter may be reinforced as follows:

(1) When the spacing between a pair of adjacent openings is equal to or greater than twice the average diameter of the pair, and this is so for all opening pairs, the head thickness may be determined by rules in (c).

(2) When the spacing between adjacent openings in a pair is less than twice but equal to or greater than $1^1/_4$ the average diameter of the pair, the required head thickness shall be that determined by (c) multiplied by factor h, where

$$h = \sqrt{0.5 / e}$$

$$e = \left[\left(p - d_{avg} \right) / p \right]_{smallest}$$

where

d_{avg} = average diameter of the same two adjacent openings

e = smallest ligament efficiency of adjacent opening pairs in the head

p = center-to-center spacing of two adjacent openings

(3) Spacings of less than $1^1/_4$ times the average diameter of adjacent openings shall be treated by rules of TG-100.2(c).

(4) In no case shall the width of ligament between two adjacent openings be less than one-quarter the diameter of the smaller of the two openings in the pair.

(5) The width of ligament between the edge of any one opening and the edge of the flat head shall not be less than one-quarter the diameter of that one opening.

TD-640 LIMITS OF REINFORCEMENT

(a) 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 must be located in order to have value as reinforcement are designated as the limits of reinforcement for that plane (see Figure TD-610.3-2). Figure TD-640 depicts thicknesses t, t_e, and t_n, or t_i and diameter d used in establishing the limits of reinforcement.

(b) The limits of reinforcement, measured parallel to the vessel wall, shall be at a distance, on each side of the axis of the opening, equal to the greater of the following:

(1) the diameter d of the finished opening in the corroded condition

(2) the radius R_n of the finished opening in the corroded condition plus the nominal thickness of the vessel wall t, plus the nominal thickness of the nozzle wall t_n

(c) 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 smaller of the following:

(1) $2^1/_2$ times the nominal thickness of the vessel wall less corrosion allowance

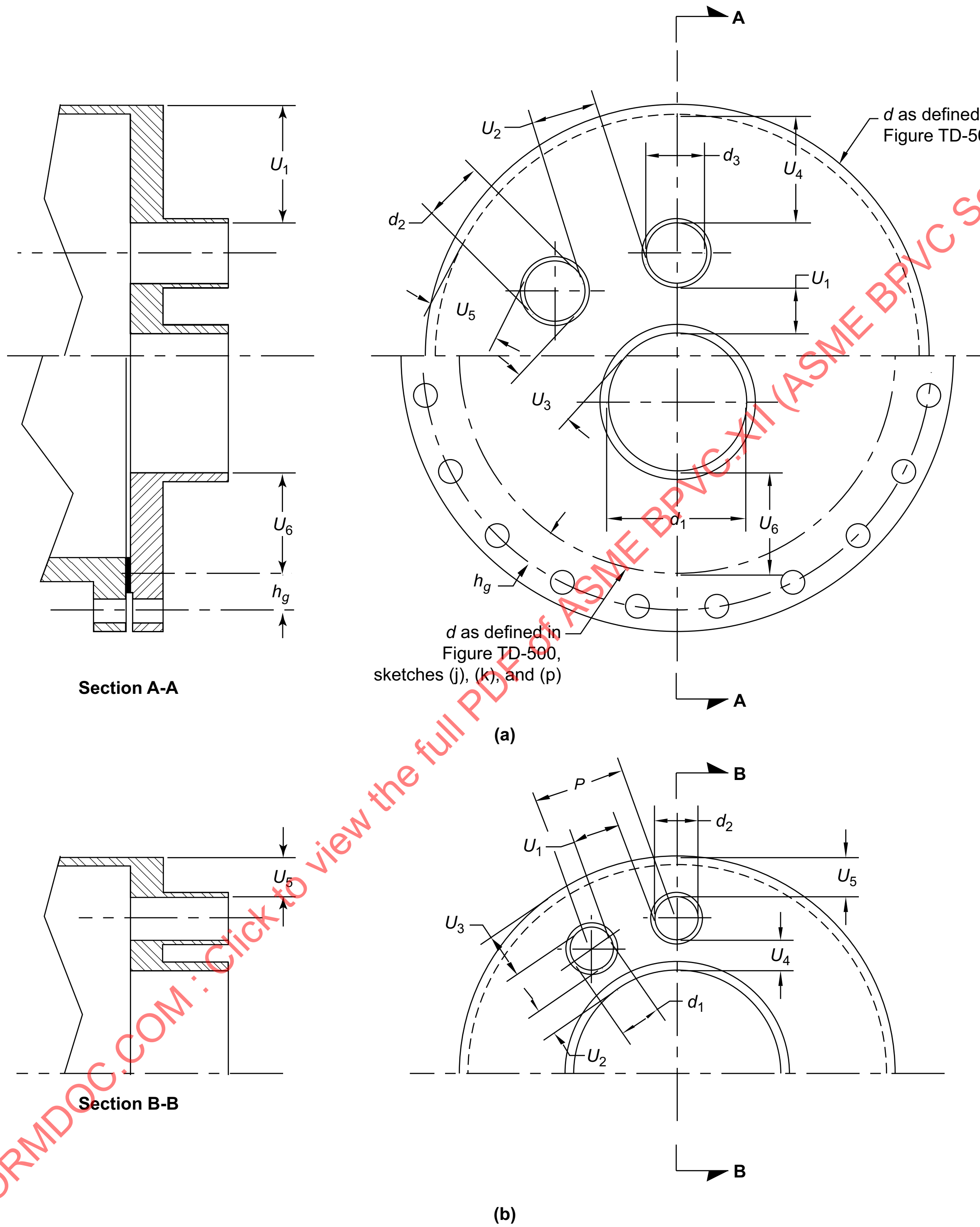
(2) $2^1/_2$ times the nominal nozzle wall thickness less corrosion allowance, plus the thickness t_e as defined in Figure TD-640.

(d) Metal within the limits of reinforcement that may be considered to have reinforcing value shall include the following:

(1) metal in the vessel wall over and above the thickness required to resist pressure and the thickness specified as corrosion allowance, the area in the vessel wall available as reinforcement is the larger of the values of A_1 given by the equations in Figure TD-610.3-2.

(2) metal over and above the thickness required to resist pressure and the thickness specified as corrosion allowance in that part of a nozzle wall extending outside the vessel wall. The maximum area in the nozzle wall available as reinforcement is the smaller of the values of A_2 given by the equations in Figure TD-610.3-2.

Figure TD-630
Openings in Flat Heads and Covers



Legend:

p = spacing, center-to-center, between openings
$U_1, U_2, \ldots$ = ligament width
$(d_1 + d_2)/2$ = average diameter of pair of openings

Figure TD-640
Some Representative Configurations Describing the Reinforcement Dimension, t_e, and the Opening Dimension, d

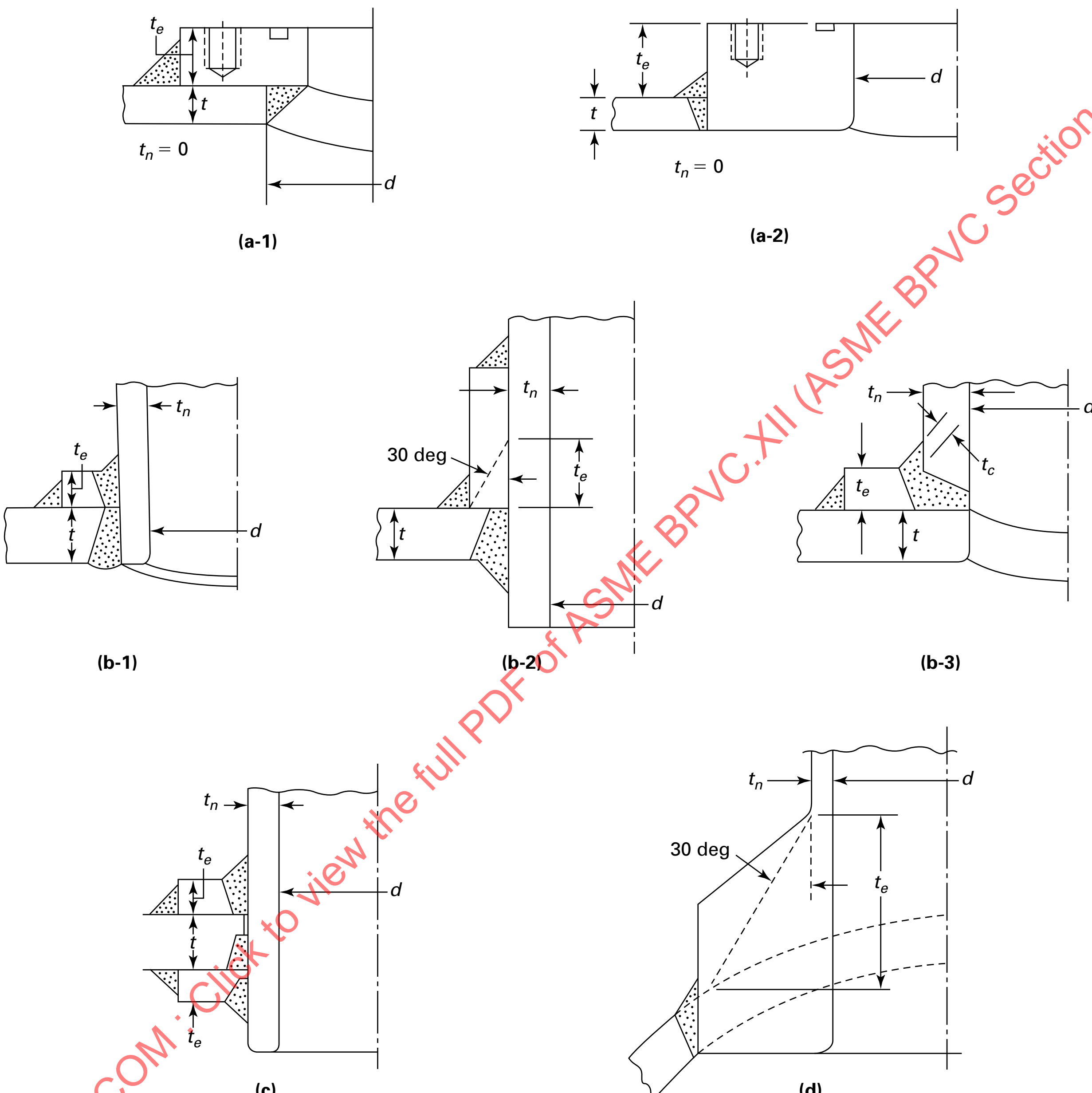
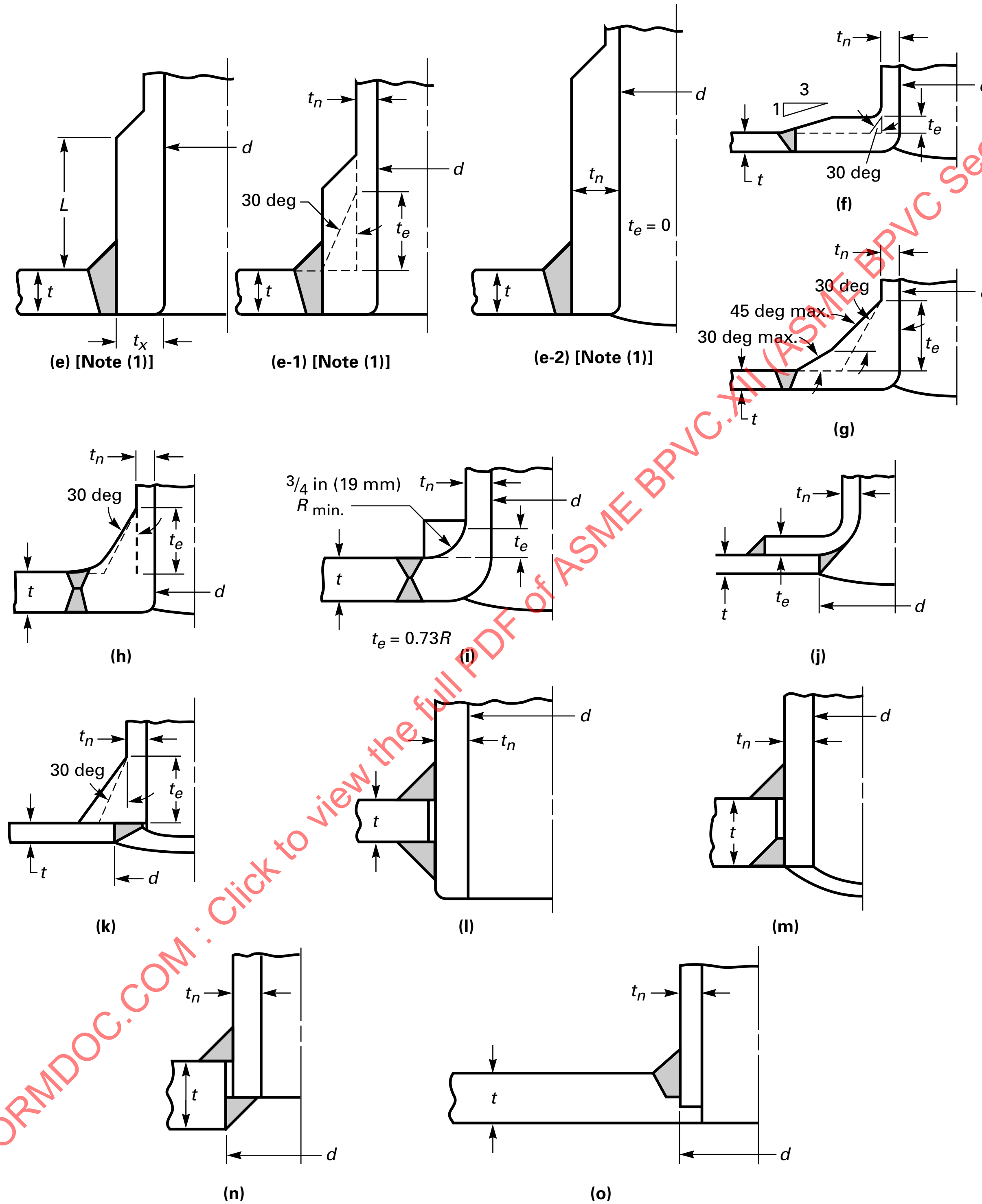


Figure TD-640
Some Representative Configurations Describing the Reinforcement Dimension, t_e, and the Opening Dimension, d (Cont'd)



NOTE: (1) If $L < 2.5t_x$, use sketch (e-1); if $L \geq 2.5t_x$, use sketch (e-2).

All metal in the nozzle wall extending inside the vessel wall A_3 may be included after proper deduction for corrosion allowance on the entire exposed surface is made. No allowance shall be taken for the fact that a differential pressure on an inwardly extending nozzle may cause opposing stress to that of the stress in the shell around the opening:

(3) metal in attachment welds A_4 and metal added as reinforcement A_5.

(e) With the exception of studding outlet-type flanges, bolted flange material within the limits of reinforcement shall not be considered to have reinforcing value.

TD-650 STRENGTH OF REINFORCEMENT

(a) Material used for reinforcement shall have an allowable stress value equal to or greater than that of the material in the vessel wall, except that when such material is not available, lower strength material may be used, provided the area of reinforcement is increased in inverse proportion to the ratio of the allowable stress values of the two materials to compensate for the lower allowable stress value of the reinforcement. No credit may be taken for the additional strength of any reinforcement having a higher allowable stress value than that of the vessel wall. Deposited weld metal outside of either the vessel wall or any reinforcing pad used as reinforcement shall be credited with an allowable stress value equivalent to the weaker of the materials connected by the weld. Vessel-to-nozzle or pad-to-nozzle attachment weld metal within the vessel wall or within the pad may be credited with a stress value equal to that of the vessel wall or pad, respectively.

(b) The welds that attach elements of compensation, not an integral part of the vessel wall, shall have a strength, W, equal to the load carried by those elements defined as follows:

$$W = (A - A_1)S_v$$

where A, A_1, and S_v are defined in Figure TD-610.3-2.

(c) When a reinforcing pad is required by the rules of TD-610.3, the welds attaching the nozzle to the pad and shell shall be checked independently to ensure that the loads carried by the individual elements can be transmitted by the attaching welds.

(d) Welds attaching elements of reinforcement need not satisfy the weld strength requirements of (b) and (c) under the following circumstances:

(1) openings that are exempt in TD-600.2 from reinforcement calculations

(2) openings with elements of compensation attached by full-penetration welds as listed in TW-140.2(c)

(e) The minimum required weld sizes shall not be smaller than the minimum required by TW-140.2.

(f) Nozzles, other connections, and their reinforcements may be attached to transport tanks by arc or gas welding. Sufficient welding shall be provided on either side of the line through the center of the opening parallel to the longitudinal axis of the shell to develop the required strength of the reinforcing parts as prescribed in TD-650 through each load-carrying path, in shear or tension, whichever is applicable. See Table TD-650 for example calculations.

(1) The stress correction factors in (g) shall apply.

(2) The strength of fillet welds shall be based on one-half the area subjected to shear, computed on the mean diameter of the weld using the weld leg dimension in the direction under consideration.

(3) The strength of groove welds shall be based on one-half the area subjected to shear or tension, as applicable, computed using the minimum weld depth dimension in the direction under consideration.

(4) Strength calculations for nozzle attachment welds are not required for the following:

(-a) Figure TW-140.2-1, sketches (a) through (g), (x-1), (y-1), and (z-1)

(-b) openings exempt from the reinforcement requirements by TD-600.3(c)(3)

(g) Stress Values for Weld Metal. The allowable stress values for groove and fillet welds in percentages of stress values for the vessel material are as follows:

(1) groove-weld tension, 74%

(2) groove-weld shear, 60%

(3) fillet-weld shear, 49%

NOTE: These values are obtained by combining the following factors: 87.5% for combined end and side loading, 80% for shear strength, and the applicable joint efficiency factors.

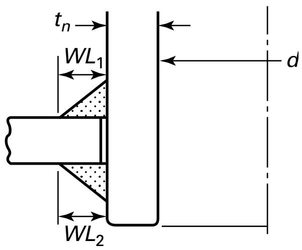
(h) Reinforcing plates and saddles of nozzles attached to the outside of a vessel shall be provided with at least one vent hole [maximum diameter 11 mm ($^7/_{16}$ in.)] that may be tapped with straight or tapered threads. These vent holes may be left open or may be plugged when the vessel is in service. If the holes are plugged, the plugging material used shall not be capable of sustaining pressure between the reinforcing plate and the vessel wall.

(i) Segmental reinforcing elements are allowed, provided the individual segments are joined by full penetration butt welds. These butt welds shall comply with all the applicable requirements of Part TW. Each segment of the reinforcing element shall have a vent hole as required by (h). Unless the provisions given below are satisfied, the area A_5 as defined in Figure TD-610.3-2 shall be multiplied by 0.75. The area A_5 does not require any reduction if one of the following is satisfied:

(1) Each butt weld is radiographed or ultrasonically examined to confirm full penetration, or

(2) For openings in cylinders, the weld is oriented at least 45 deg from the longitudinal axis of the cylinder.

Table TD-650
Nozzle Attachment Welds

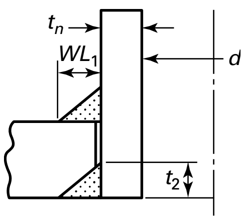


Required Weld Strength:

$$W = (A - A_1)\,S_v$$

Weld Strength:

$$= (WL_1 + WL_2 \text{ in shear})\,S_v$$
$$= \left[0.49\left(\frac{1}{2}\right)WL_1\,\pi(d + 2t_n + WL_1)S_wf_{r1} + 0.49\left(\frac{1}{2}\right)WL_2\,\pi(d + 2t_n + WL_2)S_wf_{r1}\right]$$

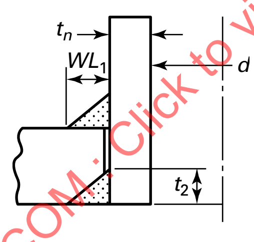


Required Weld Strength:

$$W = (A - A_1)\,S_v$$

Weld Strength:

$$= (WL_1 \text{ in shear} + t_2 \text{ in tension})S_v$$
$$= \left[0.49\left(\frac{1}{2}\right)WL_1\,\pi(d + 2t_n + WL_1)S_wf_{r1} + 0.74\left(\frac{1}{2}\right)t_2\,\pi(d + 2t_n)S_wf_{r1}\right]$$



Required Weld Strength:

$$W = (A - A_1)\,S_v$$

Weld Strength:

$$= (WL_2 \text{ in shear} + t_2 \text{ in tension})\,S_v$$
$$= \left[0.49\left(\frac{1}{2}\right)WL_2\,\pi(D_p + WL_2)S_wf_{r3} + 0.74\left(\frac{1}{2}\right)t_2\,\pi(d + 2t_n)S_wf_{r1}\right]$$

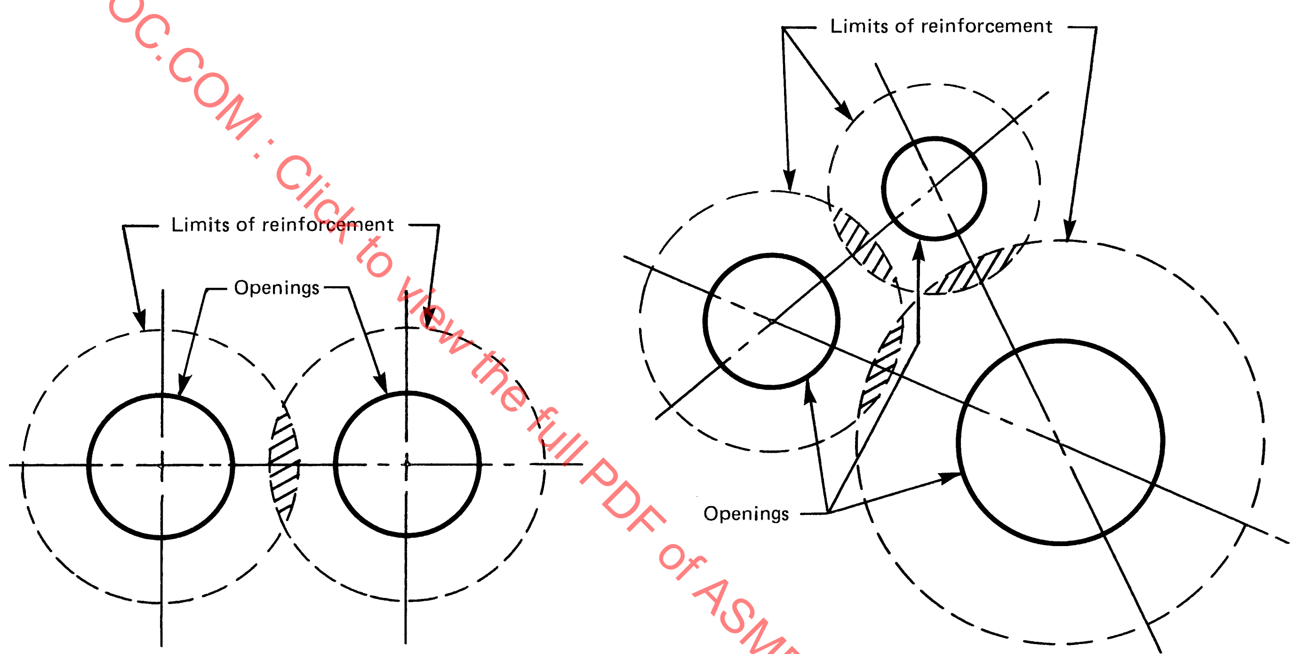
Check Nozzle to Pad and Shell:

$$W = (A - A_1 - A_2 - A_3)\,S_v$$

Weld Strength:

$$= WL_1 \text{ in shear} + t_2 \text{ in tension}$$
$$= 0.49\left(\frac{1}{2}\right)WL_1\,\pi(d + 2t_n + WL_1)S_wf_{r1} + 0.74\left(\frac{1}{2}\right)t_2\,\pi(d + 2t_n)S_wf_{r1}$$

Figure TD-660
Examples of Multiple Openings



(a) Two Openings Spaced at Less Than Two Times Their Average Diameter

(b) More Than Two Openings Spaced at Less Than Two Times Their Average Diameter

TD-660 REINFORCEMENT OF MULTIPLE OPENINGS

NOTE: See TD-630 for multiple openings in flat heads.

(a) When any two openings are spaced at less than two times their average diameter, so that their limits of reinforcement overlap [see Figure TD-660, sketch (a)], the two openings shall be reinforced in the plane connecting the centers, in accordance with the rules of TD-610, TD-620, TD-640, and TD-650 with a combined reinforcement that has an area not less than the sum of the areas required for each opening. No portion of the cross section is to be considered as applying to more than one opening, nor to be considered more than once in a combined area.

(1) The overlap area shall be proportioned between the two openings by the ratio of their diameters.

(2) If the area of reinforcement between the two openings is less than 50% of the total required for the two openings, the supplemental rules of TD-610.7(g) shall be used.

(3) A series of openings, all on the same centerline, shall be treated as successive pairs of openings.

(b) When more than two openings are spaced as in (a) [see Figure TD-660, sketch (b)], and are to be provided with a combined reinforcement, the minimum distance between centers of any two of these openings shall be $1\frac{1}{3}$ times their average diameter, and the area of reinforcement between any two openings shall be at least equal to 50% of the total required for the two openings. If the distance between centers of two such openings is less than $1\frac{1}{3}$ times their average diameter, no credit for reinforcement shall be taken for any of the material between these openings. Such openings must be reinforced as described in (c).

(c) Alternatively, any number of adjacent openings, in any arrangement, may be reinforced by using an assumed opening enclosing all such openings. The limits for reinforcement of the assumed opening shall be those given in TD-640(b)(1) and TD-640(c)(1). The nozzle walls of the actual openings shall not be considered to have reinforcing value. When the diameter of the assumed opening exceeds the limits in TD-600.2, the supplemental rules of TD-610.7 shall also be used.

(d) When a group of openings is reinforced by a thicker section butt welded into the shell or head, the edges of the inserted section shall be tapered as prescribed in TW-130.2(c).

TD-670 METHODS OF ATTACHMENT OF PIPE AND NOZZLE NECKS TO VESSEL WALLS

(a) General. Nozzles may be attached to the shell or head of a vessel by any of the methods of attachment given in this paragraph, except as limited in TD-610.

(b) Welded Connections. Attachment by welding shall be in accordance with the requirements of TW-140.1 and TW-140.2.

(c) Studded Connections. Connections may be made by means of studs. The vessel shall have a flat surface machined on the shell, on a built-up pad, or on a properly attached plate or fitting. 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. The tapped holes shall also conform to the requirements of (d). Studded connections shall meet the requirements for reinforcement in TD-600 through TD-660.

(d) Threaded Connections. Pipes, tubes, and other threaded connections that conform to 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 TD-670 after allowance has been made for curvature of the vessel wall. 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. A built-up pad or a properly attached plate or fitting may be used to provide the metal thickness and number of threads required in Table TD-670, or to furnish reinforcement when required.

Threaded connections larger than DN 100 (NPS 4) shall not be used in vessels that contain liquids having a flash point below 43°C (110°F), or flammable vapors or flammable liquids at temperatures above that at which they boil under atmospheric pressure.

Threaded connections larger than DN 80 (NPS 3) shall not be used when the maximum allowable working pressure exceeds 861 kPa (125 psi) , except that this DN 80 (NPS 3) restriction does not apply to plug closures used for inspection openings, end closures, or similar purposes.

Table TD-670
Minimum Number of Pipe Threads for Connections

Size of Pipe Connection, DN (NPS)	Threads Engaged	Minimum Plate Thickness Required, mm (in.)
15 and 20 (½ and ¾)	6	11.0 (0.43)
25, 32, and 40 (1, 1¼, and 1½)	7	15.5 (0.61)
50 (2)	8	17.8 (0.70)
65 and 80 (2½ and 3)	8	25.4 (1.0)
100–150 (4–6)	10	31.8 (1.25)
200 (8)	12	38.1 (1.5)
250 (10)	13	41.2 (1.62)
300 (12)	14	44.5 (1.75)

Table TD-680
Nozzle Neck Thickness

Nozzle Nominal Pipe Size, DN (NPS)	Minimum Thickness, mm (in.)
15 (½)	2.4 (0.095)
20 (¾)	2.5 (0.099)
25 (1)	3.0 (0.116)
32 (1¼)	3.2 (0.123)
40 (1½)	3.2 (0.123)
50 (2)	3.4 (0.135)
65 (2½)	4.6 (0.178)
80 (3)	4.8 (0.189)
100 (4)	5.3 (0.207)
125 (5)	5.8 (0.226)
150 (6)	6.2 (0.245)
200 (8)	7.2 (0.282)
250 (10)	8.1 (0.319)
300 (12)	8.3 (0.328)
350 (14)	8.3 (0.328)
400 (16)	8.3 (0.328)
450 (18)	8.3 (0.328)
500 (20)	8.3 (0.328)
600 (24)	8.3 (0.328)

GENERAL NOTES:
(a) These values are based on nominal thickness specified in ASME B36.10M, Table 2, less 12.5%.
(b) For nozzles having a specified outside diameter not equal to the outside diameter of an equivalent standard DN (NPS) size, the DN (NPS) size chosen from the table shall be one having an equivalent outside diameter larger than the nozzle outside diameter.
(c) For nozzles larger than the largest pipe size in this table, use the largest thickness shown.

TD-680 NOZZLE NECK THICKNESS

The minimum wall thickness of nozzle necks shall be determined as given below.

(a) For access openings and openings used only for inspection

$$t_{TD-680} = t_a$$

(b) For other nozzles, determine t_b.

$$t_b = \min.[t_{b3},\ \max.(t_{b1},\ t_{b2})]$$

$$t_{TD-680} = \max.(t_a,\ t_b)$$

where

t_a = minimum neck thickness required for internal and external pressure using Articles TD-3 and TD-4 (plus corrosion and threading allowance), as applicable. The effects of external forces and moments from supplemental loads (see Article TD-2) shall be considered. Shear stresses caused by Article TD-2 loadings shall not exceed 70% of the allowable tensile stress for the nozzle material

t_{b1} = for vessels under internal pressure, the thickness (plus corrosion allowance) required for pressure (assuming E = 1.0) for the shell or head at the location where the nozzle neck or other connection attaches to the vessel but in no case less than the minimum thickness specified for the material in TD-100.1

t_{b2} = for vessels under external pressure, the thickness (plus corrosion allowance) obtained by using the external design pressure as an equivalent internal design pressure (assuming E = 1.0) in the formula for the shell or head at the location where the nozzle neck or other connection attaches to the vessel but in no case less than the minimum thickness specified for the material in TD-100.1

t_{b3} = the thickness given in Table TD-680 plus the thickness added for corrosion allowance

t_{TD-680} = minimum wall thickness of nozzle necks

TD-690 INSPECTION OPENINGS

Dimensions referred to in the following paragraphs are all nominal:

(a) All vessels subject to internal corrosion or having parts subject to erosion or mechanical abrasion (see TD-130), except as permitted otherwise in this paragraph, shall be provided with suitable manhole, handhole, or other inspection openings for examination and cleaning.

(b) Vessels that require access or inspection openings shall be equipped as follows:

(1) All vessels 457 mm (18 in.) to 914 mm (36 in.), inclusive, I.D. shall have a manhole or at least two handholes or two plugged, threaded inspection openings of not less than DN 50 (NPS 2).

(2) All vessels over 914 mm (36 in.) I.D. shall have a manhole, except that those whose shape or use makes one impracticable shall have at least two handholes 102 mm × 152 mm (4 in. × 6 in.) or two equal openings of equivalent area.

(3) 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.

(4) Openings with removable heads or cover plates intended for other purposes may be used in place of the required inspection openings, provided they are equal at least to the size of the required inspection openings.

(5) 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.

(6) Flanged and/or threaded connections from which piping, instruments, or similar attachments can be removed may be used in place of the required inspection openings, provided that

(-a) the connections are at least equal to the size of the required openings

(-b) the connections are sized and located to afford at least an equal view of the interior as the required inspection openings

(c) When inspection or access openings are required, they shall comply at least with the following requirements:

(1) An elliptical or obround manhole shall be not less than 305 mm × 406 mm (12 in. × 16 in.). A circular manhole shall be not less than 406 mm (16 in.) I.D.

(2) A handhole opening shall be not less than 51 mm × 76 mm (2 in. × 3 in.), but should be as large as is consistent with the size of the vessel and the location of the opening.

(d) All access and inspection openings in a shell or unstayed head shall be designed in accordance with the rules of this Section for openings.

(e) 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 section for that material. 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.

(f) 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 18 mm ($^{11}/_{16}$ in.).

PART TW
REQUIREMENTS FOR TANKS FABRICATED BY WELDING

ARTICLE TW-1
GENERAL REQUIREMENTS FOR TANKS FABRICATED BY WELDING

TW-100 GENERAL

The rules in Part TW are applicable to pressure vessels and vessel parts fabricated by welding and used in the transportation of dangerous goods.

TW-100.1 SERVICE RESTRICTIONS

(a) Except where otherwise permitted in each Modal Appendix of this Section, when vessels are to contain fluids with United Nations Hazard Classifications 2.1 (Flammable Gas), 2.3 (Toxic Gas) or 6.1 (Toxic Materials), either liquid or gaseous, all butt-welded joints in the vessel shall be fully radiographed, except under the provisions of TE-230.1(a)(3). When fabricated of carbon or low alloy steel, such vessels shall be postweld heat treated. [See TG-100.3 and *United Nations Recommendations on the Transport of Dangerous Goods — Model Regulations*.]

(1) The type of welded joints of various joint categories (see TE-220.1) shall be as follows:

(-a) Except under provisions of (b)(1), all joints of Category A shall be Type No. (1) of Table TW-130.4.

(-b) All joints of Categories B and C shall be Type No. (1) or Type No. (2) of Table TW-130.4.

(-c) All joints of Category C for fabricated lap joint stub ends shall be as follows:

(-1) The weld is made in two steps as shown in Figure TW-100.1.

Step 1. Before making weld No. 2, weld No. 1 is examined by full radiography in accordance with Part TE, regardless of size. The weld and fusion line between the weld buildup and neck is examined by ultrasonic examination in accordance with Part TE.

Step 2. Weld No. 2 is examined by full radiography in accordance with Part TE.

(-2) The finished stub ends shall be machined from forging.

(-3) The finished stub ends may conform to ASME B16.9 dimensional requirements or may be of other sizes, provided all requirements of this Section are met.

(-d) All joints of Category D shall be full-penetration welds extending through the entire thickness of the vessel wall or nozzle wall.

(b) When carbon and low alloy steel vessels are to operate below −48°C (−55°F) (unless the coincident ratio defined in Figure TM-240.3-1 is less than 0.35), or impact tests of the material or weld metal for high alloy steels are required by TM-250, the joints of various categories (see TW-130.3) shall be as follows:

(1) All joints of Category A shall be Type No. (1) of Table TW-130.4, except that for austenitic chromium-nickel stainless steels Types 304, 304L, 316, 316L, 321, and 347, which satisfy the requirements of TM-250.6, Type No. (2) joints may be used.

(2) All joints of Category B shall be Type No. (1) or Type No. (2) of Table TW-130.4.

(3) All joints of Category C shall be full-penetration welds extending through the entire thickness at the joint.

(4) All joints of Category D shall be full-penetration welds extending through the entire thickness of the vessel wall.

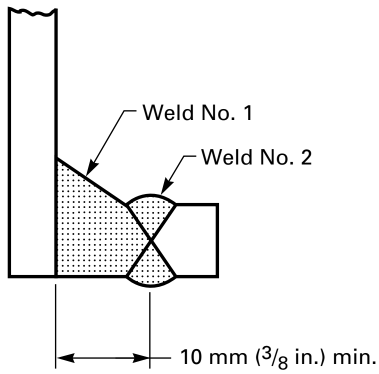
TW-120 MATERIALS

TW-120.1 GENERAL

(a) Pressure Parts. Materials used in the construction of welded pressure parts shall comply with the requirements for materials given in Article TM-1.

(b) Nonpressure Parts. Materials used for nonpressure parts that are welded to the pressure vessel shall be proven of weldable quality as described below.

Figure TW-100.1
Fabricated Lap Joint Stub Ends for Fluids With United Nations Hazard Classifications Defined in TW-100.1(a)



(1) For material identified in accordance with TM-110.10, TM-120, TM-130.1, or TM-140.2, satisfactory qualification of the welding procedure under Section IX is considered as proof of weldable quality.

(2) For materials not identifiable in accordance with TM-110.10, TM-120, TM-130.1, or TM-140.2, but identifiable as to nominal chemical analysis and mechanical properties, S-Number under Section IX, Table QW/QB-422, or to a material specification not permitted in this Division, satisfactory qualification of the welding procedure under Section IX is considered as proof of weldable quality. For materials identified by S-Numbers, the provisions of Section IX, QW-420 may be followed for welding procedure qualification. The welding procedure need only be qualified once for a given nominal chemical analysis and mechanical properties or material specification not permitted in this Section.

(c) Two materials of different specifications may be joined by welding, provided the requirements of Section IX, QW-250, are met.

(d) Materials joined by the inertia and continuous drive friction welding processes shall be limited to materials assigned P-Numbers in Section IX and shall not include rimmed or semikilled steel.

TW-130 DESIGN OF WELDED JOINTS

TW-130.1 GENERAL

The rules in the following paragraphs apply specifically to the design of pressure vessels and vessel parts that are fabricated by welding and shall be used in conjunction with the requirements of Parts TD, TF, and TE for the class of material used.

TW-130.2 DESIGN OF WELDED JOINTS

(a) Permissible Types. The types of welded joints permitted in arc and gas welding processes are listed in Table TW-130.4, together with the limiting plate thickness permitted for each type. Butt-type joints only are permitted with pressure welding processes [see TF-200(b)].

(b) Welding Grooves. The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and complete joint penetration. Qualification of the welding procedure, as required in TF-210.2, is acceptable as proof that the welding groove is satisfactory.

(c) Tapered Transitions. A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections, as shown in Figure TW-130.2, shall be provided at joints between sections that differ in thickness by more than one-fourth of the thickness of the thinner section, or by more than 3.2 mm ($^1/_8$ in.), whichever is less. The transition may be formed by any process that will provide a uniform taper. When the transition is formed by removing material from the thicker section, the minimum thickness of that section, after the material is removed, shall be not less than that required by TD-210(d). 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 TF-220.10. The butt weld may be partly or entirely in the tapered section or adjacent to it. This paragraph also applies when there is a reduction in thickness within a spherical shell or cylindrical shell course and to a taper at a Category A joint within a formed head. Provisions for tapers at circumferential, butt-welded joints connecting formed heads to main shells are contained in TW-130.5.

(d) Except when the longitudinal joints are radiographed 100 mm (4 in.) each side of each circumferential welded intersection, vessels made up of two or more courses shall have the centers of the welded longitudinal joints of adjacent courses staggered or separated by a distance of at least five times the thickness of the thicker plate.

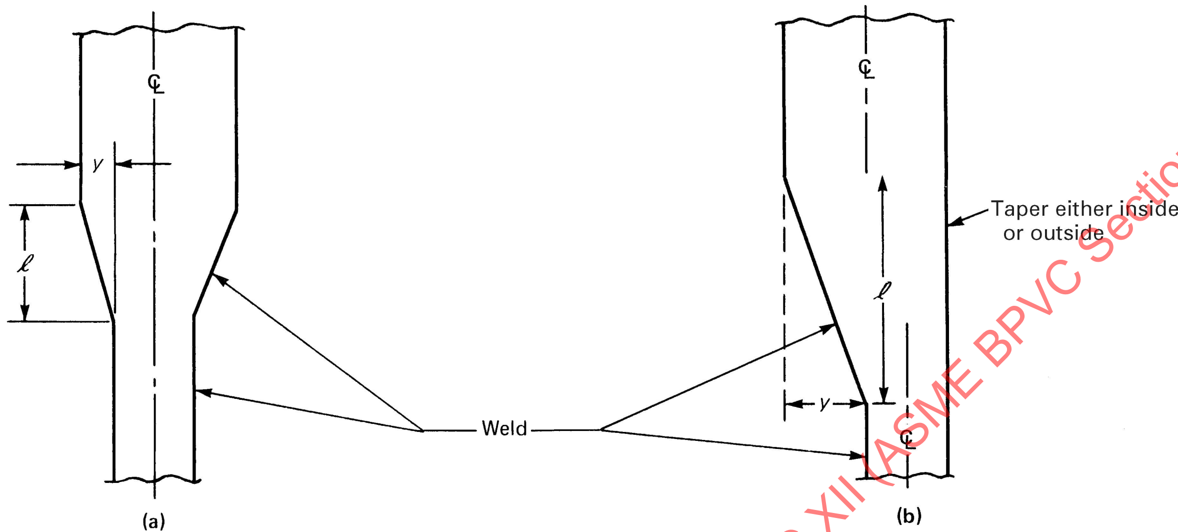
(e) Lap Joints. For lapped joints, the surface overlap shall be not less than four times the thickness of the inner plate, except otherwise provided for heads in TW-130.5.

(f) Minimum Weld Sizes. Sizing of fillet and partial penetration welds shall take into consideration the loading conditions in TD-200 but shall be not less than the minimum sizes specified elsewhere in this Section.

TW-130.3 WELDED JOINT CATEGORIES

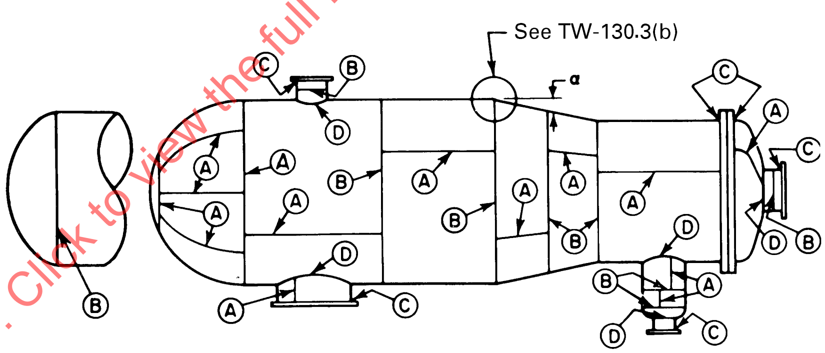
(a) The term *Category* as used herein defines the location of a joint in a vessel, but not the type of joint. The *Categories* established by this paragraph are for use in

Figure TW-130.2
Butt Welding of Plates of Unequal Thickness



GENERAL NOTES:
(a) $\ell \geq 3y$, where ℓ is the required length of taper and y is the offset between the adjacent surfaces of abutting sections.
(b) Length of required taper, ℓ, may include the width of the weld.
(c) In all cases, ℓ shall be not less than $3y$.

Figure TW-130.3
Illustration of Welded Joint Locations Typical of Categories A, B, C, and D



this Section 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 as described below and shown in Figure TW-130.3.

(1) Category A Locations. Category A locations are longitudinal welded joints within the main shell, communicating chambers,[8] transitions in diameter, or nozzles; any welded joint within a sphere, within a formed or flat head; and circumferential welded joints connecting hemispherical heads to main shells, to transitions in diameter, to nozzles or to communicating chambers.

(2) Category B Locations. Category B locations are circumferential welded joints within the main shell, communicating chambers,[8] nozzles, or transitions in diameter, including joints between the transition and a cylinder at either the large or small end; and circumferential welded joints connecting formed heads other than hemispherical to main shells, to transitions in diameter, to nozzles, or to communicating chambers.[8]

(3) Category C Locations. Category C locations are welded joints connecting flanges, tubesheets, or flat heads to the main shell, to formed heads, to transitions in diameter, to nozzles, or to communicating chambers.[8]

(4) Category D Locations. Category D locations are welded joints connecting communicating chambers or nozzles to main shells, to spheres, to transitions in diameter, to heads, or to flat sided tanks; and nozzles at the small end of a transition in diameter and those joints connecting nozzles to communicating chambers.[8]

(b) When butt-welded joints are required elsewhere for Category B, an angle joint connecting a transition in diameter to a cylinder shall be considered as meeting this requirement, provided the angle a (as shown in Figure TW-130.3) does not exceed 30 deg. All requirements that apply to the butt joint shall apply to the angle joint.

(25) TW-130.4 JOINT EFFICIENCIES

Table TW-130.4 gives the joint efficiencies E to be used in the equations of this Section for joints completed by an arc or gas welding process. Except as required by TE-230.1(a)(4), a joint efficiency depends only on the type of joint and on the degree of examination of the joint and does not depend on the degree of examination of any other joint. The User or the User's designated agent shall establish the type of joint and the degree of examination when the rules of this Section do not mandate specific requirements. Rules for determining the applicability of the efficiencies are found in the various paragraphs covering design equations [e.g., see TM-190(a) and TD-300].

(a) A value of E not greater than that given in column (a) of Table TW-130.4 shall be used in the design calculations for fully radiographed butt joints [see TE-230.1(a)], except that when the requirements of TE-230.1(a)(4) are not met, a value of E not greater than that given in column (b) of Table TW-130.4 shall be used.

(b) A value of E not greater than that given in column (b) of Table TW-130.4 shall be used in the design calculations for spot radiographed butt-welded joints [see TE-230.1(b)].

(c) A value of E not greater than that given in column (c) of Table TW-130.4 shall be used in the design calculations for welded joints that are neither fully radiographed nor spot radiographed [see TE-230.1(c)].

(d) Values of E to be used in thickness calculations for seamless vessel sections or heads shall be as follows:

(1) E shall be as specified in Table TW-130.4 when the weld joint connecting the seamless vessel sections or heads is Category A, Type 1.

(2) $E = 1$, if the Category B weld joining the seamless vessel sections or heads meets the spot radiography requirements of TE-230.1(a)(4)(-b).

(3) $E = 0.85$, when the weld does not meet the spot radiography requirements of TE-230.1(a)(4)(-b), or when the Category A or B welds joining seamless vessel sections or heads are Type No. 3, 4, 5, or 6 of Table TW-130.4.

(e) Welded pipe or tubing shall be treated in the same manner as seamless, but with allowable tensile stress taken from the welded product values of the stress tables, and the requirements of (d) applied.

(f) A value of E not greater than 0.80 may be used in the equations of this Section for joints completed by any of the pressure welding processes given in TF-200(b), except for electric resistance welding, provided the welding process used is permitted by the rules in the applicable parts of Subsection C for the material being welded. The quality of such welds used in vessels or parts of vessels shall be provided as follows: Test specimens shall be representative of the production welding of each vessel. They may be removed from the shell itself or from a prolongation of the shell including the longitudinal joint, or, in the case of vessels not containing a longitudinal joint, from a test plate of the same material and thickness as the vessel and welded in accordance with the same procedure. One reduced-section tension test and two side-bend tests shall be made in accordance with, and shall meet the requirements of Section IX, QW-150 and QW-160.

TW-130.5 ATTACHMENT DETAILS

(a) Definitions

c = basic dimension used for the minimum sizing of welds equal to t_n or t_x, whichever is less
t_h = minimum thickness of head after forming, mm (in.)
t_n = nominal thickness of shell or nozzle wall to which flange or lip is attached
t_p = minimum distance from outside surface of flat head to edge of weld preparation measured as shown in Figure TW-130.5-2, mm (in.)
t_s = nominal thickness of shell, mm (in.)
t_x = two times the thickness g_o, when the design is calculated as an integral flange or two times the thickness of shell nozzle wall required for internal pressure, when the design is calculated as a loose flange, but not less than 6 mm ($\frac{1}{4}$ in.)

See TW-130.5, TD-300, TD-310, TD-400, and TD-500 and other paragraphs for additional definitions.

(b) Formed Heads and Shells

(1) Ellipsoidal, torispherical, and other types of formed heads, shall be attached to the shell as illustrated in the applicable Figure TW-130.5-1, sketches (a) through (e) and (k). The construction shown in sketch (f) may also be used for end heads when the thickness of the shell section of the vessel does not exceed 16 mm ($\frac{5}{8}$ in.) [see also (c)]. Limitations relative to the use of these attachments shall be as given in the sketches and related notes and in Table TW-130.4.

Table TW-130.4
Maximum Allowable Joint Efficiencies for Arc- and Gas-Welded Joints

(25)

Type No.	Joint Description	Limitations	Joint Category	Degree of Radiographic Examination		
				(a) Full	(b) Spot	(c) None
(1)	Butt joints as attained by double-welding or by other means that will obtain the same quality of deposited weld metal on the inside and outside weld surfaces to agree with the requirements of TF-220.4. Welds using metal backing strips that remain in place are excluded.	None	A, B, C, and D	1.00 [Note (1)]	0.85 [Note (2)]	0.70
(2)	Single-welded butt joint with backing strip other than those included under (1)	*(a)* None except as in (b) below	A, B, C, and D	0.90 [Note (1)]	0.80 [Note (2)]	0.65
		(b) Circumferential butt joints with one plate offset; see TW-130.5(b)(4) and Figure TW-130.5-1, sketch (k)	A, B, and C	0.90 [Note (1)]	0.80 [Note (2)]	0.65
(3)	Single-welded butt joint without use of backing strip	Circumferential butt joints only, not over 16 mm (⅝ in.) thick and not over 600 mm (24 in.) outside diameter	A, B, and C	NA [Note (1)]	NA [Note (2)]	0.60
(4)	Double full fillet lap joint	*(a)* Longitudinal joints not over 10 mm (⅜ in.) thick	A	NA [Note (1)]	NA [Note (2)]	0.55
		(b) Circumferential joints not over 16 mm (⅝ in.) thick	B and C [Note (4)]	NA [Note (1)]	NA [Note (2)]	0.55
(5)	Single full fillet lap joints with plug welds conforming to UW- 17 (Section VIII, Div. 1)	*(a)* Circumferential joints [Note (3)] for attachment of heads not over 600 mm (24 in.) outside diameter to shells not over 13 mm (½ in.) thick	B	NA [Note (1)]	NA [Note (2)]	0.50
		(b) Circumferential joints for the attachment to shells of jackets not over 16 mm (⅝ in.) in nominal thickness where the distance from the center of the plug weld to the edge of the plate is not less than 1½ times the diameter of the hole for the plug.	C	NA [Note (1)]	NA [Note (2)]	0.50
(6)	Single full fillet lap joints without plug welds	*(a)* For the attachment of heads convex to pressure to shells not over 16 mm (⅝ in.) required thickness, only with use of fillet weld on inside of shell; or	A and B	NA [Note (3)]	NA [Note (4)]	0.45
		(b) for attachment of heads having pressure on either side, to shells not over 600 mm (24 in.) inside diameter and not over 6 mm (¼ in.) required thickness with fillet weld on outside of head flange only	A and B	NA [Note (3)]	NA [Note (4)]	0.45

Table TW-130.4
Maximum Allowable Joint Efficiencies for Arc- and Gas-Welded Joints (Cont'd)

Type No.	Joint Description	Limitations	Joint Category	Degree of Radiographic Examination (a) Full	(b) Spot	(c) None
(7)	Corner joints, full penetration, partial penetration, and/or fillet welded	As limited by Figures TW-130.5-2 and TW-140.2-1	C [Note (5)] and D [Note (5)]	NA [Note (3)]	NA [Note (4)]	NA
(8)	Angle joints	Design per TG-100.2(c) for Category B and C joints	B, C, and D	NA [Note (3)]	NA [Note (4)]	NA

GENERAL NOTES:
(a) The single factor shown for each combination of joint category and degree of radiographic examination replaces both the stress reduction factor and the joint efficiency factor considerations previously used in this Section.
(b) E = 1.0 for butt joints in compression.

NOTES:
(1) See (a), TE-110.2, TE-120, and TE-250.2(a).
(2) See (b) and TE-250.2(b).
(3) Joints attaching hemispherical heads to shells are excluded.
(4) For Type No. 4 Category C joint, limitation not applicable for bolted flange connections.
(5) There is no joint efficiency E in the design equations of this Division for Category C and D corner joints. When needed, a value of E not greater than 1.00 may be used.

Figure TW-130.5-1, sketches (g), (h), and (j) are examples of attachment methods that are not permissible.

(2) Formed heads, concave or convex to the pressure, shall have a skirt length not less than that shown in Figure TW-130.5-1, using the applicable sketch. Heads that are fitted inside or over a shell shall have a driving fit before welding.

(3) A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections as shown in Figure TW-130.5-1, sketches (l) and (m) shall be provided at joints between formed heads and shells that differ in thickness by more than one-fourth the thickness of the thinner section or by more than 3.2 mm ($^1/_8$ in.), whichever is less. When a taper is required on any formed head thicker than the shell and intended for butt-welded attachment [see Figure TW-130.5-1, sketches (n) and (o)], the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line. When the transition is formed by removing material from the thicker section, the minimum thickness of that section, after the material is removed, shall be not less than that required by TD-210(d). 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 TF-220.10. The centerline misalignment between shell and head shall be not greater than one-half the difference between the actual shell and head thickness, as illustrated in Figure TW-130.5-1, sketches (l) through (o).

(4) Shells and head may be attached to shells or heads using a butt weld with one plate offset as shown in Figure TW-130.5-1, sketch (k). The weld bead may be deposited on the inside of the vessel only when the weld is accessible for inspection after the vessel is completed. The offset shall be smooth and symmetrical and shall not be machined or otherwise reduced in thickness. There shall be a uniform force fit with the mating section at the root of the weld. Should the offset contain a longitudinal joint the following shall apply:

(-a) The longitudinal weld within the area of the offset shall be ground substantially flush with the parent metal prior to the offsetting operation.

(-b) The longitudinal weld from the edge of the plate through the offset shall be examined by the magnetic particle method after the offsetting operation. Cracks and crack-like defects are unacceptable and shall be repaired or removed. (See Mandatory Appendix V.)

(-c) As an acceptable alternative to magnetic particle examination or when magnetic particle methods are not feasible because of the nonmagnetic character of the weld deposit, a liquid-penetrant method shall be used. Cracks and crack-like defects are unacceptable and shall be repaired or removed. (See Mandatory Appendix VI.)

(c) Intermediate heads, without limit to thickness, of the type shown in Figure TW-130.5-1, sketch (f), may be used for all types of vessels, provided that the outside diameter of the head skirt is a close fit inside the overlapping ends of the adjacent length of cylinder.

The butt weld and fillet weld shall be designed to take shear based on $1^1/_2$ times the maximum differential pressure that can exist. The allowable stress value for the butt weld shall be 70% of the stress value for the vessel material and that of the fillet 55%. The area of the butt weld in shear is the width at the root of the weld times the length of weld. The area of the fillet weld is the minimum leg dimension times the length of the weld. The fillet weld may be omitted if the construction precludes access to make the weld, and the vessel is in noncorrosive service.

(d) The requirements for the attachment of welded unstayed flat heads to shells are given in TD-500 and in (e) and (f).

(e) When shells, heads, or other pressure parts are welded to a forged or rolled plate to form a corner joint, as in Figure TW-130.5-2, the joint shall meet the following requirements [see also TM-140.1(d)(3)]:

(1) On the cross section through the welded joint, the line of fusion 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 (see Figure TW-130.5-2).

(2) For flange rings of bolted flanged connections, and for flat heads with a projection having holes 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.

(3) For other components, the sum *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 tube sheets without a projection having holes for a bolted connection, and the side plates of a rectangular vessel.

(4) Other dimensions at the joint shall be in accordance with details as shown in Figure TW-130.5-2.

(5) 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 permissible. See Figure TW-130.5-2, sketches (o), (p), and (q).

(f) In the case of nozzle necks that attach to piping of a lesser wall thickness, a tapered transition from the weld end of the nozzle may be provided to match the piping thickness although that thickness is less than otherwise required by the rules of this Section. This tapered transition shall meet the limitations as shown in Figure TW-130.5-3.

Figure TW-130.5-1
Heads Attached to Shells (See Table TW-130.4 for Limitations)

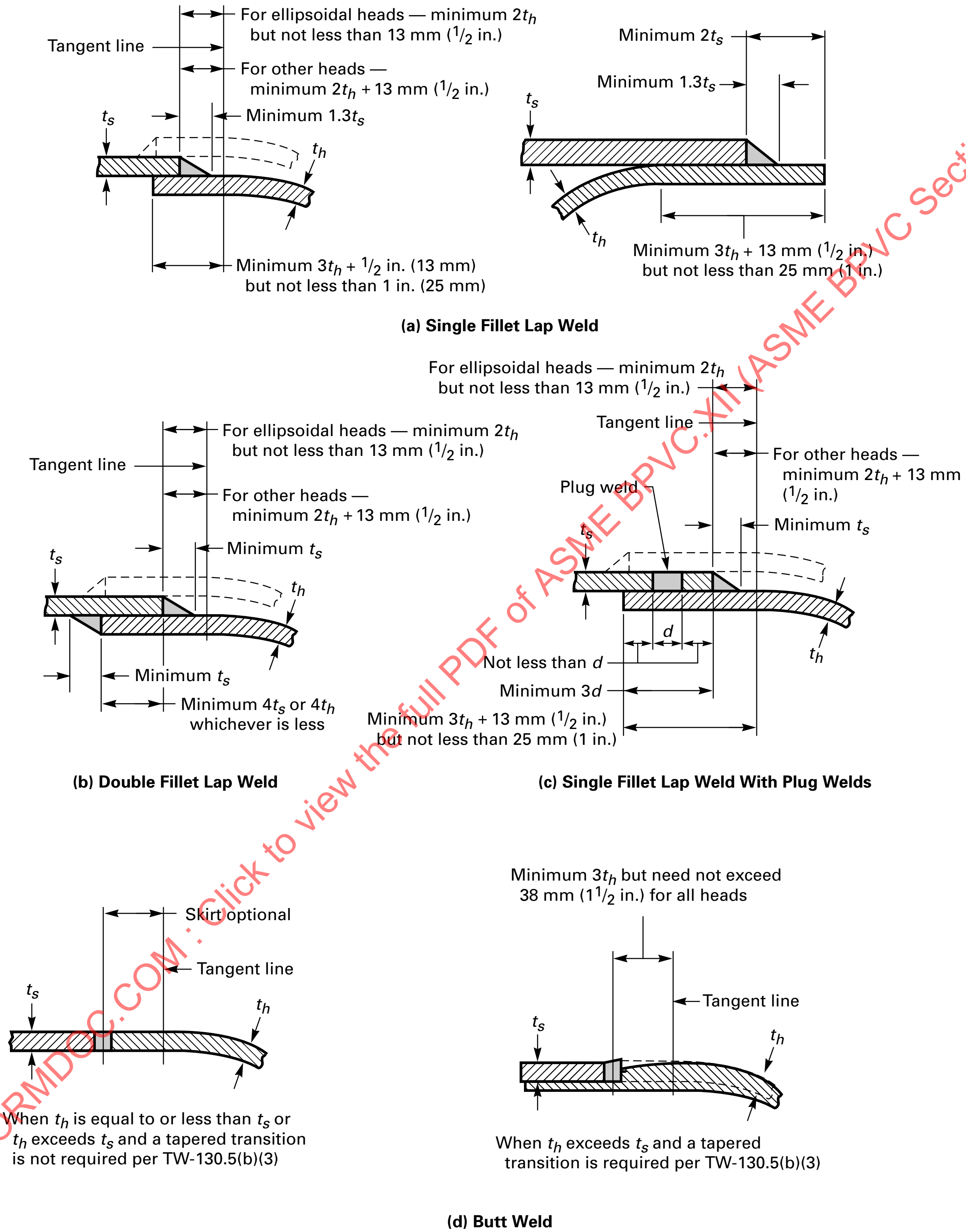
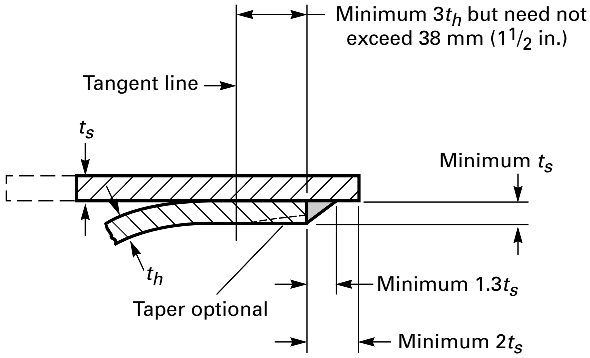
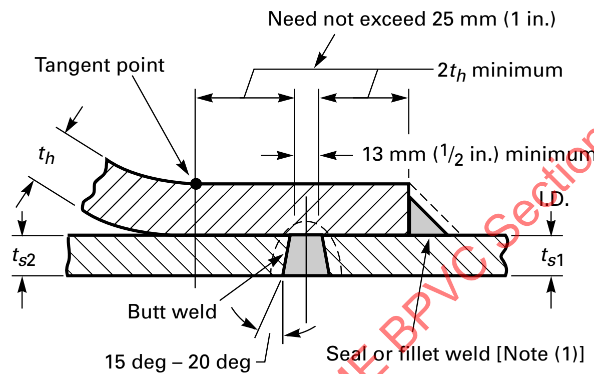


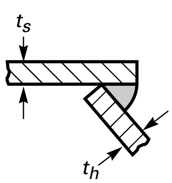
Figure TW-130.5-1
Heads Attached to Shells (See Table TW-130.4 for Limitations) (Cont'd)



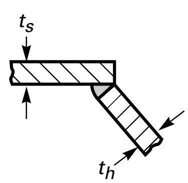
(e) Single Fillet Lap Weld



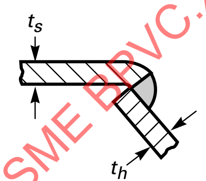
(f) Intermediate Head [Notes (2) and (3)]



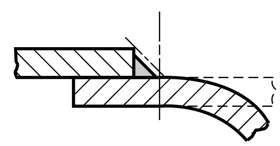
(g-1) Not Permissible



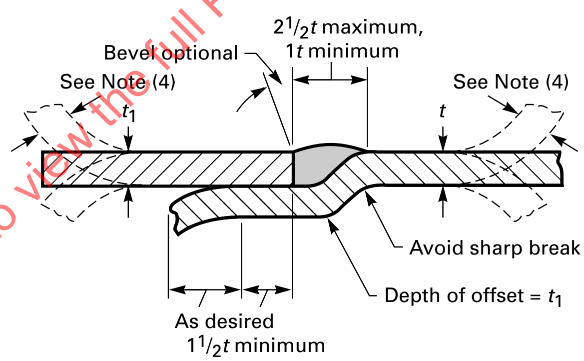
(g-2) Not Permissible



(h) Not Permissible



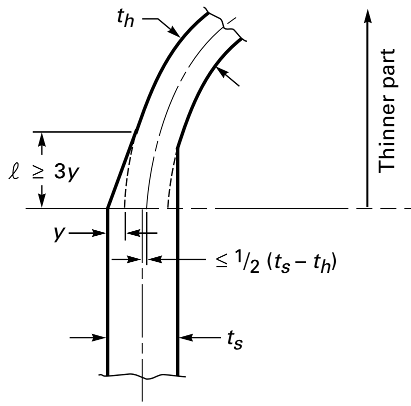
(j) Not Permissible



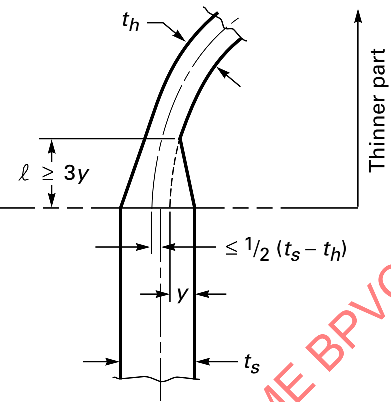
t or t_1 = $^5/_8$ maximum [see Note (5)]

(k) Butt Weld With One Plate Edge Offset

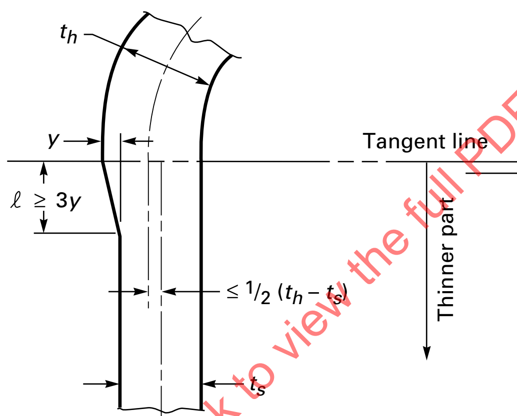
Figure TW-130.5-1
Heads Attached to Shells (See Table TW-130.4 for Limitations) (Cont'd)



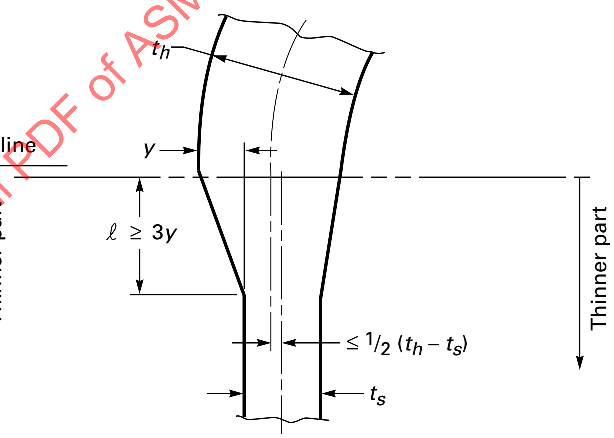
(l) [Notes (6) and (7)]



(m) [Notes (6) and (7)]



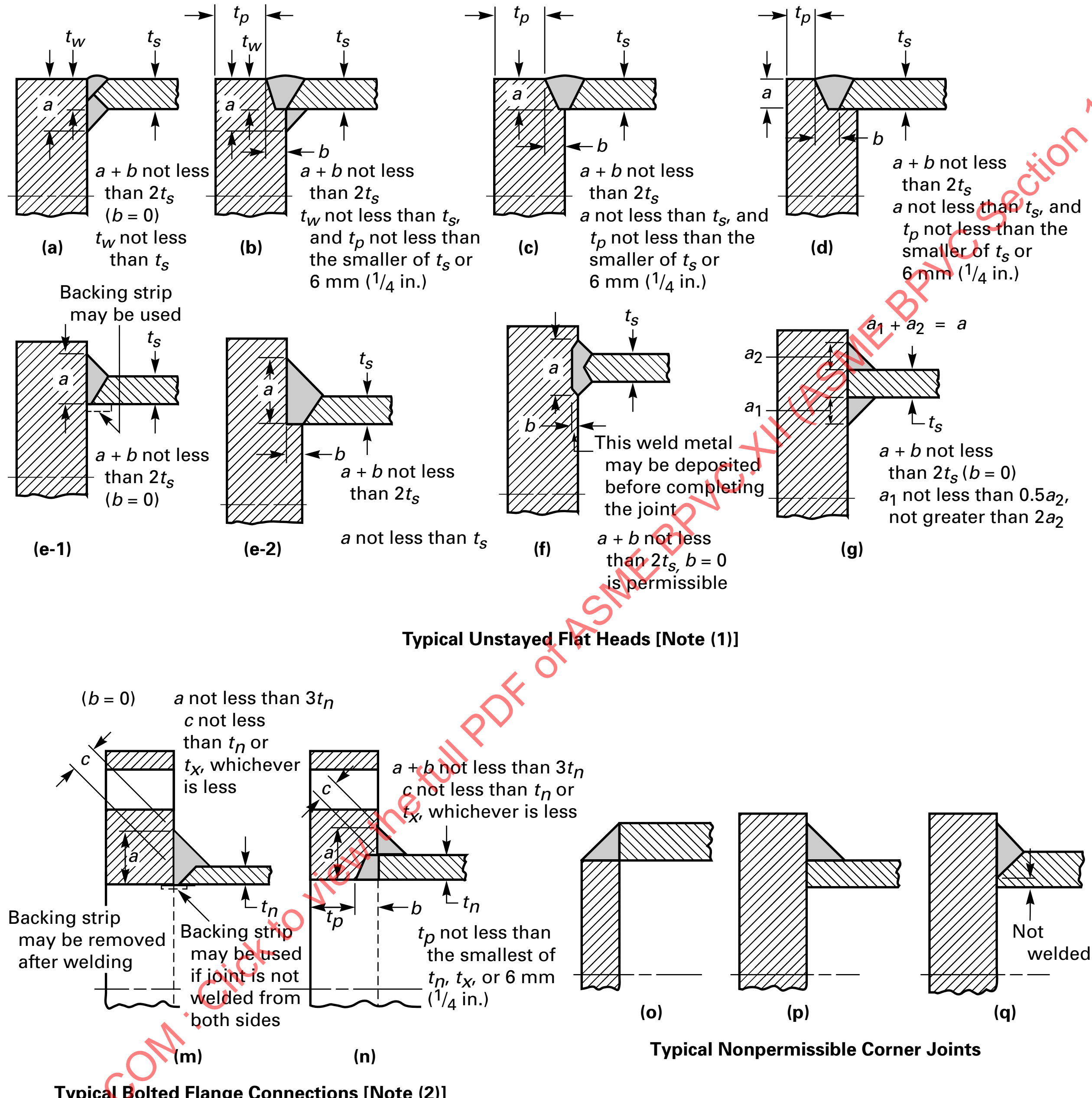
(n) [Notes (7) and (8)]



(o) [Notes (7) and (8)]

NOTES:
(1) See TW-130.5(c).
(2) Butt weld and fillet weld, if used, shall be designed to take shear at $1\frac{1}{2}$ times the differential pressure than can exist.
(3) t_{s1} and t_{s2} may be different.
(4) See TW-130.5(b)(4) for limitation when weld bead is deposited from inside.
(5) For joints connecting hemispherical heads to shells, the following shall apply:
    (a) t or t_1 = 10 mm ($^3/_8$ in.) maximum.
    (b) Maximum difference in thickness between t or t_1 = 2.5 mm ($^3/_{32}$ in.).
    (c) Use of this Figure for joints connecting hemispherical heads to shells shall be noted in the "Remarks" part of the Data Report Form.
(6) In all cases, the projected length of taper, ℓ, shall be not less than $3y$.
(7) Length of required taper, ℓ, may include the width of the weld. The shell plate centerline may be on either side of the head plate centerline.
(8) In all cases, ℓ shall be not less than $3y$ when t_h exceeds t_s. Minimum length of skirt is $3t_h$ but need not exceed 38 mm ($1\frac{1}{2}$ in.) except when necessary to provide required length of taper. When t_h is equal to or less than $1.25t_s$, length of skirt shall be sufficient for any required taper.

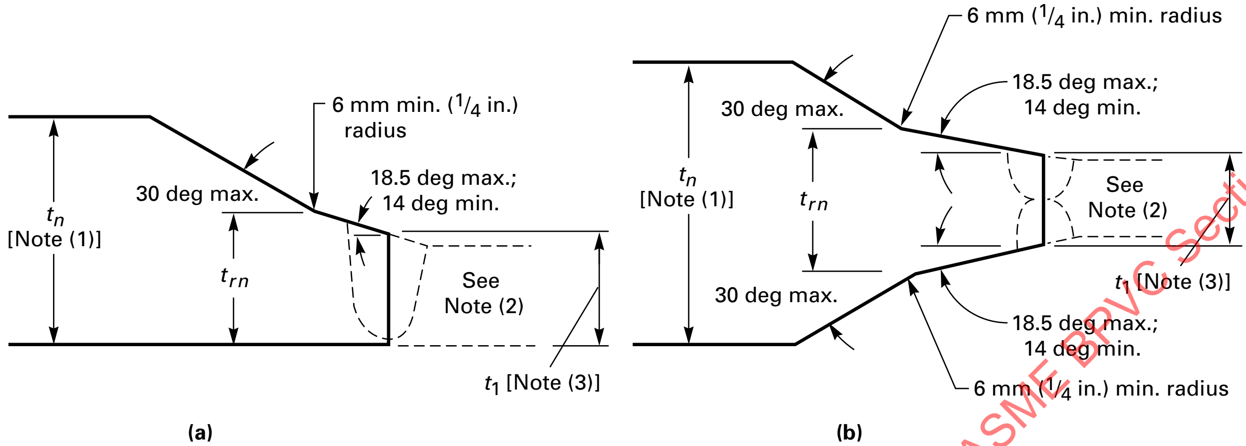
Figure TW-130.5-2
Attachment of Pressure Parts to Flat Plates to Form a Corner Joint



GENERAL NOTES:
(a) t_s is defined in TD-500(b).
(b) Dimension b is produced by the weld preparation and shall be verified after fit up and before welding.

NOTES:
(1) For unstayed flat heads, see also TD-500.
(2) c, t_n, and t_x are as defined in TW-130.5.

Figure TW-130.5-3
Nozzle Necks Attached to Piping of Lesser Wall Thickness



NOTES:
(1) As defined in TD-640. t_n shall be not less than the thickness required by TD-680.
(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

TW-130.6 FILLET WELDS

(a) Fillet welds may be employed as strength welds for pressure parts within the limitations given elsewhere in Section XII. Particular care shall be taken in the layout of joints in which fillet welds are to be used in order to ensure complete fusion at the root of the fillet.

(b) Corner or tee joints may be made with fillet welds, provided the plates are properly supported independently of such welds, except that independent supports are not required for joints used for the purposes stated in TF-120.4.

(c) Figures TW-130.5-1 and TW-130.5-2 show several construction details that are not acceptable.

(d) Unless the sizing basis is given elsewhere in Section XII, the allowable load on fillet welds shall equal the product of the weld area (based on minimum leg dimension), the allowable stress value in tension of the material being welded, and a joint efficiency of 55%.

TW-130.7 NOZZLES IN TANKS CONSTRUCTED OF FERRITIC STEELS WITH TENSILE PROPERTIES ENHANCED BY HEAT TREATMENT

(a) All openings regardless of size shall meet the requirements for reinforcing, nozzle geometry, and nozzle attachments and shall conform to the details shown in Figures TW-130.7-1 and TW-130.7-2, or Figure TW-140.2-1, sketch (y-1) or sketch (z-1) when permitted by the provisions of TF-610.4(a), or as shown in Figure TW-140.2-1 when permitted by the provisions of TF-610.4(b).

(b) Except for nozzles covered in (c), all nozzles and reinforcing pads shall be made of material with the specified minimum yield strength within ±20% of that of the tank shell to which they are attached; however, pipe flanges, pipe, or communicating chambers may be of carbon, low, or high alloy steel welded to nozzle necks or the required material, provided

(1) the joint is a circumferential butt weld located not less than $\sqrt{Rt_n}$ that, except for the nozzle type shown in Figure TW-130.7-1, sketch (f), is measured from the limit of reinforcement as defined in TD-640. For Figure TW-130.7-1, sketch (f), the $\sqrt{Rt_n}$ is measured as shown in that figure. In these equations

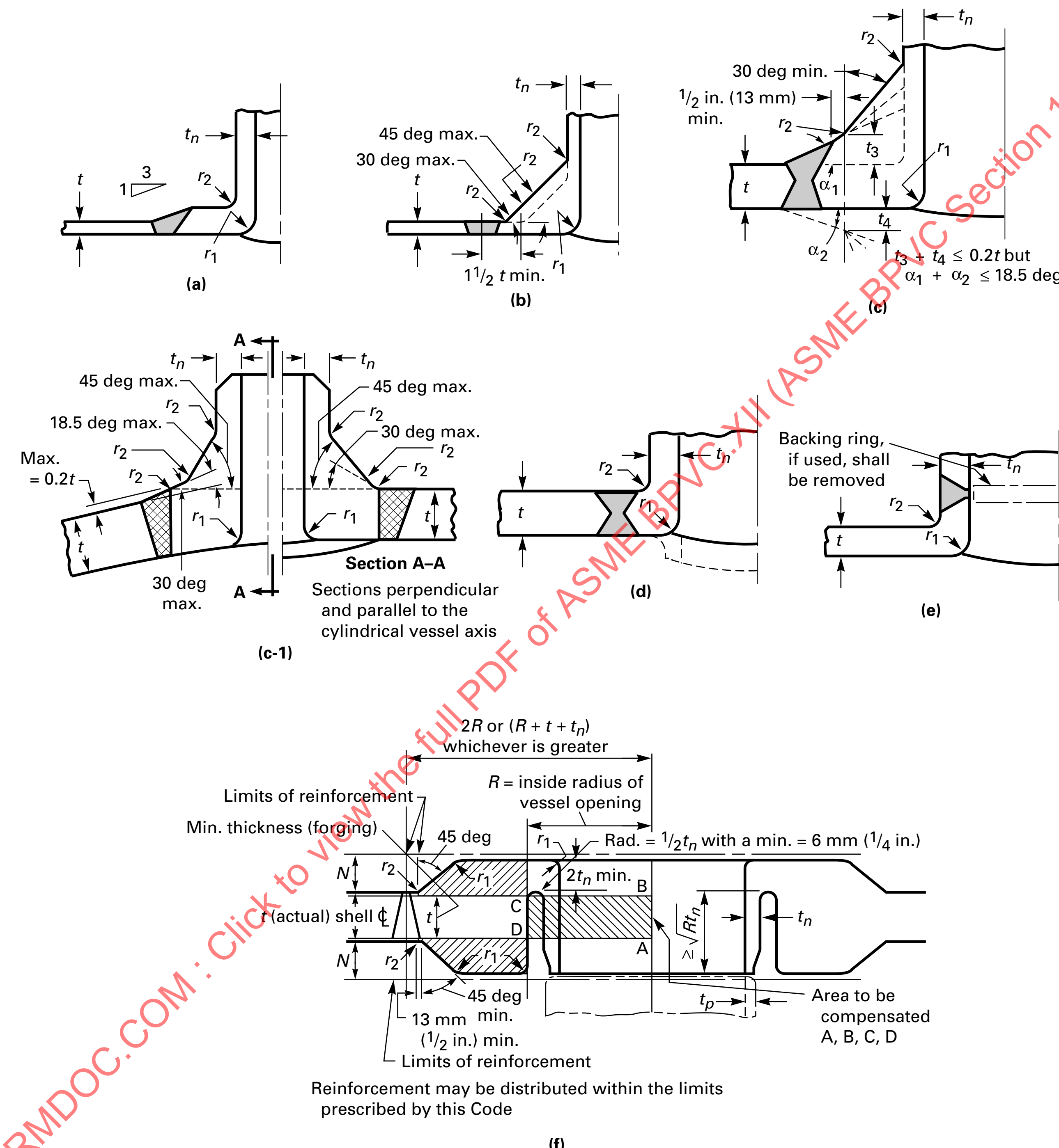
R = inside radius of the nozzle neck, except for Figure TW-130.7-1, sketch (f), where it is the inside radius of the vessel opening as shown in that figure, mm (in.)

(2) the design of the nozzle neck at the joint is made on the basis of the allowable stress value of the weaker material.

(3) the slope of the nozzle neck does not exceed 3:1 for at least a distance of $1.5t_n$ from the center of the joint.

(4) the diameter of the nozzle neck does not exceed the limits given in TD-610.7 for openings designed to TD-100.5 and TD-600 through TD-670.

Figure TW-130.7-1
Acceptable Welded Nozzle Attachment Readily Radiographed to Code Standards



Legend:

$N \leq 2\frac{1}{2}t_n$

$r_1 = \frac{1}{8}t$ to $\frac{1}{2}t$

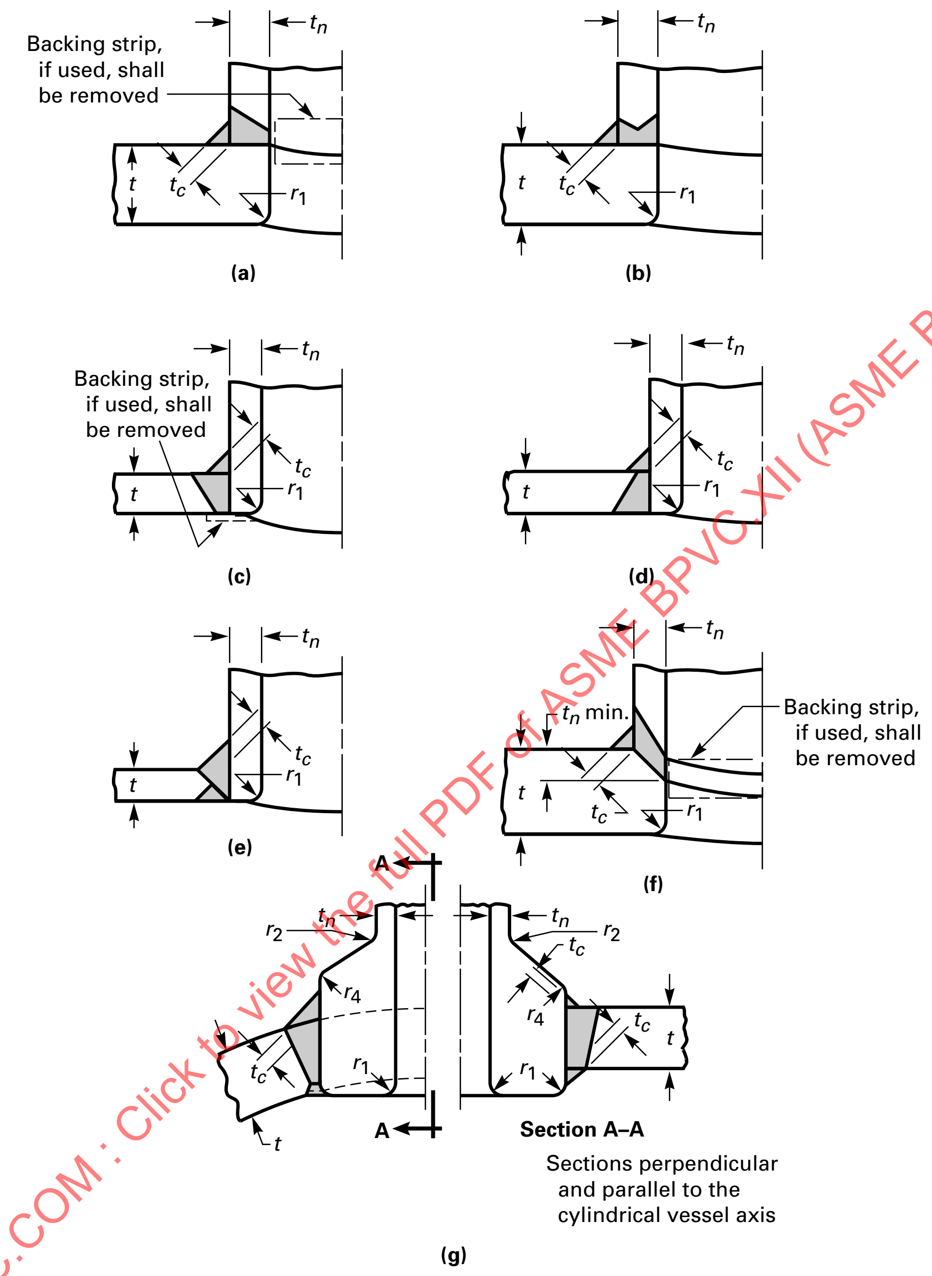
$r_2 \geq 19$ mm ($\frac{3}{4}$ in.)

t = nominal thickness of shell or head

t_n = nominal thickness of nozzle

t_p = nominal thickness of attached pipe

Figure TW-130.7-2
Acceptable Full Penetration Welded Nozzle Attachments Radiographable With Difficulty and Generally Requiring Special Techniques Including Multiple Exposures to Take Care of Thickness Variations



Legend:

r_1	=	$\frac{1}{8}t$ to $\frac{1}{2}t$	t	=	nominal thickness of shell or head
r_2	≥	19 mm ($\frac{3}{4}$ in.)	t_c	≥	$0.7t_n$ or 6 mm ($\frac{1}{4}$ in.), whichever is less
r_4	≥	6 mm ($\frac{1}{4}$ in.)	t_n	=	nominal thickness of nozzle

(c) Nozzles of nonhardenable austenitic-type stainless steel may be used in vessels constructed of steels conforming to SA-353, SA-553 Types I and II, or SA-645 Grade A, provided the construction meets all of the following conditions:

(1) The nozzles are nonhardenable austenitic-type stainless steel conforming to one of the following specifications: SA-182, SA-213, SA-240, SA-312, SA-336, SA-403, SA-430, or SA-479.

(2) The maximum nozzle size is limited to DN 100 (NPS 4).

(3) None of the nozzles is located in a Category A or B joint.

(4) The nozzles are located so that the reinforcement area of one nozzle does not overlap the reinforcement area of an adjacent nozzle.

TW-140 WELDED CONNECTIONS

(a) Nozzles, other connections, and their reinforcements may be attached to pressure vessels by arc or gas welding. Sufficient welding shall be provided on either side of the line through the center of the opening parallel to the longitudinal axis of the shell to develop the strength of the reinforcing parts as prescribed in TM-100 through shear or tension in the weld, whichever is applicable.

(b) The strength of groove welds shall be based on the area subjected to shear or to tension. The strength of fillet welds shall be based on the area subjected to shear (computed on the minimum leg dimension). The inside diameter of a fillet weld shall be used in figuring its length.

(c) Strength calculations for nozzle attachment welds for pressure loading are not required for the following:

(1) Figure TW-140.2-1, sketches (a) through (g), (x-1), (y-1), and (z-1), and all the sketches in Figure TW-130.7-1

(2) openings that are exempt from the reinforcement requirements by TD-600.3(c)

(d) The allowable stress values for groove and fillet welds in percentages of stress values for the vessel material, which are used in TD-650 calculations, are as follows:

(1) groove-weld tension, 74%

(2) groove-weld shear, 60%

(3) fillet-weld shear, 49%

NOTE: These values are obtained by combining the following factors: 87½% for combined end and side loading, 80% for shear strength, and the applicable joint efficiency factors.

(e) Reinforcing plates and saddles of nozzles attached to the outside of a vessel shall be provided with at least one telltale hole (maximum size NPS ¼ tap) that may be tapped for a preliminary compressed air and soap-suds 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.

TW-140.1 OPENINGS IN OR ADJACENT TO WELDS

(a) Any type of opening that meets the requirements for reinforcement given in TD-610 or TD-630 may be located in a welded joint.

(b) Single openings meeting the requirements given in TD-600.3(c) may be located in head-to-shell or Category B or C butt-welded joints, provided the weld meets the radiographic requirements in Part TE for a length equal to three times the diameter of the opening with the center of the hole at midlength. Defects that are completely removed in cutting the hole shall not be considered in judging the applicability of the weld.

(c) In addition to meeting the radiographic requirements of (b), when multiple openings meeting the requirements given in TD-600.3(c) are in line in a head-to-shell or Category B or C butt-welded joint, the openings shall be reinforced in accordance with TD-610 through TD-660.

(d) Except when the adjacent butt weld satisfies the requirements for radiography in (b), the edge of openings in a solid plate meeting the requirements of TD-600.3(c) shall not be placed closer than 13 mm (½ in.) from the edge of Category A, B, or C weld for material 38 mm (1½ in.) thick or less.

TW-140.2 MINIMUM REQUIREMENTS FOR ATTACHMENT WELDS AT OPENINGS

(a) *General*

(1) The terms *nozzles, connections, reinforcements, necks, tubes, fittings, pads*, and other similar terms used in this paragraph define essentially the same type of construction and form a Category D weld joint between the nozzle (or other term) and the shell, head, etc., as defined in TW-130.3.

(2) The location and minimum size of attachment welds for nozzles and other connections shall conform to the requirements of this paragraph in addition to the strength calculations required in TW-140.

(b) *Symbols.* The symbols used in this paragraph and in Figures TW-140.2-1 and TW-140.2-2 are defined as follows:

D_o = outside diameter of neck or tube attached by welding on inside of tank shell only

G = radial distance between hole in tank wall and outside diameter of nozzle neck or tube

Radius = 3.2 mm (⅛ in.) minimum blend radius

r_1 = minimum inside corner radius, the lesser of ¼t or 19 mm (¾ in.)

t = nominal thickness of tank shell or head

t_c = not less than the smaller of 6 mm ($^1/_4$ in.) or $0.7t_{min}$ (inside corner welds may be further limited by a lesser length or projection of the nozzle wall beyond the inside face of the tank wall)

t_{min} = the smaller of 19 mm ($^3/_4$ in.) or the thickness of the thinner of the parts joined by fillet, single-bevel, or single-J weld

t_n = nominal thickness of nozzle wall

t_w = dimension of attachment welds (fillet, single-bevel, or single-J), measured as shown in Figure TW-140.2-1

t_1 or t_2 = not less than the smaller of 6 mm ($^1/_4$ in.) or $0.7t_{min}$

(c) Necks Attached by a Full-Penetration Weld. Necks abutting a vessel wall shall be attached by a full-penetration groove weld. See Figure TW-140.2-1, sketches (a) and (b) for examples. Necks inserted through the tank wall may be attached by a full-penetration groove weld. See Figure TW-140.2-1, sketches (c), (d), and (e). When complete joint penetration cannot be verified by visual inspection or other means permitted in this Section, backing strips or equivalent shall be used with full-penetration welds deposited from one side.

If additional reinforcement is required, it shall be provided as integral reinforcement as described in (1), or by the addition of separate reinforcement elements (plates) attached by welding as described in (2).

(1) Integral reinforcement is that reinforcement provided in the form of extended or thickened necks, thickened shell plates, forging-type inserts, or weld buildup that is an integral part of the shell or nozzle wall and, where required, is attached by full-penetration welds. Figure TW-140.2-1, sketches (a) through (g), (x-1), (y-1), and (z-1), for examples of nozzles with integral reinforcement where the F factor in TD-610.2 may be used.

(2) Separate reinforcement elements (plates) may be added to the outside surface of the shell wall, the inside surface of the tank shell wall, or to both surfaces of the tank wall. When this is done, the nozzle and reinforcement is no longer considered a nozzle with integral reinforcement and the F factor in TD-610.1 shall be $F = 1.0$. See Figure TW-140.2-1, sketches (a-1), (a-2), and (a-3) depict various applications of reinforcement elements added to sketch (a). Any of these applications of reinforcement elements may be used with necks of the types shown in Figure TW-140.2-1, sketches (b) through (e), or any other integral reinforcement types listed in (1). When a pad is added, the nozzle and reinforcement is no longer considered a nozzle with integral reinforcement. The reinforcement plates shall be attached by welds at the outer edge of the plate, and at the nozzle neck periphery or inner edge of the plate if no nozzle neck is adjacent to the plate. The weld at the outer edge and the weld at the inner edge of the reinforcement plate, which does not abut a nozzle neck, shall be a fillet weld with a minimum throat dimension of $^1/_2 t_{min}$. See Figure TW-140.2-1, sketch (h), for an example of a fillet weld attachment. The welds attaching the reinforcement plate to a nozzle neck abutting a vessel wall shall be a full-penetration weld plus a fillet weld with minimum throat dimension t_w not less than $0.7t_{min}$.

(d) Neck Attached by Fillet or Partial Penetration Welds

(1) Necks inserted into or through the vessel wall may be attached by fillet or partial penetration welds, one on each face of the vessel wall. The welds may be any desired combination of fillet, single-bevel, and single-J welds. The dimension of t_1 or t_2 for each weld shall be not less than the smaller of 6 mm ($^1/_4$ in.) or $0.7t_{min}$, and their sum shall be not less than $1^1/_4 t_{min}$. See Figure TW-140.2-1, sketches (i) through (l).

If additional reinforcement is required, it may be provided in the form of extended or thickened necks, thickened shell plates, forgings, and/or separate reinforcement elements (plates) attached by welding. Weld requirements shall be the same as given in (c)(2), except as follows. The welds attaching the neck to the vessel wall or to the reinforcement plate shall consist of one of the following:

(-a) a single-bevel or single J-weld in the shell plate, and a single-bevel or single-J weld in each reinforcing plate. The dimension t_w of each weld shall be not less than $0.7t_{min}$. See Figure TW-140.2-1, sketches (q) and (r).

(-b) a full-penetration groove weld in each reinforcement plate, and a fillet, single-bevel, or single-J weld with a weld dimension t_w not less than 0.7 t_{min} in the tank shell plate. See Figure TW-140.2-1, sketch (s).

(2) Nozzle necks, flared necks, and studding outlet-type flanges may be attached by fillet welds or partial-penetration welds between the outside diameter or the attachment and the outside surface of the shell and at the inside of the opening in the shell. The throat dimension of the outer attachment weld shall be not less than $^1/_2 t_{min}$. The dimension t_w of the weld at the inside of the shell cutout shall be not less than 0.7 t_{min}. See Figure TW-140.2-1, sketches (m), (n), and (p).

(e) Necks and Tubes up to and Including DN 150 (NPS 6) Attached From One Side Only. Necks and tubes not exceeding DN 150 (NPS 6) may be attached from one side only on either the outside or inside surface of the tank.

(1) When the neck or tube is attached from the outside only, a welding groove shall be cut into the surface to a depth of not less than t_n on the longitudinal axis of the opening. It is recommended that a recess 1.6 mm ($^1/_{16}$ in.) deep be provided at the bottom of the groove in which to center the nozzle. The dimension t_w of the attachment weld shall be not less than t_n nor less than 6 mm ($^1/_4$ in.). See Figure TW-140.2-1, sketches (t) and (u).

(2) When the neck or tube is attached from the inside only, the depth of the welding groove or throat of fillet weld shall be at least equal to $1^1/_4 t_{min}$. Radial clearance

between vessel hole and nozzle outside diameter at the unwelded side shall not exceed tolerances given in Figure TW-140.2-1, sketches (v-1), (v-2), (w-1), and (w-2). Such attachments shall satisfy the rules for reinforcement of openings, except that no material in the nozzle neck shall be counted as reinforcement.

(f) Fittings: Internally Threaded, Externally Threaded, Socket Welded, or Butt Welded. The attachment of fittings shall meet the following requirements:

(1) Except as provided for in (2) through (6), fittings shall be attached by a full-penetration groove weld or by two fillet or partial-penetration welds, one on each face of the tank wall. The minimum weld dimensions shall be as shown in Figure TW-140.2-1, sketches (x), (y), (z), and (aa).

(2) Fittings not exceeding DN 80 (NPS 3) shown on Figure TW-140.2-1, sketches (x), (y), (z), (aa), and (bb), may be attached by welds that are exempt from size requirements with the following limitations:

(-a) TW-140(a) requirements shall be satisfied for TD-680 loadings.

(-b) For partial penetration welds or fillet welds, t_1 or t_2 shall be not less than the smaller of 2.5 mm ($^3/_{32}$ in.) or $0.7t_{min}$.

(3) Fittings and bolting pads not exceeding DN 80 (NPS 3), as shown in Figure TW-140.2-2, may be attached to tanks by a fillet weld deposited from the outside only with the following limitations:

(-a) maximum vessel wall thickness of 10 mm ($^3/_8$ in.).

(-b) the maximum size of opening in the vessel is limited to the outside diameter of the attached pipe plus 19 mm ($^3/_4$ in.), but not greater than one-half of the vessel inside diameter.

(-c) the attachment weld throat shall be the greater of the following:

(-1) the minimum nozzle neck thickness required by TD-680 for the same nominal size connection

(-2) that necessary to satisfy the requirements of TW-130.5 for the applicable loadings in TD-200

(-d) the typical fitting dimension t_f, as shown in Figure TW-140.2-1, sketch (p), shall be sufficient to accommodate a weld leg, which will provide a weld throat dimension.

If the opening exceeds the requirements of (3)(-b) or (5)(-d) in any direction, or is greater than one-half the vessel inside diameter, the part of the vessel affected shall be subjected to a proof test as required in TD-600.1(b), or the opening shall be reinforced in accordance with TD-610 and the nozzle or other connection attached, using a suitable detail in Figure TW-140.2-1, if welded.

(4) Fittings not exceeding DN 80 (NPS 3) may be attached by a fillet groove weld from the outside only as shown in Figure TW-140.2-1, sketch (bb). The groove weld t_w shall be not less than the thickness of Schedule 160 pipe (ASME B36.10M).

(5) Flange-type fittings not exceeding DN 50 (NPS 2), with some acceptable types such as those shown in Figure TW-140.2-2, may be attached without additional reinforcement other than that in the fitting and its attachment to the tank wall. The construction satisfies the requirements of this Section without further calculation or proof test as permitted in TD-600.3(c), provided all of the following conditions are met:

(-a) Maximum vessel wall thickness shall not exceed 10 mm ($^3/_8$ in.).

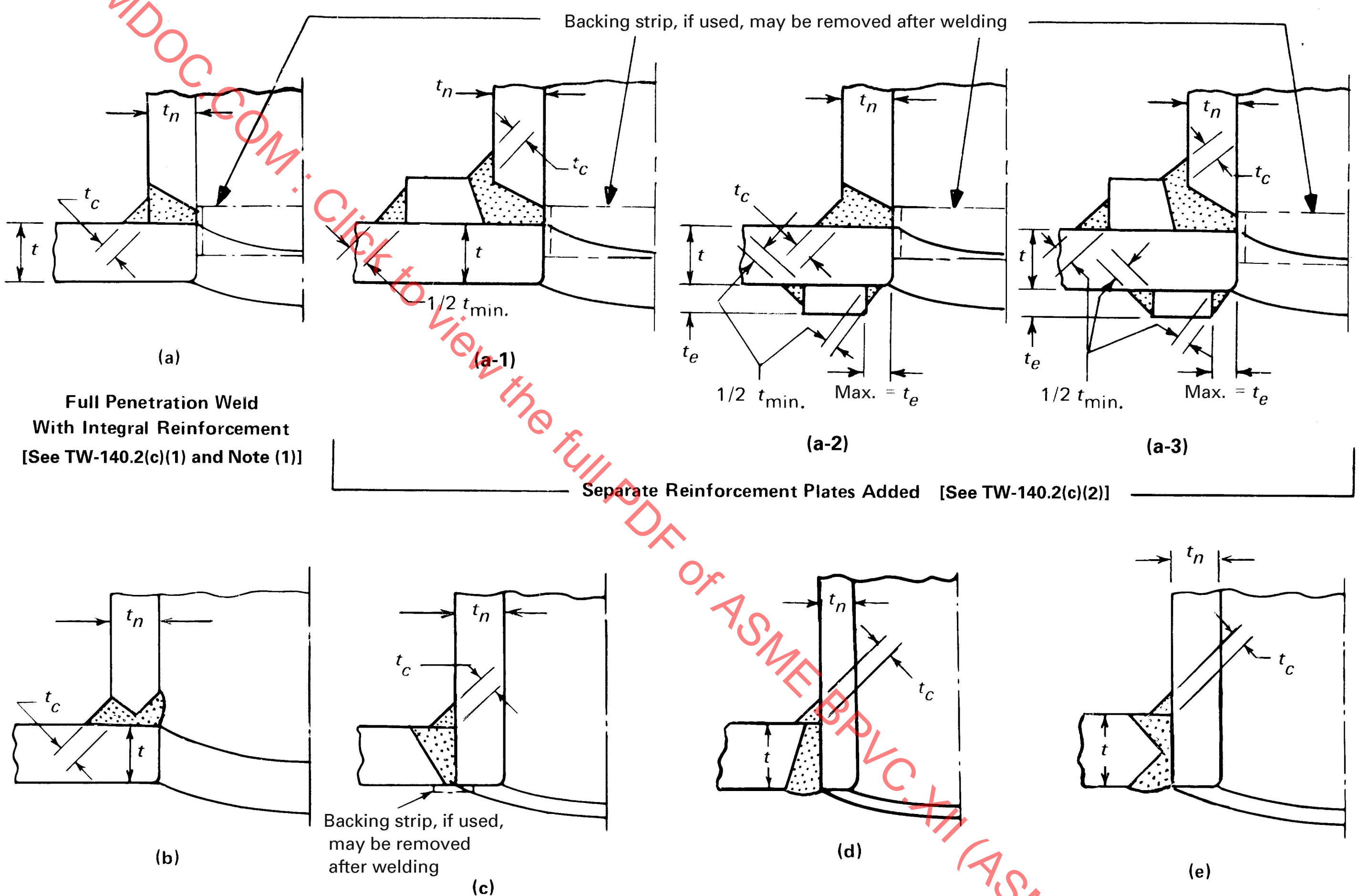
(-b) Maximum design pressure shall not exceed 2.4 MPa (350 psi).

(-c) Minimum fillet leg t_f is 2.5 mm ($^3/_{32}$ in.).

(-d) The finished opening, defined as the hole in the tank wall, shall not exceed the outside diameter of the nominal pipe size plus 19 mm ($^3/_4$ in.).

(6) Fittings conforming to Figure TW-140.2-2, sketch (k), not exceeding DN 80 (NPS 3) may be attached by a single fillet weld on the inside of the tank only, provided the criteria of (e)(2) and Figure TW-140.2-1, sketch (w) are met.

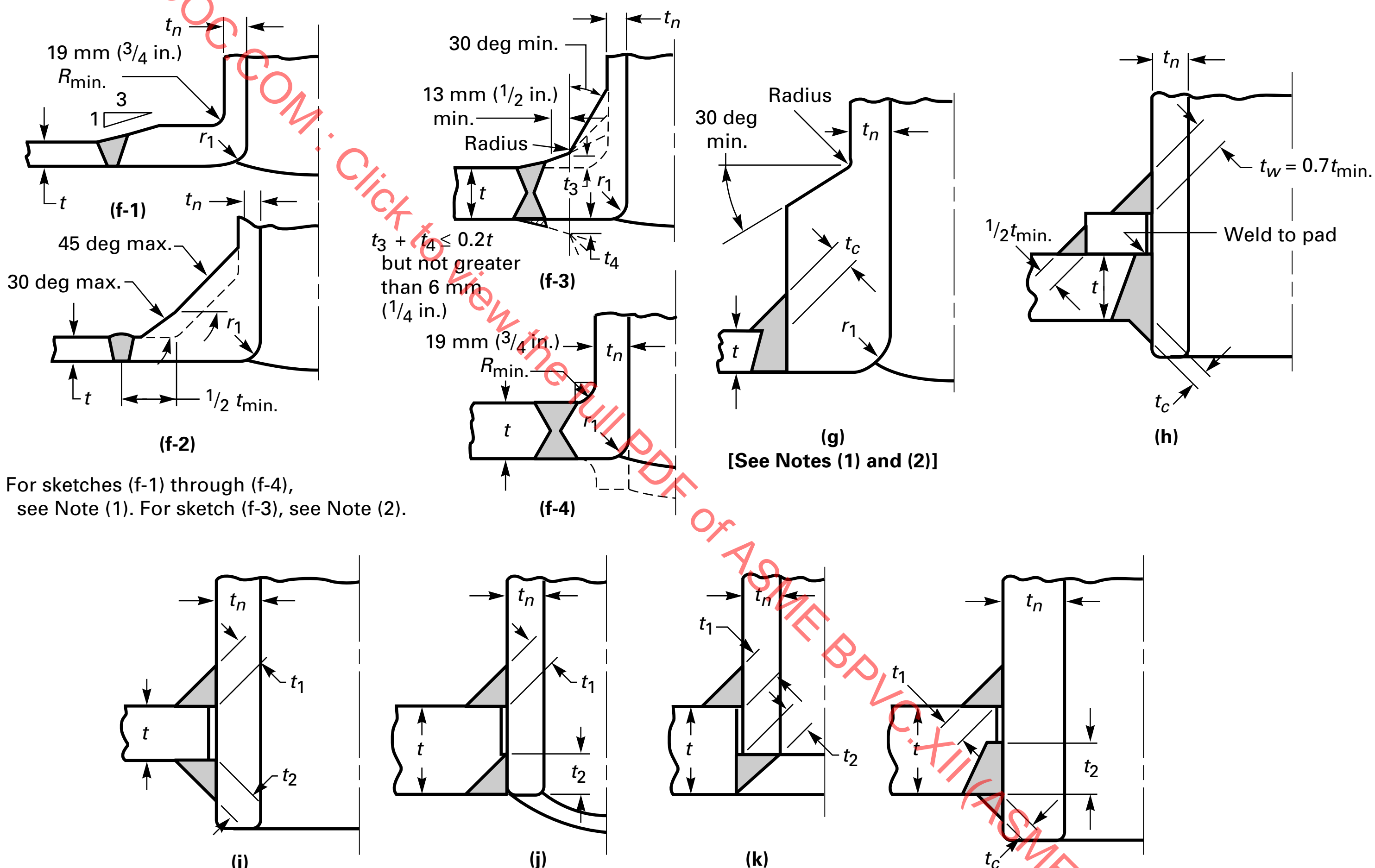
Figure TW-140.2-1
Some Acceptable Types of Welded Nozzles and Other Connections to Shells, Heads, Etc.



Full Penetration Welds to Which Separate Reinforcement Plates May Be Added [See TW-140.2(c)(2) and Note (1)]

Notes follow on last page of this Figure.

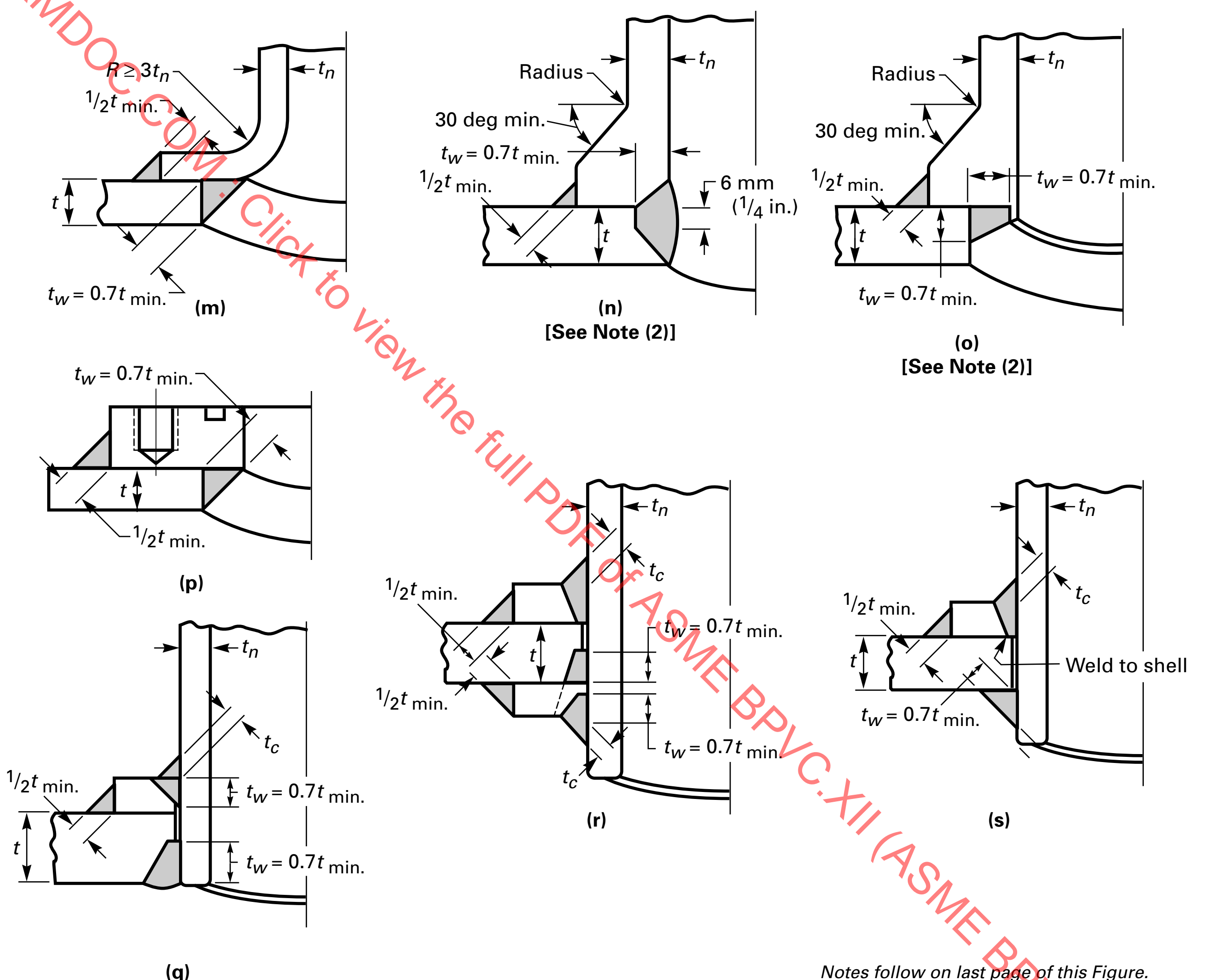
Figure TW-140.2-1
Some Acceptable Types of Welded Nozzles and Other Connections to Shells, Heads, Etc. (Cont'd)



$t_1 + t_2 \geq 1^1/_4 t_{min.}$
t_1 or t_2 not less than the smaller of 6 mm ($^1/_4$ in.) or $0.7t_{min.}$

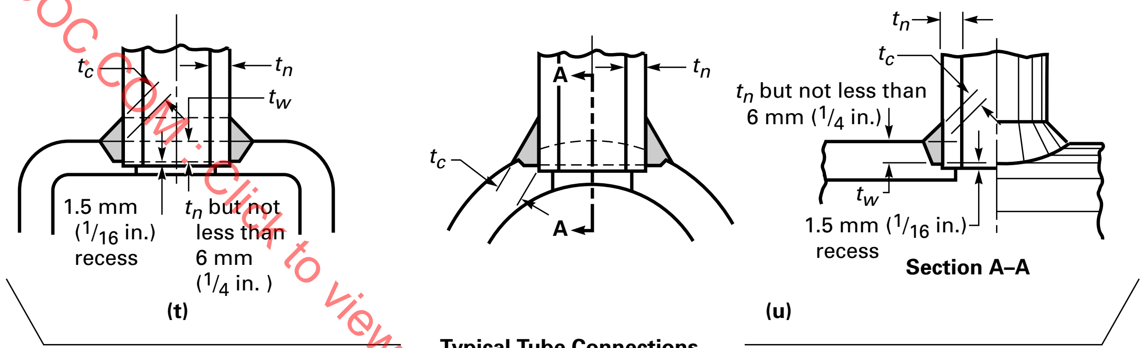
Notes follow on last page of this Figure.

Figure TW-140.2-1
Some Acceptable Types of Welded Nozzles and Other Connections to Shells, Heads, Etc. (Cont'd)

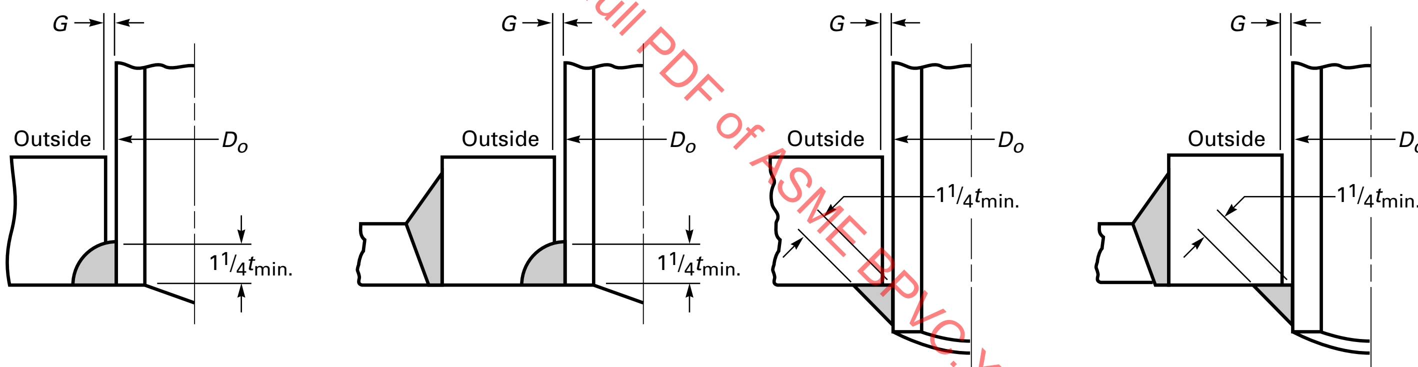


Notes follow on last page of this Figure.

Figure TW-140.2-1
Some Acceptable Types of Welded Nozzles and Other Connections to Shells, Heads, Etc. (Cont'd)



(When used for other than square, round, or oval headers, round off corners)



(v-1)
[See Note (3)]

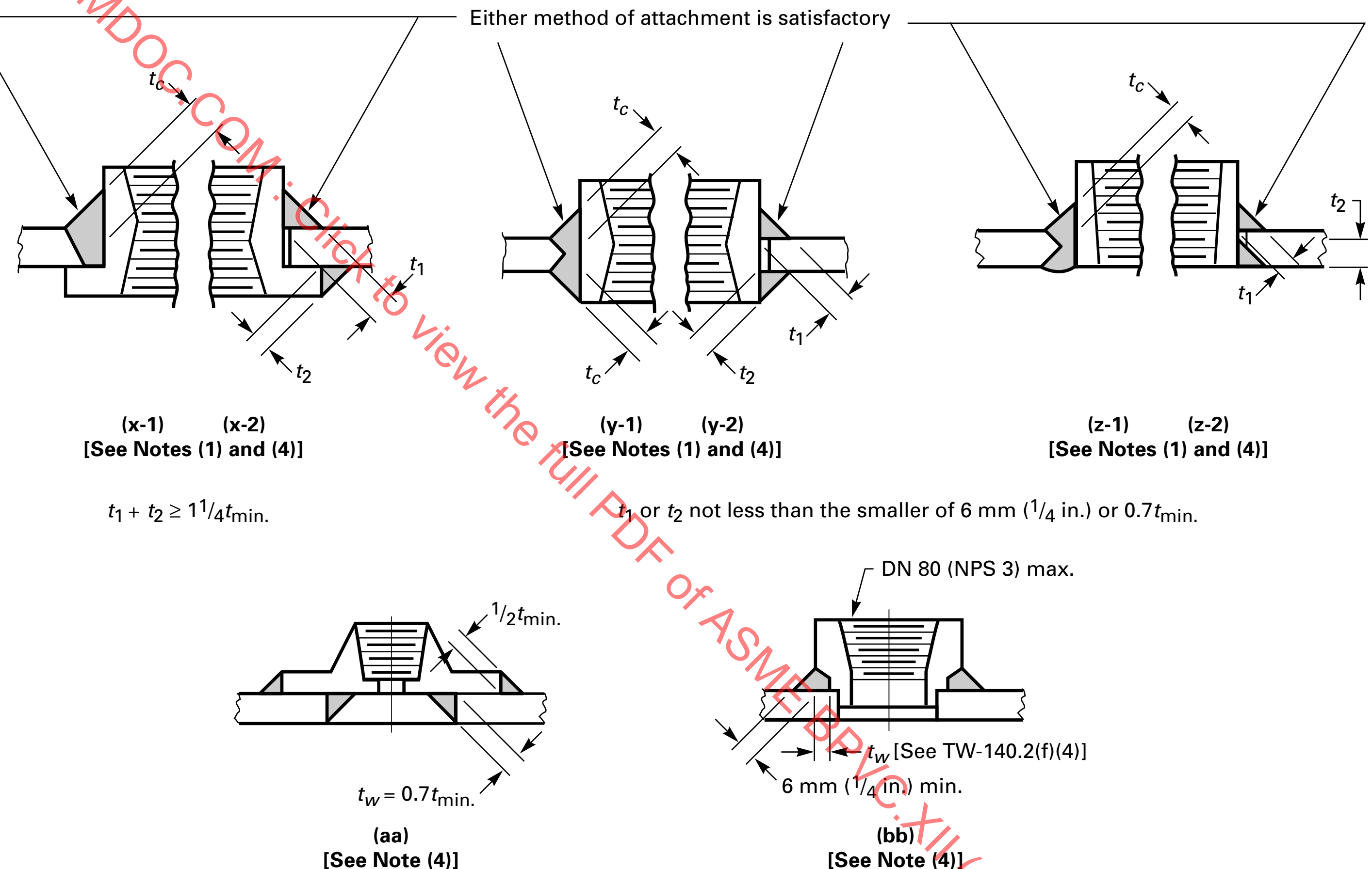
(v-2)
[See Note (3)]

(w-1)
[See Note (3)]

(w-2)
[See Note (3)]

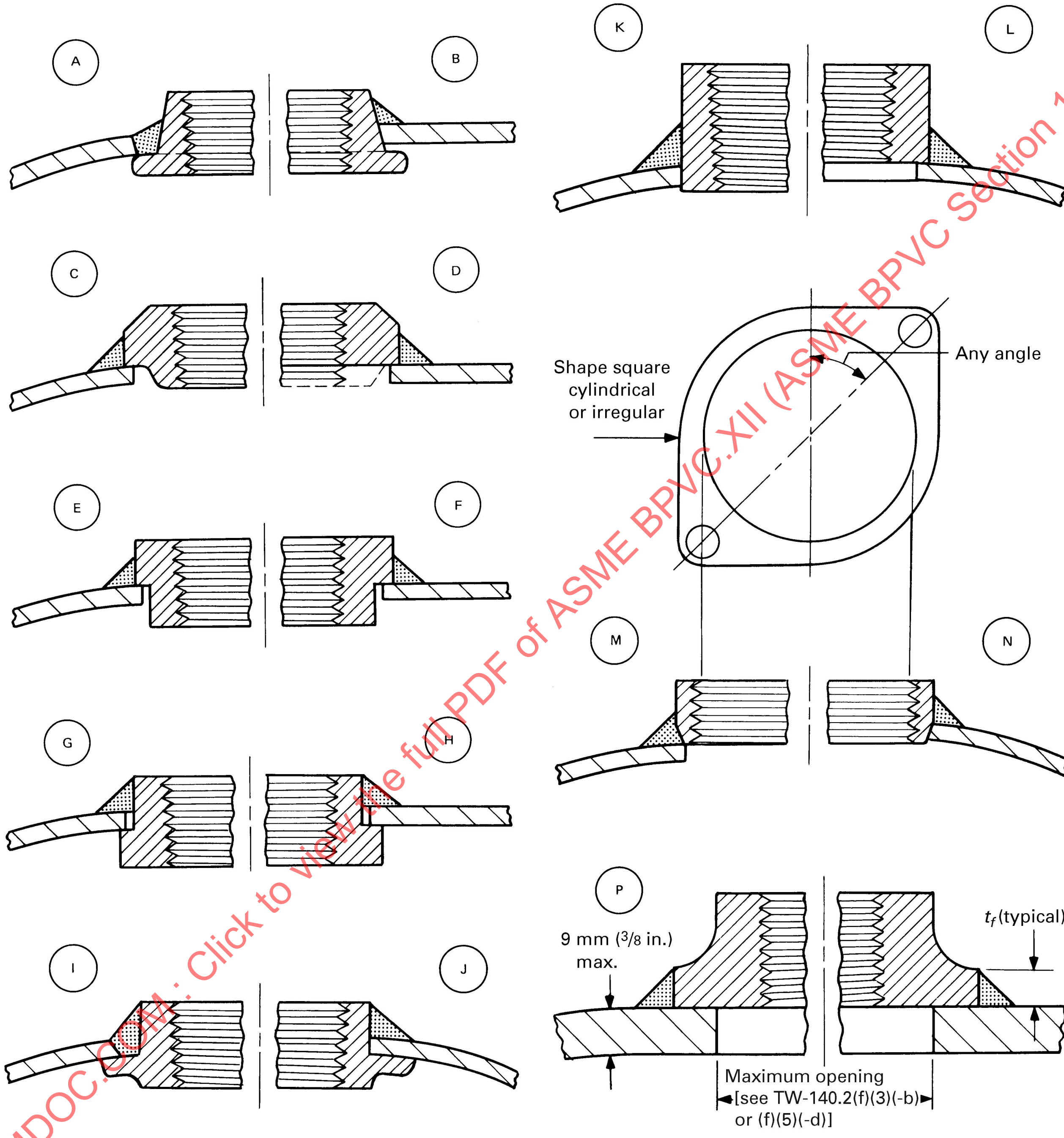
Notes follow on last page of this Figure.

Figure TW-140.2-1
Some Acceptable Types of Welded Nozzles and Other Connections to Shells, Heads, Etc. (Cont'd)



NOTES:
(1) Sketches (a) through (g), (x-1), (y-1), and (z-1) are examples of nozzles with integral reinforcement.
(2) Where the term *Radius* appears, provide a 3 mm ($^1/_8$ in.) minimum blend radius.
(3) For sketches (v-1) through (w-2):
(a) For applications where there are no external loads, G = 3 mm ($^1/_8$ in.) max.
(b) With external loads:
G = 0.005 for $D_o \leq$ 25 mm (1 in.); G = 0.010 for 25 mm (1 in.) < $D_o \leq$ 100 mm (4 in.); G = 0.015 for 100 mm (4 in.) < $D_o \leq$ 170 mm ($6^5/_8$ in.).
(4) For DN 80 (NPS 3) and smaller, see exemptions in TW-140.2(f)(2).

Figure TW-140.2-2
Some Acceptable Types of Small Fittings [See TW-140.2(f)(3) for Limitations]



PART TF FABRICATION REQUIREMENTS

ARTICLE TF-1 GENERAL REQUIREMENTS FOR FABRICATION

TF-100 GENERAL

The fabrication of pressure vessels and parts shall conform to the requirements in Part TF.

TF-110 MATERIALS

TF-110.1 CUTTING PLATE 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 oxygen or arc cutting. After oxygen or arc cutting, all slag and detrimental discoloration of material that has been molten shall be removed by mechanical means prior to further fabrication or use.

(b) Ends of nozzles or manhole necks that are to remain unwelded in the completed tank may be cut by shearing, provided sufficient additional material is removed by any other method that produces a smooth finish.

(c) Exposed inside edges shall be chamfered or rounded.

(25) TF-110.2 MATERIAL IDENTIFICATION

(a) 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 by TM-140.3 for the material will be plainly visible. The vessel Manufacturer shall maintain traceability of the material to the original identification markings by one or more of the following methods:

(1) accurate transfer of the original identification markings to a location where the markings will be visible on the completed tank

(2) identification by a coded marking traceable to the original required marking

(3) recording the required markings using methods such as material tabulations or as-built sketches that ensure identification of each piece of material during fabrication and subsequent identification in the completed vessel

Such transfers of markings shall be made prior to cutting, except that the Manufacturer may transfer markings immediately after cutting, provided the control of these transfers is described in the Manufacturer's written Quality Control System (see Mandatory Appendix I). Except as indicated in (b), material may be marked by any method acceptable to the Inspector. The Inspector need not witness the transfer of the marks but shall verify that it has been correctly done.

(b) Where service conditions or thickness prohibit die-stamping for material identification, and when so specified by the User, the material Manufacturer or supplier shall mark the required data on the plates in a manner that will allow positive identification upon delivery. The markings must be recorded so that each plate will be positively identified in its position in the completed vessel to the satisfaction of the Inspector. Material that is to be divided shall be done as in (a).

(c) When material is formed into shapes by anyone other than the Manufacturer of the completed 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, one set shall be accurately transferred by the Manufacturer of the shape. Manufacturer's Partial Data Reports and parts stamping are not a requirement unless there has been fabrication to the shapes that include welding, except as exempted by TM-110.10.

TF-110.3 REPAIR OF DEFECTS IN MATERIALS

(a) Pressure-retaining material shall be examined by nondestructive methods as required by the rules of this Section.

(b) The requirements of this Part for repair by welding, including examination of the repair welds, shall be met wherever repair welds are made to pressure-retaining material.

(c) Elimination of Defects by Blend Grinding. Defects shall be removed or reduced to an acceptable-sized imperfection. Defects may be removed by grinding or machining, provided the following requirements are met:

(1) the remaining thickness of the section is not reduced below that required by Part TD, except as noted in TF-120.1(b)

(2) the depression, after defect elimination, is blended uniformly into the surrounding surface

(d) *Base Material Repair by Welding*. The Manufacturer may repair the base material by welding after the defects have been removed, with the concurrence of the Inspector.

(1) *Defect Removal*. The defect shall be removed by suitable mechanical, thermal cutting, or gouging methods and the cavity shall be prepared for repair. After thermal cutting, all slag and detrimental material that has been molten shall be removed by mechanical means suitable for the material prior to weld repair. When thermal cutting is used, the effect on the mechanical properties shall be taken into consideration. The surface to be welded shall be uniform and smooth.

(2) *Qualification of Welding Procedures and Welders*. The welding procedure and welders or welding operators shall be qualified in accordance with the requirements of Article TF-2 and Section IX.

(3) *Examination of Repair Welds*. Each repair weld shall be examined by the magnetic particle or the liquid-penetrant method.

(4) *Heat Treatment After Repairs*. The product shall be heat treated after repair as required by Article TF-7.

(e) *Time of Examination of Repair Welds (see also TE-200)*

(1) When radiographic examination of repair welds is required, it shall be performed after postweld heat treatment.

(2) Magnetic particle or liquid-penetrant examination of repair welds shall be performed after final heat treatment.

(f) *Fasteners*. Weld repair of bolts, studs, and nuts is not permitted.

TF-120 FORMING AND FABRICATION

TF-120.1 FORMING OF SHELL SECTIONS AND HEADS

(a) All plates 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. Limits are provided on cold working of all carbon and low alloy steels, high alloy steels, and ferritic steels with tensile properties enhanced by heat treatment (see TF-310.1, TF-410.4, and TF-610.1).

(b) If the plates are to be rolled, the adjoining edges of longitudinal joints of cylindrical tanks 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 TF-120.2).

(c) When the vessel shell sections, heads, or other pressure boundary parts are formed by other than the Manufacturer of the vessel, the required certification of the part shall indicate whether or not the part has been heat treated and, if so, the temperature(s) at which it was heat treated (see TF-310.1, TF-410.4, and TF-610.1).

TF-120.2 PERMISSIBLE OUT-OF-ROUNDNESS OF CYLINDRICAL AND SPHERICAL SHELLS

(a) *Internal Pressure*. The shell of a completed vessel shall be substantially round and shall meet the following requirements:

(1) The difference between the maximum and minimum inside diameters at any cross section shall not exceed 1% of the nominal diameter 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 Figure TF-120.2-1). When the cross section passes through any other location normal to the axis of the vessel, including head-to-shell junctions, the difference in diameters shall not exceed 1%. For vessels with longitudinal lap joints, the permissible difference in inside diameters may be increased by the nominal plate thickness.

(b) *External Pressure*. The shell of a completed vessel intended to operate under external pressure shall meet the following requirements at any cross-section:

(1) The out-of-roundness limitations prescribed in (a)(1).

(2) The maximum plus-or-minus deviation from the true circular form, measured radially on the outside or inside of the vessel, shall not exceed the maximum permissible deviation e obtained from Figure TF-120.2-2. Use $e = 1.0t$ or $e = 0.2t$, respectfully, for points falling above or below these curves. Measurements shall be made from a segmental circular template having the design inside or outside radius (depending upon where the measurements are taken) and cord length equal to twice the arc length obtained from Figure TD-410.2-2. The values of L and D_o in Figures

Figure TF-120.2-1
Example of Differences Between Maximum and Minimum Inside Diameters in Cylindrical, Conical, and Spherical Shells

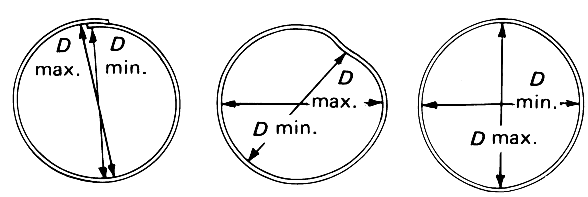
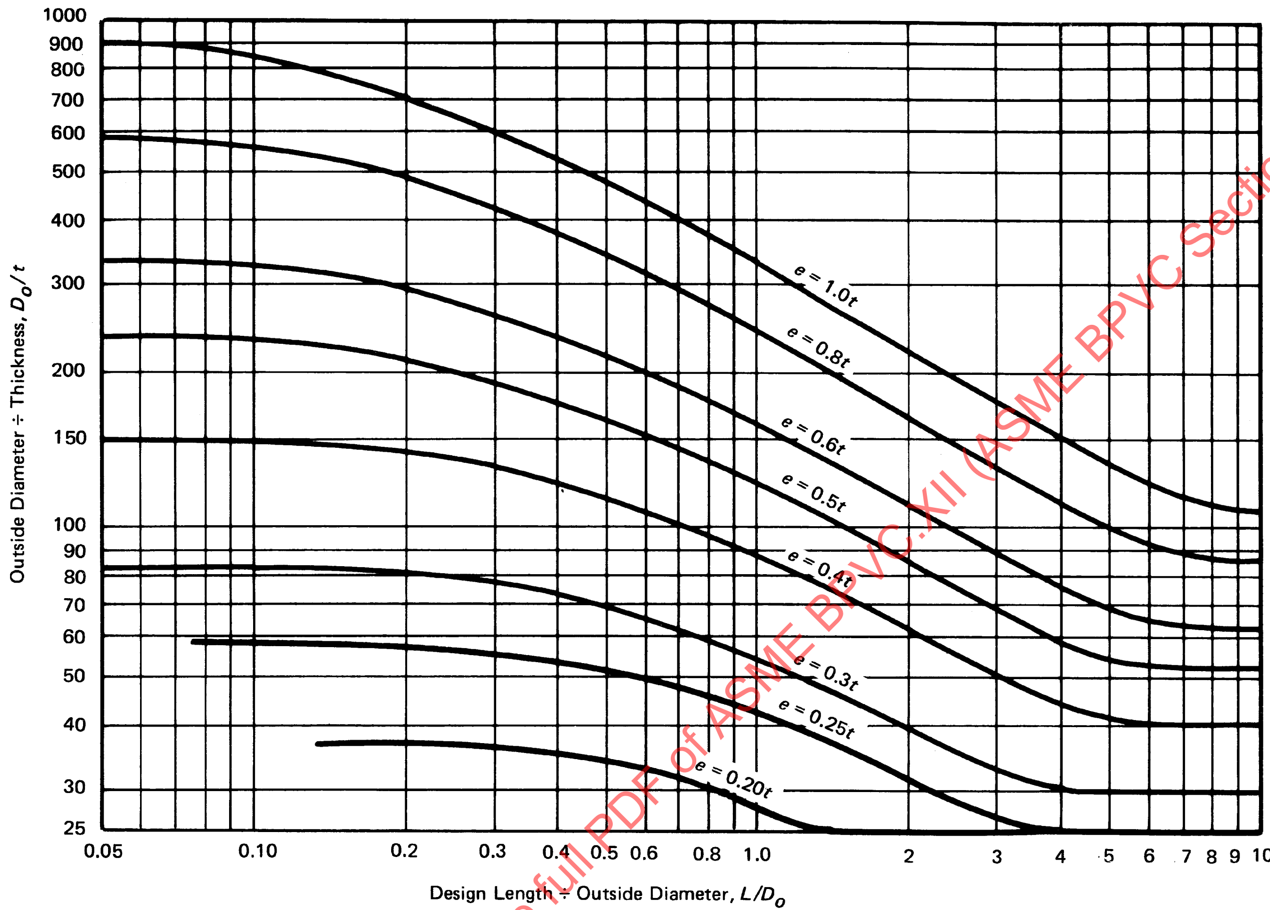


Figure TF-120.2-2
Maximum Permissible Deviation From a Circular Form, *e*, for Vessels Under External Pressure



TD-410.2-2 and TF-120.2-2 shall be determined as follows:

(-a) for cylinders, L and D_o as defined in TD-400.1

(-b) for spheres, L is one-half of the outside diameter D_o

(3) For cylinders and spheres, the value of t shall be determined as follows:

(-a) For vessels with butt joints, t is the nominal plate thickness less corrosion allowance.

(-b) For vessels with longitudinal lap joints, t is the nominal plate thickness and the permissible deviation is $t + e$.

(-c) Where the shell at any cross section is made of plates having different thicknesses, t is the nominal thickness of the thinnest plate less corrosion allowance.

(4) The requirements of (2) shall be met in any plane normal to the axis of revolution for cylinders and in the plane of any great circle for spheres.

(5) Measurements shall be taken on the surface of the base metal and not on welds or other raised parts of the material.

(6) The dimensions of the completed vessels may be brought within the requirements of this paragraph by any process that will not impair the strength of the material.

(7) Sharp bends and flat spots shall not be permitted unless provision is made for them in the design.

(8) If the nominal thickness of plate used for a cylindrical vessels exceeds the minimum thickness required by TD-400.2 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 cord length for measuring e_{max} shall be determined by D_o/t for the nominal plate thickness used.

(9) Vessels fabricated of pipe may have permissible variations in diameter (measured outside) in accordance with those permitted under the specification covering its manufacture.

TF-120.3 TOLERANCE FOR FORMED HEADS

(a) The inner surface of a torispherical, toriconical, hemispherical, or ellipsoidal head shall not deviate outside of the specified shape by more than 1.25% of D nor inside the specified shape by more than 0.625% of D, where D is the nominal inside diameter of the vessels shell at point of attachment. 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) Measurements for determining the deviations specified in (a) shall be taken from the surface of the base metal and not from welds.

(c) The skirts of heads shall be sufficiently true to round so that the difference between the maximum and minimum diameters shall not exceed 1% of the nominal diameter.

(d) When the skirt of any unstayed formed head is machined to make a driving fit into or over a shell, the thickness shall not be reduced to less than 90% of that required for a blank head or the thickness of the shell at the point of attachment. When so machined, the transition from the machined thickness to the original thickness of the head shall not be abrupt but shall be tapered for a distance of at least three times the difference between the thicknesses.

TF-120.4 LUGS, FITTINGS, AND OTHER ATTACHMENTS

(a) Lugs, brackets, saddle-type nozzles, manhole frames, reinforcement around openings, and other appurtenances shall be formed and fitted to conform reasonably to the curvature of the shell or surface to which they are attached.

(b) When pressure parts, such as saddle-type nozzles, manhole frames, and reinforcement around openings, extend over pressure-retaining welds, such welds shall be ground flush for the portion of the weld to be covered.

(c) When nonpressure parts, such as lugs, brackets, clips, and support legs and saddles, extend over pressure-retaining welds, such welds shall be ground flush as described in (a), or such parts shall be notched or coped to clear those welds.

TF-120.5 INSPECTION DURING FABRICATION

(a) The Manufacturer shall examine the pressure-retaining parts to make certain they conform to the prescribed shape and meet the thickness requirements after forming.

(b) Before attaching nozzles, manhole frames, nozzle reinforcement, and other appurtenances to the inside or outside of the vessel, they shall be examined to make certain they properly fit the vessel curvature.

(c) When conditions permit entry into the vessel, as complete examination as possible shall be made by the Inspector before the final closure.

(d) The Inspector shall make an external inspection of the completed vessel at the time of the final hydrostatic test or pneumatic test.

ARTICLE TF-2
REQUIREMENTS FOR WELDING FABRICATION

(25)
TF-200 GENERAL REQUIREMENTS FOR ALL WELDS

The following requirements apply to the fabrication of pressure vessels and parts that are fabricated by welding:

(a) Arc and gas welding processes that may be used in the construction of transport tanks under this Article are: shielded metal arc, submerged arc, flux core arc, gas tungsten arc, gas metal arc, plasma arc, atomic hydrogen metal arc, oxyfuel gas welding, electrogas, electron beam, and laser beam. Those not listed are not permitted.

(b) Pressure welding processes that may be used in the construction of transport tanks under this Article are: flash induction, resistance, pressure gas, and forge welding. Those not listed are not permitted.

(c) No mechanical pressure or blows shall be applied, as part of the welding process, except as permitted for peening and forge welding.

(d) Manufacturers are prohibited from welding pressure-retaining materials that have a carbon content that exceeds 0.35% by heat analysis. Attachment welds that are not welded directly to pressure parts are excluded.

(e) The method used to prepare the base metal shall leave the weld preparation with reasonably smooth surfaces. The surfaces for welding shall be free of scale, rust, oil, grease, and other deleterious material. The work shall be protected from deleterious contamination and from rain, snow, and wind during welding. Welding shall not be performed on wet surfaces.

(f) Each Manufacturer or parts Manufacturer shall be responsible for the quality of the welding done by the Manufacturer's or parts Manufacturer's organization and shall conduct tests not only of the welding procedure to determine its suitability to ensure welds that will meet the required tests, but also of the welders and welding operators to determine their ability to apply the procedure properly. Procedure qualification shall be by the methods specified in Section IX.

(g) No Production welding shall be undertaken until after the welding procedures that are to be used have been qualified. Only Welders and Welding Operators who are qualified in accordance with Section IX shall be used in production.

TF-210 WELDING QUALIFICATIONS, RECORDS, AND IDENTIFYING STAMPS (25)

(a) All welding shall be performed in accordance with the Manufacturer's welding procedure specifications, which have been qualified by the Manufacturer in accordance with the requirements of this Article.

(b) All welders shall be qualified by the Manufacturer in accordance with the requirements of this Article. This includes Welders and Welding Operators used to join permanent or temporary attachments to pressure parts and to make permanent or temporary tack welds.

(c) The Manufacturer shall maintain a record of the qualified welding procedures, the supporting procedure qualification records, and the qualification records of the Welders and Welding Operators qualified by him, showing the date and results of tests and the identification mark assigned to each welder. These records shall be reviewed, verified, and certified by the Manufacturer by signature or some other method of control in accordance with the Manufacturer's Quality System and shall be accessible to the Inspector.

(d) In addition to the records of (c), the Manufacturer shall document welding performed by Welders or Welding Operators in order to establish compliance with the maintenance of qualification requirements of Section IX.

(e) Each Welder or Welding Operator shall apply the identification mark assigned by the Manufacturer on or adjacent to all permanent welded joints or series of joints in accordance with TF-220.7. The marking shall be done with either a blunt nose continuous or blunt nose interrupted dot die stamps. As an alternative, the Manufacturer shall keep a record of permanent welded joints in each item and of the Welders and Welding Operators used in making each of the joints.

TF-210.1 WELDERS NOT IN THE EMPLOY OF THE MANUFACTURER (25)

Welders not in the employ of the Manufacturer may be used to fabricate transport tanks constructed in accordance with this Section, provided all the following conditions are met:

(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 the Manufacturer's discretion without involvement of any other organization

(c) requirement for Assignment of Welder Identification symbols

(d) evidence that this program has been accepted by the Manufacturer's Inspector

(e) the Manufacturer shall be responsible for Code compliance of the pressure vessel or part, including applying the Certification Mark with appropriate Designator and providing Data Report Forms properly executed and countersigned by the Inspector

(f) all Code construction shall be the responsibility of the Manufacturer

(g) all welding shall be performed in accordance with the Manufacturer's welding procedure specifications that have been qualified by the Manufacturer in accordance with the requirements of TF-210(a)

(h) all welders shall be qualified by the Manufacturer in accordance with the requirements of TF-210(b)

(i) the Manufacturer's Quality Control System shall include as a minimum:

(1) a requirement for complete and exclusive administrative and technical supervision of all welders by the Manufacturer

(2) evidence of the Manufacturer's authority to assign and remove welders at the Manufacturer's discretion without involvement of any other organization

(3) a requirement for Assignment of Welder Identification symbols

(4) evidence that this program has been accepted by the Manufacturer's Inspection Organization for Class 1 and Class 2 vessels and by the Society for Class 3 vessels

TF-210.2 QUALIFICATION OF WELDING PROCEDURE

(a) The procedure used in welding pressure parts and in joining load-carrying nonpressure parts, such as all permanent or temporary clips and lugs, to pressure parts shall be qualified in accordance with TF-210(a).

(b) The procedure used in welding non-pressure-bearing attachments that 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 the requirements of TF-210(a).

(2) When the welding is any automatic welding process performed in accordance with a Welding Procedure Specification, procedure qualification testing is not required.

(3) Welding of all test coupons shall be conducted by the Manufacturer. Testing of all test coupons shall be the responsibility of the Manufacturer. Qualification of a welding procedure by one Manufacturer shall not qualify that procedure for any other Manufacturer, except as provided in TF-210.4.

TF-210.3 TESTS OF WELDERS AND WELDING OPERATORS

The Welders and Welding Operators used in welding pressure parts and in joining load-carrying nonpressure parts (attachments) to pressure parts shall be qualified in accordance with TF-210(b).

(a) 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 work piece.

(b) When stud welding is used to attach load-carrying studs, a production stud weld test of each Welder or 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 by the bend or torque stud weld testing procedure described in Section IX or equivalent standard.

(c) The Welders and Welding Operators used in welding non-pressure-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. When the welding process is manual, machine, or semiautomatic, qualification in accordance with TF-210(b) is required.

(d) When welding is done by any automatic welding process, performance qualification testing is not required.

(e) Each Welder and Welding Operator shall be assigned an identifying number, letter, or symbol by the Manufacturer, which shall be used to identify the work of that welder or welding operator in accordance with TF-210(e).

(f) The Manufacturer shall maintain a record of the Welders and Welding Operators showing the date and result of tests and the identification mark assigned to each. These records shall be certified to by the Manufacturer and be accessible to the Inspector.

(g) Welding of all test coupons shall be conducted by the Manufacturer. Testing of all test coupons shall be the responsibility of the Manufacturer. A performance qualification test conducted by one Manufacturer shall not qualify a Welder or Welding Operator to do work for any other Manufacturer.

TF-210.4 USE OF STANDARD WELDING PROCEDURE

AWS Standard Welding Specifications that have been accepted by Section IX may be used for Section XII construction, provided the welding meets the requirements of this Section. The Section XII requirements shall govern. Manufacturers intending to use AWS

Standard Welding Procedures shall describe in their Quality Control System the measures used to ensure that the welding meets the requirements of this Section and Section IX.

TF-220 REQUIREMENTS FOR PRODUCTION WELDING

TF-220.1 CUTTING, FITTING, AND ALIGNMENT

(a) When plates are shaped by oxygen or arc cutting, the edges to be welded shall be uniform and smooth and shall be free of all loose scale and slag accumulations before welding.

(b) Plates that are being welded shall be fitted, aligned, and retained in position during the welding operation. Bars, jacks, clamps, tack welds, or other appropriate means may be used to hold the edges of parts in alignment.

(c) Tack welds used to secure 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, whether removed or left in place, shall be made using a fillet weld or butt weld procedure qualified in accordance with TF-200(a). Tack welds to be left in place shall be made by Welders qualified in accordance with TF-210(b) and shall be examined visually for defects, and if found to be defective shall be removed.

(d) The edges of butt joints shall be held during welding so that the tolerances of TF-220.3 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 tolerances are within the specified limits. Where fillet welds are used, the lapped plates shall fit closely and shall be kept in contact during welding.

TF-220.2 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 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) 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.

TF-220.3 ALIGNMENT TOLERANCE

(a) Alignment of sections at edges to be butt welded shall be such that the maximum offset is not greater than the applicable amount for the welded joint category under consideration, as listed in Table TF-220.3. The section thickness, t, is the nominal thickness of the thinner section at the joint.

(b) Any offset within the allowable tolerance provided above shall be faired at a three to one taper over the width of the finished weld, or if necessary, 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 TF-220.10.

TF-220.4 FINISHED LONGITUDINAL AND CIRCUMFERENTIAL JOINTS

(a) Butt-welded joints shall have complete penetration and full fusion. As-welded surfaces are permitted; however, the surface of 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 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 0.8 mm ($^1/_{32}$ in.) or 10% of the nominal thickness of the adjoining surface, whichever is less.[9]

(c) When a single-welded butt joint is made by using a backing strip that is left in place, the requirement for reinforcement applies only to the side opposite the backing strip.

(d) To ensure 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,[10] 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 values in Table TF-220.4.

Table TF-220.3
Maximum Offset Values

	Joint Categories	
Section Thickness, mm (in.)	**A**	**B, C, and D**
Up to 13 ($^1/_2$), incl.	$^1/_4t$	$^1/_4t$
Over 13 ($^1/_2$) to 19 ($^3/_4$), incl.	3 mm ($^1/_8$ in.)	$^1/_4t$
Over 19 ($^3/_4$) to 38 ($1^1/_2$), incl.	3 mm ($^1/_8$ in.)	5 mm ($^3/_{16}$ in.)

Table TF-220.4
Thickness of Weld Reinforcement

Material Nominal Thickness, mm (in.)	Maximum Reinforcement, mm (in.)	
	Category B and C Butt Welds	Other Welds
Less than 2.5 ($^3/_{32}$)	2.5 ($^3/_{32}$)	0.8 ($^1/_{32}$)
2.5 ($^3/_{32}$) to 5 ($^3/_{16}$), incl.	3 ($^1/_8$)	1.5 ($^1/_{16}$)
Over 5 ($^3/_{16}$) to 13 ($^1/_2$), incl.	4 ($^5/_{32}$)	2.5 ($^3/_{32}$)
Over 13 ($^1/_2$) to 25 (1), incl.	5 ($^3/_{16}$)	2.5 ($^3/_{32}$)
Over 25 (1) to 50 (2), incl.	6 ($^1/_4$)	3 ($^1/_8$)

TF-220.5 FILLET WELDS

In making fillet welds, the weld metal shall be deposited in such a way that adequate penetration into the base metal at the root of the weld is secured. 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.

TF-220.6 MISCELLANEOUS WELDING REQUIREMENTS

(a) The reverse side of double-welded joints shall be prepared by chipping, grinding, or melting out, in order to secure sound metal at the base of weld metal first deposited, before applying weld metal from the reverse side.

(b) The requirements in (a) 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 defects.

(c) If the welding is stopped for any reason, extra care shall be taken in restarting to get the required penetration and fusion. For submerged arc welding, chipping out a groove in the crater is recommended.

(d) 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.

(e) In welding plug welds, a fillet around the bottom of the hole shall be deposited first.

(25) ## TF-220.7 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 0.9 m (3 ft) along the welds in steel plates 6 mm ($^1/_4$ in.) and greater in thickness and in nonferrous plates 13 mm ($^1/_2$ in.) and greater in thickness.

(b) When a multiple number of permanent structural attachment welds, nonstructural welds, fillet welds, socket welds, welds of specially designed seals, weld metal cladding, or hard surfacing welds are made on an item, the Manufacturer need not identify the Welder or Welding Operator who 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 or part 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, and

(1) the Manufacturer maintains a system that will identify the Welders or Welding Operators who made such welds on each item 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

(3) records shall be kept by the Manufacturer of welders and welding operators employed on each joint, which shall be available to the Inspector

(d) For identifying welds on pressure vessels in which the wall thickness is less than 6 mm ($^1/_4$ in.) for steel material and less than 13 mm ($^1/_2$ in.) for nonferrous material, suitable stencil or other surface markings shall be used; or a record shall be kept by the Manufacturer of Welders and Welding Operators employed on each joint, which shall be available to the Inspector, or a stamp may be used, provided the vessel part is not deformed and the following additional requirements are met:

(1) For ferrous material

(-a) the materials shall be limited to P-Nos. 1 and 2

(-b) the minimum nominal plate thickness shall be 4.8 mm (0.1875 in.) or the minimum nominal pipe wall thickness shall be 3.9 mm (0.154 in.)

(-c) the minimum design metal temperature shall be no colder than −29°C (−20°F)

(2) For nonferrous materials

(-a) the materials shall be limited to aluminum as follows: SB-209 Alloys 3003, 5083, 5454, and 6061; SB-241 Alloys 3003, 5083, 5086, 5454, 6061, and 6063; and SB-247 Alloys 3003, 5083, and 6061

(-b) the minimum nominal plate thickness shall be 6.3 mm (0.249 in.), or the minimum nominal pipe thickness shall be 3.4 mm (0.133 in.)

TF-220.8 PRECAUTIONS TO BE TAKEN BEFORE WELDING

(a) Identification, Handling, and Storing of Electrodes and Other Welding Materials. The Manufacturer is responsible for control of the welding electrodes and other materials that 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.

(b) Lowest Permissible Temperature for Welding. When the base metal temperature is less than 0°C (32°F), the base metal shall be preheated to at least 16°C (60°F) and this minimum temperature be maintained during welding. No welding shall be done when the surfaces to be welded are wet or covered with ice, when snow is falling on the surfaces, or during periods of high wind unless the Welders and Welding Operators and the work are protected against these conditions.

TF-220.9 REPAIR OF WELD DEFECTS

Defects, such as cracks, pinholes, and incomplete fusion, detected visually or by hydrostatic or pneumatic test or by the examinations prescribed in TE-220.2 shall be removed by mechanical means or by thermal gouging process, after which the joint shall be rewelded [see TF-220.10 and TF-700(e)].

TF-220.10 SURFACE WELD METAL BUILDUP

Construction in which 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 TW-130.2(c) and TF-220.3(b) shall be performed in accordance with the following rules:

(1) 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.

(2) All weld metal buildup must be examined over the full surface by either magnetic particle examination to the requirements of TE-110.4, or by liquid-penetrant examination to the requirements of TE-110.5.

When such surface weld buildup is used in welded joints that require full- or spot-radiographic examination, the weld metal buildup shall be included in the examination.

TF-220.11 SPIN-HOLES

Spin-holes are permitted at the center of heads to facilitate forming. Spin-holes not greater than 60 mm ($2^3/_8$ in.) in diameter may be closed with a full-penetration weld using either a welded plug or weld metal. The weld and plug shall be not thinner than the head material adjacent to the spin-hole.

The finished weld shall be examined[11] and shall meet the acceptance requirements of Mandatory Appendix V or Mandatory Appendix VI of this Section. Radiographic examination, if required by TE-230.1(a), and additional inspections, if required by the material specification, shall be performed.

This weld is a butt weld, but it is not categorized. It shall not be considered in establishing the joint efficiency of any part of the head or of the head-to-shell weld.

ARTICLE TF-3
REQUIREMENTS FOR VESSELS CONSTRUCTED OF CARBON AND LOW ALLOY STEELS

TF-300 GENERAL

The rules in Article TF-3 are applicable to pressure vessels and parts that are constructed of carbon and low alloy steels listed in Table TM-130.2-1 and shall be used in conjunction with the general requirements in Article TF-1 and with the requirements in Article TF-2 for welded fabrication.

TF-310 FABRICATION

TF-310.1 FORMING SHELL SECTIONS, HEADS, AND OTHER PRESSURE BOUNDARY PARTS

The following provisions shall apply in addition to the general rules for forming given in TF-120.1:

(a) Carbon and low alloy steel plates shall not be formed cold by blows.

(b) Carbon and low alloy steel plates may be formed by blows at a forging temperature, provided the blows do not objectionably deform the plate and it is subsequently postweld heat treated.

(c) Vessel shell sections, heads, and other pressure boundary parts of carbon and low alloy steel plates fabricated by cold forming shall be heat treated subsequently (see TF-710) when the resulting extreme fiber elongation is more than 5% from the as-rolled condition and any of the following conditions exist:

(1) The tank will contain substances listed in TW-100.1(a).

(2) The material requires impact testing.

(3) The thickness of the part before forming exceeds 16 mm ($^5\!/_8$ in.).

(4) The reduction by cold forming from the as-rolled thickness is more than 10% at any location where the extreme fiber elongation exceeds 5%.

(5) The temperature of the material during forming is in the range of 120°C to 480°C (250°F to 900°F).

For P-No. 1 Group Nos. 1 and 2 materials the extreme fiber elongation may be as great as 40% when none of the conditions listed in (c)(1) through (c)(5) exist. The extreme fiber elongation shall be determined by the following equations:

For double curvature shells (e.g., heads)

$$\text{percent extreme fiber elongation} = \frac{75t}{R_f}\left(1 - \frac{R_f}{R_o}\right)$$

For single curvature shells (e.g., cylinders)

$$\text{percent extreme fiber elongation} = \frac{50t}{R_f}\left(1 - \frac{R_f}{R_o}\right)$$

where

R_f = final centerline radius, mm (in.)
R_o = original centerline radius (equals infinity for flat plate), mm (in.)
t = plate thickness, mm (in.)

TF-310.2 HEAT TREATMENT OF TEST SPECIMENS

The following provisions shall apply in addition to, or as exceptions to the general rules for heat treatment and marking given in TM-140.2.

(a) Heat treatment as used in this Section shall include all thermal treatments of the material during fabrication exceeding 480°C (900°F) except as exempted below.

(b) The material used in the vessel shall be represented by test specimens, which have been subjected to the same heat treatments above the lower transformation temperature and postweld heat treatment, except as provided in (d) through (h). 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 subjected during fabrication, except as permitted in (g). Material from which the specimens are prepared shall be heated at the specified temperature within reasonable tolerances such as are normal 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.

(c) Thermal treatment of material is not intended to include such local heating as thermal cutting, preheating, welding, or heating below the lower transformation temperature of tubing and pipe for bending or sizing.

(d) An exception to the requirements of (b) and TM-140.2 shall apply to standard items. These may be subject to postweld heat treatment with the tank or tank part without the same treatment being required of the test specimens. This exception shall not apply to specially designed cast or wrought fittings.

(e) Materials conforming to one of the specifications listed in P-No. 1 Group Nos. 1 and 2 of Section IX, QW/QB-422 and all carbon and low alloy steels used in the annealed condition as permitted by the material specification are exempt from the requirements of (b) when the heat treatment during fabrication is limited to postweld heat treatment at temperatures below the lower transformation temperature of the steel.

(f) Materials listed in Section IX, QW/QB-422 as P-No. 1 Group 3 and P-No. 3 Group Nos. 1 and 2 that are certified in accordance with (b) from test specimens subjected to the postweld heat treatment requirements of Tables TF-710-1(a) through TF-710-1(h) need not be recertified if subjected to the alternate postweld heat treatment conditions permitted by Table TF-710-2.

(g) The simulation of cooling rates for test specimens from nonimpact-tested materials 75 mm (3 in.) and less in thickness is not required for heat treatments below the lower transformation temperature.

(h) All thermal treatments that 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.

TF-320 WELDED JOINTS

TF-320.1 LOW TEMPERATURE SERVICE

(a) Welded joints shall comply with TW-100.1(b) when the minimum design temperature is colder than −48°C (−55°F), unless the coincident ratio defined in Figure TM-240.3-1 is less than 0.35.

(b) Welded joints shall be postweld heat treated in accordance with the requirements of TF-700 when required by other rules of this Section or when the minimum design metal temperature is colder than −48°C (−55°F), and the coincident ratio defined in Figure TM-240.3-1 is 0.35 or greater.

ARTICLE TF-4
REQUIREMENTS FOR VESSELS CONSTRUCTED OF HIGH ALLOY STEEL

TF-400 GENERAL

The rules in Article TF-4 are applicable to pressure vessels and parts that are constructed of high alloy steel listed in Table TM-130.2-2 and shall be used in conjunction with the general requirements in Article TF-1 and with the requirements in Article TF-2 for welded fabrication.

TF-400.1 USES

Some of the uses of high alloy steel are to resist corrosion, to avoid contamination of contents with iron, to provide strength or scaling resistance at high temperatures, and to provide impact resistance at low temperatures.

TF-400.2 CONDITIONS OF SERVICE

Specific chemical compositions, heat treatment procedures, fabrication requirements, and supplementary tests may be required to ensure that the vessel will be in its most favorable condition for the intended service. This is particularly true for vessels subject to severe corrosion. These rules do not indicate the selection of an alloy suitable for the intended service or the corrosion allowance to be provided. It is recommended that Users assure themselves by appropriate tests, or otherwise, that the high alloy steel selected and its heat treatment during fabrication will be suitable for the intended service both with respect to corrosion resistance and to retention of satisfactory mechanical properties during the desired service life.

TF-410 FABRICATION

TF-410.1 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 base metal. The use of filler metal that will deposit weld metal with practically the same composition as the material joined is recommended. When the Manufacturer is of the opinion that a physically better joint can be made by departure from these limits, filler metal of a different composition may be used, provided the strength of the weld metal at the operating temperature is not appreciably less than that of the high alloy material to be welded, and the User is satisfied that its resistance to corrosion is satisfactory for the intended service. The columbium content of weld metal shall not exceed 1%.

TF-410.2 WELDED JOINTS

When radiographic examination is required for butt-welded joints by TE-230.3, joints of Categories A and B (see TW-130.3), shall be of Type Nos. (1) and (2) of Table TW-130.4.

TF-410.3 WELDING PROCEDURE QUALIFICATION AND PERFORMANCE QUALIFICATION

When higher tensile properties are permitted by the Modal Appendices than those given in the material specification, a separate welding procedure qualification test shall be performed to demonstrate the higher tensile properties. Previously qualified welding procedures may be used to requalify welding the material of the same P-No. and Group No. designation of the lesser strength. Any change of the P-No. or Group No. from those used in the previous qualification shall require retesting.

TF-410.4 FORMING SHELL SECTIONS AND HEADS

(a) The following cold-formed parts of pressure-retaining components manufactured of Types 201-1 or 201-2 (UNS designation S20100), Type 201LN (UNS designation S20153), or Type 204 (UNS designation S20400) austenitic alloys shall be solution annealed by heating at 1 065°C (1,950°F) for 0.8 min/mm (20 min/in.) of thickness or 10 min, whichever is greater, followed by rapid cooling (see Table TM-130.2-2 for specifications and product forms produced to UNS designations S20100, S20153, and S20400):

(1) all cold-formed heads

(2) all other pressure parts when the forming strains exceeding 4%

(b) The forming strains shall be calculated as follows:

(1) cylinders formed from plate:

$$\% \text{ strain} = \frac{50t}{R_f}\left(1 - \frac{R_f}{R_o}\right)$$

(2) spherical or dished heads formed from plate:

$$\% \text{ strain} = \frac{75t}{R_f}\left(1 - \frac{R_f}{R_o}\right)$$

(3) tube or pipe bends: the larger of

$$\% \text{ strain} = \frac{100r}{R_o}$$

or

$$\% \text{ strain} = \left(\frac{t_A - t_B}{t_A}\right)100$$

where

r = nominal outside radius of pipe or tube
R_f = final centerline radius, in.
R_o = original centerline radius (equals infinity for flat plate), in.
t = plate thickness, in.
t_A = measured average wall thickness of pipe or tube
t_B = measured minimum wall thickness of extrados of the bend

(c) When forming strains cannot be calculated as shown in (b), the Manufacturer shall have the responsibility to determine the maximum forming strain.

ARTICLE TF-5
REQUIREMENTS FOR VESSELS CONSTRUCTED OF NONFERROUS MATERIALS

TF-500 GENERAL

The rules in Article TF-5 are applicable to pressure vessels and parts that are constructed of nonferrous materials listed in Tables TM-130.2-3, TM-130.2-4, TM-130.2-5, and TM-130.2-7 and shall be used in conjunction with the general requirements in Article TF-1 and with the requirements for welded fabrication in Article TF-2.

TF-500.1 USES

Some of the uses of nonferrous materials are to resist corrosion, to provide strength or scaling resistance at high temperatures, and to provide notch toughness at low temperatures.

TF-500.2 CONDITIONS OF SERVICE

Specific chemical compositions, heat treatment procedures, fabrication requirements, and supplementary tests may be required to ensure that the vessel will be in its most favorable condition for the intended service. This is particularly true for vessels subject to severe corrosion. These rules do not indicate the selection of nonferrous material suitable for the intended service or the amount of the corrosion allowance to be provided. It is recommended that Users assure themselves by appropriate tests, or otherwise, that the nonferrous material selected will be suitable for the intended use both with respect to corrosion and to retention of satisfactory mechanical properties during the desired service life, taking into account any heating or heat treatment that might be performed during fabrication.

TF-510 FABRICATION

TF-510.1 FORMING OF SHELL SECTIONS AND HEADS

(a) The following provisions shall apply in addition to the general rules for forming given in TF-120.1.

(1) The selected thickness of material shall be such that the forming processes will not reduce the thickness of the material at any point below the minimum value required by the design computation.

(2) Relatively small local bulges and buckles may be removed from formed parts for shells and heads by hammering or by local heating and hammering.

(3) A shell section that has been formed by rolling may be brought true-to-round for its entire length by pressing, rolling, or hammering.

(b) Nonferrous materials can be formed and fabricated into a variety of types of assemblies with the same type of equipment as are used for steel. The details of some fabricating procedures vary among the several nonferrous materials and differ from those used for steel because of differences in the inherent mechanical properties of these materials. Detailed information regarding procedures best suited to the several metals may be obtained from the literature of the materials producers and from other reliable sources, such as the latest editions of handbooks issued by the American Welding Society and the American Society for Metals.

TF-510.2 CUTTING

In general, nonferrous materials cannot be cut by the conventional oxyacetylene equipment commonly used for steels. They may be melted and cut by the 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, and other mechanical means after thermal cutting and prior to use or further fabrication.

ARTICLE TF-6
REQUIREMENTS FOR VESSELS CONSTRUCTED OF FERRITIC STEELS THAT ARE HEAT TREATED TO ENHANCE TENSILE PROPERTIES

TF-600 GENERAL

(a) The rules in Article TF-6 apply specifically to the fabrication of pressure vessels and parts that are constructed of heat-treated ferritic steels listed in Table TM-130.2-6, suitable for welding, whose tensile properties have been enhanced by heat treatment, and shall be used in conjunction with the general requirements for fabrication in Article TF-1 and, when applicable, with the requirements in Article TF-2 for welded fabrication.

(b) The heat treatment may be applied to the individual parts of a vessel prior to assembly by welding to partially fabricated components, or to an entire vessel after completion of welding. This Article is not intended to apply to those steels approved for use under the rules of Article TF-3, but which 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. Integrally forged vessels, quenched and tempered, which do not contain welded seams, are not intended to be covered by the rules of this Article.

TF-610 FABRICATION

TF-610.1 FORMING SHELL SECTIONS AND HEADS

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

(a) Pieces that are formed after heat treatment at a temperature lower than the final tempering shall be heat treated in accordance with Table TF-740 when the extreme fiber elongation from forming exceeds 5% as determined by the equations in TF-310.1.

(b) Pieces that are formed at temperatures equal to or higher than the original tempering shall be reheat treated in accordance with the applicable material specification, either before or after welding into the vessel.

TF-610.2 HEAT TREATMENT

(a) All vessels and vessel parts shall be postweld heat treated as required by TF-740.

(b) Identical heat treatment shall be applied to the test specimens required by the material specifications, including the cooling rate specified by the fabricator, which shall in no case be slower than that specified in the applicable material specification.

(c) Furnaces for heating, quenching, normalizing, and tempering shall be provided with suitable equipment for the automatic recording of temperatures. The temperature of the vessel or vessel part during the holding period shall be recorded and shall be controlled within ±14°C (±25°F).

(d) Liquid quenching of flat plates and individual parts shall be done as required by the applicable material specifications.

(e) Formed plates for shell sections and heads may be quenched by sprays or immersion.

(f) Entire tanks, after completion of all welding operations, may be quenched by sprays or immersion.

(g) The design and operation of spray equipment and the size of holding tanks and provisions 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.

TF-610.3 HEAT TREATMENT VERIFICATION TESTS

(a) Tests shall be made to verify that the heat treatments and subsequent thermal treatments performed by the fabricator have produced the required properties.

(b) 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. The requirements of (d) and (e) are to be taken as minimum steps toward these objectives.

(c) All test specimens shall be prepared from the material in its final heat-treated condition or from full thickness samples of the same heat similarly and simultaneously heat treated. Test samples shall be of such size that

the prepared test specimens are free from any change in properties due to edge effects.

(d) Heat Treatment of Test Coupons

(1) One or more test coupons from each lot of material in each vessel 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 13 mm ($^1/_2$ in.) 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 tests shall be taken from the same locations relative to thickness as are required by the material specification for plates used in the component to be treated. The gage length of tensile specimens and the middle third of the length of impact specimens must be located at a minimum distance of *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.

(2) 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 conditions as the part that it represents. It shall be so proportioned that the test specimens may be taken from the locations prescribed in (1).

(e) Tempering

(1) Attached Test Coupons. The 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 treatments, if any, to which the tank or tank 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.

(2) Separate Test Coupons. Test coupons that are quenched separately as described in (d)(2) shall be tempered similarly and simultaneously with the vessel or vessel component that they represent. The conditions for subjecting the test coupons to subsequent thermal treatment(s) shall be as described in (d)(1).

(f) Number of Tests. One tensile test and one impact test shall be made on material from coupons representing each lot of material in each tank or tank component heat treated. A *lot* is defined as material from the same melt quenched simultaneously and whose thicknesses are within ±20% or 13 mm ($^1/_2$ in.) of nominal thickness, whichever is smaller.

(1) Coupons not containing welds shall meet the complete tensile requirements of the material specification and impact requirements of this Article.

(2) 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 Section IX, QW-462.1(d). Yield strength and elongation are not a requirement of this test. Charpy impact testing shall be in accordance with the requirements prescribed in this Article.

TF-610.4 WELDED JOINTS

(a) In vessel or vessel parts constructed of heat-treated steels covered by this Article, except as permitted in (b), all joints of Categories A, B, and C, as defined in TW-130.3, and all other welded joints between parts of the pressure-containing enclosure that are not defined by the Category designations shall be in accordance with Type No. (1) of Table TW-130.4. All joints of Category D shall be in accordance with Type No. (1) of Table TW-130.4 and Figure TW-130.7-1 when the thickness is 51 mm (2 in.) or less.

(b) For materials SA-333 Grade 8, SA-334 Grade 8, SA-353, SA-522, SA-553, and SA-645 Grade A, the joints of various Categories (see TW-130.3) shall be as follows:

(1) All joints of Category A shall be Type No. (1) of Table TW-130.4.

(2) All joints of Category B shall be Type No. (1) or (2) of Table TW-130.4.

(3) All joints of Category C shall be full-penetration welds extending through the entire section at the welded joint.

(4) All joints of Category D attaching a nozzle neck to the tank wall and to the reinforcing pad, if used, shall be full-penetration groove welds.

TF-610.5 WELDING

(a) 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.

(b) Filler metal containing more than 0.06% vanadium shall not be used for weldments subject to postweld heat treatment.

(c) For welded pressure vessels, the welds of which are not subject to quenching or normalizing followed by tempering, the deposited weld metal and the heat-affected zone shall meet the impact test requirements of TM-260.3(a).

(d) Certain materials are exempt from production impact tests of weld metal. See TM-260.3(b) for the materials and the conditions under which these materials are exempt from production impact tests of the weld metal.

(e) For SA-517 and SA-592 materials, the requirements of (1) through (5), 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 interpass temperature or a decrease in the minimum specified preheat temperature. The specified range between the preheat and interpass temperature shall not exceed 83°C (150°F).

(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) consumables control, drying, storage, and exposure requirements shall be in accordance with the following:

(-a) Due consideration shall be given to the 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 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 shall be developed by the vessel Manufacturer or those recommended by the electrode Manufacturer.

(f) When welding materials with austenitic electrodes, the differences between the coefficients of expansion and the strengths of the base material and the weld metal should be carefully considered, particularly for applications involving cyclic stresses.

TF-610.6 METHODS OF METAL REMOVAL

(a) Plate edges, welding bevels, chamfering, and other operations involving the removal of metal shall be by machining, chipping, or grinding, except as provided in (b).

(b) When metal removal is accomplished by methods involving melting, such as gas cutting or arc-air gouging, 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 1.5 mm ($^1\!/_{16}$ in.) followed by inspection by magnetic particle or liquid-penetrant methods.

TF-610.7 WELD FINISH

The requirements of TF-220.4(a) shall be met, except that for SA-517 material the maximum weld reinforcement shall not exceed 10% of the plate thickness or 3 mm ($^1\!/_8$ in.), 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.

TF-610.8 STRUCTURAL AND TEMPORARY WELDS

(a) 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.

(b) Temporary welds shall be removed and the metal surface shall be restored to a smooth contour. The area shall be inspected by magnetic particle or liquid-penetrant method for the detection and elimination of cracks. If repair welding is required, it shall be in accordance with qualified procedures and the finished weld surface shall be inspected as required in this Article. Temporary welds and repair welds shall be considered the same as all other welds so far as requirements for qualified operators and procedures and for heat treatment are concerned.

TF-610.9 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 13 mm ($^1\!/_2$ in.) in thickness. Where die-stamping is prohibited for material identification, and where so specified by the user, the materials manufacturer shall mark the required data on the plates in a manner that will allow positive identification upon delivery. The markings must be recorded so that each plate will be positively identified in its position in the completed tank to the satisfaction of the Inspector.

TF-610.10 JOINT ALIGNMENT

The requirements of TF-220.3 shall be met, except that the following maximum permissible offset values shall be used in place of those given in Table TF-220.3:

Section Thickness, mm (in.)	Joint Direction	
	Longitudinal	Circumferential
Up to 13 ($^1/_2$), incl.	0.2t	0.2t
Over 13 ($^1/_2$) to 24 ($^{15}/_{16}$), incl.	2.5 mm ($^3/_{32}$ in.)	0.2t
Over 24 ($^{15}/_{16}$) to 38 (1$^1/_2$), incl.	2.5 mm ($^3/_{32}$ in.)	5 mm ($^3/_{16}$ in.)

ARTICLE TF-7
POSTWELD HEAT TREATMENT OF WELDMENTS

TF-700 PROCEDURES FOR POSTWELD HEAT TREATMENT

(a) The operation of postweld heat treatment shall be performed using one of the following procedures. 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 Tables TF-710-1(a) through TF-710-1(h), and Tables TF-710-2, TF-720-1 through TF-720-6, and TF-740. 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 50 mm (2 in.), whichever is less, on each side or end of the weld. The term t is the nominal thickness as defined in (f).

(1) Heating the Vessel as a Whole in an Enclosed Furnace. This procedure is preferable and should be used whenever possible.

(2) Heating the Vessel in More Than One Heat in a Furnace, Provided the Overlap of the Heated Sections of the Tank Is at Least 1.5 m (5 ft). 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 tank projects from the furnace shall not intersect a nozzle or other structural discontinuity.

(3) Heating of Shell Sections and/or Portions of Vessels to Postweld Heat Treat Longitudinal Joints or Complicated Welded Details Before Joining to Make the Completed Vessel. When the vessel is required to be postweld heat treated, and it is not practicable to postweld heat treat the completed tank as a whole or in two or more heats as provided in (2), any circumferential joints not previously postweld heat treated may be thereafter locally postweld heat treated by heating such joints by any appropriate means that will ensure 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 tanks after repairs.

(4) Heating the Vessel Internally by Any Appropriate Means and With Adequate Indicating and Recording Temperature Devices to Aid in the Control and Maintenance of a Uniform Distribution of Temperature in the Tank Wall. Previous to this operation, the vessel should be fully enclosed with insulating material, or the permanent insulation may be installed, provided it is suitable for the required temperature. In this procedure the internal pressure should be kept as low as practicable, but shall not exceed 50% of the maximum allowable working pressure at the highest metal temperature expected during the postweld heat treatment period.

(5) 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 the paragraph below, the soak band shall extend around the entire vessel and shall include the nozzle or welded attachment. 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 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 vessels after repairs.

(6) Heating the Circumferential Joints of Pipe or Tubing by Any Means Using a Soak Band That Extends Around the Entire Circumference. The portion outside the soak band shall be protected so that the temperature gradient is not harmful. The 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.

(7) 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 Uniformly to the Required

Temperature and Held for the Specified Time. The soak band shall include the nozzle or welded attachment. 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 51 mm (2 in.), whichever is less. The portion of the vessel outside of the soak band shall be protected so that the temperature gradient is not harmful.

(8) Heating of Other Configurations. Local area heating of other configurations not addressed in (1) through (7) 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 junctures), and any mechanical loads that may be present during PWHT. The portion of the vessel or component outside the soak band shall be protected so that the temperature gradient is not harmful.

(b) The temperatures and rates of heating and cooling to be used in postweld heat treatment of tanks constructed of materials for which postweld heat treatment may be required are given in TF-710, TF-720, TF-730, and TF-740.

(c) The minimum temperature for postweld heat treatment given in Tables TF-710-1(h), TF-710-2, TF-720-1 through TF-720-6, and TF-740 shall be the minimum temperature of the plate material of the shell or head of any tank. Where more than one vessel or vessel part are postweld heat treated in one furnace charge, thermocouples shall be placed on the vessels at the bottom, center, and top of the charge, or in other zones of possible temperature variation so that the temperature indicated shall be true temperature for all vessels or vessel parts in those zones.

(d) When pressure parts of two different P-Number Groups are joined by welding, the postweld heat treatment shall be that specified according to either TF-710 or TF-720, for the material being joined requiring the higher postweld heat treatment temperature.

(e) Postweld heat treatment, when required, shall be done before the hydrostatic test and after any welded repairs, except as permitted by TF-710(f). A preliminary hydrostatic test to reveal leaks prior to postweld heat treatment is permissible.

(f) The term *nominal thickness* as used in referenced tables is the thickness of the welded joint as defined below. For vessels or parts of vessels being postweld heat treated in a furnace charge, it is the greatest weld thickness in any vessel or vessel part that has not previously been postweld heat treated.

(1) When the welded joint connects parts of the same thickness, using a full penetration buttweld, the nominal thickness is the total depth of the weld exclusive of any permitted weld reinforcement.

(2) For groove welds, the nominal thickness is the depth of the groove.

(3) 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.

(4) For stud welds, the nominal thickness shall be the diameter of the stud.

(5) When a welded joint connects parts of unequal thicknesses, the nominal thickness shall be the following:

(-a) the thinner of two adjacent buttwelded parts including head to shell connections

(-b) the thickness of the shell or the fillet weld, whichever is greater, in connections to intermediate heads of the type shown in Figure TW-130.5-1, sketch (f)

(-c) the thickness of the shell in connections to tubesheets, flat heads, covers, flanges, or similar constructions

(-d) in Figures TW-140.2-1 and TW-140.2-2, the thickness of the weld across the nozzle neck, shell, head, or reinforcing pad or attachment fillet weld, whichever is the greater

(-e) the thickness of the nozzle neck at the joint in nozzle neck to flange connections

(-f) the thickness of the weld at the point of attachment when a nonpressure part is welded to a pressure part

(-g) the thickness of the weld in tube-to-tubesheet connections

The thickness of the head, shell or nozzle neck, or other parts as used above shall be the wall thickness of the part at the welded joint under consideration.

(6) For repairs, the nominal thickness is the depth of the repair weld.

TF-710 REQUIREMENTS FOR CARBON AND LOW ALLOY STEELS (25)

(a) Except as otherwise specifically provided in the Notes to Tables TF-710-1(a) through TF-710-1(h) and Table TF-710-2, all welds in vessels or vessel parts shall be given a postweld heat treatment at a temperature not less than specified in those tables when the nominal thickness, as defined in TF-700(f), including corrosion allowance, exceeds the limits in those tables. The exceptions provided in Tables TF-710-1(a) through TF-710-1(h) or Table TF-710-2 are not permitted when postweld heat treatment is a service requirement, when welding ferritic materials greater than 3 mm ($^1/_8$ in.) thick with the electron beam process, or when welding P-No. 3 and P-No. 10 materials of any thickness using the inertia and continuous drive friction welding processes. Electroslag welds in ferritic materials over 38 mm ($1^1/_2$ in.) thickness at the joint shall be given a grain refining (austenitizing) heat treatment. Electrogas welds in ferritic materials with any single pass greater than 38 mm ($1^1/_2$ in.) shall be given a grain-refining (austenitizing) heat

treatment. For P-No. 1 materials only, the heating and cooling rate restrictions of (d)(2) do not apply when the heat treatment following welding is in the austenitizing range. The materials in Tables TF-710-1(a) through TF-710-1(h) are listed in accordance with material groupings of Section IX, Table QW/QB-422.

(b) Except where prohibited in Tables TF-710-1(a) through TF-710-1(h), holding temperatures and/or holding times in excess of the minimum values given in Tables TF-710-1(a) through TF-710-1(h) may be used. Intermediate postweld heat treatments need not conform to the requirements of Tables TF-710-1(a) through TF-710-1(h). The holding time at temperature as specified in Tables TF-710-1(a) through TF-710-1(h) need not be continuous. It may be an accumulation of time of multiple postweld heat treatment cycles.

(c) When pressure parts of two different P-Number groups are joined by welding, the postweld heat treatment shall be that specified in either of Tables TF-710-1(a) through TF-710-1(h) or Tables TF-720-1 through TF-720-6, with applicable notes, for the material requiring the higher postweld heat treat temperature. When nonpressure parts are welded to pressure parts, the postweld heat treatment temperature of the pressure part shall control.

(d) The operation of postweld heat treatment shall be carried out by one of the procedures given in TF-700 in accordance with the following requirements:

(1) The temperature of the furnace shall not exceed 425°C (800°F) at the time the vessel or part is placed into it.

(2) Heating and cooling rates above 425°C (800°F) shall not exceed the following, where the thickness is the maximum material thickness of the vessel or vessel part being heat treated:

	Maximum Rate, °C/h	Maximum Rate, °F/hr
Heating rate	5,500 divided by the thickness in mm but not greater than 220	400 divided by the thickness in inches but not greater than 400
Cooling rate	7,000 divided by the thickness in mm but not greater than 280	500 divided by the thickness in inches but not greater than 500

During the heating period there shall not be a greater variation in temperature throughout the portion of the vessel being heated than 140°C (250°F) within any 4.6 m (15 ft) interval of length. Cooling shall be done in a closed furnace or cooling chamber until below 425°C (800°F), after which the vessel or vessel part may be removed and cooled in still air.

(3) The vessel or vessel part shall be held at or above the temperature specified in Tables TF-710-1(a) through TF-710-1(h) or Table TF-710-2 for the period of time specified in the tables. During the holding period, there shall not be a greater difference than 83°C (150°F) between the highest and lowest temperature throughout the portion of the vessel being heated, except where the range is further limited in Tables TF-710-1(a) through TF-710-1(h).

(4) 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) Except as permitted in (f), vessels or parts of vessels that have been postweld heat treated in accordance with the requirements of this paragraph shall again be postweld heat treated after welded repairs have been made.

(f) Weld repairs to P-No. 1 Group Nos. 1, 2, and 3 materials and to P-No. 3 Group Nos. 1, 2, and 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 TW-100.1(a), except for the exemptions in Tables TF-710-1(a) through TF-710-1(h), or as a service requirement in accordance with TF-320. The welded repairs shall meet the requirements of (1) through (6). These requirements do not apply when the welded repairs are minor restorations of the material surface, such as those required after removal of construction fixtures, and provided that the surface is not exposed to the vessel contents.

(1) The Manufacturer shall give prior notification of the repair to the User or to the User's designated agent and shall not proceed until acceptance has been obtained. Such repairs shall be recorded on the Manufaturer's Data Report.

(2) The total repair depth shall not exceed 38 mm (1½ in.) for P-No. 1 Group Nos. 1, 2, and 3 materials and 16 mm (⅝ in.) for P-No. 3 Group Nos. 1, 2, and 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.

(3) After removal of the defect, the groove shall be examined using either the magnetic particle or the liquid-penetrant examination methods.

(4) In addition to the requirements of Section IX for qualification of Welding Procedure Specifications for groove welds, the following requirements shall apply:

(-a) The weld metal shall be deposited by the GTAW or SMAW processes using low hydrogen electrodes or gases that are not susceptible to hydrogen contamination. The electrodes shall be property conditioned in accordance with Section II, Part C, SFA-5.5, Appendix A6.11. The maximum bead width shall be four times the electrode core diameter.

(-b) For P-No. 1 Group Nos. 1, 2, and 3 materials, the repair area shall be preheated and maintained at a minimum temperature of 95°C (200°F) during welding.

(-c) For P-No. 3 Group Nos. 1, 2, and 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 175°C (350°F) during welding. The maximum interpass temperature shall be 230°C (450°F). The initial layer of weld metal shall be deposited over the entire area using 3 mm ($^1/_8$ in.) 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 4 mm ($^5/_{32}$ in.) maximum diameter electrodes in such a manner as to ensure 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 ensure tempering of the base material heat-affected zone. After completing all welding the repair area shall be maintained at a temperature of from 205°C to 260°C (400°F to 500°F) for a minimum period of 4 hr. The final temper bead reinforcement layer shall be removed substantially flush with the surface of the base material.

(5) After the finished repair weld has reached ambient temperature, it shall be inspected using the same nondestructive examination that was used in (3), except that for P-No. 3 Group 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 the magnetic particle method, only the alternating current yoke type is acceptable. In addition, welded repairs greater than 10 mm ($^3/_8$ in.) deep in materials and in welds that are required to be radiographed by the rules of these Articles, shall be radiographically examined to the requirements of TE-230.

(6) The vessel shall be hydrostatically tested after making the welded repair.

Table TF-710-1(a)
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 1

Material	Minimum Normal Holding Temperature, °C (°F)	Minimum Holding Time at Normal Temperature for Nominal Thickness [See TF-700(f)]		
		Up to 50 mm (2 in.)	Over 50 mm to 125 mm (2 in. to 5 in.)	Over 125 mm (5 in.)
P-No. 1 Gr. Nos. 1, 2, 3	595 (1,100)	1 hr/25 mm (1 in.), 15 min minimum	2 hr plus 15 min for each additional 25 mm (1 in.) over 50 mm (2 in.)	2 hr plus 15 min for each additional 25 mm (1 in.) over 50 mm (2 in.)
Gr. No. 4	NA	None	None	None

GENERAL NOTES:
(a) See Table TM-130.2-1.
(b) 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 TF-710-2.
(c) Postweld heat treatment is mandatory under the following conditions:
(1) for welded joints over 38 mm ($1^1/_2$ in.) nominal thickness
(2) for welded joints over 32 mm ($1^1/_4$ in.) nominal thickness through $1^1/_2$ in. (38 mm) nominal thickness unless preheat is applied at a minimum temperature of 95°C (200°F) during welding
(3) for welded joints of all thicknesses if required by TW-100.1, except postweld heat treatment is not mandatory under the conditions specified below:
(a) for groove welds not over 13 mm ($^1/_2$ in.) size and fillet welds with a throat not over 13 mm ($^1/_2$ in.) that attach nozzle connections that have a finished inside diameter not greater than 50 mm (2 in.) , provided the connections do not form ligaments that require an increase in shell or head thickness, and preheat to a minimum temperature of 95°C (200°F) is applied.
(b) for groove welds not over 13 mm ($^1/_2$ in.) in size or fillet welds with a throat thickness of 13 mm ($^1/_2$ in.) or less that attach tubes to a tubesheet when the tube diameter does not exceed 50 mm (2 in.). A preheat of 95°C (200°F) minimum must be applied when the carbon content of the tubesheet exceeds 0.22%.
(c) for groove welds not over 13 mm ($^1/_2$ in.) in size or fillet welds with a throat thickness of 13 mm ($^1/_2$ in.) or less used for attaching nonpressure parts to pressure parts provided preheat to a minimum temperature of 95°C (200°F) is applied when the thickness of the pressure part exceeds 32 mm ($1^1/_4$ in.).
(d) for studs welded to pressure parts provided preheat to a minimum temperature of 95 °C (200°F) is applied when the thickness of the pressure part exceeds 32 mm ($1^1/_4$ in.).
(d) NA = not applicable

Table TF-710-1(b)
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 3

Material	Minimum Normal Holding Temperature, °C (°F)	Minimum Holding Time at Normal Temperature for Nominal Thickness [See TF-700(f)] Up to 50 mm (2 in.)	Over 50 mm to 125 mm (2 in. to 5 in.)	Over 125 mm (5 in.)
P-No. 3 Gr. Nos. 1, 2, 3	595 (1,100)	1 hr/25 mm (1 in.), 15 min minimum	2 hr plus 15 min for each additional 25 mm (1 in.) over 50 mm (2 in.)	2 hr plus 15 min for each additional 25 mm (1 in.) over 50 mm (2 in.)

GENERAL NOTES:

(a) See Table TM-130.2-1.

(b) 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 TF-710-2.

(c) Postweld heat treatment is mandatory on P-No. 3 Gr. No. 3 material in all thicknesses.

(d) Except for the exemptions in Note (e), postweld heat treatment is mandatory under the following conditions:

(1) on P-No. 3 Gr. No. 1 and P-No. 3 Gr. No. 2 over 16 mm (5/8 in.) nominal thickness. For these materials, postweld heat treatment is mandatory on material up to and including 16 mm (5/8 in.) nominal thickness unless a welding procedure qualification described in TF-710(a) has been made in equal or greater thickness than the production weld.

(2) on material in all thicknesses if required by TW-100.1.

(e) For welding connections and attachments to pressure parts, postweld heat treatment is not mandatory under the conditions specified below:

(1) for attaching to pressure parts that 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 nonpressure parts with groove welds not over 13 mm (1/2 in.) in size or fillet welds that have a throat thickness of 13 mm (1/2 in.) or less, provided preheat to a minimum temperature of 95°C (200°F) is applied

(2) for circumferential butt welds in pipe or tube where the pipe or tube have both a nominal wall thickness of 13 mm (1/2 in.) 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)

(3) for studs welded to pressure parts that 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 95°C (200°F) is applied

Table TF-710-1(c)
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 9A

Material	Minimum Normal Holding Temperature, °C (°F)	Minimum Holding Time at Normal Temperature for Nominal Thickness [See TF-700(f)]
P-No. 9A Gr. No. 1	595 (1,100)	1 hr minimum, plus 15 min/25 mm (1 in.) for thickness over 25 mm (1 in.)

GENERAL NOTES:
(a) See Table TM-130.2-1.
(b) 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 [540°C (1,000°F) minimum] for longer periods of time in accordance with Table TF-710-2.
(c) Except for exemptions in [Note (d)] below, postweld heat treatment is mandatory under the following conditions:
(1) on material over 16 mm (5/8 in.) nominal thickness. For material up to and including 16 mm (5/8 in.) nominal thickness, postweld heat treatment is mandatory unless a welding procedure qualification described in TF-710(a) has been made in equal or greater thickness than the production weld.
(2) on material of all thicknesses if required by TW-100.1.
(d) Postweld heat treatment is not mandatory under conditions specified below:
(1) for circumferential butt welds in pipe or tubes where the pipe or tubes comply with all the following conditions:
(a) a maximum nominal outside diameter of 100 mm (4 in.) (DN 100)
(b) a maximum thickness of 13 mm (1/2 in.)
(c) 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)
(d) a minimum preheat of 120°C (250°F)
(2) for pipe or tube materials meeting the requirements of (d)(1)(a), (d)(1)(b), and (d)(1)(c) above, having attachments fillet welded to them, provided:
(a) the fillet welds have a throat thickness of 13 mm (1/2 in.) or less.
(b) the material is preheated to 120°C (250°F) 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 shall not be limited to the following:
(-1) The throat thickness of fillet welds shall be 13 mm (1/2 in.) or less.
(-2) The maximum continuous length of fillet welds shall be not over 100 mm (4 in.).
(-3) 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.
(3) for attaching nonpressure parts to pressure parts with groove welds not over 13 mm (1/2 in.) in size or fillet welds that have a throat thickness of 13 mm (1/2 in.) or less, provided preheat to a minimum temperature of 95°C (200°F) is applied
(4) for studs welded to pressure parts provided preheat to a minimum temperature of 95°C (200°F) is applied
(e) When the heating rate is less than 10°C/h (50°F/hr) between 425 °C (800°F) and the holding temperature, the additional 15 min/25 mm (1 in.) 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/25 mm (1 in.) holding time is not required.

Table TF-710-1(d)
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 9B

Material	Minimum Normal Holding Temperature, °C (°F)	Minimum Holding Time at Normal Temperature for Nominal Thickness [See TF-700(f)]
P-No. 9B Gr. No. 1	595 (1,100)	1 hr minimum, plus 15 min/25 mm (1 in.) for thickness over 25 mm (1 in.)

GENERAL NOTES:
(a) See Table TM-130.2-1.
(b) 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 [540°C (1,000°F) minimum] for longer periods of time in accordance with Table TF-710-2.
(c) The holding temperature for postweld heat treatment shall not exceed 635°C (1,175°F).
(d) Except for exemptions in Note (e) below, postweld heat treatment is mandatory under the following conditions:
(1) on material over 16 mm (5/8 in.) nominal thickness. For material up to and including 16 mm (5/8 in.) nominal thickness, postweld heat treatment is mandatory unless a welding procedure qualification described in TF-710(a) has been made in equal or greater thickness than the production weld.
(2) on material of all thicknesses if required by TW-100.1.
(e) Postweld heat treatment is not mandatory under the conditions specified below:
(1) for attaching nonpressure parts to pressure parts with groove welds not over 13 mm (1/2 in.) in size or fillet welds that have a throat thickness of 13 mm (1/2 in.) or less, provided preheat to a minimum temperature of 95°C (200°F) is applied
(2) for studs welded to pressure parts provided preheat to a minimum temperature of 95°C (200°F) is applied
(f) When the heating rate is less than 10°C/h (50°F/hr) between 425°C (800°F) and the holding temperature, the additional 15 min/25 mm (1 in.) 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/25 mm (1 in.) holding time is not required.

Table TF-710-1(e)
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 10A

Material	Minimum Normal Holding Temperature, °C (°F)	Minimum Holding Time at Normal Temperature for Nominal Thickness [See TF-700(f)]
P-No. 10A Gr. No. 1	595 (1,100)	1 hr minimum, plus 15 min/25 mm (1 in.) for thickness over 25 mm (1 in.)

GENERAL NOTES:
(a) See Table TM-130.2-1.
(b) See below.
(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 TF-710-2.
(2) 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 temperature for longer holding times.
(c) Except for exemptions in Note (d) below, postweld heat treatment is mandatory under the following conditions:
(1) on all thicknesses of SA-487 Class 1Q material.
(2) on all other P-No. 10A materials over 16 mm ($^5/_8$ in.) nominal thickness. For these materials up to and including 16 mm ($^5/_8$ in.) nominal thickness, postweld heat treatment is mandatory unless a welding procedure qualification described in (a) has been made in equal or greater thickness than the production weld.
(3) on material of all thicknesses if required by TW-100.1.
(d) Postweld heat treatment is not mandatory under the conditions specified below:
(1) for attaching to pressure parts that 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 nonpressure parts with groove weld not over 13 mm ($^1/_2$ in.) in size or fillet welds having a throat thickness of 13 mm ($^1/_2$ in.) or less, provided preheat to a minimum temperature of 95°C (200°F) is applied
(2) for circumferential butt welds in pipes or tube where the pipe or tube has both a nominal wall thickness of 13 mm ($^1/_2$ in.) or less and a specified maximum carbon content of not more than 0.25% (SA material specification carbon content, except when further limited by purchaser to a value within the specification limits) provided preheat to a minimum temperature of 95°C (200°F) is applied
(3) for studs welded to pressure parts that have a specified maximum carbon content of not more than 0.25% (SA material specification carbon content, except when further limited by purchaser to a value within the specification limits) provided preheat to a minimum temperature of 200°F (95°C) is applied
(e) When the heating rate is less than 10°C/h (50°F/hr) between 425°C (800°F) and the holding temperature, the additional 15 min/25 mm (1 in.) 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/25 mm (1 in.) holding time is not required.

Table TF-710-1(f)
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 10B

Material	Minimum Normal Holding Temperature, °C (°F)	Minimum Holding Time at Normal Temperature for Nominal Thickness [See TF-700(f)]
P-No. 10B Gr. No. 1	595 (1,100)	1 hr minimum, plus 15 min/25 mm (1 in.) for thickness over 25 mm (1 in.)

GENERAL NOTES:
(a) See Table TM-130.2-1.
(b) Postweld heat treatment is mandatory for P-No. 10B materials for all thicknesses.
(c) When the heating rate is less than 10°C/h (50°F/hr) between 425°C (800°F) and the holding temperature, the additional 15 min/25 mm (1 in.) 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/25 mm (1 in.) holding time is not required.

Table TF-710-1(g)
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 10C

Material	Minimum Normal Holding Temperature, °C (°F)	Minimum Holding Time at Normal Temperature for Nominal Thickness [See TM-150.3(a)]
P-No. 10C Gr. No. 1	540 (1,000)	1 hr minimum, plus 15 min/25 mm (1 in.) for thickness over 25 mm (1 in.)

GENERAL NOTES:
(a) See Table TM-130.2-1.
(b) 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 TF-710-2.
(c) Except for exemptions in [Note (d)] below, postweld heat treatment is mandatory under the following conditions:
(1) for material over 38 mm ($1^1/_2$ in.) nominal thickness. Postweld heat treatment is mandatory on materials over 32 mm ($1^1/_4$ in.) nominal thickness through 38 mm ($1^1/_2$ in.) nominal thickness unless preheat is applied at a minimum temperature of 95°C (200°F) during welding.
(2) on material of all thicknesses if required by TW-100.1.
(d) Postweld heat treatment is not mandatory under the conditions specified below:
(1) for groove welds not over 13 mm ($^1/_2$ in.) in size and fillet welds with throat not over 13 mm ($^1/_2$ in.) that attach nozzle connections that have a finished inside diameter not greater than 50 mm (2 in.), provided the connections do not form ligaments that require an increase in shell or head thickness and preheat to a minimum temperature of 95°C (200°F) is applied
(2) for groove welds not over 13 mm ($^1/_2$ in.) in size or fillet welds having throat thickness of 13 mm ($^1/_2$ in.) or less used for attaching nonpressure parts to pressure parts and preheat to a minimum temperature of 95°C (200°F) is applied when the thickness of the pressure part exceeds 32 mm ($1^1/_4$ in.)
(3) for studs welded to pressure parts provided preheat to a minimum temperature of 95°C (200°F) is applied when the thickness of the pressure part exceeds 32 mm ($1^1/_4$ in.)
(e) When the heating rate is less than 10°C/h (50°F/hr) between 425°C (800°F) and the holding temperature, the additional 15 min/25 mm (1 in.) 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/25 mm (1 in.) holding time is not required.

Table TF-710-1(h)
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 10F

Material	Minimum Normal Holding Temperature, °C (°F)	Minimum Holding Time at Normal Temperature for Nominal Thickness [See TF-700(f)]
P-No. 10F Gr. No. 1	540 (1,000)	1 hr minimum, plus 15 min/25 mm (1 in.) for thickness over 25 mm (1 in.)

GENERAL NOTES:
(a) See Table TM-130.2-1.
(b) Postweld heat treatment is mandatory for P-No. 10F materials for all thicknesses.
(c) When the heating rate is less than 10°C/h (50°F/hr) between 425°C (800°F) and the holding temperature, the additional 15 min/25 mm (1 in.) 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/25 mm (1 in.) holding time is not required.

Table TF-710-2
Alternative Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels

Decrease in Temperature Below Minimum Specified Temperature, °C (°F)	Minimum Holding Time at Decreased Temperature, hr [Note (1)]
10 (50)	2
38 (100)	4
85 (150) [Note (2)]	10
110 (200) [Note (2)]	20

GENERAL NOTE: Applicable only when permitted in Table TF-710-1(h).

NOTES:
(1) Minimum holding time for 25 mm (1 in.) thickness or less. Add 15 min per mm (1 in.) of thickness for thicknesses greater than 25 mm (1 in.).
(2) These lower postweld heat treatment temperatures permitted only for P-No. 1 Gr. Nos. 1 and 2 materials.

TF-720 REQUIREMENTS FOR HIGH ALLOY STEELS

(a) All welded vessels or vessel parts shall be given a postweld heat treatment at a temperature not less than specified in Tables TF-720-1 through TF-720-6 when the nominal thickness, as defined in TF-700(f), including corrosion allowance, of any welded joint in the vessel or vessel part exceeds the limits in the Notes to Tables TF-720-1 through TF-720-6. The exemptions provided for in the Notes to Tables TF-720-1 through TF-720-6 are not permitted when postweld heat treatment is a service requirement as set forth in TW-100.1, when welding ferritic materials greater than 3 mm ($^1/_8$ in.) thick with the electron beam welding process. The materials in Tables TF-720-1 through TF-720-6 are listed in accordance with the material groupings of Section IX, Table QW/QB-422.

(b) Holding temperatures and/or holding times in excess of the minimum values given in Tables TF-720-1 through TF-720-6 may be used. The holding time at temperature as specified in Tables TF-720-1 through TF-720-6 need not be continuous. It may be an accumulation of time of multiple postweld heat treat cycles. Long time exposure to postweld heat treatment temperatures may cause sigma phase formation.

(c) When pressure parts of two different P-Number groups are joined by welding, the postweld heat treatment shall be that specified in either of Tables TF-720-1 through TF-720-6 or Tables TF-710-1(a) through TF-710-1(h), with applicable notes, for the material requiring the higher postweld temperature. When nonpressure parts are welded to pressure parts, the postweld heat treatment temperature of the pressure part shall control. Ferritic steel parts, when used in conjunction with austenitic chromium–nickel stainless steel parts or austenitic/ferritic duplex steel, shall not be subjected to the solution heat treatment described in Section II, Part D, Nonmandatory Appendix A, A-350.

(d) The operation of postweld heat treatment shall be carried out by one of the procedures given in TF-700 in accordance with the requirements of TF-710(d), except as modified by the Notes to Tables TF-720-1 through TF-720-6.

(e) Vessels or parts of vessels that have been postweld heat treated in accordance with the requirements of this paragraph shall again be postweld heat treated after repairs have been made. 8

TF-730 REQUIREMENTS FOR NONFERROUS MATERIALS

(a) Postweld heat treatment of nonferrous material is not normally necessary nor desirable.

(b) No postweld heat treatment shall be performed, except by agreement between the User and the Manufacturer. The temperature, time, and method of heat treatment shall be covered by agreement.

TF-740 REQUIREMENTS FOR FERRITIC STEELS WITH TENSILE PROPERTIES ENHANCED BY HEAT TREATMENT

(a) Postweld heat treatment shall be required for all thicknesses of vessels or vessel parts constructed of steels listed in Table TM-130.2-6.

(b) Before applying the detailed requirements of postweld heat treatment for steels listed in Table TM-130.2-6, satisfactory weld procedure qualifications of the procedures to be used shall be performed in accordance with all of the variables in Section IX, including the conditions of postweld heat treatment and including restrictions listed below.

(c) Postweld heat treatment shall be performed in accordance with TF-710, as modified by the requirements of Table TF-740. In no case shall the PWHT temperature exceed the tempering temperature. PWHT and tempering may be accomplished concurrently. The maximum cooling rate established in TF-710(d)(2) 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.

(d) All welding connections and attachments shall be postweld heat treated whenever required by Table TF-740 based on the greatest thickness of material at the point of attachment of the head or shell [see (b) and (c)].

(e) When material of SA-333 Grade 8, SA-334 Grade 8, SA-353, SA-522, SA-553, and SA-645 Grade A are postweld heat treated, the complete vessel or vessel component being so heat treated shall be maintained within the permissible temperature range defined in Table TF-740.

Table TF-720-1
Postweld Heat Treatment Requirements for High Alloy Steels — P-No. 6

Material	Minimum Normal Holding Temperature, °C (°F)	Minimum Holding Time at Normal Temperature for Nominal Thickness [See TF-720(d)]		
		Up to 50 mm (2 in.)	Over 50 mm to 125 mm (2 in. to 5 in.)	Over 125 mm (5 in.)
P-No. 6 Gr. Nos. 1, 2, 3	675 (1,250)	1 hr/25 mm (1 in.), 15 min minimum	2 hr plus 15 min for each additional 25 mm (1 in.) over 50 mm (2 in.)	2 hr plus 15 min for each additional 25 mm (1 in.) over 50 mm (2 in.)

GENERAL NOTES:
(a) See Table TM-130.2-2.
(b) Postweld heat treatment is not required for vessels constructed of Type 410 material for SA-182 Grade F6a, SA-240, SA-268, and SA-479 with carbon content not to exceed 0.08% and welded with electrodes that produce an austenitic chromium–nickel weld deposit or a non-air-hardening nickel–chromium–iron weld deposit, provided the plate thickness at the welded joint does not exceed 10 mm ($^3/_8$ in.), and for thicknesses over 10 mm ($^3/_8$ in.) to 38 mm ($1^1/_2$ in.) provided a preheat of 230°C (450°F) is maintained during welding and that the joints are completely radiographed.
(c) Postweld heat treatment shall be performed as prescribed in TF-700 and TF-710(e).

Table TF-720-2
Postweld Heat Treatment Requirements for High Alloy Steels — P-No. 7

Material	Minimum Normal Holding Temperature, °C (°F)	Minimum Holding Time at Normal Temperature for Nominal Thickness [See TF-720(d)]		
		Up to 50 mm (2 in.)	Over 50 mm to 125 mm (2 in. to 5 in.)	Over 125 mm (5 in.)
P-No. 7 Gr. Nos. 1, 2	730 (1,350)	1 hr/25 mm (1 in.), 15 min minimum	2 hr plus 15 min for each additional 25 mm (1 in.) over 50 mm (2 in.)	2 hr plus 15 min for each additional 25 mm (1 in.) over 50 mm (2 in.)

GENERAL NOTES:
(a) See Table TM-130.2-2.
(b) Postweld heat treatment is not required for vessels constructed of Type 405 or Type 410S materials for SA-240 and SA-268 with carbon content not to exceed 0.08%, welded with electrodes that produce an austenitic–chromium–nickel weld deposit or a non-air-hardening nickel–chromium–iron weld deposit, provided the plate thickness at the welded joint does not exceed 10 mm ($^3/_8$ in.) and for thicknesses over 10 mm ($^3/_8$ in.) to 38 mm ($1^1/_2$ in.) provided a preheat of 230°C (450°F) is maintained during welding and that the joints are completely radiographed.
(c) Postweld heat treatment shall be performed as prescribed in TF-700 and TF-710(e) except that the cooling rate shall be a maximum of 56°C/h (100°F/hr) in the range above 650°C (1,200°F) after which the cooling rate shall be sufficiently rapid to prevent embrittlement.
(d) Postweld heat treatment is not required for vessels constructed of Grade TP XM-8 material for SA-268 and SA-479 or of Grade TP 18Cr–2Mo for SA-240 and SA-268.

Table TF-720-3
Postweld Heat Treatment Requirements for High Alloy Steels — P-No. 8

Material	Minimum Normal Holding Temperature, °C (°F)	Minimum Holding Time at Normal Temperature for Nominal Thickness [See TF-720(d)]		
		Up to 50 mm (2 in.)	Over 50 mm to 125 mm (2 in. to 5 in.)	Over 125 mm (5 in.)
P-No. 8 Gr. Nos. 1, 2, 3, 4	...	...	...	...

GENERAL NOTES:
(a) See Table TM-130.2-2.
(b) Postweld heat treatment is neither required nor prohibited for joints between austenitic stainless steels of the P-No. 8 group. See A-300, Appendix A, Part D, Section II.

Table TF-720-4
Postweld Heat Treatment Requirements for High Alloy Steels — P-No. 10H

Material	Minimum Normal Holding Temperature, °C (°F)	Minimum Holding Time at Normal Temperature for Nominal Thickness [See TF-720(d)]		
		Up to 50 mm (2 in.)	Over 50 mm to 125 mm (2 in. to 5 in.)	Over 125 mm (5 in.)
P-No. 10H Gr. No. 1	...	...	...	...

GENERAL NOTES:
(a) See Table TM-130.2-2.
(b) 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, °C (°F)
S32550	1 040–1 120 (1,900–2,050)
S31260 and S31803	1 020–1 100 (1,870–2,010)
S32900 (0.08 max. C)	940–955 (1,725–1,750)
S31200	1 040–1 095 (1,900–2,000)
S31500	975–1 025 (1,785–1,875)
S32304	950–1 050 (1,740–1,920)
J93345	1 120 min. (2,050 min.)
S32750	980–1 130 (1,800–2,060)
S32950	1 000–1 025 (1,825–1,875)

Table TF-720-5
Postweld Heat Treatment Requirements for High Alloy Steels — P-No. 10I

Material	Minimum Normal Holding Temperature, °C (°F)	Minimum Holding Time at Normal Temperature for Nominal Thickness [See TF-720(d)]		
		Up to 50 mm (2 in.)	Over 50 mm to 125 mm (2 in. to 5 in.)	Over 125 mm (5 in.)
P-No. 10I Gr. No. 1	730 (1,350)	1 hr/25 mm (1 in.), 15 min minimum	1 hr/25 mm (1 in.)	1 hr/25 mm (1 in.)

GENERAL NOTES:
(a) See Table TM-130.2-2.
(b) Postweld heat treatment shall be performed as prescribed in TF-700 and TF-710(e) except that the cooling rate shall be a maximum of 56°C/h (100°F/hr) in the range above 650°C (1,200°F) after which the cooling rate shall be rapid to prevent embrittlement.
(c) Postweld heat treatment is neither required nor prohibited for a thickness of 13 mm ($^1/_2$ in.) or less.
(d) 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 1 010°C (1,850°F) minimum followed by rapid cooling to below 425°C (800°F).

Table TF-720-6
Postweld Heat Treatment Requirements for High Alloy Steels — P-No. 10K

Material	Minimum Normal Holding Temperature, °C (°F)	Minimum Holding Time at Normal Temperature for Nominal Thickness [See TF-720(d)]		
		Up to 50 mm (2 in.)	Over 50 mm to 125 mm (2 in. to 5 in.)	Over 125 mm (5 in.)
P-No. 10K Gr. No. 1	...	...	...	...

GENERAL NOTES:
(a) See Table TM-130.2-2.
(b) 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 816°C to 1 066°C (1,500°F to 1,950°F) for a period not to exceed 10 min followed by rapid cooling.

Table TF-740
Postweld Heat Treatment Requirements for Ferritic Steels Enhanced by Heat Treatment

Spec. No.	Grade or Type	P-No./Gr. No.	Nominal Thickness Requiring PWHT	Note	PWHT Temp., °C (°F)	Holding Time: hr/25 mm (1 in.)	Holding Time: Minimum, hr
Plate Steels							
SA-353	9Ni	11A/1	All	...	550–585 (1,025–1,085)	1	2
SA-517	Grade A	11B/1	All	[Note (1)]	540–595 (1,000–1,100)	1	$^1/_4$
SA-517	Grade B	11B/4	All	[Note (1)]	540–595 (1,000–1,100)	1	$^1/_4$
SA-517	Grade E	11B/2	All	[Note (1)]	540–595 (1,000–1,100)	1	$^1/_4$
SA-517	Grade F	11B/3	All	[Note (1)]	540–595 (1,000–1,100)	1	$^1/_4$
SA-517	Grade J	11B/6	All	[Note (1)]	540–595 (1,000–1,100)	1	$^1/_4$
SA-517	Grade P	11B/8	All	[Note (1)]	540–595 (1,000–1,100)	1	$^1/_4$
SA-533	Types B, D, Cl. 3	11A/4	All	...	540–565 (1,000–1,050)	$^1/_2$	$^1/_2$
SA-553	Types I, II	11A/1	All	...	550–585 (1,025–1,085)	1	2
SA-645	Grade A (5Ni–$^1/_4$ Mo)	11A/2	All	...	550–585 (1,025–1,085)	1	2
SA-724	Grade A, B	1/4	All	...	550–585 (1,050–1,150)	1	$^1/_2$
SA-724	Grade C	1/4	All	...	550–585 (1,050–1,150)	1	$^1/_2$
Forgings							
SA-522	Type I	11A/1	All	...	550–585 (1,025–1,085)	1	2
SA-592	Grade A	11B/1	All	[Note (1)]	540–595 (1,000–1,100)	1	$^1/_4$
SA-592	Grade E	11B/2	All	[Note (1)]	540–595 (1,000–1,100)	1	$^1/_4$
SA-592	Grade F	11B/3	All	[Note (1)]	540–595 (1,000–1,100)	1	$^1/_4$
Pipes and Tubes							
SA-333	Grade 8	11A/1	All	...	550–585 (1,025–1,085)	1	2
SA-334	Grade 8	11A/1	All	...	550–585 (1,025–1,085)	1	2
Castings							
SA-487	Class 4B	11A/3	All	...	540–565 (1,000–1,050)	1	$^1/_4$
SA-487	Class 4E	11A/3	All	...	540–565 (1,000–1,050)	1	$^1/_4$
SA-487	Class CA 6NM	36/4	All	...	565–620 (1,050–1,150)	1	$^1/_4$

GENERAL NOTE: See Table TM-130.2-6.

NOTE: (1) See TF-610.5(e).

ARTICLE TF-8
REQUIREMENTS FOR VESSELS LINED FOR CORROSION/EROSION CONTROL

TF-800 GENERAL

The rules in Article TF-8 are applicable to vessels or vessel parts that are constructed of base material with corrosion-resistant rubber, polymer, and similar linings for tanks or tank parts that are fully lined for corrosion control. The rules in Article TF-8 shall be used in conjunction with the supplemental requirements of the Modal Appendices.

TF-810 FABRICATION

TF-810.1 GENERAL

The material used for lining the vessel or vessel parts shall be homogeneous, nonporous, imperforate when applied, at least as elastic as the material of the tank or tank part proper, and have thermal expansion characteristics compatible with the tank or tank part proper. The lining shall be immune to attack by the contents to be transported therein. It shall be uniform in thickness and shall be directly bonded. The lining shall be spark tested in accordance with Article TT-4.

TF-810.2 PRESSURE TESTING

Consideration should be given to performing the required pressure test prior to the application of the lining.

PART TE EXAMINATION REQUIREMENTS

ARTICLE TE-1 REQUIREMENTS FOR EXAMINATION PROCEDURES AND PERSONNEL QUALIFICATION

TE-100 GENERAL

Nondestructive examinations shall be conducted in accordance with the methods of Section V, as modified by the requirements of this Article.

TE-110 NONDESTRUCTIVE EXAMINATION PROCEDURES

TE-110.1 GENERAL

(a) All nondestructive examinations required by this Article shall be performed in accordance with the detailed written procedures that have been proven by actual demonstration to the satisfaction of the Inspector. The procedures shall comply with the appropriate article of Section V for the particular examination method. Written procedures, records of demonstration of procedure capability, and records of personnel qualification to these procedures shall be made available to the Inspector.

(b) Following any nondestructive examination in which examination materials are applied to the part, the part shall be thoroughly cleaned in accordance with applicable material or procedure specifications.

(25) TE-110.2 RADIOGRAPHIC EXAMINATION

(a) Radiographic examination shall be in accordance with Section V, Article 2, except as specified below:

(1) A complete set of radiographs and records, as described in Section V, Article 2, T-291 and T-292, for each tank or tank part shall be retained by the Manufacturer until the Manufacturer's Data Report has been signed by the Inspector.

(2) The requirements of Section V, Article 2, T-274.2 are to be used only as a guide. Final acceptance of radiographs shall be based on the ability to see the prescribed image quality indicator (IQI) image and the specified hole or the designated wire of a wire IQI.

(b) All welded joints to be examined by Real Time Radioscopic Examination shall be examined in accordance with Section V, Article 2, Mandatory Appendix II as specified below.

(1) A complete set of records, as described in Section V, Article 2, T-292, shall be evaluated by the Manufacturer prior to being presented to the Inspector. Records shall be retained by the Manufacturer until the Manufacturer's Data Report has been signed by the Inspector.

(2) The use of Real Time Radioscopic Examination shall be noted on the Manufacturer's Data Report.

(3) Provisions for training, experience, qualification, and certification of personnel responsible for equipment setup, calibration, operation, and evaluation of examination data shall be described in the Manufacturer's Quality Control System. (See Mandatory Appendix I.)

(c) As an alternative to the radiographic examination requirements above, all welds in material 6 mm ($\frac{1}{4}$ in.) and greater in thickness may be examined using the ultrasonic (UT) method in accordance with the requirements of Section VIII, Division 2, 7.5.5, if radiographic examination is not specifically required by applicable Modal Appendices or other governing documents.

TE-110.3 ULTRASONIC EXAMINATION

Ultrasonic examination of welded joints, when required or permitted by this Section, shall be performed in accordance with Mandatory Appendix IX [see TE-230.1(a)(5) and TE-250.2(a)(2)(-c)]. Imperfections shall be evaluated to the acceptance standards specified in TE-250.3. 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 imperfections described in this Section.

TE-110.4 MAGNETIC PARTICLE EXAMINATION

Magnetic particle examination shall be performed in accordance with Mandatory Appendix V. Imperfections shall be evaluated to the acceptance standards specified in TE-250.4.

TE-110.5 LIQUID-PENETRANT EXAMINATION

Liquid-penetrant examination shall be performed in accordance with Mandatory Appendix VI. Imperfections shall be evaluated to the acceptance standards specified in TE-250.5.

TE-120 QUALIFICATION AND CERTIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL

TE-120.1 GENERAL

(a) Organizations performing and evaluating nondestructive examinations required by this Section shall use personnel qualified to the requirements of Section V, Article 1, T-120; and TE-120.2 through TE-120.5.

(b) For nondestructive examination methods that consist of more than one operation or type, it is permissible to use personnel qualified to perform one or more operations. As an example, one person may be used who is qualified to conduct radiographic examination and another who is qualified may be used to interpret and evaluate the radiographic film.

TE-120.2 QUALIFICATION OF PERSONNEL

(a) Personnel performing radiographic or ultrasonic examinations shall be qualified under their Employer's written practice, prepared in compliance with the ASNT SNT-TC-1A. Alternatively, personnel performing radiographic or ultrasonic examination may be qualified in accordance with ASNT CP-189 or ASNT ACCP-1 for examination and test requirements. The Employer's written practice shall address education and experience requirements.

(b) The written practice and the procedures used for examination and qualification of personnel shall be referenced in the Employer's Quality Control System.

(c) The documented number of hours of training and experience may be fewer than required by the referenced document when examiners are qualified to perform only one operation of a multiple operation nondestructive examination method or examinations of a limited scope. The required hours of training and experience, and limitations or restrictions on examiner certification, shall be specified in the Employer's written practice and on the certificate of qualification.

(d) The Manufacturer shall certify that each magnetic particle or liquid-penetrant examination shall be in accordance with Mandatory Appendices V and VI. Personnel performing these examinations may, as an alternative, be qualified to ASNT SNT-TC-1A, ASNT CP-189, or ASNT ACCP.

TE-120.3 CERTIFICATION OF PERSONNEL

(a) The Employer retains responsibility for the adequacy of the program and is responsible for certification of Levels I, II, and III Nondestructive Examination personnel.

(b) The examination results shall be included with the Employer's records in accordance with TE-120.5.

TE-120.4 VERIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL CERTIFICATION

The Manufacturer is responsible for the verification of qualification and certification of nondestructive examination personnel employed by subcontractors who provide nondestructive examination services to them.

TE-120.5 RECORDS

Personnel qualification records shall be retained by the Employer.

ARTICLE TE-2
EXAMINATION OF WELDS AND ACCEPTANCE CRITERIA

TE-200 TIME OF EXAMINATION OF WELDED JOINTS

Acceptance examinations of welded joints shall be performed during the fabrication process as stipulated below during construction.

(a) All butt-welded joints shall be visually examined after completion of any required heat treatment.

(b) Magnetic particle or liquid-penetrant examinations of base metal repairs shall be performed after any required postweld heat treatment, except the welds in P-No. 1 material may be examined either before or after postweld heat treatment.

(c) The magnetic particle or liquid-penetrant examination of weld surfaces that are not accessible after a postweld heat treatment (PWHT) shall be performed prior to PWHT.

TE-210 EXAMINATION OF WELD EDGE PREPARATION SURFACES

(a) When a pressure part is to be welded to a flat plate thicker than 13 mm ($\frac{1}{2}$ in.) to form a corner joint where the peripheral edge will not be covered by weld metal, the weld joint preparation and peripheral edge of the flat plate shall be examined before welding by either the magnetic particle or liquid-penetrant method. After welding, both the peripheral edge of the flat plate and any other remaining exposed surfaces of the weld joint preparation shall be reexamined.

(b) Particular attention shall be given to cut edges and other parts of rolled plate that would disclose the existence of serious laminations, shearing cracks, and other imperfections.

(c) These requirements do not apply if the configuration of the corner joint is such that the toe of the weld is farther in distance from the peripheral edge of the flat plate than its thickness.

TE-220 TYPES OF WELDED JOINTS AND THEIR EXAMINATION

TE-220.1 WELDED JOINT CATEGORIES

The term *Category* defines the location of a welded joint in a tank, but not the type of joint. See TW-130.3 for description and location of the various categories of welded joints. See TW-130.4 for permissible types of welded joints for the various welded joint categories and the degree of radiographic examination for the various types of welded joints.

TE-220.2 EXAMINATION OF WELDED JOINTS

The examination of welded joints shall be dictated by the assigned joint efficiency of the joints under Parts TD and TW (see TW-130.4). These examinations shall be performed as specified in this Article.

TE-230 RADIOGRAPHIC AND ULTRASONIC EXAMINATION

TE-230.1 GENERAL REQUIREMENTS FOR RADIOGRAPHIC AND ULTRASONIC EXAMINATION (25)

(a) Full Radiography. The following welded joints shall be examined radiographically for their full length in the manner prescribed in TE-110.2 and TE-250.2(a):

(1) all butt welds in the shell and heads of vessels used to contain fluids with United Nations Hazard Classifications 2.1, 2.3, or 6.1 [see TW-100.1(a)].

(2) all butt welds in vessels in which the nominal thickness at the welded joint exceeds 38 mm ($1\frac{1}{2}$ in.), or exceeds the lesser thickness prescribed in TE-230.2, TE-230.3, TE-230.4, or TE-230.5 for the materials permitted by Part TM; however, except as required by TE-230.5(a), Categories B and C butt welds in nozzles and communicating chambers that neither exceed NPS 10 nor 29 mm ($1\frac{1}{8}$ in.) wall thickness do not require radiographic examination.

(3) all butt welds in nozzles, communicating chambers, etc., attached to vessel sections or heads that are required to be fully radiographed under (1) or (2); however, except as required by TE-230.5(a), Categories B and C butt welds in nozzles and communicating chambers that neither exceed NPS 10 nor 29 mm ($1\frac{1}{8}$ in.) wall thickness do not require any radiographic examination.

(4) all Categories A and D butt welds in vessel sections and heads where the design of the joint or part is based on a joint efficiency permitted by TW-130.4(a), in which case:

(-a) Categories A and B welds connecting the vessel sections or heads shall be of Type No. (1) or Type No. (2) of Table TW-130.4.

(-b) Categories B and C butt welds [but not including those in nozzles or communicating chambers, except as required in (2)] that intersect the Category A butt welds in vessel sections or heads shall, as a minimum, meet the requirements for spot radiography in accordance with TE-250.2(b). Spot radiographs required by this paragraph shall not be used to satisfy the spot radiography rules as applied to any other weld increment.

(5) ultrasonic examination in accordance with TE-110.3 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.

(b) Spot Radiography

(1) Except as required in (a)(4)(-b), butt-welded joints made in accordance with Type No. (1) or Type No. (2) of Table TW-130.4, which are not required to be fully radiographed by (a), may be examined by spot radiography. Spot radiography shall be in accordance with TE-250.2(b). If spot radiography is specified for the entire vessel, radiographic examination is not required of Categories B and C butt welds in nozzles and communicating chambers that exceed neither NPS 10 nor 29 mm (1⅛ in.) wall thickness.

NOTE: This requirement specifies spot radiography for butt welds of Type No. 1 or Type No. 2 that are used in a vessel, but does not preclude the use of fillet and/or corner welds permitted by other paragraphs, such as for nozzle and manhole attachments, welded stays, flat heads, etc., which need not be spot radiographed.

(2) Spot radiography shall be made in accordance with the technique prescribed in TE-110.2(a). The minimum length of spot radiograph shall be 150 mm (6 in.). Spot radiographs may be retained or discarded by the Manufacturer after acceptance of the tank by the Inspector.

(3) Minimum Extent of Spot Radiographic Examination

(-a) One spot shall be examined on each tank for each 15 m (50 ft) increment of weld or fraction thereof for which a joint efficiency from column (b) of Table TW-130.4 is selected. However, for identical tanks, each with less than 15 m (50 ft) of weld for which a joint efficiency from column (b) of Table TW-130.4 is selected, 15 m (50 ft) increments of weld may be represented by one spot examination.

(-b) For each increment of weld to be examined, a sufficient number of spot radiographs shall be taken to examine the welding of each welder or welding operator. Under conditions where two or more Welders or Welding Operators make weld layers in a joint, or on the two sides of a double-welded butt joint, one spot may represent the work of all Welders or Welding Operators.

(-c) Each spot examination shall be made as soon as practicable after completion of the increment of weld to be examined. The location of the spot shall be chosen by the Inspector after completion of the increment of welding to be examined, except that when the Inspector has been notified in advance and cannot be present or otherwise make the selection, the fabricator may exercise judgment in selecting the spots.

(-d) Radiographs required at specific locations to satisfy the rules of other paragraphs shall not be used to satisfy the requirements of spot radiography.

(c) No Radiography. Except as required in (b)(3)(-a), no radiographic examination of welded joints is required when the vessel or vessel part is designed for external pressure only, or when the joint design complies with TW-130.4(c).

(d) In addition to the requirements in (b)(3)(-a) and (b)(3)(-b), all welds made by the electron beam process shall be ultrasonically examined for their entire length in accordance with the requirements of Mandatory Appendix IX.

(e) For radiographic and ultrasonic examination of butt welds, the definition of nominal thickness at the welded joint under consideration shall be the nominal thickness of the thinner of the two parts joined.

TE-230.2 ADDITIONAL REQUIREMENTS FOR VESSELS CONSTRUCTED OF CARBON AND LOW ALLOY STEELS

In addition to the requirements in TE-230.1, complete radiographic examination is required for each butt-welded joint at which the thinner of the plate or tank wall thicknesses at the welded joint exceeds the thickness limit above which full radiography is required in Table TE-230.2.

Table TE-230.2
Thickness Above Which Full Radiographic Examination of Butt-Welded Joints Is Mandatory

P-No. and Gr. No. Classification of Materials	Nominal Thickness Above Which Butt-Welded Joints Shall Be Fully Radiographed, mm (in.)
1 Gr. 1, 2, 3	32 (1¼)
3 Gr. 1, 2, 3	19 (¾)
9A Gr. 1	16 (⅝)
9B Gr. 1	16 (⅝)
10A Gr. 1	19 (¾)
10B Gr. 2	16 (⅝)
10C Gr. 1	16 (⅝)
10F Gr. 6	19 (¾)

TE-230.3 ADDITIONAL REQUIREMENTS FOR VESSELS CONSTRUCTED OF HIGH ALLOY STEELS

(a) The requirements for radiographic examination in Part TE apply to high alloy steels, except as provided in (b) (see TF-410.2).

(b) Butt-welded joints in vessels conforming to Type 405 welded with straight chromium electrodes and to Types 410, 429, and 430 welded with any electrode shall be radiographed in all thicknesses. The final radiographs of all straight chromium ferritic welds, including major repairs to these welds, shall be made after postweld heat treatment has been performed.

(c) Butt-welded joints in vessels constructed of austenitic chromium-nickel stainless steels that are radiographed because of the thickness requirements of TE-230.1, or for lesser thicknesses where the joint efficiency reflects the credit for radiographic examination of Table TW-130.4, shall be radiographed following post heating if such is performed.

TE-230.4 ADDITIONAL REQUIREMENTS FOR VESSELS CONSTRUCTED OF NONFERROUS MATERIALS

(a) Tanks or parts of tanks constructed of nonferrous materials shall be radiographed in accordance with the requirements of TE-230.1.

(b) Welded butt joints in tanks constructed of materials listed in Table TM-130.2-5, with the exception of alloys 200 (UNS No. N02200), 201 (UNS No. N02201), 400 (UNS No. N04400), 401 (UNS No. N04401), and 600 (UNS No. N06600) shall be examined radiographically for their full length as prescribed in TE-230.1 when the thinner of the plate or tank wall thicknesses at the welded joint exceeds 10 mm ($^3/_8$ in.).

(c) Where a defect removed and welding repair is not necessary, care shall be taken to contour notches or corners. The contoured surface shall then be reinspected by the same means originally used for locating the defect to be sure it has been completely removed.

TE-230.5 ADDITIONAL REQUIREMENTS FOR VESSELS CONSTRUCTED OF FERRITIC STEELS THAT ARE HEAT TREATED TO ENHANCE TENSILE PROPERTIES

(a) Radiography. Radiographic examination for the complete length of weld in accordance with the requirements of Part TE is required for all welded joints of Type No. 1 of Table TW-130.4.

(b) Nozzle Attachment Welds. Nozzle attachment welds as provided for in TW-130.7, Figures TW-130.7-1 and TW-130.7-2 shall be radiographically examined in accordance with the requirements of Part TE.

TE-240 MAGNETIC PARTICLE AND LIQUID-PENETRANT EXAMINATION

TE-240.1 EXAMINATION OF WELDS ON PNEUMATICALLY TESTED VESSELS

On welded pressure vessels to be pneumatically tested in accordance with TT-210(b), the full length of the following welds shall be examined by the magnetic particle or liquid-penetrant methods for the purpose of detecting cracks:

(a) all welds around openings

(b) all attachment welds, including welds attaching nonpressure parts to pressure parts, having a throat thickness greater than 6 mm ($^1/_4$ in.)

Examination shall be by magnetic particle or liquid-penetrant methods when the material is ferromagnetic, or by liquid-penetrant method when the material is nonmagnetic.

TE-240.2 EXAMINATION OF WELDS IN CARBON AND LOW ALLOY STEEL VESSELS

All welds around nozzles, including reinforcing plate attachment welds, shall be examined by the magnetic particle method or liquid-penetrant method whenever full radiography of butt-welded joints is mandatory (see TE-230.2).

TE-240.3 LIQUID-PENETRANT EXAMINATION OF WELDS IN HIGH ALLOY STEEL VESSELS

All austenitic chromium-nickel alloy steel and austenitic-ferritic duplex steel welds, both groove and fillet, that exceed 19 mm ($^3/_4$ in.) shall be examined for 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.

TE-240.4 LIQUID-PENETRANT EXAMINATION OF WELDS IN VESSELS OF NONFERROUS MATERIALS

(a) All welds, both groove and fillet, in tanks constructed of materials covered by UNS N06625 (for Grade 2 only in SB-443, SB-444, and SB-446), UNS N10001, and UNS N10665 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 removed by grinding, or grinding and filing. Where a defect is removed and welding repair is not necessary, care shall be taken to contour notches or corners. The contoured surface shall then be reinspected by the same means originally used for locating the defect to be sure it has been completely removed.

(b) Welded joints in tanks or parts of tanks, constructed of materials listed in Table TM-130.2-5, with the exception of alloys 200 (UNS No. N02200), 201 (UNS No. N02201), 400 (UNS No. N04400), 405 (UNS No. N04405), and 600 (UNS No. N06600), shall be examined by the liquid-penetrant method when they are not required to be fully radiographed.

(c) Laser welded lap joints are exempt from liquid-penetrant examination requirements of (a) and (b).

TE-240.5 EXAMINATION OF WELDS IN VESSELS OF FERRITIC STEELS THAT ARE HEAT TREATED TO ENHANCE TENSILE PROPERTIES

(a) Magnetic Particle Method. All welds, including welds for attaching nonpressure parts to heat-treated steel listed in Table TM-130.2-6, shall be examined by the magnetic particle method after the hydrostatic test, except that those surfaces not accessible after the hydrostatic test shall be examined by the magnetic particle method at the last feasible stage of vessel fabrication. All welds to be stress relieved shall be examined after the PWHT. A magnetization method shall be used that will avoid arc strikes. Cracks are unacceptable and shall be repaired or removed. Any relevant indications greater than 1.5 mm ($^1/_{16}$ in.) shall be repaired or removed (see Mandatory Appendix V).

(b) 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 weld deposits, a liquid-penetrant method 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 Grade A materials, welds not examined radiographically shall be examined by the liquid-penetrant method either before or after the hydrostatic test. Cracks are unacceptable and shall be repaired or removed. Relevant indications are those that result from imperfections. Any relevant indications greater than 1.5 mm ($^1/_{16}$ in.) shall be repaired or removed (see Mandatory Appendix VI).

TE-250 ACCEPTANCE CRITERIA

TE-250.1 GENERAL

(a) Linear indications are indications in which the length is more than three times the width. Rounded indications on the radiograph are indications, which are circular or elliptical with the length less than three times the width.

(b) When using magnetic particle examination, mechanical discontinuities at or near the surface will be indicated by the retention of the examination medium. However, all indications are not necessarily imperfections, because certain metallurgical discontinuities and magnetic permeability variations may produce similar indications, which are not relevant to the detection of unacceptable discontinuities.

(c) When using liquid-penetrant examination, mechanical discontinuities at the surface will be indicated by bleeding out of the penetrant. However, localized surface imperfections, such as may occur from machining marks, surface conditions, or an incomplete bond between base metal and cladding, may produce similar indications, which are not relevant to the detection of imperfections.

TE-250.2 RADIOGRAPHIC ACCEPTANCE CRITERIA

(a) Full Radiography

(1) Indications in welds that are shown by full radiography to be any of the following types of imperfections are unacceptable:

(-a) any indication characterized as a crack or zone of incomplete fusion or penetration

(-b) any other linear indication that has a length greater than:

(-1) 6 mm ($^1/_4$ in.) for t < 19 mm ($^3/_4$ in.)

(-2) t/3 for 19 mm ($^3/_4$ in.) ≤ t ≤ 57 mm (2$^1/_4$ in.)

where

t = thickness of the weld, excluding any allowable weld reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses.

(-c) any group of aligned, rounded indications having an aggregate length greater than t in a length of 12t, unless the minimum distance between successive indications exceeds 6L, in which case the aggregate length is unlimited, L being the length of the largest indication in the group

(-d) rounded indications in excess of those shown as acceptable in Mandatory Appendix IV

(2) Evaluation, Repair, and Retest

(-a) Unacceptable indications shown on the radiographs of welds shall be repaired by removing such defects by mechanical means or by thermal gouging processes, then repair welding, and radiographing the repair to the requirements of Part TE.

(-b) Repair welding shall be performed using a qualified procedure and a qualified welder in a manner acceptable to the Inspector.

(-c) At the option of the Manufacturer, the repair may be ultrasonically examined in accordance with TE-110.3 and to the satisfaction of the Inspector, provided the defect is confirmed by ultrasonic examination prior to making the repair. This ultrasonic examination shall be noted under "Remarks" on the Manufacturer's Data Report Form.

(b) Spot Radiography

(1) The acceptability of welds examined by spot radiography shall be judged by the following methods:

(-a) Welds in which indication characterized as cracks or zones of incomplete fusion or penetration shall be unacceptable.

(-b) Welds in which indications are characterized as slag inclusion or cavities shall be unacceptable if the length of any such indication is greater than $\frac{2}{3}t$, where t is the thickness of the weld excluding any allowable reinforcement. For butt welds 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. If several indications within the above limitations exist in line, the welds shall be judged acceptable if the sum of the longest dimensions of all such indications is not more than t in a length of $6t$ (or proportionately for radiographs shorter than $6t$) and if the longest indications considered are separated by at least $3L$ of acceptable weld metal, where L is the length of the longest indication. The maximum length of acceptable indications shall be 19 mm ($\frac{3}{4}$ in.). Any such indications shorter than 6 mm ($\frac{1}{4}$ in.) shall be acceptable for any plate thickness.

(-c) Rounded indications are not a factor in the acceptability of welds not required to be fully radiographed.

(2) Evaluation, Repair, and Retests

(-a) When a spot, radiographed as required in TE-230.1(b)(3), is acceptable in accordance with (1), the entire weld increment represented by this radiograph is acceptable.

(-b) When a spot, radiographed as required in TE-230.1(b)(3), has been examined and the radiograph discloses welding that does not comply with the minimum quality requirements of (1), two additional spots shall be radiographically examined at the same weld increment at locations away from the original spot. The location of these additional spots shall be determined by the Inspector or fabricator as provided for the original spot examination in TE-230.1(b)(3)(-c).

(-1) If the two additional spots examined show welding that meets the minimum quality requirements of (1), the entire weld increment represented by the three radiographs is acceptable, provided the defects disclosed by the first of the three radiographs are removed and the area is repaired by welding. The repaired area shall be radiographically examined and evaluated in accordance with the requirements in (b) and TE-230.1(b).

(-2) If either of the two additional spots examined shows welding that does not comply with minimum quality requirements of (1), the entire increment 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 increment of weld represented shall be completely radiographed and only defects need be corrected.

(-3) Repair welding shall be performed using a qualified procedure and a qualified welder in a manner acceptable to the Inspector. The repaired area shall be reexamined reevaluated at one location in accordance with the requirements of (b) and TE-230.1(b).

TE-250.3 ULTRASONIC ACCEPTANCE CRITERIA

The ultrasonic examination acceptance criteria shall be as specified in Mandatory Appendix IX, IX-3.

TE-250.4 MAGNETIC PARTICLE EXAMINATION ACCEPTANCE CRITERIA

The evaluation of indications revealed by magnetic particle examination shall be as specified in Mandatory Appendix V, V-3 and the acceptance criteria shall be as specified in Mandatory Appendix V, V-4.

TE-250.5 LIQUID-PENETRANT EXAMINATION ACCEPTANCE CRITERIA

The evaluation of indications revealed by liquid-penetrant examination shall be as specified in Mandatory Appendix VI, VI-3 and the acceptance criteria shall be as specified in Mandatory Appendix VI, VI-4.

PART TT
TESTING REQUIREMENTS

ARTICLE TT-1
GENERAL REQUIREMENTS FOR TESTING

TT-100 GENERAL

The testing of transport tanks shall be performed in accordance with the requirements in this Part.

ARTICLE TT-2
REQUIREMENTS FOR PRESSURE TESTING

TT-200 GENERAL

(a) A pressure test shall be conducted on all completed tanks after

(1) all fabrication is complete except for cosmetic grinding, which does not affect the required thickness

(2) all examinations have been performed, except those required after the test

(b) The completed vessel shall have successfully passed one of the pressure tests prescribed in this Article.

TT-210 TEST REQUIREMENTS

(a) *Hydrostatic Test Requirements*

(1) Vessels designed for internal pressure shall be subjected to a hydrostatic test pressure at every point in the tank at least equal to 1.3 times the maximum allowable working pressure (MAWP) to be marked on the vessel, multiplied by the lowest ratio (for the material of which the vessel is constructed) of the stress value S for the test temperature on the vessel to the stress value S for the design temperature (see TD-210). The MAWP may be assumed to be the same as the design pressure when calculations are not made to determine the MAWP. The above requirements shall apply when the vessel specification provides no test pressure. All loadings that may exist during this test shall be given consideration.

(2) Unless otherwise specified in the appropriate Modal Appendix, there is no upper limit on the hydrostatic test pressure. However, if the hydrostatic test pressure is allowed to exceed the value determined as prescribed in (1) to the degree that the tank shows visible permanent distortion, the Inspector has the right to reject the tank.

(3) It is recommended that the metal temperature during hydrostatic test be maintained at least 17°C (30°F) above the minimum design metal temperature [see TD-140, General Note (f) to Figure TM-240.3-2, and TM-240.4], to minimize the risk of brittle fracture, but need not exceed 48°C (120°F).

(4) Single-wall vessels designed for a vacuum or partial vacuum only, or chambers or multi-chamber vessels designed for vacuum or partial vacuum only, shall be subjected to internal hydrostatic test or, when a hydrostatic test is not possible, to a pneumatic test in accordance with the provisions of (b). Either type of test shall be made at a pressure not less than 1.3 times the difference between normal atmospheric pressure and the minimum design internal absolute pressure.

(5) Following the application of the hydrostatic test pressure, an inspection shall be made of all joints and connections. This inspection shall be made at a pressure not less than the test pressure divided by 1.3. The visual inspection of joints and connections for leaks may be waived, provided a suitable gas leak test is applied with the agreement of the Inspector, and the tank will not contain a hazardous substance [see TW-100.1(a)].

(6) Any leakage through the base metal or weld joints is cause for rejection.

CAUTION: A small liquid relief valve set to $1\frac{1}{3}$ times the test pressure is recommended for the pressure test system, in case a tank, while under test, is likely to be warmed up materially.

(b) *Pneumatic Test Requirements*

(1) Subject to the provisions of TT-200(a), a pneumatic test prescribed in (b) may be performed in lieu of the hydrostatic test prescribed in (a) for vessels

(-a) that are so designed and/or supported that they cannot safely be filled with water

(-b) that are not readily dried, to be used in services where traces of the testing liquid cannot be tolerated, and the parts of which have been, where possible, previously tested by hydrostatic pressure to the pressure required in (a)

(2) Pneumatically tested vessels shall be subjected to the additional examination requirements of TE-240.1 prior to the test.

(3) Under the following conditions, pressure vessels fabricated under the provisions of Section XII may be subjected to pneumatic testing in lieu of hydrostatic testing:

(-a) For nonjacketed tanks, the following shall apply:

(-1) The test pressure shall be not less than 1.3 MAWP.

(-2) The MAWP shall be not greater than 3 447 kPa (500 psi).

(-3) For butt joints, the nominal thickness at the thickest welded joint shall not exceed 38 mm ($1\frac{1}{2}$ in.).

(-4) If used, pneumatic testing shall be noted on the Manufacturer's Data Report.

(-b) For jacketed tanks, one of the following two options may be followed:

(-1) Option 1

(+a) The test pressure of the bare inner vessel shall be not less than 1.3 × (MAWP + liquid head + vacuum pressure), where vacuum pressure = 101.4 kPa (14.7 psi).

(+b) When the tank is jacketed and fully assembled and the vacuum jacket is evacuated, the test pressure of the inner vessel shall be not less than 1.3 × (MAWP + liquid head + vacuum pressure), where vacuum pressure = 101.4 kPa (14.7 psi).

(+c) The MAWP shall be not greater than 3 447 kPa (500 psi).

(+d) For butt joints, the nominal thickness at the thickest welded joint shall not exceed 38 mm ($1\frac{1}{2}$ in.).

(+e) If used, pneumatic testing shall be noted on the Manufacturer's Data Report.

(-2) Option 2

(+a) The test pressure of the bare inner vessel shall be not less than the MAWP of the tank.

(+b) When the tank is jacketed and fully assembled and the vacuum jacket is evacuated, the test pressure of the inner vessel shall be not less than 1.3 × (MAWP + liquid head + vacuum pressure), where vacuum pressure = 101.4 kPa (14.7 psi), and the tank shall be pressurized with a 10% helium and 90% nitrogen mixture. While the inner tank is pressurized with the helium/nitrogen mix, tie into annular space with a helium mass spectrometer and check for leakage of helium into the annular space.

(+c) The MAWP shall be not greater than 3 447 kPa (500 psi).

(+d) For butt joints, the nominal thickness at the thickest welded joint shall not exceed 38 mm ($1\frac{1}{2}$ in.).

(+e) If used, pneumatic testing shall be noted on the Manufacturer's Data Report.

CAUTION: For all pneumatic testing listed above, the vessel shall be tested in such a manner as to ensure personnel safety from a release of total stored energy of the vessel during testing. Safe distance calculations for bare tank pressure testing shall be calculated per ASME PCC-2, Article 501, Mandatory Appendix III.

(4) The pneumatic test pressure of a completed vessel, or a chamber in a multi-chamber vessel, shall not exceed that value which results in a membrane stress in the vessel wall greater than 87% of the tabulated yield strength in Section II, Part D, Subpart 1, Table Y-1.

(5) The metal temperature during the pneumatic test shall be maintained at least 17°C (30°F) above the minimum design metal temperature (MDMT) to minimize the risk of brittle fracture [see TD-140, General Note (f) to Figure TM-240.3-2, and TM-240.4].

(6) The pressure in the vessel shall be gradually increased to not more than one-half of the test pressure. Thereafter, the test pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached. Then the pressure shall be reduced to the test pressure divided by 1.3 and held for a sufficient time to permit visual inspection of the vessel. The visual inspection may be waived, provided

(-a) a suitable gas leak test is applied

(-b) substitution of the above gas leak test is by agreement reached between the Manufacturer and Inspector

(-c) all weld seams that will be hidden by assembly will be given a visual examination for workmanship prior to assembly

(-d) the vessel will not contain a substance listed in TW-100.1(a)

(c) Any evidence of leakage through the base metal or weld joints is reason for rejection. When leakage is observed, the test should be terminated, the pressure released, and the tank repaired, reinspected and retested in accordance with the requirements of this Section.

TT-220 TEST MEDIA

(a) No flammable or combustible liquids shall be used. Only fluid that is liquid at the hydrostatic test temperature and pressure and is not corrosive to the tank parts shall be used for the test. Appropriate measures shall be taken to ensure condensation on exterior surfaces does not mask indications of leakage.

(b) Air or gas is hazardous when used as a testing medium. Special precautions should be taken when air or gas is used for test purposes.

TT-230 APPURTENANCES

(a) Vents shall be provided at all high points of the tank in the position at which it is to be tested to purge possible air pockets while the tank is filling for a hydrostatic test.

(b) Before applying pressure, the test equipment shall be examined 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.

(c) Vessels may be painted or otherwise coated either internally or externally, and may be lined internally prior to the pressure test.

TT-240 TEST GAGES

(a) An indicating gage shall be connected directly to the tank. 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.

(b) Dial indicating pressure gages used in testing shall be graduated over a range of about double the intended test pressure, but in no case shall the range be less than $1\frac{1}{2}$ nor more than four times that pressure. Digital reading pressure gages may be used with a wider range, provided the accuracy is equivalent to or better than the dial indicating gages.

(c) All gages shall be calibrated against a standard deadweight tester or a calibrated master gage. Gages shall be recalibrated at any time there is reason to believe that they are in error.

ARTICLE TT-3
REQUIREMENTS FOR PROOF TESTING TO ESTABLISH MAXIMUM ALLOWABLE WORKING PRESSURE (MAWP)

(25) TT-300 GENERAL

(a) The maximum allowable working pressure (MAWP) for tanks or tank parts for which the strength cannot be computed with a satisfactory assurance of accuracy shall be established in accordance with these requirements using one of the test procedures applicable to the type of loading and to the material used in the construction.

(b) Provision is made in these rules for burst testing to determine the internal MAWP.

(c) Safety of testing personnel should be given serious consideration when conducting proof tests, and particular care should be taken during bursting tests.

(d) The tests in these paragraphs may be used only for the purpose of establishing MAWP of those elements or component parts for which the thickness cannot be determined by means of the design rules given in this Section. The MAWP of all other elements or component parts shall be not greater than that determined by means of the applicable design rules.

(e) Tests to establish MAWP of tanks, or tank parts, shall be witnessed by and be acceptable to the Inspector, as indicated by the Inspector's signature on the Manufacturer's report of the test. The report shall include sufficient detail to describe the test, the instrumentation and methods of calibration used, and the results obtained. The report shall be made available to the Inspector for each application.

TT-310 PREVIOUS TESTS

The tank or tank part for which MAWP is to be established shall not have been previously subjected to a pressure greater than 1.3 times the desired or anticipated maximum allowable working pressure, adjusted for operating temperature as provided in TT-330.4.

TT-320 DUPLICATE AND SIMILAR PARTS

(a) When the MAWP of a tank or tank part has been established by a proof test, duplicate parts or geometrically similar parts that meet all of the requirements in (b) or (c) need not be proof tested but shall be given a hydrostatic pressure test in accordance with TT-210(a) or a pneumatic pressure test in accordance with TT-210(b).

(b) Duplicate Parts. All of the following requirements shall be met in order to qualify a part as a duplicate of the part that had been proof tested:

(1) The duplicate part shall have the same basic design configuration and type of construction.

(2) The material of the duplicate part is either

(-a) the same material specifications

(-1) alloy

(-2) grade, class

(-3) type, form

(-4) heat treatment

(-b) the same or closely similar material when only the material specification, the alloy, grade, or form is different, provided the material meets the following requirements:

(-1) has allowable stress in tension equal to or greater than the material used in the proof tested part at both the design temperature and the test temperature

(-2) has the same P Number (Section IX)

(-3) for carbon or low alloy steels, has the same or tougher material grouping in TM-240.1, Figure TM-240.1-1, and Notes

(3) The nominal dimensions (diameter or width and height) of the duplicate parts shall be the same, and the corresponding nominal thicknesses shall be the same as those used in the proof test. The length shall not be longer than that proof tested.

(4) Heat treatment shall be the same as performed on the original part that was tested.

(5) The MAWP shall be calculated according to TT-330.

(6) When there are permissible deviations from the original part that was proof tested, a supplement to the original Proof Test Report shall be prepared that states and evaluates each deviation.

(c) Geometrically Similar Parts. The MAWP for geometrically similar parts may be established by a series of proof tests that uniformly cover the complete range of sizes, pressure, or other variables by interpolation from smooth curves plotted from the results of the tests.

(1) Sufficient tests shall be performed to provide at least five data points that are at increments that are within 20% to 30% of the range covered.

(2) The curves shall be based on the lower bound of the test data.

(3) Extrapolation is not permitted.

TT-330 EVALUATION

TT-330.1 GENERAL

(a) Proof test method TT-340.3 establishes the pressure at which the test is terminated. The results of the test are recorded in a Proof Test Report according to TT-300.

(b) The MAWP for the first duplicate part, as defined in TT-320, to be put in service, shall be calculated according to the equations given for the proof test method applied. The requirements for nondestructive examination (NDE) are given in Parts TG and TF. Other requirements are based on thickness or material. These apply to parts that are to be put into service. It is not necessary to examine the part actually tested.

(c) For subsequent duplicate parts, the MAWP may be recalculated for a different extent of NDE in a supplement to the original Proof Test Report.

(d) The effect of the location of a weld joint may be evaluated and included in the Proof Test Report.

TT-330.2 RETEST

A retest shall be allowed on a duplicate tank or tank part if errors or irregularities are obvious in the test results.

TT-330.3 DETERMINATION OF TENSILE STRENGTH

(a) For proof tests based on bursting in accordance with TT-340.3, the tensile strength of the material in the part tested shall be determined in accordance with the method prescribed in the applicable material specification and as described in ASTM E8, Tension Testing of Metallic Materials.

(b) The tensile strength so determined shall be the average from three or four specimens cut from the part tested after the test is completed. The specimens shall be cut from a location where the stress during the test has not exceeded the yield strength. The specimens shall not be flame cut because this might affect the strength of the material. If yield or tensile strength is not determined by test specimens from the pressure part tested, alternative methods are given in TT-340.3 for evaluation of proof test results to establish the MAWP.

(c) When excess stock from the same piece of wrought material is available and has been given the same stress relieving heat treatment as the pressure part, the test specimens may be cut from this excess stock. The specimen shall not be removed by flame cutting or any other method involving sufficient heat to affect the properties of the specimen. When sheet material is used, the test specimens obtained from another piece cut from the same coil or sheet used in the proof tested component meet the requirements of this paragraph.

TT-330.4 MAXIMUM ALLOWABLE WORKING PRESSURE AT HIGHER TEMPERATURES

The MAWP for tanks and tank parts that are to operate at temperatures at which the allowable stress value of the material is less than at the test temperature shall be determined by the following equation:

$$P_o = P_t \frac{S}{S_2}$$

where

P_o = maximum allowable working pressure at the design temperature, MPa (psi)

P_t = maximum allowable working pressure at the test temperature, MPa (psi)

S = maximum allowable stress value at the design temperature, as given in the tables referenced in TD-210, MPa (psi)

S_2 = maximum allowable stress value at test temperature as given in the tables referenced in TD-210, MPa (psi)

TT-340 PROCEDURES

TT-340.1 APPLICATION OF PRESSURE

In the procedure given in TT-340.3, the hydrostatic pressure in the tank or tank part shall be increased gradually until approximately one-half the anticipated working pressure is reached. Thereafter, the test pressure shall be increased in steps of approximately one-tenth or less of the anticipated MAWP until the pressure required by the test procedure is reached.

TT-340.2 CORROSION ALLOWANCE

The test procedures in this paragraph give the MAWP for the thickness of material tested. The thickness of the pressure tank that is to be proof tested should be the corroded thickness. When this is not practical and when the thickness as tested includes extra thickness as provided in TD-130, the MAWP at which the tank shall be permitted to operate shall be determined by multiplying the MAWP obtained from the test by the ratio

$$\frac{(t - c)^n}{t^n}$$

where

c = allowance added for corrosion, erosion, and abrasion, in.

n = 1 for curved surfaces such as parts of cylinders, spheres, cones with angle a equal to or less than 60 deg; for stayed surfaces similar to those described in Part TF, and parts whose stress due to bending is equal to or less than 67% of the total stress

= 2 for flat or nearly flat surfaces, such as flat sides, flanges, or cones with angle a greater than 60 deg (except for stayed surfaces noted above) unless it can be shown that the stress due to bending at the limiting location is less than 67% of the total stress

t = nominal thickness of the material at the weakest point, in.

TT-340.3 BURSTING TEST PRESSURE

(a) This procedure may be used for tanks or tank parts under internal pressure when constructed of any material permitted to be used under the rules of this Section. The MAWP of any component part proof tested by this method shall be established by a hydrostatic test to failure by rupture of a full-size sample of such pressure part. The hydrostatic pressure at which rupture occurs shall be determined. Alternatively, the test may be stopped at any pressure before rupture that will satisfy the requirements for the desired MAWP.

(b) The maximum allowable working pressure P in MPa (psi) at test temperature for parts tested under this paragraph shall be calculated by one of the following equations:

(1) parts constructed of materials other than cast materials:

$$P = \frac{B}{4} \times \frac{S_u E}{S_{u\text{ avg}}} \text{ or } P = \frac{B}{4} \times \frac{S_u}{S_{ur}}$$

(2) parts constructed of cast materials, except cast iron and ductile iron:

$$P = \frac{Bf}{4} \times \frac{S_u E}{S_{u\text{ avg}}} \text{ or } P = \frac{Bf}{4} \times \frac{S_u}{S_{ur}}$$

where

B = bursting test pressure, or hydrostatic test pressure at which the test was stopped, psi

E = efficiency of welded joint, if used (see Table TW-130.4)

f = casting quality factor as specified in TM-150.6

S_u = specified minimum tensile strength at room temperature, MPa (psi)

$S_{u\text{ avg}}$ = average actual tensile strength of test specimens at room temperature, MPa (psi)

S_{ur} = maximum tensile strength of range of specification at room temperature, MPa (psi)

The MAWP at other temperatures shall be determined as provided in TT-310.

ARTICLE TT-4
REQUIREMENTS FOR ELASTOMERIC LINING TEST

TT-400 GENERAL

Tanks lined with an elastomeric lining shall be inspected in accordance with the requirements of this Article when required by the Modal Appendices. Procedures for performing this test shall be written using the lining Manufacturer's instructions and the requirements of this Article. Personnel performing this test shall be trained in the procedure and equipment used, as well as the requirements of this Article. Personnel qualifications shall be certified by the Employer.

TT-400.1 EQUIPMENT

The following equipment is required to test the elastomeric linings of tanks:

(a) high frequency spark test machine capable of sufficient voltage with sufficient cable.

(b) an L-shaped probe of 2.4 mm ($^3/_{32}$ in.) diameter with a maximum bottom leg length of 300 mm (12 in.).

(c) a calibration block measuring 300 mm × 300 mm (12 in. × 12 in.) covered with the same elastomer to be tested and applied to the same thickness as the tank lining. The calibration block liner shall be pierced to produce a test hole of at least 22-gauge diameter.

TT-400.2 TEST CONDITIONS

(a) Prior to performing the test on the tank, the equipment shall be calibrated using the calibration block. The probe shall be in constant motion. The voltage should be adjusted to the lowest setting that will produce a 13 mm ($^1/_2$ in.) spark at the pierced hole. The spark will be white or light blue.

(b) While performing the tank test, the equipment shall be periodically validated against the calibration block using the same block, power source, probe, settings, and cable length.

(c) While performing the test, the probe must be kept in constant motion to prevent overheating the lining. A slow steady motion is required to ensure proper coverage.

TT-400.3 RESULTS

(a) Any voids detected require removal of the lining at the defect and an examination of the tank shell to inspect for corrosion and remaining metal thickness.

(b) Welded repairs shall be accomplished in accordance with this Code.

(c) The elastomeric lining shall be repaired in accordance with the manufacturer instructions and reexamined in accordance with this Article.

PART TR
PRESSURE RELIEF DEVICES

All Section XII pressure relief device requirements have been transferred from Part TR to Section XIII, and the remaining Section XII overpressure protection requirements have been restructured within the new Part TOP.

PART TOP
OVERPRESSURE PROTECTION

ARTICLE TOP-1
GENERAL REQUIREMENTS

TOP-100 GENERAL

(a) This Part provides the acceptable methods and requirements for overpressure protection for transport tanks constructed to the requirements of this Section. Acceptable methods include pressure relief devices and open flow paths. This Part establishes the type, quantity, and settings of acceptable pressure relief devices and relieving capacity requirements, including maximum allowed relieving pressures. Unless otherwise specified, the required pressure relief devices shall be constructed, capacity certified, and bear the ASME Certification Mark in accordance with Section XIII. In addition, this Part provides requirements for installation of pressure relief devices.

(b) All transport tanks within the scope of this Section, irrespective of size or pressure, shall be provided with overpressure protection in accordance with the requirements of this Part and the applicable modal appendix.

(c) Regulatory authorities issuing national and international codes and regulations governing the requirements for the use of transport tanks (such as IMDG, TDG, ADR/RID, RINA, 49 U.S. CFR, and Canadian CTC) may specify different operating characteristics for pressure relief devices (i.e., set points and capacity requirements) used for various modal applications. In cases where the codes and/or regulations governing these operating characteristics conflict with or exceed the requirements of this Section, the applicable regulatory requirements for the subject transport tank shall govern the selection and application of such devices.

(d) A secondary relief device may be provided as specified by the applicable modal appendix.

(e) As an alternative to the requirements of this Section, pressure relief devices bearing the ASME Certification Mark with the UV Designator in accordance with Section XIII may be used for Section XII applications if they meet the additional requirements of Section XII, particularly the modal appendices.

TOP-110 DEFINITIONS

Unless otherwise defined in this Section, the definitions relating to pressure relief devices in Section XIII shall apply.

competent authority (CA): a local or national agency responsible under law for the control or regulation of a particular aspect of the transportation of hazardous materials (dangerous goods).

gas: substances having a vapor pressure greater than 300 kPa (40 psia) at 40°C (100°F).

TOP-120 RESPONSIBILITIES (25)

Except as permitted by the applicable modal appendix

(a) It is the responsibility of the User or the User's designated agent to determine the required relief rate, size and select the device, and design the relief system.

(b) It is the responsibility of the User to ensure that the required overpressure protection is properly installed prior to initial operation.

(c) It is the responsibility of the User and transport tank Manufacturer or its designated agent to size and select the pressure relief device(s) based on its intended service. Intended service consideration shall include, but not necessarily be limited to, the following:

(1) normal operating and upset conditions
(2) fluids
(3) fluid phases

The overpressure protection system shall be supplied by the transport tank Manufacturer unless all details pertinent to the design of the pressure relief system, like size and configuration of the inlet and outlet piping, insulation system of the tank, if any, material of piping, etc., are furnished to the entity that is designing and installing the pressure relief system. "Transport tank" or "tank" is an all-inclusive term comprising pressure vessel, service equipment, and external structural components.

TOP-130 DETERMINATION OF PRESSURE-RELIEVING REQUIREMENTS

(a) Except as permitted by the applicable modal appendix, it is the responsibility of the User/Manufacturer or the User's/Manufacturer's designated agent to identify all potential overpressure scenarios and the method of overpressure protection used to mitigate each scenario.

(b) The aggregate capacity of the pressure relief devices connected to any transport tank or system of tanks for the release of a liquid, air, steam, or other vapor shall be sufficient to carry off the maximum quantity that can be generated or supplied to the attached equipment without permitting a rise in pressure within the tank of more than that specified in TOP-140.

(c) Transport tanks covered by this Section shall not be subjected to pressure exceeding the maximum pressure allowed in the applicable modal appendix, except as noted in (e).

(d) Calculation of required pressure relief capacity should consider fire engulfment and comply with the most restrictive requirements of the regulatory authority authorizing use of the tank.

(1) Normally, the required relief capacity for liquids will be based on the uninsulated surface area of the tank.

(2) Required capacity for liquefied compressed gases and compressed gases is calculated for the specific gas in a specific tank.

(e) There are certain dangerous goods that may experience unacceptable pressures due to conditions that may occur during normal transit, requiring special provisions for overpressure protection and safe transport to be issued by the cognizant regulatory authorities. Where these regulatory requirements conflict or exceed the requirements of this Section, the requirements of the regulatory authority shall govern the selection and application of pressure relief devices.

TOP-140 OVERPRESSURE LIMITS

(a) The pressure at which the pressure relief device is fully opened for a specific transport tank shall be as set forth in the applicable modal appendix. Pressure relief devices shall be selected and set to prevent exceeding this pressure.

(b) A combination relief device shall have the pressure relief valve set per TOP-160 and the applicable modal appendix.

(c) The requirements of the applicable modal appendix shall also be met.

TOP-150 PERMITTED PRESSURE RELIEF DEVICES

TOP-150.1 PRESSURE RELIEF VALVES

(a) Pressure relief valves bearing the ASME Certification Mark with the TV Designator in accordance with Section XIII may be used for overpressure protection. Pressure relief valves shall be of the direct-acting, spring-loaded type.

(b) Pressure relief valves bearing the ASME Certification Mark with the UV Designator in accordance with Section XIII may be used in transport tank service, provided that the tank Manufacturer or User of the tank has determined them to be suitable for the intended service application. Suitability shall be determined based on the temperatures, pressures, and compatibility with the goods transported in the specific application.

TOP-150.2 NONRECLOSING PRESSURE RELIEF DEVICES

(a) Rupture disk and pin devices bearing the ASME Certification Mark with the TD Designator in accordance with Section XIII may be used as the sole pressure-relieving device on the transport tank under the provisions of (c).

(b) Rupture disk or pin devices bearing the ASME Certification Mark with the UD Designator in accordance with Section XIII may be used in transport tank service, provided that the Manufacturer or User of the tank has determined them to be suitable for the intended service application. Suitability shall be determined based on the temperatures, pressures, and goods transported in the specific application. When using rupture disk devices, the User shall provide the margin between tank-operating pressure and rupture-disk-bursting pressure recommended by the rupture disk Manufacturer to reduce the potential for premature activation of the rupture disk. The use of a single rupture disk that responds to both overpressure and underpressure, or two separate rupture disks designed to independently relieve overpressure and underpressure, should be considered when there is the potential for tank failure from vacuum as well as overpressure conditions.

When using pin devices, the User shall provide the margin between tank-operating pressure and pin activation force recommended by the pin Manufacturer to reduce the potential for premature activation of the pin. The use of a single pin that responds to both overpressure and underpressure, or two separate pins designed to independently relieve overpressure and underpressure, should be considered when there is the potential for tank failure from vacuum as well as overpressure conditions.

(c) Nonreclosing pressure relief devices shall be used only as part of a combination relief device, except where their use as the sole overpressure protection device is specifically authorized by the competent authority(ies) with jurisdiction over the tank's operation. The design of the combination pressure relief device system shall be such that upon operation of the nonreclosing pressure relief device, the function of the pressure relief valve is not adversely affected.

(d) Rupture disk and pin devices may be installed between a pressure relief valve and the tank, provided they meet the requirements of Section XIII, Part 8.

(e) A rupture disk or pin device shall not be installed on the discharge side of a pressure relief valve.

TOP-160 PRESSURE SETTING AND PERFORMANCE REQUIREMENTS

(a) The set pressure of the pressure relief device(s) shall be as set forth in the applicable modal appendix.

(b) The set pressure of a pressure relief device shall not be adjusted outside the range of set pressure specified by the device Manufacturer. The initial adjustment shall be performed by the Manufacturer, its authorized representative, or an Assembler, and a valve data tag shall be provided that identifies the set pressure capacity and date. The valve's means of adjustment, if present, shall be sealed with a seal identifying the Manufacturer, its authorized representative, or the Assembler performing the adjustment.

(c) The set pressure tolerances of pressure relief valves shall not exceed ±15 kPa (±2 psi) for pressures up to and including 500 kPa (70 psi) and ±3% for pressures above 500 kPa (70 psi).

(d) Every nonreclosing pressure relief device shall have a marked burst pressure established by the rules of Section XIII, 4.5.2(a) within a manufacturing design range at a specified temperature and shall be marked with a lot number. The burst pressure tolerance at the specified temperature shall not exceed ±15 kPa (±2 psi) for marked burst pressures up to and including 300 kPa (40 psi), and ±5% for marked burst pressures above 300 kPa (40 psi) unless other requirements are identified by the competent authority or by the modal appendices.

TOP-170 INSTALLATION

(a) Pressure relief device(s) intended for gas/vapor service on tanks permanently mounted in a frame or on a vehicle shall

(1) have the inlet of the pressure relief device(s) located such that it communicates with the vapor space of the tank. The vapor space is typically at or near the top center of the tank but not in all cases, such as, but not limited to, CO_2 and NO_2 cargo tanks.

(2) be readily acceptable for testing, inspection, replacement, and repair.

(3) be installed to minimize the potential for damage or otherwise being rendered inoperable during expected operating conditions.

(b) The opening through all pipe, fittings, and nonreclosing pressure relief devices (if installed) between a transport tank and its pressure relief devices shall have at least the area of the pressure relief valve inlet. The 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 relief devices. The opening in the transport tank wall shall be designed to provide unobstructed flow between the tank and its pressure relief devices.

(c) When two or more required pressure relief devices are placed on one connection, the inlet internal cross-sectional area of this connection shall be either sized to avoid restricted flow to the pressure relief devices or made at least equal to the combined inlet areas to the pressure relief devices connected to it. The flow characteristics of the upstream system shall satisfy the requirements of (b) above.

(d) There shall be no intervening stop valves between the transport tank and its pressure relief device or devices, or between the pressure relief device and the point of discharge. Any diverter valve used in the pressure relief system shall, at all positions, provide the minimum flow area or flow coefficient, C_v, used for it in the pressure drop calculations of the pressure relief system of the tank.

(e) The pressure relief devices on all transport tanks shall be installed so that their proper functioning will not be hindered by the transport tank's contents.

(f) Discharge lines from pressure relief devices shall be designed to facilitate drainage or shall be fitted with drains to prevent liquid from lodging in the discharge side of the pressure relief 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 pressure relief devices below that required to properly protect the transport tank, or adversely affect the proper operation of the pressure relief devices. (See Section XIII, 3.2.2 and the applicable modal appendix.)

(g) Materials shall be selected to minimize deterioration from exposure to the ambient atmosphere or goods transported.

(h) The design of the pressure relief device or its installation configuration shall not allow accumulation of rainwater or debris into outlet openings, potentially interfering with the pressure relief device operation.

(i) Following installation of a rupture disk marked with only a lot number in accordance with Section XIII, 4.7.1(b), the metal tag shall be sealed to the installation in a manner that will prevent removal of the disk without breaking the seal. The seal shall identify the organization responsible for performing the installation.

PART TS
STAMPING, MARKING, CERTIFICATION, REPORTS, AND RECORDS

ARTICLE TS-1
CONTENTS AND METHOD OF STAMPING TRANSPORT TANKS

(25) TS-100 REQUIRED MARKINGS

Each transport tank to which the Certification Mark is applied shall be marked with the following:

(a) the official Certification Mark with T Designator shown in Figure TS-100.

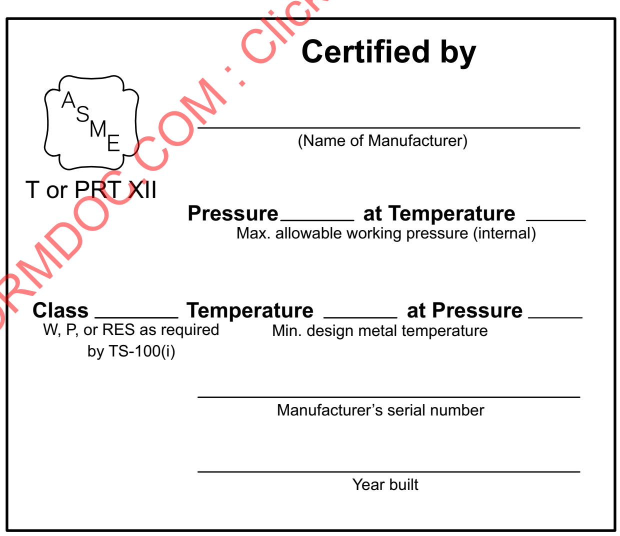
(b) the name of the Manufacturer of the transport tank, preceded by the words "Certified by."

(c) the maximum allowable working pressure ____ at temperature ____. When a transport tank is expected to operate at more than one pressure and temperature, other values of coincident pressure and design temperature may be added, such as external pressure. This is not required for parts.

(d) the minimum design metal temperature ____ at pressure ____.

(e) the Manufacturer's serial number.

(25) **Figure TS-100**
Form of Stamping



(f) the year built.

(g) the T or PRT XII Designator, indicated directly under the Certification Mark.

(h) the vessel Class shall be indicated directly under the T Designator by applying the appropriate Class number based on the applicable Modal Appendix used for construction as follows:

Vessel Class
CLASS 1
CLASS 2
CLASS 3

(i) The type of construction used for the vessel shall be indicated directly under the vessel Class by applying the appropriate letter(s) as follows: vessels having Category A, B, or C joints (except nozzles or other openings and their attachments) in or joining parts of the vessel:

Type of Construction	Letter(s)
Arc or gas welded	W
Cold-stretching	CS
Pressure welded (except resistance)	P
Resistance welded	RES

Vessels embodying a combination of types of construction shall be marked to indicate all of the types of construction used.

(j) the maximum allowable working pressure and temperature to be indicated on transport tanks embodying a combination of types of construction and material shall be based on the most restrictive detail of construction and material used.

(k) when a transport tank has been radiographed in accordance with Part TE, marking shall be applied under the type of construction as follows:

(1) "RT-1" when all pressure-retaining butt welds, other than Categories B and C butt weld associated with nozzles and communicating chambers that neither exceed DN 250 (NPS 10) nor 29 mm ($1^1/_8$ in.) wall thickness, except as required by TE-230.5, have been radiographically examined for their full length in the manner prescribed in TE-230.1(a); full radiography of the above exempted Categories B and C butt welds, if performed, may be recorded on the Manufacturer's Data Report

(2) "RT-2" when the completed transport tank satisfies the requirements of TE-230.1(a)(4)(-a) and when the spot radiography requirements of TE-230.1(a) and TE-230.1(a)(4)(-b) have been applied

(3) "RT-3" when the completed transport tank satisfies the spot radiography requirements of TE-230.1(b)

(4) "RT-4" when only part of the completed transport tank has satisfied the radiographic requirements of TE-230.1(a) or where none of the markings "RT-1," "RT-2," or "RT-3" are applicable.

The extent of radiography and the applicable joint efficiencies shall be noted on the Manufacturer's Data Report.

(l) The letters "HT" shall be applied under the radiography mark when the complete vessel has been postweld heat treated as provided in TF-700.

(m) The letters "PHT" shall be applied under the radiography mark when only part of the complete vessel has been postweld heat treated.

The extent of the postweld heat treatment shall be noted on the Manufacturer's Data Report.

(25) TS-100.1 METHODS OF MARKING

The required marking shall be applied to the vessel by one of the following methods:

(a) attaching a nameplate as provided in TS-130

(b) stamping directly on the vessel under the following conditions:

(1) General. Unless the requirements of (2) or (3) are met, stamping shall not be used on vessels constructed of steel plates less than 6 mm ($^1/_4$ in.) thick or of nonferrous plates less than 13 mm ($^1/_2$ in.) thick but may be used on vessels constructed of thicker plates.

(2) For Ferrous Materials

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

(-b) The minimum nominal plate thickness shall be 5 mm (0.1875 in.), or the minimum nominal pipe wall thickness shall be 4 mm (0.154 in.).

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

(3) For Nonferrous Materials

(-a) The materials shall be limited to aluminum as follows: SB-209 alloys 3003, 5083, 5454, and 6061; SB-241 alloys 3003, 5083, 5086, 5454, 6061, and 6063; and SB-247 alloys 3003, 5083, and 6061.

(-b) The minimum nominal plate thickness shall be 6.30 mm (0.249 in.), or the minimum nominal pipe thickness shall be 3.38 mm (0.133 in.).

(c) electrochemically etching, including the Certification Mark, directly on the vessel under the following conditions:

(1) The electrochemically etched marking is acceptable to the user.

(2) The material of construction shall be limited to high alloy steels and nonferrous materials.

(3) The process controls for electrochemical etching shall be described in the Quality Control System and shall be acceptable to the Authorized Inspector. The process controls shall be established so that it can be demonstrated that the characters will be at least 0.102 mm (0.004 in.) deep.

(4) The external vessel-surface condition where electrochemical etching is acceptable shall be clean, uncoated, and unpainted.

(5) The electrochemical etching shall not result in any detrimental effect on the materials of the vessel.

TS-100.2 METHODS OF MARKING MULTICOMPARTMENT TRANSPORT TANKS

The requirements of either (a) or (b) shall be applied when marking tanks having two or more independent pressure compartments designed for the same or different operating conditions.

(a) The markings may be grouped in one location on the tank, provided they are arranged so as to indicate clearly the data applicable to each compartment, including the maximum differential pressure for the common elements, when this pressure is less than the higher pressure in the adjacent compartments.

(b) The complete markings may be applied to each independent compartment. In addition to the marking information stated in TS-100, the maximum pressure differential for pressure-retaining elements common to more than one pressure compartment shall be included. This differential pressure may be greater or lesser than the pressure rating for the adjacent pressure compartment.

TS-100.3 LOCATION OF MARKINGS

(a) The markings required by TS-100 shall be stamped on a nameplate attached in a readily accessible location.

(b) An additional nameplate containing identical markings may be attached to the support, jacket, or other permanent attachment for greater access or visibility. The additional nameplate shall be marked "Duplicate" above the required markings. The stamping and attachment of this additional nameplate need not be witnessed by the Inspector, but shall be verified to correspond with the required markings prior to completion of the Manufacturer's Data Report.

(25) TS-110 MARKING OF PARTS

TS-110.1 REQUIRED MARKING

Parts of transport tanks for which Partial Data reports are required in TS-310, shall be marked by the parts Manufacturer with the following:

(a) official Certification Mark shown in Figure TS-100 above the letters "PRT XII"

(b) Class (1, 2, or 3)

(c) name of the manufacturer of the tank part, preceded with the words "Certified by"

(d) Manufacturer's serial number

Parts may be stamped with the Certification Mark without being pressure tested prior to shipment. If testing was not performed, it shall be noted in the "Remarks" section of the Manufacturer's Partial Data Report.

These requirements do not apply to standard pressure parts such as handhole covers, manhole covers, and other components supplied under the provisions of TG-130.

TS-110.2 ALTERNATIVE MARKING REQUIREMENTS

As an alternative to nameplates or stamping, parts 125 mm (5 in.) O.D. and under may be marked with an identification acceptable to the Inspector and traceable to the Manufacturer's Partial Data Report Form. Such marking shall be of a type that will remain visible until the parts are installed. The Certification Mark is not required.

A nameplate furnished with the Certification Mark on prefabricated or preformed parts may be removed from the completed pressure vessel if the following conditions are satisfied:

(a) The nameplate interferes with further fabrication or service.

(b) The Manufacturer of the completed vessel has an agreement with the Authorized Inspector to remove the nameplate.

(c) The removal of the nameplate shall be noted in the "Remarks" section of the vessel Manufacturer's Data Report.

(d) The removed nameplate shall be destroyed.

TS-120 APPLICATION OF CERTIFICATION MARK

(a) The Manufacturer completing construction of a Code tank shall have a valid Certificate of Authorization for applying the Certification Mark. The Certification Mark shall be applied only with the authorization of the Inspector. Application of the Certification Mark, together with the Manufacturer's final certification of the Data Report, shall be the Manufacturer's confirmation that all applicable Code requirements have been met.

(b) Except as provided in TS-110(c), the Certification Mark shall be applied after the required final pressure test of the completed tank.

(c) The Certification Mark may be preapplied to a nameplate. The nameplate may be attached to the vessel after completion of fabrication, but before the final pressure test, provided the procedure for controlling the Certification Mark and attachment of the nameplate is described in the Manufacturer's Quality Control System.

TS-130 NAMEPLATES (25)

The markings required in TS-100 shall be applied to a separate nameplate permanently attached to the tank. Removal of the nameplate or its attachment hardware shall require the willful destruction of it.

TS-130.1 NAMEPLATE ATTACHMENT

Nameplates shall have permanent and legible markings. Nameplates may be attached by

(a) welding, brazing, or soldering

(b) tamper-resistant mechanical fasteners

(c) adhesive attachments (see Mandatory Appendix XI)

TS-130.2 STAMPING OF NAMEPLATE

The Certification Mark and the Manufacturer's serial number shall be stamped on the nameplate unless process controls for mechanical etching or laser annealing by the Manufacturer of the certified vessel have been described in the accepted Quality Control System and approved by the Authorized Inspector. The other required data may be produced by stamping, casting, etching, embossing, debossing, engraving, or laser annealing. The characters shall be not less than 4 mm ($^5/_{32}$ in.) high, excluding characters for pressure relief device markings, which may be smaller. Characters produced by processes other than laser annealing shall be either indented or raised at least 0.10 mm (0.004 in.). Laser annealing is allowed only on stainless steel and aluminum. No coating that obscures the laser annealing marking shall be allowed. The arrangement shall be substantially shown as in Figure TS-100.

TS-130.3 VERIFICATION OF NAMEPLATE DATA

If the nameplate is marked and the Certification Mark applied before it is affixed to the vessel, the Manufacturer and the Inspector shall verify that the nameplate markings are correct for the vessel to which it will be attached.

ARTICLE TS-2
OBTAINING AND APPLYING CERTIFICATION MARKS TO TRANSPORT TANKS

TS-200 CERTIFICATION MARKS

A Certificate of Authorization to apply the Certification Mark with T or PRT XII Designator shown in Figure TS-100 to completed tanks and/or parts will be granted by the Society pursuant to the provisions of the following paragraphs. Stamps for applying the Certification Mark shall be in accordance with ASME CA-1.

TS-200.1 APPLICATION FOR AUTHORIZATION

Any organization desiring a Certificate of Authorization shall apply to the ASME in accordance with the certification process of ASME CA-1. Application for a Certificate of Authorization shall comply with ASME CA-1.

TS-200.2 ISSUANCE OF AUTHORIZATION

Issuance of authorization shall be in accordance with ASME CA-1. Authorization to use Certification Marks may be granted, renewed, suspended, or withdrawn as specified in ASME CA-1 (see Nonmandatory Appendix D).

TS-200.3 INSPECTION AGREEMENT: DESIGNATED OVERSIGHT

The Manufacturer shall comply with the requirements of ASME CA-1 for designated oversight by use of the appropriate Inspection entity as defined in TG-430.

TS-200.4 QUALITY CONTROL SYSTEM

The Quality Control System shall be prepared to comply with the requirements of Mandatory Appendix I and ASME CA-1.

TS-200.5 EVALUATION FOR AUTHORIZATION AND SUBSEQUENT RENEWALS

(a) Before issuance or renewal of a Certificate of Authorization, the Manufacturer's facilities and organization are subject to a joint review in accordance with ASME CA-1. 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.

(b) Certificates of Authorization shall be in accordance with ASME CA-1 and state the scope of activities authorized, including tank class(es). 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.

(c) 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 demonstrate sufficient knowledge and capabilities to produce the Code items covered by the intended Certificate of Authorization. Fabrication functions may be demonstrated using current work, a mockup, or a combination of the two.

(d) 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 Classes 1, 2, and 3 vessels, the Qualified Inspector for Classes 2 and 3 vessels, and the ASME Designee for Class 3 vessels.

(e) For those areas where there is no competent authority, or where a competent authority 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 competent authority is the Manufacturer's inspection agency, the joint review and joint report shall be made by the competent authority and an ASME Designee selected by ASME.

TS-200.6 CODE CONSTRUCTION BEFORE RECEIPT OF CERTIFICATE OF AUTHORIZATION

Code construction before receipt of a Certificate of Authorization shall be in accordance with ASME CA-1.

TS-200.7 MULTIPLE, DUPLICATE PRESSURE VESSELS (25)

Manufacturers must possess Section XII, Class 1 or Class 2 Certificates of Authorization to fabricate multiple, duplicate pressure vessels. When such fabrication makes it impracticable for the Inspector to personally perform each of the Inspector's required duties,[12] the Manufacturer, in collaboration with the Inspector, shall prepare an inspection and quality control procedure setting forth, in complete detail, the method by which the requirements[12] of this Section will be maintained. This procedure shall be included in the Manufacturer's written Quality Control System. This procedure shall be submitted to and shall receive the acceptance of the Inspection Agency. It shall then be submitted by the Inspection Agency for written acceptance by the competent authority concerned and by an ASME Designee. Joint reviews shall include an ASME Designee. The inspection procedure shall be used in the plant of the named Manufacturer by the Inspection Agency submitting it and shall be carried out by an Inspector in the employ of that Inspection Agency. Any changes in this inspection and quality control procedure that affect the requirements of this Section are subject to review and acceptance by the parties required for a joint review. The Data Report for such a vessel shall include under "Remarks" the statement: "Constructed under the provisions of TS-200.7." Such certificate will identify the Certification Mark to be used and the type of shop and/or field operations for which authorization is granted (see Nonmandatory Appendix D).

ARTICLE TS-3
REPORT FORMS AND RECORD MAINTENANCE

TS-300 MANUFACTURER'S DATA REPORTS

A Manufacturer's Data Report, Form T-1A, Form T-1B, or Form T-1C, or Manufacturer's Partial Data Report shall be completed and signed by the Manufacturer and signed by the Inspector for each tank or part to be marked with the Certification Mark. For sample Data Report Forms and guidance in preparing Data Reports, see Nonmandatory Appendix C.

TS-300.1 DISTRIBUTION OF MANUFACTURER'S DATA REPORTS

(a) The Manufacturer shall

(1) furnish a copy of the Manufacturer's Data Report to the User, Assembler and, upon request, to the Inspector

(2) submit a copy of the Manufacturer's Data Report to the appropriate enforcement authority

(3) keep a copy of the Manufacturer's Data Report on file for a minimum of 10 yr

(b) In lieu of (a)(2) or (a)(3), the vessel may be registered with The National Board of Boiler and Pressure Vessel Inspectors, which will maintain the required Manufacturer's Data Report.

(25) TS-310 PARTIAL DATA REPORTS

(a) The parts Manufacturer shall indicate under "Remarks" the organization responsible for the design of the part. For guidance in preparing Partial Data Reports, see Nonmandatory Appendix C.

(b) Partial Data Reports for tank parts requiring inspection under this Section, which are furnished by other than the shop of the Manufacturer responsible for the completed tank, shall be completed by the parts Manufacturer and the Inspector in accordance with the requirements of this Section and shall be forwarded, in duplicate, to the Manufacturer of the complete tank (see TG-320.2). These Partial Data Reports, together with a final inspection of the completed tank, shall be sufficient for the Inspector to authorize and witness the application of a Certification Mark to the tank (see TS-120). When Form T-2A, Form T-2B, or Form T-2C is used, it shall be attached to the Form T-1A, Form T-1B, or Form T-1C prepared by the Manufacturer of the completed tank.

(c) Data Reports for those parts of a tank that are furnished by a parts Manufacturer to the User of an existing Code tank as replacement of repair parts, shall be executed on Form T-2A, Form T-2B, or Form T-2C by the parts Manufacturer and the Inspector in accordance with the requirements of this Section. A copy of the parts Manufacturer's Partial Data Report shall be furnished to the User or the User's designated agent and a copy shall be maintained in accordance with TS-300.1.

ARTICLE TS-4
SPECIAL REQUIREMENTS

TS-400 GENERAL

Tanks subject to the requirements of Modal Appendices shall meet the additional stamping requirements given in Articles TS-1 through TS-3, in addition to the requirements of the applicable Modal Appendix.

PART TP
REQUIREMENTS FOR REPAIR, ALTERATION, TESTING, AND INSPECTION FOR CONTINUED SERVICE

ARTICLE TP-1
GENERAL REQUIREMENTS AND RESPONSIBILITIES

TP-100 GENERAL

(a) The rules of this Article shall apply when it is necessary or desirable to repair or alter the pressure vessel of a transport tank within the scope of this Section. See Article TG-1 for the geometric scope for pressure boundary determination.

(b) The rules of this Article, supplemented by the Modal Appendices for a particular transport tank specification, describe the required compliance intervals, inspections, and tests for continued service of a pressure vessel.

(c) The Owner shall have the responsibility for performing the required inspections and tests for continued service of a pressure vessel.

(d) The Owner/User/Inspector may perform these inspections for repairs, alterations, and tests, provided the requirements of TG-440(c) are met.

(e) Inspections shall be performed by the Inspector specified in TG-430.

(f) Continued service inspections made by Users shall comply with the requirements of TG-440(b) or TG-440(c).

(g) Markings required to signify completion and acceptance of continued service inspections and tests may be as required by the competent authority. See TG-100.3.

TP-100.1 DEFINITIONS

alteration: any change to the original design and construction of a pressure vessel that affects its structural integrity or pressure-containing capability. This includes rerating for pressure or temperature.

corrosive: any lading that meets jurisdictional requirements for corrosive service or is shown through experience to be corrosive to the vessel.

repair: any welding done on a pressure vessel to return it to its original design and construction specification.

ARTICLE TP-2
REQUIREMENTS FOR REPAIRS AND ALTERATIONS

TP-200 GENERAL REQUIREMENTS

(a) All repairs and alterations to the pressure vessel of a transport tank shall be performed by organizations holding a National Board "R" Certificate of Authorization or the equivalent recognized by the competent authority and be in possession of the appropriate National Board Code Symbol Stamp or the equivalent recognized by the competent authority. Alternatively, organizations employing Owner/User/Inspectors and in possession of a valid Owner/User Certificate of Authorization issued by the National Board of Boiler and Pressure Vessel Inspectors or the equivalent recognized by the competent authority may repair and perform alterations on transport tanks owned and operated by the Owner/User Certificate of Authorization holder. See TG-440(c).

(b) All repairs and alterations shall be performed in accordance with the National Board Inspection Code (ANSI/NB-23) or the equivalent recognized by the competent authority (see TG-130).

(c) Where another competent authority has jurisdiction, see TG-100.3.

ARTICLE TP-3
REQUIREMENTS FOR TESTS AND INSPECTIONS

TP-300 GENERAL REQUIREMENTS

(a) A pressure vessel of a transport tank shall be subject to the tests and inspections prescribed in (b) through (e) prior to use

(1) if it shows evidence of leakage, internal or external corrosion, or any other condition that would render the vessel unsafe, including accident damage to the pressure boundary.

(2) if it is repaired or altered.

(3) if it has reached the end of its periodic inspection interval. (The inspection interval is defined in the appropriate Modal Appendix.)

(b) A pressure vessel for which a test or inspection required is due may not be filled and offered for transport until the test or inspection has been successfully completed. This does not apply to vessels filled prior to the test or inspection due date.

(c) A pressure vessel shall meet the acceptance criteria for the required tests and inspections.

(d) A pressure vessel meeting the acceptance criteria for the required tests and inspections shall be marked as required in TP-100.

(e) A pressure vessel that fails to meet the acceptance criteria of a required test or inspections specified in (a) shall be repaired and retested or be removed from service and the nameplate bearing the ASME Certification Mark removed.

ARTICLE TP-4
TESTS AND INSPECTIONS

TP-400 GENERAL

(a) This Article defines the types of inspections and tests required by this Article for pressure vessels that have been repaired, altered, or for continuation in service.

(b) The Owner or User shall be responsible for performing these inspections and tests.

TP-410 TYPES OF TESTS AND INSPECTIONS

TP-410.1 VISUAL INSPECTION

(a) External Visual Inspection. An external visual inspection shall include as a minimum the following:

(1) tank pressure boundary items for corroded or abraded areas, dents, distortions, and defects in welds and leakage

(2) all markings required by this Section

(3) thickness test for corroded or abraded areas

(4) results recorded as specified in this Article

(b) Internal Visual Inspection. An internal visual inspection shall include as a minimum the following:

(1) see (a)(1)

(2) lining inspections as specified in this Article

(3) thickness test for corroded or abraded areas

(c) Lining Inspection. A lining inspection shall include as a minimum the following:

(1) lining tests shall be performed in accordance with TT-400

(2) degraded or defective linings shall be removed and the tank wall visually inspected for corrosion and the thickness tested

(3) results of inspection recorded as specified in this Article

TP-410.2 THICKNESS TESTING

Thickness testing shall include the following requirements:

(a) Personnel performing the thickness testing shall be trained in the use of the equipment.

(b) Measurements shall be made using a device capable of measuring thickness to a tolerance of ±0.05 mm (±0.002 in.)

(c) Thickness testing shall be performed in the following areas of the transport tank wall, as a minimum:

(1) shell and heads

(2) high shell stress areas, such as the bottom center of the tank

(3) around openings

(4) areas around weld joints

(5) areas around shell reinforcements

(6) areas around appurtenance attachments

(7) areas near coupler and suspension attachments

(8) known thin areas

(9) connecting structures joining multiple cargo tanks of carbon steel in a self-supporting cargo tank motor vehicle

(d) The results of thickness tests shall be recorded as specified in this Article.

TP-410.3 PRESSURE TESTS

Each pressure vessel shall be pressure tested as follows when a repair or alteration is performed or when retesting is required (see TP-300).

(a) Prior to applying pressure the following must be performed:

(1) internal and external inspection of tank

(2) the internal inspection is waived if no manway is provided in the tank

(3) reclosing pressure relief devices must be removed and tested for set pressure and reseating or replaced

(4) the upper coupler assembly must be removed and the area covered inspected for defects, wear, and corrosion, and repaired if needed

(5) pressure vessels constructed of ferritic steels heat treated to enhance tensile properties and subject to stress corrosion cracking, such as those in anhydrous ammonia or propane service, shall be examined internally using the wet fluorescent magnetic particle method of NDE

(b) Each pressure vessel shall be hydrostatically tested in accordance with Part TT and the Modal Appendices; however, when a hydrostatic test is not practical or possible due to contamination of the tank or its contents, another test medium may be used. The hold time at test pressure shall be a minimum of 10 min.

(c) When the test pressure exceeds the set pressure of a pressure relief device, the device shall be removed or prepared for the pressure test as recommended by the device Manufacturer.

(d) Insulation jackets need not be removed for pressure testing if the required test pressure can be reached and maintained.

(e) Results of the tests shall be recorded as specified in this Article.

TP-410.4 LEAK TEST

(a) Each transport tank shall be tested for leaks at the frequency specified in the applicable Modal Appendix.

(b) The leak test shall include product piping with all valves and accessories in place and operative, except that any venting devices set to discharge at less than the leakage test pressure shall be removed or rendered inoperative during the test. All internal and external self-closing valves shall be tested for leak tightness. Each cargo tank of a multicargo tank motor vehicle must be tested with the adjacent cargo tanks empty and at atmospheric pressure.

(c) The test pressure shall be maintained for 5 min or longer.

(d) Transport tanks may be leak tested with the hazardous materials contained in the tank during the test.

(e) Transport tanks in liquefied compressed gas service shall be externally inspected for leaks during the leak test.

(f) Leak tests shall be conducted at a pressure not less than 80% of the MAWP as marked on the nameplate, except as follows:

(1) A transport tank with a MAWP of 690 kPa (100 psi) or more may be leak tested at its maximum normal operating pressure, provided it is in dedicated service or services.

(2) An MC 331 cargo tank in dedicated liquefied petroleum gas service or in dedicated anhydrous ammonia service may be leak tested at not less than 414 kPa (60 psi) .

(3) Cargo tanks used to transport petroleum distillate fuels equipped with vapor collection equipment may be leak tested in accordance with the Environmental Protection Agency's "Method 27 — Determination of Vapor Tightness of Gasoline Delivery Tank Using Pressure-Vacuum" as set forth in Appendix A to 40 CFR Part 63. This test method, if used, shall be performed with air. The hydrostatic alternative in Method 27 is not permitted.

(g) On MC 331 cargo tanks, the hose assembly and piping system shall be visually inspected while under leak test pressure. Delivery hose assemblies not permanently attached to the cargo tank motor vehicle may be tested and inspected separately from the cargo tank motor vehicle. The internal self-closing stop valves on MC 331 cargo tanks shall be tested for leak tightness using a meter creep test.

(h) A transport tank that fails to retain the leak test pressure shall not be returned to service as a specification cargo tank unless repaired, retested, and inspected. See TP-300(e) for other requirements.

(i) The Inspector shall record the results of the leak test as required in TP-600.

ARTICLE TP-5
CRITERIA FOR TESTS AND INSPECTIONS

TP-500 GENERAL

The following rules shall be applied. However, the competent authority may impose additional requirements (see TG-100.3).

(a) For corroded areas, the remaining thickness may be evaluated as an local thin area (LTA) using the method given in (b).

(b) LTAs may be evaluated in accordance with the procedures in API Recommended Practice 579 (see TG-130) or equivalent method. The remaining strength factor (RSF) shall be not less than 0.90.

(c) Dents in the pressure boundary that include welds shall not exceed a depth of 13 mm ($^1/_2$ in.). For other dents away from welds, the maximum allowable depth is $^1/_{10}$ of greatest dimension of the dent but in no case shall exceed 25 mm (1 in.).

(d) Gouges may be repaired by blending so the width of the blending is at least three times the maximum depth around the full periphery of the gouge. Gouges may then be evaluated as an LTA in accordance with (b).

(e) Weld defects such as cracks, pinholes, or incomplete fusion are not acceptable and shall be repaired prior to placing in service.

(f) Any defect in liner integrity is not acceptable and shall be repaired in accordance with industry standards.

(g) Any pressure vessel that fails the required pressure test or shows permanent distortion shall be repaired and retested.

ARTICLE TP-6
REPORTS AND RECORDS

TP-600 REPORTS AND RECORDS

The Owner shall maintain a record of each test and inspection that includes the following:

(a) type of test or inspection performed and a list of the items tested and inspected

(b) Manufacturer's serial number or National Board number of the pressure vessel

(c) tank designation (e.g., DOT 406, etc.)

(d) test date

(e) location of defects found and repair method for each pressure vessel

(f) results and evaluations of tests and inspections

(g) name and credential of Inspector

(h) disposition statement

(i) ASME Manufacturer's Data Report

The Owner/User shall maintain these records on file for a minimum of 5 yr unless otherwise required by the competent authority.

MODAL APPENDIX 1
CARGO TANKS

ARTICLE 1
GENERAL

1-1.1 SCOPE

This Appendix applies to cargo tanks carrying hazardous materials with MAWPs not exceeding 34.5 bar (500 psi). There are five categories of tanks under this classification, which are circular in cross section except as noted, as follows:

(a) Category 406 is for tanks with circular or noncircular cross section subject to MAWPs not exceeding 0.276 bar (4 psi). The minimum design pressure shall be 0.183 bar (2.65 psi). These tanks are not allowed for external pressure loading. All Category 406 tanks are Class 3 tanks. Article 2 covers specific requirements for these tanks.

(b) Category 407 is for tanks subject to MAWPs not exceeding 6.90 bar (100 psi). These tanks shall be designed for a minimum MAWP of 1.72 bar (25 psi) and, if subject to vacuum loading, shall be designed for at least 1.03 bar (15 psi) external pressure. Category 407 tanks with MAWP over 2.41 bar (35 psi) are Class 1 tanks. All others are Class 3 tanks. Article 2 covers the specific requirements for these tanks.

(c) Category 412 is for tanks subject to MAWPs up to 6.90 bar (100 psi) with a minimum MAWP of 0.345 bar (5 psi). These tanks are of circular cross section except that, for MAWPs ≤1.03 bar (15 psi), they may be of noncircular cross section. Category 412 tanks >1.03 bar (15 psi) MAWP are Class 1 tanks, and those ≤1.03 bar (15 psi) MAWP are Class 3 tanks. Article 2 covers the specific requirements for these tanks.

(d) Category 331 is for tanks primarily for transportation of compressed gases at MAWPs not exceeding 34.5 bar (500 psi). These tanks shall be designed for minimum MAWPs of at least 6.90 bar (100 psi) . All Category 331 tanks are Class 1 tanks. Article 3 covers the specific requirements for these tanks.

(e) Category 338 is for vacuum insulated tanks for products requiring MAWPs not exceeding 34.5 bar (500 psi). The minimum design MAWP shall be at least 1.75 bar (25.3 psi). These tanks are enclosed in an outer structural vacuum jacket. All Category 338 inner tanks are Class 1 tanks. Article 4 covers the specific requirements for these tanks. Paragraphs 1-1.3 through 1-1.11 shall not be used for Category 338 tanks.

1-1.2 DEFINITIONS (25)

appurtenance: any cargo tank accessory attachment that has no lading retention or containment function and provides no structural support to the cargo tank.

baffle: non-liquid-tight transverse partition device that deflects, checks, or regulates fluid motion in a tank.

bulkhead: liquid-tight transverse closure at the ends or between cargo tanks.

cargo tank: bulk packaging, namely a tank intended primarily for the carriage of liquids or gases. It includes appurtenances, reinforcements, fittings, and closures to a tank permanently attached to or forming a part of a motor vehicle. Because of its size, construction, or attachment to a motor vehicle, it is loaded or unloaded without being removed from the motor vehicle and is not fabricated under another specification. A cargo tank is a highway transport tank.

cargo tank manufacturer: entity that manufactures the primary lading retention structure of a cargo tank intended to transport hazardous materials.

cargo tank motor vehicle: motor vehicle with one or more cargo tanks permanently attached to or forming an integral part of the motor vehicle.

cargo tank motor vehicle intermediate manufacturer: entity who performs any functions that a CTMVM performs that require certification and supplies the CTMVM with certification required of the work it performed.

cargo tank motor vehicle manufacturer (CTMVM): entity that is engaged in the manufacture of the completed cargo tank motor vehicle who is responsible for certifying that it meets the requirements of the competent authority and includes the remount of an existing tank on a motor vehicle chassis.

cargo tank wall: those parts of a cargo tank that make up the primary lading retention structure including the shell, bulkheads, and fittings that, when closed during transport of lading, yields the minimum volume of the cargo tank assembly.

charging line: a hose, tube, pipe, or similar device used to pressurize a tank with material other than the lading.

companion flange: one of two mating flanges where the flange faces are in contact or separated by a thin leak sealing gasket and secured to each other by bolts or clamps.

connecting structure: the structure joining two cargo tanks.

construction thickness: the thickness of the cargo tank as actually built.

cryogenic cargo tank: a bulk tank used for transport of refrigerated liquids as listed in Article 4.

defined incident loading: a loading caused by a catastrophic occurrence such as an incident in which a cargo tank can be damaged even irreparably but will be considered to retain substantially its contents under the assumption that the stresses and deformations of the tank under such loadings do not exceed specified limits. This is based on the assumption of elastic or elastic–plastic behavior or qualification by certified test or analysis.

design certifying engineer: a qualified person approved as such by a competent authority to prepare, review, and certify cargo tank designs as meeting the requirements of said competent authority.

design type: one or more cargo tanks that are made

(a) by the same manufacturer

(b) to the same engineering drawings and calculations except for minor variations in piping that do not affect the lading retention capability of the cargo tank

(c) of the same materials of construction except for minor non–stress-bearing parts

(d) to the same cross sectional dimensions

(e) to a length including volume not varying more than 5%

(f) for Category 338 tanks only, with insulation providing the same or better thermal performance

(g) to the same specification

dump body: tank designed for hauling highly viscous lading or semisolids like emulsions or gels that are difficult to unload by pressure or gravity alone. These tanks are designed such that one end of the tank may be lifted via a hydraulic cylinder or similar device that is mounted to the chassis frame or subframe, if applicable, and the other end of the tank is secured by a hinge. The tank may be designed to be unloaded by pressure or gravity so that the tank is not full while being hoisted. The hinge and lift devices may be the devices securing the tank to the chassis.

emergency discharge control: means the ability to stop a cargo tank from unloading in the event of an unintentional product release.

exceptional inspection and test: inspections and tests necessary when a cargo tank shows evidence of damage, corroded areas, leakage, or other conditions indicating a deficiency that could affect the integrity of the cargo tank [i.e., the tank has been in an accident and damaged to an extent that may adversely affect its product retention capability, the tank has been out of hazardous materials transport service for 1 yr or longer, or the tank has been modified from its previous design specifications (see Article TP-2) or as otherwise directed by the competent authority]. The extent of the inspection and test shall depend on the amount of damage or deterioration of the cargo tank. It shall include at least the inspection and a pressure test as required for periodic testing. Pressure relief devices need not be tested or replaced unless there is reason to believe the relief devices have been affected by the damage or deterioration.

excess flow valve, integral excess flow valve, or excess flow feature: valve that will close automatically if the flow rate of the product through the valve reaches or exceeds the rated flow of product specified by the original valve manufacturer.

extreme dynamic loading: maximum single-acting loading a cargo tank might experience during its expected life excluding defined incident loadings.

flammable gases: gases that, at 20°C (68°F) and a standard pressure of 1.02 bar (14.7 psi), are ignitable when in a mixture of 13% or less by volume with air; or have a flammable range with air of at least 12 percentage points regardless of the lower flammable limit. (Flammability shall be determined by tests or by calculations in accordance with methods adopted by ISO 10156.)

gross vehicle weight (GVW): maximum loaded weight of a tank trailer with a hitch and front wheels or a fifth wheel mounted tank and its permanently attached running gear plus appurtenances without consideration of the tractor weight. The GVW of a truck mounted tank shall be the entire weight of the vehicle plus the loaded tank and its appurtenances.

inspection pressure: pressure used for leak testing.

lading: hazardous material contained in a cargo tank.

loading/unloading connection: fitting in the unloading line farthest from the loading/unloading outlet to which the loading/unloading hose or device is attached.

loading/unloading outlet: tank outlet used for normal loading/unloading operations.

loading/unloading stop-valve: stop-valve farthest from the tank loading/unloading outlet to which the loading/unloading connection is attached.

local stress: stress induced by a local load around the point of application and confined to that area.

minimum thickness: the greater of either of the following:

(a) the specified minimum thickness as mandated by these rules

(b) the required thickness (design thickness) determined from required loads and allowable stresses.

multi-specification cargo tank motor vehicle: cargo tank motor vehicle equipped with two or more cargo tanks fabricated to more than one cargo tank specification.

normal operating loading: loading a cargo tank may be expected to experience routinely in operation.

nozzle: subassembly consisting of a pipe or tubular section with or without a welded or forged flange on one end.

outlet: any opening in the shell or head of a tank (including the means for attaching a closure), except that the following are not outlets: a threaded opening securely closed with a threaded plug or threaded cap; a flanged opening securely closed during transportation with a bolted or welded blank flange, a manhole, or gauging devices; thermometer wells; and safety relief devices.

outlet stop-valve: stop-valve at the tank loading/unloading outlet.

periodic inspection and test: those inspections and tests conducted at intervals specified by the competent authority and include internal (unless exempted) and external examination and, unless exempted, a pressure test as specified in this definition. The pressure test may be hydrostatic or pneumatic using an inert gas to a pressure not less than the test pressure on the specification plate. The test shall be performed in accordance with Part TT of this section. During test, reclosing pressure relief devices, except line safeties, shall be removed from the tank and tested separately unless they can be tested while installed on the cargo tank.

periodic test pressure: the pressure at which the cargo tank shall be tested at intervals specified by the competent authority.

pipe coupling: a fitting with internal threads on both ends.

rear underride: structure designed to prevent a vehicle or object from underriding the rear of a motor vehicle.

rear-end tank protection device: structure designed to protect a cargo tank and any lading retention piping or devices in case of a rear-end collision.

refrigerated liquid: a material that has a boiling point not less than −90°C (−130°F) at atmospheric pressure.

sacrificial device: an element, such as a shear section designed to fail under load in order to prevent damage to any lading retention part or device. The device must break under strain at no more than 70% of the strength of the weakest piping element between the tank and the sacrificial device. Operation of the sacrificial device must leave the remaining piping and its attachment to the tank intact and capable of retaining lading.

self-closing stop-valve: stop valve held in the closed position by means of self-stored energy, which opens only by application of an external force and which closes when the external force is removed. When designated as external, the self-closing energy source is located outside the tank and the welded flange. When designated as internal, the stop-valve is designed so the self-stored energy source is located inside the tank or tank sump or within the welded flange, and the valve seat is located within the tank or within 1 in. of the external face of the welded flange or sump of the tank.

shear section: sacrificial device fabricated in such a manner as to reduce abruptly the wall thickness of the adjacent piping or valve material by at least 30%.

shell: pressure-retaining portion of the tank exclusive of heads and attachments.

sump: protrusion from the bottom of a tank shell designed to facilitate complete loading and unloading of lading.

tank vessel support structure: structure attached directly or through pads to the tank wall for the primary purpose of providing static or dynamic load bearing support of the tank.

vacuum tank: tank that is loaded by reducing the pressure in the tank to below atmospheric pressure.

variable specification cargo tank: cargo tank that is constructed in accordance with one specification, but that may be altered to meet another specification by changing relief devices, closures, lading discharge devices, and other lading retention devices.

1-1.3 MATERIALS

The materials allowed in the construction of the lading retention parts of tanks built under this specification are listed in Part TM. Except where otherwise required in this Modal Appendix or Mandatory Appendix II of this Section, the use of materials listed in Table TM-130.2-6 shall conform to the requirements of TM-180, TM-260, TW-130.7, TF-6, and TF-740 except that

(a) stiffeners, structures, or appurtenances welded directly to a tank wall constructed of SA-517 plate material; or SA-592 flange or forged materials shall be constructed of either of these materials, but pad material shall be SA-517 material of thickness no less than 6 mm (1/4 in.) and not greater than the thickness of the tank wall to which it is attached.

(b) all type 1 joints shall be designed and inspected according to the requirements of TW-130.4 of this Section.

(c) tank vessels shall be postweld heat treated to the requirements of TF-7 of this Section but in no case less than 566°C (1,050°F). All materials exposed to the lading shall be compatible with the lading.

1-1.4 DESIGN REQUIREMENTS COMMON TO MORE THAN ONE CATEGORY

(25)

1-1.4.1 CARGO TANK EVALUATION

(a) Each category of DOT 400 cargo tank shall conform to the design conditions outlined in this Section. The sum of the calculated stresses due to pressure, weight, and other sustained loadings shall be evaluated in accordance with allowable stresses given in TD-210 and Section II, Part D, Subpart 1, Table 1A or those obtained from the alternate criteria summarized in this Appendix. Rollover and transport g loadings need not be considered as acting concurrently. Allowable stress levels shall be based on one of the following:

(1) The maximum allowable stresses obtained from TD-210 for materials listed in Part TM.

(2) The specified yield stress and tensile stress obtained from Section II, Part D, Subpart 1, Table 1A for a Part TM material and the methods for establishing the allowable stresses given in the following sections.

(3) The actual material properties for the material used in each cargo tank may be established by a Material Test Report from the material Manufacturer as defined in III-2, and the methods for establishing the allowable stresses given in (4) through (8) below.

(4) Allowable stresses, both membrane and bending, for accident-loading conditions are defined in 1-1.6.

For pressure design using materials listed in TM-130, only allowable stresses listed in TD-210 are permitted except for the alternative criteria permitted in TD-440 for compressive stresses and this Modal Appendix. These alternative criteria apply to tanks having D_o/t ratios over 450 and length between supports greater than $7(D_o)$.

(5) When the Section II, Part D, Subpart 1, Table 1A tensile strength and yield strengths are used as the determining criterion for design temperatures equal to or colder than 66°C (150°F), the lower of the following shall be used:

(-a) the specified minimum tensile strength at room temperature divided by 3.5

(-b) two-thirds of the specified minimum yield strength at room temperature

If (-a) is the lower number, then tensile strength is the determining criterion; if (-b) is the lower number, then yield strength is the determining criterion.

(6) For Categories 406, 407, and 412 Class 3 tanks, where tensile strength is the determining criterion, the tensile strength used in the design shall not exceed that permitted by Section II, Part D or that permitted by the Figure 1-1.4(a)-1.

(7) Categories 406, 407, and 412 Class 3 tank shells not designed for external pressure and at design temperatures of 66°C (150°F) and below and having circumferential stiffeners spaced up to 1 520 mm (60 in.) can be designed to the rules of TD-440. When using the TD-440 rules, the allowable compressive design stress shall not exceed that permitted by Figure 1-1.4(a)-2 yield strength limits.

For noncircular tanks with flat areas subject to longitudinal compressive stresses where there is no radius of shell curvature, use the allowable tensile stress with an effective width of flat shell of $20T$ on each side of a longitudinal stiffener or circumferentially curved shell section as effective bending where T is the shell thickness. Longitudinal stiffeners or locally thicker shell can be used in high stress areas provided the length of such reinforced construction is sufficient to keep stresses at or below their allowable values.

(8) Nonmandatory examples of methods for establishing allowable stresses:

(-a) *Nomenclature*

S_{all} = controlling stress to be used in design, ksi
S_U = minimum specified tensile strength from Section II, Part D, Subpart 1, Table 1A, ksi
S_{UR} = tensile strength at room temperature from Material Test Report, ksi
S_Y = minimum specified yield strength from Section II, Part D, Subpart 1, Table 1A, ksi
S_{YR} = yield strength at room temperature from Material Test Report, ksi

EXAMPLES:

(1) Allowable stress based on TD-210 and Section II, Part D, Subpart 1, Table 1A values:

Given:

- Tank shell material is SA-240, Type 304
- Section II, Part D, Table 1A: S_U = 75 ksi, S_Y = 30 ksi

Problem: Is S_U or S_y or the determining criterion for design temperatures equal to or colder than 150°F? [75/3.5 = 21.43 ksi and 2/3(30) = 20 ksi.]

Solution: From Figure 1-1.4(a)-2, E_y = 20 ksi/20 ksi = 1.00 and therefore D_y = 1.00 and S_{all} = 20 ksi. Therefore, the yield strength is the controlling stress and S_{all} = 20 ksi.

(2) Allowable stress based on Material Test Report values:

Given:

– Tank shell material is SA-240, Type 304
– Section II, Part D, Table 1A: S_U = 75 ksi and S_Y = 30 ksi
– Values from Material Test Report: S_{UR} = 90 ksi and S_{YR} = 39 ksi

Problem: Is S_U or S_Y or the determining criterion for design temperatures equal to or colder than 150°F?

Solution:

– Material Test Report tensile strength = E_t = 90/75 = S_{UR}/S_U = 1.2; and from Figure 1-1.4(a)-1, D_t = 1.2 and S_{all} = $(D_t)(S_U/3.5)$ = 1.2(75/3.5) = 25.7 ksi
– Material Test Report yield strength = E_y = 34/30 = 1.13; and from Figure 1-1.4(a)-2, D_y = 1.13 and S_{all} = $D_y(S_Y/1.5)$ = 1.13(30/1.5) = 22.6 ksi.

Therefore, the yield is the controlling stress and S_{all} = 22.6 ksi

(3) Allowable stress based on Material Test Report values:

Given:

– Tank shell material is SA-240, Type 304
– Section II, Part D, Table 1A: S_U = 75 ksi and S_Y = 30 ksi
– Values from Material Test Report: S_{UR} = 81 ksi and S_{YR} = 44 ksi

Problem: Is S_U or S_Y or the determining criterion for design temperatures equal to or colder than 150°F?

Solution:

– Material Test Report tensile strength = E_t = 81/75 = S_{UR}/S_U = 1.08; and from Figure 1-1.4(a)-1, D_t = 1.08 and S_{all} = $(D_t)(S_U/3.5)$ = 1.08 (75/3.5) = 23.1 ksi
– Material Test Report yield strength = E_y = 44/30 = S_{YR}/S_Y = 1.47; and from Figure 1-1.4(a)-2, D_y = 1.32 and S_{all} = $D_y(S_Y/1.5)$ = 1.32 (30/1.5) = 26.4 ksi.

Therefore, the tensile is the controlling stress and S_{all} = 23.1 ksi.

NOTE: Circumferential and longitudinal compressive stresses where buckling is a design factor will result in lower allowable stresses than those determined by the methods above. See Article TD-2 and TD-440.

(b) Pressure Design. For tanks of circular cross section (all categories of tanks), including openings and reinforcements, the design rules of Part TD are applicable. For noncircular tanks (406 and 412 tanks only), the rules and limitations of Mandatory Appendix VIII are applicable. Noncircular tanks may be qualified by testing in accordance with Article TT-3. Minimum thicknesses for shells, heads, and baffles shall be not less than 2.5 mm (0.100 in.) for steel and 3.8 mm (0.151 in.) for aluminum.

(c) Loading Conditions. The loading conditions to be considered for Category 331, 406, 407, and 412 tanks shall be as indicated in Figure 1-1.4. Where high shear stresses and high normal stresses exist together, the maximum principal stresses shall not exceed the allowables of TD-210 as determined by the equations for maximum principal stresses that are as follows:

$$s_{smax} = \left[0.25(s_x - s_y)^2 + s_s^2\right]^{1/2}$$

$$s_{max} = 0.5\left(s_x + s_y\right) \pm s_{smax}$$

where

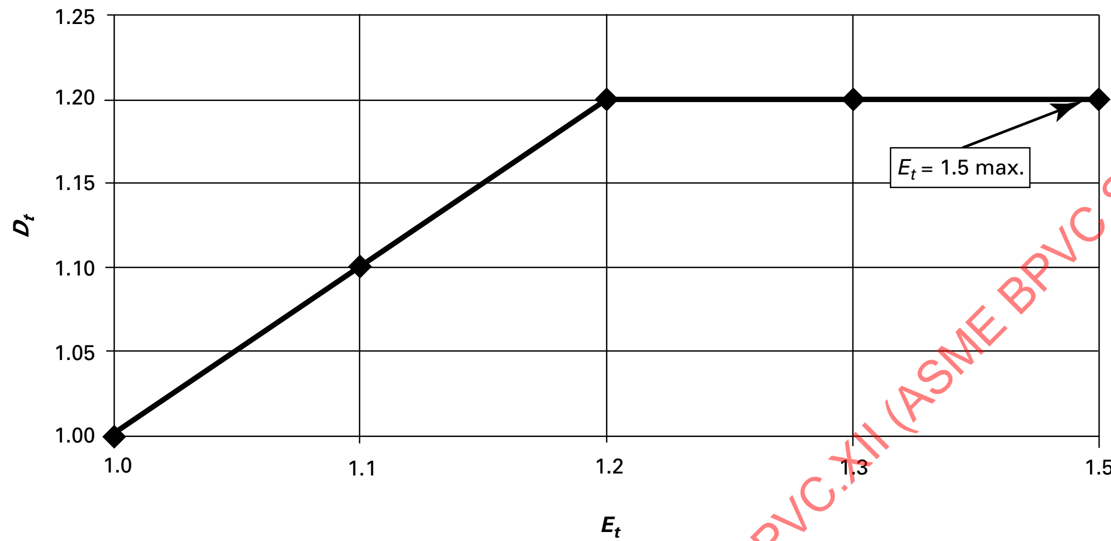
s_{max} = principal normal stress
s_s = shear stress in x and y planes
s_{smax} = principal shear stress
s_x = normal stress in x direction
s_y = normal stress in y direction

In addition to the loading conditions listed above, there are emergency loading and energy absorption conditions that must be met by tanks of all categories. The load conditions to be considered are described in (1) through (6). [For all load cases, evaluation shall include both internal MAWP and external MAWP (even if zero) conditions. Shell torsion and shear stresses shall be evaluated for transverse loads.]

(1) Static Load Condition A: the stationary tank fully loaded with lading subject to MAWP and supported by running gear. The loading condition for multicompartment tanks and single compartment tanks shall be those that cause the maximum shell bending moments as well as the maximum shear forces at supports. The weight of appurtenances attached to the tank shall be allowed for as well as the nonuniform weight distribution from a variable cross-section tank such as a double conical tank. The weight of the running gear need not be included in the load applied to bend the tank.

(2) Dynamic Load Condition B: the worst case loading condition of a fully loaded tank at MAWP subject to an incremental change in the vertical and longitudinal forces of ±35% of the tank weight ±20% of the tank weight in the transverse direction uniformly distributed. The longitudinal force shall be applied as a decelerative force (Condition B1) and as an accelerative force (Condition B2). The accelerative force will be applied at the fifth wheel, and the decelerative force will be applied entirely at the rear wheels (Condition B1a) and at the fifth wheel (Condition B1b). For truck mounted tanks, the longitudinal forces shall be applied at the mounts.

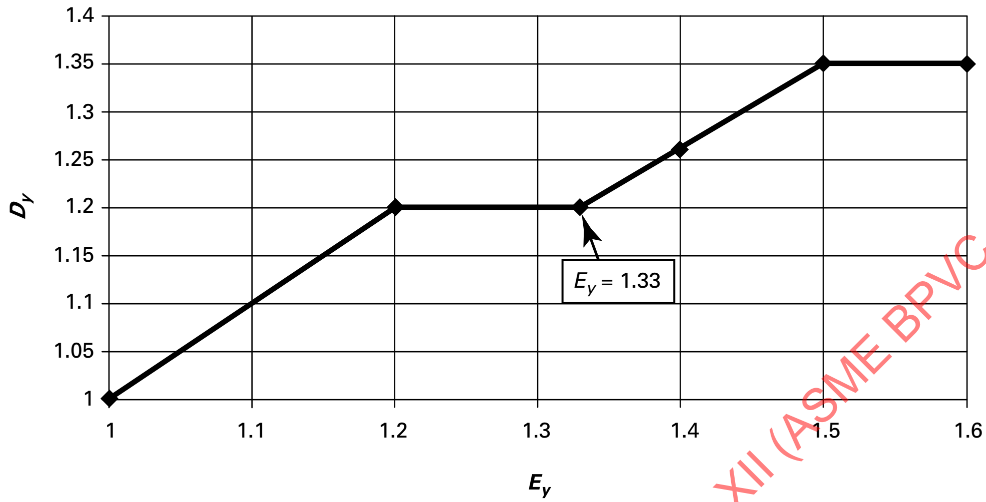
Figure 1-1.4(a)-1
Maximum Range for Tensile Strength Properties, for Categories 406, 407, and 412 Class 3 Tanks Where Allowable Tensile Strength Is the Determining Criterion for Allowable Tensile, and Compressive, Stresses, When Buckling (Article TD-4) Is Not Controlling



Legend:
D_t = (Design tensile strength)/(Section II, Part D tensile strength)
E_t = (Material Test Report tensile strength)/(Section II, Part D tensile strength)

GENERAL NOTES:
(a) Determine E_t, then detemine D_t from this Figure.
(b) Design tensile strength = D_t (Section II, Part D tensile strength).
(c) $1.0 \le E_t < 1.2$: $D_t = E_t$; $1.2 \le E_t \le 1.5$: D_t = 1.20 max.

Figure 1-1.4(a)-2
Maximum Range for Tensile Strength Properties, for Categories 406, 407, and 412 Class 3 Tanks Where Yield Strength Is the Determining Criterion for Allowable Tensile or Compressive Stresses per TD-440



Legend:
D_y = (Design yield strength)/(Section II, Part D tensile strength)
E_y = (Material Test Report yield strength)/(Section II, Part D yield strength)

GENERAL NOTES:
(a) Determine E_y, then detemine D_y from this Figure.
(b) Design yield strength = D_y (Section II, Part D tensile strength).
(c) $1.0 \le E_y < 1.2$: $D_y = E_y$; $1.2 \le E_y \le 1.33$: $D_y = 1.20$; $1.33 < E_y \le 1.5$: $D_y = 0.9E_y$. If $E_y > 1.5$, then $D_y = 1.35$ max.

(3) Dynamic Load Condition C: the worst case loading of a fully loaded tank, subject to a 70% vertical load increase (1.7 g total) in combination with MAWP, maximum allowable external working pressure, or atmospheric pressure (whichever results in highest stress at location considered). For Categories 406, 407, and 412 tanks, a vertical load increase of 42% (1.42 g total) may be used.

(4) Dynamic Load Condition D: the worst case condition for a fully loaded tank subject to a longitudinal force of 70% of the gross vehicle weight (GVW) in both accelerative and decelerative directions and applied at the fifth wheel (Condition D1) and the rear wheels (Condition D2)

(5) Dynamic Load Condition E: a fully loaded tank subject to a uniform transverse force of 0.4G applied at the vertical center of gravity of the tank and resisted by the front and rear supports.

(6) Extreme Load Condition F: a fully loaded tank at MAWP subject to a decelerative force of twice the gross vehicle weight (GVW) applied to the front head and, for 406, 407, and 412 tanks only, reduced by 25% of the GVW for each baffle or interior bulkhead up to a total of four such units. The allowable design stress for this condition shall be 75% of the ultimate tensile strength.

(d) Special Provisions

(1) Category 406, 407, and 412 tanks of shell thicknesses less than 9.5 mm (0.375 in.) shall have circumferential reinforcement or stiffening at a maximum spacing of 150 cm (60 in.) unless designed per TD-210 for full vacuum (1.01 bar or 14.7 psi). Such reinforcement or stiffening shall not cover any circumferential shell joint except for doubler plates and knuckle pads and shall be continuous around the perimeter and welded to the shell with spaced welds for at least half the perimeter. The minimum values of stiffener section modulus shall be $I/c = KwL$, where I/c = section modulus in cubic centimeters (cubic inches), K = 0.000686 (SI units for steel), 0.00119 (SI units for aluminum), 0.00027 (U.S. Customary for steel), and 0.00047 (U.S. Customary for aluminum), w = tank width (or diameter) in centimeters (inches), and L = stiffener tributary spacing in centimeters (inches). In computing the effective section modulus, a portion of the tank shell between the stiffener legs attached to the tank plus 20 times the shell thickness on each welded side of the stiffener may be included as effective. Hat-shaped or open-channel ring stiffeners that prevent visual inspection of the tank shell are prohibited on Category 406, 407, and 412 cargo tank motor vehicles constructed of carbon steel.

Figure 1-1.4
Loading Conditions

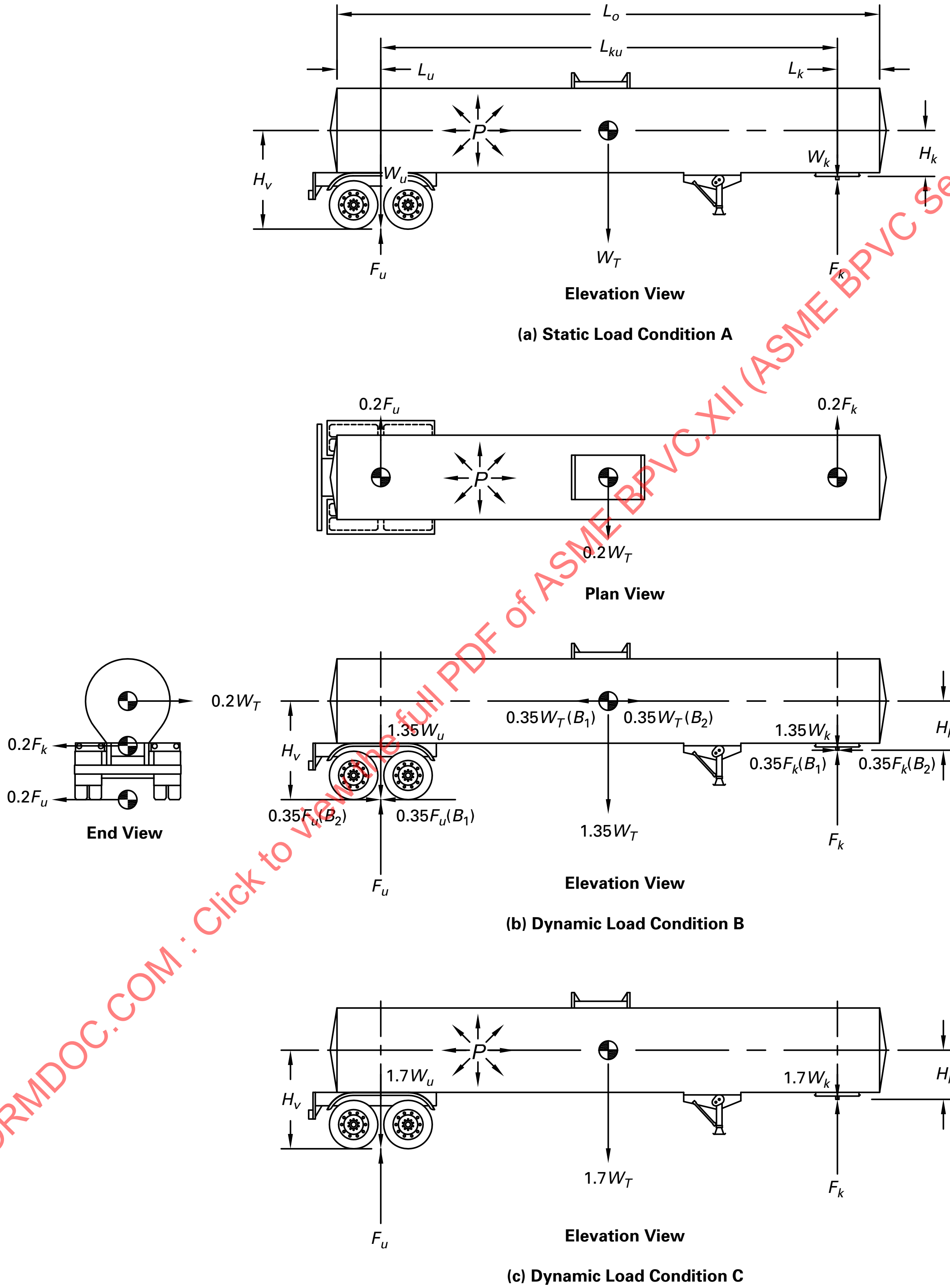
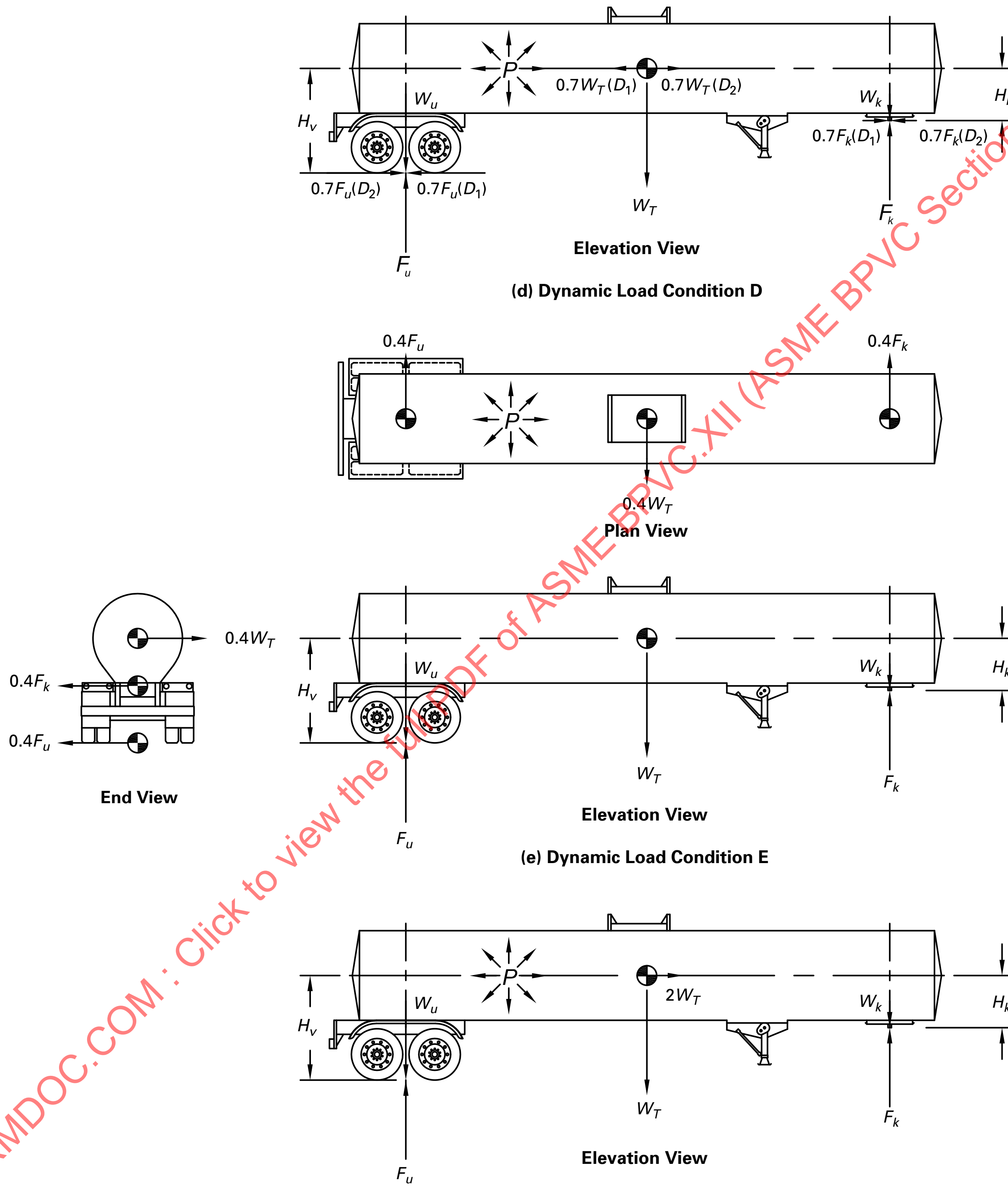


Figure 1-1.4
Loading Conditions (Cont'd)



Legend:

F_k = reaction force at the kingpin support
F_u = reaction force at the undercarriage support
H_k = height of vessel centerline from kingpin support
H_v = height of vessel centerline from ground
L_k = length from front to kingpin support

Figure 1-1.4
Loading Conditions (Cont'd)

(Cont'd)

L_{ku} = length from kingpin support to undercarriage support
L_o = overall length of vessel
L_u = length from rear to undercarriage support
P = MAWP
W_k = weight of the kingpin supports
W_T = distributed weight of vessel and payload, including weight of all equipment
W_u = weight of the undercarriage supports

The unwelded portions of length shall be no greater than the following:

Unwelded Portion of Length	Number of Times the Shell Thickness
For stiffening rings over a heat panel or similar structure that provides additional stiffness to the shell, and is welded to a plate over the unwelded portion, provided the plate used in place of the shell to compute section modulus provides 75% of the section modulus required above.	300
For openings in internal baffles	100
Other unwelded portions	40

(2) Tanks over 1.51 m^3 (53.5 ft^3) in capacity, except for Category 331 and 338 tanks, shall have a manhole complying with the requirements of TD-690(c)(1) for accessibility. See Article 3 for manhole requirements for 331 tanks and Article 4 for 338 tanks. For Category 406, 407, and 412 tanks, each manhole, fill opening, and washout assembly must structurally be capable of withstanding, without leakage or permanent deformation that would affect its structural integrity, a static internal fluid pressure of at least 2.48 bar (36 psi), or cargo tank test pressure, whichever is greater. The manhole assembly manufacturer shall verify compliance with this requirement by hydrostatically testing at least 1% (or one manhole closure, whichever is greater) of all manhole closures of each type produced every three months, as follows:

(-a) The manhole, fill opening, or washout assembly must be tested with the venting devices blocked. Any leakage or deformation that would adversely affect the product retention capability shall constitute a failure.

(-b) If the manhole, fill opening, or washout assembly fails, then five more covers from the same lot must be tested. If one of these covers fails, then all covers in the lot from which the test covers were selected are to be 100% tested or rejected for service.

(-c) Each manhole, filler, and washout cover must be fitted with a safety device that prevents the cover from opening fully when internal pressure is present.

(-d) Each manhole and fill cover must be secured with fastenings that will prevent opening of the covers as a result of vibration under normal transport conditions or shock impact due to a rollover accident on the roadway or shoulder where the fill cover is not struck by a substantial obstacle.

(-e) Each manhole cover must be permanently marked by stamping or other means with the manufacturer's name, the test pressure in suitable units, and with a statement certifying that the device meets the requirements of this article.

(-f) All fittings and devices mounted on a manhole cover coming in contact with the lading must withstand the same static internal fluid pressure and contain the same permanent compliance markings as that required for the manhole cover. The fitting or device manufacturer shall verify compliance using the same test procedure and frequency of testing as noted above.

(3) Tanks to which supports and appurtenances are attached shall be designed to limit the stresses in the tank to required values of this Section for the tank. All supports and appurtenances that are a necessary part of the pressure retention system of the tank shall be included in the design of the tank. Such devices that are not necessary parts of the pressure retention system shall not be subject to these stress limits even though they may contribute to the pressure retention capability of the tank.

(4) Variable category tanks are permitted provided separate nameplates are provided for each category with only one of them, the one under which the tank is operating, being displayed.

(5) A cargo tank motor vehicle may be composed of more than one cargo tank made to the same specification or, for 406, 407, and 412 tanks, of different specifications. Any void within the connecting structure must be vented to atmosphere and have a drain located at the bottom centerline, the drain being accessible and kept open at all times. The drain in any void within the connecting structure of a carbon steel, self-supporting cargo tank may be either a single drain 25 mm (1.0 in.) minimum diameter nominal pipe size (NPS) or two or

more drains 12.5 mm (0.5 in.) minimum diameter (NPS) located a maximum of 15 cm (6 in.) apart, with one drain at the bottom centerline of the tank.

(6) Vacuum relief devices are not required for tanks designed to withstand full vacuum [with vacuum condition included in dynamic conditions in (c)].

(-a) A tank may be designed to be loaded by vacuum but transported under a relieved vacuum condition if the cargo tank is provided with a vacuum relief system that limits the vacuum to less than 80% of the design vacuum capability in the dynamic conditions in (c). In this case, the dynamic conditions in (c) are not applicable when considering the loading case but shall be considered the relieved condition. The maximum design external pressure for both static and dynamic conditions shall be included on the nameplate with "(LOADING ONLY)" and "(TRANSPORT)" amended, respectively.

(-b) Vacuum relief systems, when installed, shall limit the vacuum to less than 80% of the design vacuum capability of the cargo tank. If pressure loading or unloading devices are provided, the relief system shall have adequate vapor and liquid capacity to limit the tank pressure to the cargo tank test pressure at maximum loading or unloading rate, and these rates shall be noted on the metal specification plate.

(7) Local stresses in tension, bending, and torsion that occur at pads or cradles or other supports shall be considered in the design.

(8) For Category 406, 407, and 412 tanks, the knuckle radius and dish radius vs. diameter limitations of TD-310.5 do not apply, provided

(-a) knuckle radii of flanged heads are at least 3 times the material nominal thickness and in no case less than 13 mm (0.5 in.)

(-b) tank MAWP does not exceed 1.03 bar (15 psi) for Category 412 tanks, and 2.41 bar (35 psi) for Category 407 tanks

(9) The butt weld in a two piece head can have a joint efficiency of 85% for pressure load if not nondestructive tested. The head shall be formed after welding the plates together.

(10) For Category 406, 407, and 412 cargo tanks, the minimum allowed thicknesses are as specified in (b). Equivalent thickness rules of Mandatory Appendix XIII do not apply to these tanks.

(11) Category 406, 407, and 412 tank shells not designed for external pressure and having circumferential stiffeners spaced 1 520 mm (60 in.) maximum with section modulus meeting the requirements of (1) can be designed according to the rules of Article TD-4. When using the Article TD-4 rules, the allowable membrane tensile and longitudinal compressive stresses may be increased by 20% per 1-1.4. In addition, the reported yield point stress from the certified material test reports may be used in lieu of that listed in Section II, Part D, where the greater of 1.2 times the minimum yield strength from Section II, Part D or 0.9 times the reported yield stress from the material test reports can be used.

For noncircular tanks with flat areas subject to compressive stress where there is no radius of shell curvature, use the allowable tensile stress with an effective width of shell of $20t$ on each side of a longitudinal stiffener or a circumferentially curved shell section, where t is the shell thickness. Longitudinal stiffeners or locally thicker shell can be used in high stress areas, provided the length of such reinforced construction is sufficient to keep stresses at or below their allowables.

1-1.4.2 CARGO STANK SECUREMENT OR ATTACHMENT

(a) Securement of a highway transport tank to its vehicle chassis (for a vehicle with a frame) or to vehicle suspension and coupler components where the tank forms all or an integral part of the vehicle frame shall be designed to withstand static loading of $1W_T$ independently applied in the vertical-up and vertical-down directions, $2W_T$ in longitudinal direction (direction of travel), and $0.5W_T$ in the transverse (lateral) direction, where W_T is the weight of the tank including the maximum lading weight and all tank-mounted accessories, and the loading is considered about the center of gravity of the tank. W_T does not include the tare weight of the vehicle chassis or undercarriage. Allowable design stress shall not exceed 0.6 times the minimum specified yield strength of the materials used for securement.

(b) A tank that is not an integral part of a vehicle chassis (such as some in dump bodies as defined in 1-1.2 where the tank is mounted on a subframe while the subframe is mounted on the vehicle chassis frame or trailer frame) shall be secured by components that prevent separation of the tank from the frame. Anchors, stops, or other components shall restrict relative motion between the tank and the vehicle chassis, except as required to absorb normal chassis flex when the vehicle is in operation. Such components shall be readily accessible for inspection and maintenance, except that insulation and jacketing may cover them. The design requirements specified above shall apply for these components also.

(c) The designer shall ensure that appropriate and conservative loading is considered for the securement devices. The designer may apply free-body methods if found more appropriate. In no case shall the load value on the individual devices be less than the average load value, assuming the weight, W_T, is uniformly and equally distributed to the number of securement devices installed on the tank vehicle unit. There is no restriction on the number of these devices on a cargo tank motor vehicle. Designers are cautioned to ensure that excessive stiffness may introduce cracks in the device or on the tank support structure that is involved

in the tank vehicle attachment due to flexure in the vehicle chassis or trailer frame.

(d) When the W_T cannot be distributed uniformly for any reason (e.g., because the configuration of the accessories mounted on the tank are nonuniform), then the loads that are experienced by the individual device(s) need to be determined before applying the aforementioned design criteria.

(e) These loads, allowable stresses, and design margin are for structural components of securement devices, while the parameters specified in 1-1.4.1(a) are for the pressure boundary. In the case of dump bodies, where the lifting devices are attached to either the tank head or the shell, the stresses in the areas where these cylinders are attached shall not exceed the allowable stresses specified in 1-1.4.1(a).

(25) 1-1.5 SPECIAL REQUIREMENTS

(a) Appurtenances, attachments, and protective devices that depend on the strength of pressure-retaining parts of the tank to function properly shall have such pressure-retaining parts designed to accommodate the applied loads into the tank using stress levels and deformations compatible with the nature of such loads. For example, where loads are catastrophic in nature such as in collision or overturning provisions, stresses and deformations as permitted for accident protection shall be used rather than normal code allowable stresses (see 1-1.3). Appurtenances, attachments, and protective devices that do not depend on the pressure-retaining parts of the tank for their function such as rear-end tank protection devices are not specifically covered by this Code and shall be designed according to rules established by other authorities having jurisdiction over such items.

(b) Appurtenances and other accessories to cargo tanks must, where practicable, be installed on suspension subframes, accident protection, or external rings. A lightweight attachment to a cargo tank, such as a conduit or brakeline clip, skirting structure, lamp mounting bracket, or placard holder, shall be of a construction of lesser strength than the cargo tank wall materials and may not be more than 72% of the thickness of the material to which it is attached and may be directly attached to the tank. Structural members may be welded directly to the tank wall if considered in the design. Except as described previously, the welding of any appurtenance to the cargo tank shall be made by attachment of a mounting pad, so there will be no adverse effect upon the lading retention integrity of the cargo tank if any force less than prescribed by 1-1.6(a)(2) is applied from any direction. The mounting pad thickness shall be between 100% and 150% of the local wall thickness but shall not required to be over 5 mm (0.187 in.). Pads must extend at least 50 mm (2 in.) in any direction from the point of appurtenance attachment, have rounded corners or otherwise be shaped to minimize stress concentrations and be welded to the wall all around except for a small gap at the lowest point for draining. Weepholes or telltale holes, if used, shall be installed in the pad before welding to the tank wall.

(c) The distance between the ground and every part of the loaded cargo tank, including any appurtenance, protective device, or structure (exclusive of wheel assemblies, mudflaps, and other equipment for undercarriage), shall be no less than $^1/_{24}$ of the distance between adjacent axles but in no case less than 254 mm (10 in.). The designer is advised to review jurisdictional requirements. Competent authority requirements shall be reviewed to determine if they are more restrictive than the rules of this Section.

1-1.6 PROTECTION AGAINST DEFINED INCIDENT LOADS

(a) Category 406, 407, and 412 Tanks

(1) Domes, manways, washouts, inlets, outlets, and fittings that retain lading, pressure, or both shall be constructed to the same standards of strength and toughness, as the tank shell is required to withstand under defined incident load conditions, and of thicknesses at least as great as the minimum specified thickness for the tank wall in 1-1.4(b), provided they extend beyond the following limits from the tank wall:

(-a) For the lower one-third of the tank shell perimeter, more than half the fitting diameter or 10 cm (4 in.), whichever is less.

(-b) For the upper two-thirds of the tank shell perimeter, more than one-fourth of the fitting diameter or 5 cm (2 in.), whichever is less.

(2) Fittings exceeding the above limits shall be protected by an external device or be 25% stronger than required for an external device where the stress in pressure-retaining parts is limited to 0.75 UTS and in non–pressure-retaining parts to UTS under the specified defined incident loads. Bottom damage protection devices will be required to protect pressure-retaining devices in the bottom one-third of the tank and shall be designed to resist loads of 70 200 kg (155,000 lb) acting independently in longitudinal and transverse directions. The 50% increase in allowable design stress for bending across the thickness is not allowed where such stresses are greater than yield point stress or ultimate stress when such stresses are permitted for design loads.

(3) Rollover protective devices shall be designed to resist a total load of twice the gross vehicle weight acting vertically toward the center of the tank as well as longitudinally and transversely, each acting independently. Multiple rollover protective device assemblies and/or fittings can be used to resist the specified loads but each such assembly or fitting shall be designed to

resist at least 25% of the total specified load. Where external pressure-retaining fittings are used to resist roll-over loads, they shall be designed for at least 125% of the loads specified for non–pressure-retaining device(s).

(4) The bottom damage protection device loads shall be distributed over each surface of the device not to exceed 5 574 cm^2 (6 ft^2) in area and not to exceed 1.8 m (6 ft) in width.

(5) A lading discharge opening equipped with an internal self-closing stop valve does not require external protection provided it is protected so as reasonably to ensure against accidental loss of lading. Piping extending beyond protective devices shall have a stop valve with a sacrificial section in the piping outboard of the stop valve, and inboard of the protective device(s), having a break-away capacity no more than 70% of the load that would cause loss of lading from the tank through the piping up to the stop valve.

1-1.7 FABRICATION AND EXAMINATION

Fabrication and examination requirements are contained in Parts TF, TE, TT, and TW. However, for noncircular Category 406 and 412 tanks with MAWPs of 1.03 bar (15 psi) or less, the prerolling requirement of TF-120.1(b) does not apply as long as all other tolerance and fabrication requirements of those parts are maintained.

1-1.8 PRESSURE RELIEF DEVICES

(a) Category 406, 407, and 412 Tanks

(1) Each cargo tank shall be equipped to relieve pressure and vacuum conditions in conformance with Article TOP-1, Section XIII, and the applicable individual tank category section. The pressure and vacuum relief system shall be designed to operate and have sufficient capacity to prevent tank rupture or collapse due to overpressurization or vacuum resulting from loading, unloading, or from heating and cooling of lading. Tanks specifically designed to be loaded by vacuum or built to withstand full vacuum do not require vacuum relief devices.

(2) Type and Construction of Relief Systems and Devices

(-a) Each cargo tank shall be provided with a primary pressure relief system consisting of one or more reclosing pressure relief valves. A secondary pressure relief system consisting of another pressure relief valve in parallel with the primary pressure relief system may be used to augment the total venting capacity of the cargo tank. Nonreclosing pressure relief devices are not allowed in any cargo tank except when in series with a reclosing pressure relief device. Gravity actuated reclosing valves are not allowed in any cargo tank.

(-b) When provided by the requirements of this paragraph, cargo tanks may be equipped with a normal vent. Such vents shall be set to open at not less than 0.07 bar (1 psig) and shall be designed to prevent loss of lading through the device in case of overturn. The MAWP of the cargo tank shall be equal to or greater than the largest pressure obtained under the following conditions:

(-1) The maximum pressure during loading or unloading.

(-2) For tanks with a 0.07 bar (1 psig) normal vent, the sum of the static head plus 0.07 bar (1 psig) plus any pressure exerted by the gas padding.

(-3) The vapor pressure of gasoline lading at 42°C (115°F) shall not exceed 0.07 bar (1 psig) according to the following table based on the lading volatility class (LVC) of ASTM D439, the Reid vapor pressure (RVP), and the maximum lading ambient temperature (MLAT) based on 0.07 bar (1 psig) lading pressure at the top of the tank:

LVC	RVP, bar (psia)	MLAT, °C (°F)
A	0.62 (9)	55 (131)
B	0.69 (10)	51 (124)
C	0.79 (11.5)	47 (116)
D	0.93 (13.5)	42 (107)
E	1.0 (15)	38 (100)

(-c) Each pressure relief system and device shall be designed to withstand dynamic pressure surge reaching 2.07 bar (30 psig) above the design set pressure and sustained above the set pressure for at least 60 ms with a total volume of liquid released not exceeding 1 L (61 $in.^3$) before the relief valve closes to a leak tight condition. This requirement shall be met regardless of vehicle orientation and shall be demonstrated by suitable testing.

(-d) Each reclosing pressure relief system shall be constructed and installed in such a manner so as to prevent unauthorized adjustment of the relief valve setting.

(-e) No shutoff valve or other device that could prevent venting through the pressure relief system shall be installed in a pressure relief system.

(-f) The pressure relief system shall be mounted, shielded, and drainable so as to minimize the accumulation of material that could impair the operation or disharge capability of the system by freezing, corrosion, or blockage.

(-g) Each pressure relief device shall communicate with the vapor space above the lading as near as practicable to the center of the vapor space as the tank is in its operating attitude either pitched forward or aft. The discharge from any device shall be unrestricted. Protective devices that deflect the flow of vapor are permissible provided the required vent capacity is maintained.

(-h) The set pressure of the pressure relief system is the pressure at which it starts to open, allowing discharge. The set pressure of the primary relief valve shall be not less than 120% of the MAWP and not more than 132% of MAWP. The valve shall reclose at not less than 108% of MAWP and remain closed at lower pressures. The set pressure of each secondary relief valve shall be not less than 120% of MAWP. The venting capacity of the pressure relief system (primary and secondary including any piping) shall have sufficient venting capacity to limit the tank internal pressure to not more than the tank test pressure. The total venting capacity, rated at not more than the tank test pressure, shall be at least that specified in Tables 1-1.8 and 1-1.8M except as allowed for 406, 407, and 412 tanks in Article 2.

(-i) Unless otherwise specified in the applicable individual specification in Article 2, the primary relief system shall have a minimum venting capacity of 1 120 SCMH per 10.6 SQM (12,000 SCFH per 300 ft^2) of exposed tank area, but in any case, at least one-fourth the required total venting capacity of the cargo tank.

(-j) If the primary pressure relief system does not provide the required total venting capacity, sufficient additional capacity shall be provided by a secondary pressure relief system.

(-k) The manufacturer of any pressure relief device, including valves, frangible (rupture) disks, vacuum vents, and combination devices, shall certify that the device model was designed and tested in accordance with Part TOP, Section XIII, and the appropriate cargo tank specification in Article 2.

(-l) Each pressure relief device model shall be successfully flow capacity certification tested per Section XIII, Part 9.

(-m) Pressure relief device (PRD) manufacturers shall make available recommended practices for cleaning and/or servicing their PRDs. These practices may include limited disassembly such that the pressure setting is not altered or modified, and requirements for testing, personnel performing the work, and documentation.

(-n) If pressure loading or unloading devices are provided, the relief system shall have sufficient vapor and liquid capacity to limit the tank pressure to the cargo tank test pressure at maximum loading or unloading rate. The maximum loading rates shall be included on a specification plate attached to the tank or the vehicle.

(b) Category 331 and 338 Tanks. Category 331 and 338 tank pressure relief and venting requirements are specified in 1-3.7 and 1-4.6.

Table 1-1.8
Minimum Emergency Vent Capacity
(Interpolation Allowed)

Exposed Area, ft^2	SCFH
20	15,800
30	23,700
40	31,600
50	39,500
60	47,400
70	55,300
80	63,300
90	71,200
100	79,100
120	94,900
140	110,700
160	126,500
180	142,300
200	158,100
225	191,300
250	203,100
275	214,300
300	225,100
350	245,700
400	365,000
450	283,200
500	300,000
550	317,300
600	333,300
650	348,800
700	363,700
750	378,200
800	392,200
850	405,900
900	419,300
950	432,300
1,000	445,000

GENERAL NOTE: Values are in cubic feet/hour of free air at 60°F and one atmosphere (SCFH).

Table 1-1.8M
Minimum Emergency Vent Capacity (Interpolation Allowed)

Exposed Area, m^2	SCMH
0.71	1 480
1.06	2 220
1.41	3 380
1.77	3 690
2.12	4 430
2.47	5 170
2.83	5 920
3.18	6 660
3.53	7 400
4.24	8 880
4.94	10 350
5.65	11 830
6.36	13 310
7.06	14 790
7.95	17 890
8.83	18 990
9.71	20 040
10.53	21 050
12.36	22 580
14.13	24 760
15.89	26 760
17.66	28 860
19.42	29 670
21.19	31 170
22.55	32 620
24.72	34 010
26.49	35 370
28.25	36 680
30.02	37 360
31.78	39 210
33.55	40 430
35.31	41 620

GENERAL NOTE: Values are in cubic meters/hour of free air at 15.5°C and one atmosphere (SCMH).

1-1.9 OPERATIONS, MAINTENANCE, AND INSPECTION

(a) General. Cargo tanks shall be inspected and tested periodically at intervals required by this Code as detailed below and further described in Parts TP, TT, and TE and the competent authority. Periodic tests and inspections, and exceptional tests and inspections are defined in 1-1.2 of this Appendix. The requirements for exceptional test and inspection shall be applied when any conditions specified in the definition have been met. A cargo tank constructed in accordance with this Modal Appendix, for which a test or inspection has become due, may not be filled with product and offered for transportation or transported until the tests or inspections have been successfully completed. Except during a pressure test, a cargo tank may not be subjected to a pressure greater than the MAWP stamped on its nameplate.

(1) Table 1-1.9 specifies the type and frequency of inspections and tests required for all cargo tanks described in this Modal Appendix.

(2) The test pressure for each tank specification listed shall be that noted on the specification plate.

(3) Inspections and tests are to be witnessed and accepted by an Inspector defined in Article TG-4 and TP-100. Markings, as required by TP-100(g), shall be applied to the cargo tank.

(4) Repairs or alterations requiring the use of welding shall be performed using qualified welders and qualified procedures and shall be accomplished and documented in accordance with Part TP.

(5) A cargo tank that fails a prescribed test or inspection shall be repaired and retested or else removed from service. If scrapped, the ASME and specification plates shall be destroyed. A rerated tank shall have the ASME nameplate and specification plate made in accordance with the new rating.

(6) Only manufacturing or repair facilities registered with the competent authority and accredited as required by Part TP may perform and certify repairs and alterations to the cargo tank. If required by the competent authority, the facilities performing in-service testing and inspection shall be registered with the competent authority.

(b) Specific Requirements and Exemptions

(1) Where accessible, tanks shall be tested and inspected in accordance with Article TP-4, Table 1-1.9, and this Article unless exempted for a specific inspection or test.

(2) Where no manway or inspection openings are provided on a cargo tank, or the design precludes an internal inspection, a pressure test is required in lieu of the internal inspection.

(3) Where insulation, lining, or coating on the exterior of a cargo tank either does not allow a complete external inspection or only permits a partial external inspection, or the design does not permit a full or

Table 1-1.9
Periodic Inspection and Test Frequencies

Inspection/Test	Specification, Configuration, and Service	Frequency
Ext Visual Insp	All cargo tanks designed to be vacuum loaded with full opening in the rear head	6 months
	All other cargo tanks	1 yr
Int Visual Insp	All insulated tanks except 331 and 338	1 yr
	All cargo tanks transporting lading corrosive to the tank	1 yr
	All other cargo tanks except 338	5 yr
Lining Insp	All lined cargo tanks transporting lading corrosive to the tank	1 yr
Leakage Test	331 tanks in chlorine service	2 yr
	All other cargo tanks except 338	1 yr
	338 cargo tanks	2.5 yr
Pressure Test [Notes (1), (2)]	All cargo tanks that are insulated with no manhole or are insulated and lined except 338	1 yr
	All cargo tanks designed to be loaded by full vacuum with full opening in rear head	2 yr
	331 tanks in chlorine service	2 yr
	All other cargo tanks except 338	5 yr
Operation of All Service Equipment	338 tanks (90% of MAWP)	2.5 yr

NOTES:
(1) Pressure testing is not required for 331 tanks in dedicated sodium metal service.
(2) Pressure testing is not required for uninsulated lined cargo tanks with a design pressure or MAWP of 15 psi (100 kPa) or less, which successfully passed an external visual inspection and lining inspection at least once a year.

partial external inspection, an internal inspection is required. Those areas on a cargo tank available for external inspection shall be inspected and recorded. If the internal inspection is precluded because of an internal lining, a pressure test is required.

(4) The pressure test may be waived for an uninsulated lined cargo tank with MAWP of 1.03 bar (15 psi) or less if an annual external inspection and internal lining inspection are performed.

(5) An insulated cargo tank with manways or inspection openings may either be internally and externally inspected or hydrostatically or pneumatically tested.

(6) Ring stiffeners or other appurtenances attached to the shell or head of a cargo tank constructed of mild steel or high strength, low alloy steel that are not completely welded around their peripheries so as to prevent corrosion from occurring underneath the attachment and therefore do not allow an external inspection, must be thickness tested in accordance with Article TP-410.2 every 2 yr as a minimum. At least four symmetrically distributed readings must be taken of the shell or head adjacent to the stiffener ring or appurtenance to establish an average thickness. If any thickness reading is less than the average thickness by more than 10%, thickness testing of this section of the shell or head must be conducted from inside the tank on the area of wall covered by the stiffener ring or appurtenance.

(7) Corroded or abraded sections of the cargo tank wall must be thickness tested in accordance with Article TP-410.2.

(c) Pressure Relief Devices

(1) All reclosing pressure relief devices shall be externally inspected for any corrosion, damage, or tampering that might prevent proper operation of the device. All reclosing pressure relief devices on cargo tanks carrying lading corrosive to the valve must be removed from the cargo tank for inspection and testing. Each reclosing pressure relief device required to be removed and tested shall open at the required set pressure and reseat to a tight condition at 90% of the set-to-discharge pressure or the pressure prescribed for the applicable cargo tank specification. See Section XIII, Part 3 for testing requirements for Manufacturers and Assemblers.

(2) When a pressure test of a cargo tank is performed, all reclosing pressure relief devices, including emergency relief vents and normal vents, shall be removed from the cargo tank for inspection and testing. The pressure relief devices shall be inspected and tested as required in (1) above. Normal vents [0.07 bar (1.0 psi) vents] shall be tested according to testing criteria established by the valve manufacturer.

(3) Reclosing pressure relief devices unable to meet the test acceptance criteria in (1) above shall be repaired or replaced.

(d) Inspection and Acceptance Criteria. For visual internal and external inspections, lining inspections, pressure and leak testing, and minimum thickness tests and for evaluating damaged areas of the tank, the requirements of Article TP-5 shall be met.

1-1.10 ASME NAMEPLATE REQUIREMENTS

The ASME nameplate shall comply with Part TS of this specification and, if the vessel is designed for full vacuum, that will be noted on the nameplate.

1-1.11 JURISDICTIONAL MARKINGS

Specification plate and marking requirements in addition to the Certification Mark with T Designator are specified by the competent authority.

1-1.12 DESIGN CERTIFICATION

Each cargo tank design type shall be certified in conformance with the design requirements included herein in accordance with Part TS. The competent authority may impose additional certification requirements by its regulations.

ARTICLE 2
CATEGORY 406, 407, AND 412 CARGO TANKS

1-2.1 CATEGORY 406 SPECIAL DESIGN REQUIREMENTS

(a) Vacuum loaded cargo tanks are not allowed under this category.

(b) Each vacuum relief system shall have sufficient capacity to limit the vacuum to 0.07 bar (1 psi).

(c) The venting requirements of 1-1.8(a) are applicable, except that the set pressure limits defined in 1-1.8(a)(2)(-h) shall be as follows:

(1) The set pressure of each primary relief valve shall be not less than 110% of the MAWP or 0.23 bar (3.3 psi), whichever is greater, and not more than 138% of the MAWP. The valve must close at not less than the MAWP and remain closed at lower pressures. A vacuum relief device is required and must be set to open at no more than 15 cm (6 in.) water vacuum. The primary pressure relief valve shall have a venting capacity of at least 560 SCMH (6,000 SCFH), rated at not greater than 125% of the tank test pressure and not greater than 0.21 bar (3 psi) above the MAWP. The venting capacity required in 1-1.8 may be rated at these same pressures.

(d) Pressure relief system shall include a normal vent per 1-1.8(a)(2)(-b).

1-2.2 CATEGORY 407 SPECIAL DESIGN REQUIREMENTS

(a) Manhole assemblies must be capable of withstanding cargo tank test pressures or 2.48 bar (36 psi), whichever is greater.

(b) A vacuum relief system shall limit the vacuum to less than 80% of the design vacuum capability of the cargo tank.

1-2.3 CATEGORY 412 SPECIAL DESIGN REQUIREMENTS

(a) Cargo tanks used in dedicated service for materials classed as corrosive material, with no secondary hazard, may have a total venting capacity less than required by 1-1.8, provided they meet the requirements of the following equation:

$$Q = BA^{0.82}\left\{ZT\right\}^{0.5}\left\{LC\right\}\left\{M^{0.5}\right\}$$

where

A = exposed surface of tank shell in square meters (square feet)
B = 5 660 000 (SI units) and 3,798,000 (U.S. Customary)
C = 315
L = latent heat of vaporization of lading in calories/gram (Btu/lb)
M = molecular weight of vapor
Q = total required venting capacity in cubic meters (cubic feet) per hour at 15.6°C and 1.01 bar (60°F and 14.7 psia)
T = absolute temperature of the vapor at venting conditions, K (°R)
Z = vapor compressibility factor (use 1.00 if unknown)

(b) A vacuum relief system shall limit the vacuum to less than 80% of the design vacuum capability of the cargo tank.

ARTICLE 3
CATEGORY 331 CARGO TANKS

1-3.1 SCOPE

This Article contains specifications and minimum requirements for construction of Category 331 cargo tank vessels, the scope of which is defined in 1-1.1 of this Modal Appendix. This Article also contains additional construction requirements and restrictions for Category 331 tank vessels that transport certain hazardous ladings. Except when more stringent requirements of the competent authority are mandated, rules of this Article are sufficient for design and construction of Category 331 tank vessels.

1-3.2 DEFINITIONS

Definitions of terms relevant to the meaning of the rules in this Article are listed in Article 1 of this Modal Appendix or in Mandatory Appendix III.

1-3.3 GENERAL REQUIREMENTS

(a) General Configuration Requirements. Tank vessels shall be

(1) of welded or seamless construction

(2) constructed according to the rules of this Section

(3) constructed of steel or aluminum, except that if constructed of aluminum, tanks shall be insulated according to the requirements of the competent authority and the tank lading shall be compatible with aluminum

(4) covered with a steel jacket if the tank is insulated and one of the following:

(-a) the tank lading is defined by the competent authority to be flammable

(-b) if otherwise required by the competent authority

[See (e) below for insulation requirements.]

(b) Lower and Upper Limits for Maximum Allowable Working Pressure

(1) Lower Limits. Tank vessels shall have a maximum allowable working pressure no less than the largest value of the following pressures:

(-a) the minimum value of the pressure range for Category 331 tanks specified in 1-1.4 of this Modal Appendix

(-b) except as provided in 1-3.11.1(c)(2) and 1-3.11.1(e)(2) of this Article, the vapor pressure of the tank lading at a temperature of 46°C (115°F)

(-c) the least value for maximum allowable working pressure specified by the competent authority

(-d) where required by 1-3.11.1 of this Article, the least allowable pressure required for the applicable lading transported

(2) Upper Limits. The maximum allowable working pressure shall not be marked, nor shall safety relief devices be set for a pressure greater than the largest value for pressure range for Category 331 tanks allowed by 1-1.4 of this Modal Appendix, or a lower maximum pressure value limit set by the competent authority.

(c) Tank Openings

(1) Except as provided in 1-3.11.1(a)(5) of this Article, pressure relief valves shall be located in the top of the shell or heads.

(2) Additional requirements and restrictions for openings in Category 331 tanks specified in 1-3.11.1 of this Article shall be met if the tanks are used to transport ladings applicable to those requirements.

(d) Reflective Outer Surface. Tanks permanently attached to a motor vehicle, unless covered with a jacket made of bright nontarnishing material, shall be painted white, aluminum, or a similar reflecting color on the upper two-thirds area of the tank vessel.

(e) Insulation and Jacketing. Design, material, and thermal performance specifications for insulation of tanks shall meet the more stringent and restrictive requirements of the competent authority, or the insulation and jacket requirements in 1-3.11.1 of this Article applicable to specific tank ladings. Materials used for insulation that is in direct contact with the tank vessel shall not promote corrosion to the tank vessel, either as installed or when wet.

1-3.4 MATERIAL

(a) General

(1) Material specifications shall comply with the requirements of 1-1.3 of this Modal Appendix.

(2) Impact tests in accordance with Article TM-2 are required for material used in tanks constructed to the requirements of Article TF-6 of this Section.

(3) Identification of Material

(-a) From the time of receipt of material until completion of fabrication of tank vessels, material used for pressure parts shall be identified as required by the rules of TF-110.2 of this Section.

(-b) Unless exempted by the competent authority, the tank vessel manufacturer shall record the plate material heat and slab numbers (or heat and plate numbers) and the certified Charpy impact values [where required by (2) above] for each plate used on a sketch showing the location of each plate in the shell or heads of the tank vessel. Copies of the sketch shall be furnished to the tank user and be retained for a period specified by, and made available to, the competent authority. The use of coded markings as permitted by TF-110.2(a)(2) are not permitted for this purpose.

(4) Material Plate Orientation. The direction of final rolling of plates used in the shell of tank vessels shall be in the circumferential direction.

(b) Material Requirements for Tanks Transporting Special Ladings. Use of construction materials that are otherwise allowed by this Article shall be restricted or limited for construction of tanks to transport special ladings as required by the rules in 1-3.11.1 applicable to tank vessels intended for transport of those ladings.

1-3.5 DESIGN REQUIREMENTS

1-3.5.1 STRUCTURAL INTEGRITY

(a) General Requirements, Allowable Stress Values, and Required Loadings

(1) Maximum Allowable Stress Values

(-a) Except as allowed in (-b) for defined incident loading conditions, maximum allowable stress values in any part of the tank vessel wall, the geometric scope of which is defined by TG-110 of this Section, shall be no greater than the values allowed in 1-1.4(a) of this Modal Appendix.

(-b) The maximum allowable stress induced in the shell and heads of the tank vessel from all loads including defined incident loadings transferred into the tank vessel shall be the lesser value of the yield strength or 75% of the ultimate strength of the material used. Except when the competent authority shall establish higher values, for the purposes of this subparagraph, and for all cases where design consideration of such loads shall be required by this Article, the minimum design value of defined incident loads shall be no less than the values listed below corresponding to the following conditions:

(-1) for purposes of structural integrity requirements in this Article, the load required by 1-1.4(c)(6) of this Modal Appendix for the condition of liquid surge in a defined load incident. See Figure 1-1.4 of this Modal Appendix.

(-2) for purposes of defined incident loads transferred through tank vessel support structures, a load equal to twice the static support reaction at any tank vessel support structure. See 1-3.5.5 of this Article.

(-3) a load equal to twice the gross vehicle weight transmitted into the tank through a tank vessel structure, the weight of which is supported by the tank vessel. See 1-3.5.6 of this Article.

(-4) stress in the vessel wall due to a load equal to the static weight of the filled vessel transmitted through structures described in (-3) above, or equal to the support reaction loads of structures described in (-2) above for static loads, normal operating conditions, or extreme dynamic load conditions, shall not exceed the values allowed in 1-1.4(a) of this Modal Appendix.

(2) The values of yield strength and ultimate tensile strength shall be no greater than the relevant material properties and the limitation of use described in 1-1.4(a) of this Modal Appendix.

(3) Maximum stress shall be determined from consideration of the design loading conditions required in 1-1.4(b) and 1-1.4(c) of this Modal Appendix.

(4) Minimum thickness of shells and heads shall be the greater of the required minimum thickness or the thickness determined from specified loads and allowable stresses (design thickness).

(b) Static Design and Construction

(1) Static design of tank vessels shall conform to Part TD of this Section and 1-1.4(a), 1-1.4(b), and 1-1.4(c)(1) of this Modal Appendix, and to requirements and restrictions of 1-3.11.1 of this Article applicable to the ladings transported. Static design shall include consideration of stresses due to the effect of temperature gradients caused by differences of lading and ambient temperature extremes. Where applicable, thermal coefficients of dissimilar materials shall be used to determine temperature loads and stresses as required by TD-120 of this Section.

(2) Vessel wall local stress concentrations in tension, bending, or torsion occurring at pads or attachments of support structures shall be analyzed according to guidance of Nonmandatory Appendix A of this Section, or by alternate methods that are accurate and verifiable.

(c) Shell Design. Stresses shall be determined for the normal operating and extreme dynamic loading conditions specified in (1) and (2) below. Where applicable to the tank vessel support configuration, these stresses shall be combined as required in 1-1.4(c) of this Modal Appendix. The magnitudes, locations, and combinations of loading conditions for which stresses shall be calculated for all parts of the tank vessel shell are as follows:

(1) the normal operating loadings, as shown in illustrations (a) and (b) of Figure 1-1.4 of this Modal Appendix

(2) the extreme dynamic loadings, as shown in illustrations (c), (d), and (e) of Figure 1-1.4 of this Modal Appendix

(d) Allowable stress values in the tank vessel wall for the liquid surge defined incident condition, shown in illustration (f) of Figure 1-1.4 of this Modal Appendix, shall not exceed the value given in (a)(1)(-b) above.

(e) *Tank Vessel Stresses at Support Structure Attachments*. Stresses induced in the tank vessel wall by and through attachment of vessel support structures shall not exceed the maximum allowable values in (a) that correspond to the type of loadings specified therein.

(f) Corrosion allowance thickness shall not be included to satisfy any of the tank vessel structural design requirements of (a) through (e) or 1-3.5.5 and 1-3.5.6 of this Article.

(g) *Tank Vessel Minimum Construction Thickness Requirements*. The thickness of tank vessels shall be no less than the greater of the minimum values determined by the rules of (1), (2), and (3).

(1) *Minimum Thickness Values for All Category 331 Tank Vessels*

(-a) Steel vessel construction thickness shall be no less than 4.75 mm (0.1875 in.).

(-b) Aluminum vessel construction thickness shall be no less than 6.86 mm (0.270 in.).

(-c) Construction thickness of tank vessels that contain hazardous ladings listed in 1-3.11.1(a)(1) of this Article shall be no less than the construction thickness values, relevant to the tank lading, required by 1-3.11.1(b) through 1-3.11.1(f) of this Article.

(2) *Minimum Thickness of All Category 331 Tank Vessels Determined by Vessel Design Loading Criteria*. In no case shall the design thickness of any tank vessel be less than the greatest calculated thickness value required to comply with the maximum stress criteria for the load conditions and restrictions of (a) through (f).

(3) *Minimum Thickness of Tank Vessels That Contain Special Hazardous Ladings [See 1-3.11.1(a)(1)]*. Design thickness values shall be no less than values determined by design criteria in 1-3.11.1(b) through 1-3.11.1(f) relevant to the tank ladings listed in 1-3.11.1(a)(1) of this Article.

(h) *Attachments of Structures and Appurtenances to Tank Vessels*

(1) Except as otherwise required in (2) and (3) below, attachments to tank vessels shall conform to the requirements of 1-1.5(b) of this Modal Appendix, except that pads of 6.0 mm (0.25 in.) thickness may be used for attachment to a tank wall of 6.0 mm (0.25 in.) thickness or greater.

(2) Welded attachment of appurtenances and support structures to tank vessels constructed according to Article TF-6 of this Section shall be made to pads welded to the vessel wall. Except as required in (3) below, any material, including pads, welded directly to any pressure-retaining part of the vessel shall be made of materials that conform to the requirements of TM-180.2 of this Section.

(3) Appurtenances, support structures, or pads welded to tank vessels constructed of SA-517 steel shall conform to the requirements of 1-1.3(a) of this Modal Appendix.

(i) *Fatigue Analysis*

(1) Except as provided in (4) below, design of tank vessels constructed by the rules of this Article shall take into account the effect of cyclic loads on the vessel wall due to either of two load conditions:

(-a) the nonstatic mechanical loads required by 1-1.4(c)(2) through 1-1.4(c)(5) (Load Conditions B, C, D, and E) of this Modal Appendix

(-b) the cyclic load variations due to any variation of internal pressure equal to or greater than 20% of the sum of the value of the vessel's maximum allowable working pressure plus the value of the static liquid head of a vessel filled to its design weight of lading

(2) Load conditions for (1)(-a) and (1)(-b) above shall not be required to be considered simultaneously. However, in fatigue evaluation of any vessel part designed to withstand more than one combination of loadings due to the load conditions described in (1)(-a) and (1)(-b) above, the maximum loadings in each direction from all applicable load combinations for that load condition shall be considered to act simultaneously in determining the magnitude of alternating stresses. Fatigue life analysis shall be in accordance with Section VIII, Division 2, Part 5, 5.5, using 8×10^9 cycles for loading specified in (1)(-a) above and 10^5 cycles for the loading specified in (1)(-b) above. The Usage Factor shall not exceed 1.0.

(3) Modification of the severity of stress at any point in the vessel wall due to distribution of harmonics of the required variable loads in (1)(-a) above may be considered, provided that empirical acceleration data relevant to the specific design type, wall thickness and material, natural frequency of the tank vessel, and support system can be shown to be applicable to the vessel under consideration and to the stress modification considered.

(4) Except as otherwise required in (-c) below, consideration of cyclic loads listed in (1) above shall not be included as a minimum requirement of this subparagraph under either of the following conditions, (-a) or (-b):

(-a) Except for maximum values allowed in (b), 1-3.5.5 and 1-3.5.6 of this Article for the sum of all stresses including secondary stresses that occur in defined load conditions, the maximum allowable values for primary membrane stress conditions including the stresses induced in the vessel wall by pressure or gravity loading shall not exceed the lesser of the following:

(-1) values allowed by this Article

(-2) one-fourth of the minimum specified ultimate strength of the vessel wall material as found in Section II, Part A or Part B, as applicable

(-b) Vessels shall be constructed to all of the following design criteria:

(-1) Vessels shall have a volume smaller than 19 m^3 (5,000 gal).

(-2) Vessels shall be supported by rails parallel to the longitudinal vessel axis that are anchored so that each support rail is in continuous contact, along its entire length, to each frame of a truck chassis frame, provided

(+a) the support rails shall be continuously welded to vessel mounting pads conforming to the minimum material and thickness requirements of (h) above, the pads having a width and length sufficient that each pad edge, not including fillet welds to the vessel, shall be no closer than 50 mm (2 in.) from the center of the support rail attached to the pad

(+b) mounting pads shall extend the length of the vessel shell to within 100 mm (4 in.) of each head-to-shell girth seam

(+c) mounting pads and the support rails to which they are attached shall be designed so that reaction loads and consequent stresses induced in the vessel wall do not exceed the value limitations of 1-3.5.6

(-3) Vessels shall be constructed with the number and size of nozzles and internal standpipes into the vapor space above the design level of liquid lading, that are necessary for full vapor exchange, commensurate to the larger value of outlet flow capacity of the largest liquid drain nozzle or the capacity of a tank-installed outlet pump that can be connected to the largest outlet drain or pump flange during liquid lading transfer into or out of the vessel.

(-4) Fillet welds connecting any pads, nozzle, or nozzle reinforcement pad to the vessel wall shall be ground to a slight concave radius and all sharp edges that will provide a source of stress intensification shall be removed, except that after grinding, the throat dimension of all fillet welds shall be of sufficient value to provide the original design shear load capacity used in fillet weld and nozzle calculations.

(-c) Except for vessels designed to the more conservative maximum allowable stress values specified in (-a) above, vessels that shall not be exempt from design consideration of cyclic loads listed in (1)(-a) and (1)(-b) above shall include

(-1) vessels not meeting the exemption conditions in (-a) or (-b) above

(-2) vessels constructed of materials listed in Table TM-130.2-3 or Table TM-130.2-6 that are designed to maximum allowable stress values no lower than the values allowed in TD-210

(-3) vessels constructed for transportation of anhydrous ammonia, petroleum ladings that contain hydrogen sulfide, or any lading that is known to be associated with stress corrosion cracking

(-4) vessels constructed for ladings that are known to adversely affect the materials of tank construction, to the extent of compromising the pressure or lading retention integrity of the tank, whether the ladings are in their normal transportable condition, or are likely to be contaminated or improperly mixed; vessels constructed for ladings designated by the competent authority or specified by the user to be "corrosive to the tank"; or vessels required by the competent authority or specified by the user to be constructed with additional wall thickness for a "corrosion allowance"

(-5) vessels constructed for ladings that are designated by the competent authority as "poisonous by inhalation"

(-6) vessels required by the competent authority to be designed to consider cyclic loads

1-3.5.2 BULKHEADS AND RING STIFFENERS

Except for design requirements of vessel baffle and ring stiffeners in tank vessels designed for external pressure according to Article TD-4 of this Section, there is nothing in this Article requiring the use of bulkheads, baffles, or ring stiffeners.

1-3.5.3 MANHOLES

(a) Except as provided in (c) below, tank vessels shall be equipped with a manhole that conforms with the requirements of TD-690(c)(1) of this Section, except that a tank vessel with a volume capacity of 13 250 L (3,500 gal) or less that is not constructed to the rules of Article TF-6 of this Section may be equipped with an inspection opening that conforms to the requirements of TD-690 of this Section.

(b) Manholes shall not be located in the front head of a tank vessel.

(c) Additional requirements or restrictions for installation of manholes applicable to the tank lading are applicable to tanks constructed to the requirements of 1-3.11.1 of this Article. [See 1-3.11.1(d)(4).]

1-3.5.4 TANK VESSEL OPENINGS AND INTEGRAL HEAT TRANSFER DEVICES

(a) General Requirements. Except as otherwise required in (b) of this Article, openings in tank vessels shall meet the following requirements:

(1) An opening shall be provided in each tank vessel used for transportation of liquefied materials to provide complete drainage.

(2) Except for openings used for gauging devices, thermometer wells, pressure relief valves, manhole openings, and liquid and vapor openings for inlets and outlets for tank lading, the configuration of tank vessel openings shall be such that they can be closed with a plug, cap, or bolted flange.

(b) Design and construction of openings, inlets, and outlets applicable to the transportation of special ladings shall conform to the rules in 1-3.11.1 of this Article that are applicable to those ladings.

(c) *Marking of Inlets and Outlets*. Except for tank vessel nozzles used for gauging devices, thermometers, and pressure relief devices, or except when restricted by 1-3.11.1 of this Article, inlet and outlet nozzles shall be marked "liquid" or "vapor" to designate whether they communicate with liquid or vapor when the tank is filled to its maximum allowed filling density, except that a filling line communicating with vapor may be marked "spray fill."

(d) Refrigeration and heating coils or devices integral to or attached by welding to the tank vessel wall shall be designed, constructed, installed, and tested according to the rules of this Section and this Article where applicable. Where liquid or the vapor condensate used in such devices is subject to freezing, a method for complete drainage shall be provided.

1-3.5.5 TANK VESSEL ATTACHMENT REQUIREMENTS FOR DAMAGE PROTECTION DEVICES

(a) Except for devices required for impact protection of safety pressure relief valves, design of collision impact devices is not within the scope of this Section. However, the loads transferred into the tank vessel by damage protection devices and the resulting stresses shall be considered according to the maximum allowable stress design criteria of 1-3.5.1 of this Article. The sum of all stresses in the tank vessel wall, for all types of loads, including the stress due to the transfer of loads through protective devices, shall not exceed the value of maximum stress values allowed in 1-3.5.1(a)(1)(-b) of this Modal Appendix, that corresponds to the type of loads specified in 1-3.5.1(a)(1)(-b)(-3). Damage protection devices attached to the tank vessel shall not induce stresses in the tank vessel wall exceeding the values specified in 1-3.5.1(a)(1)(-a) of this Article under static load conditions specified in 1-3.5.1(a)(1)(-b)(-4).[13]

(b) *Protection of Safety Pressure Relief Valves*. Safety pressure relief valves shall be protected from damage resulting from collision with other vehicles or objects, trailer jackknifing, or overturn, and shall be protected so that in the event of an overturn of the tank onto a hard surface, their opening will not be prevented and their discharge will not be obstructed. Attachment to the tank vessel of protective devices through pads is required and shall meet the requirements of 1-3.5.1(h) of this Modal Appendix.

(1) Safety relief protection devices shall be designed to withstand a collision defined incident loading of magnitude required in 1-3.5.1(a)(1)(-b)(-4) of this Article, prorated according to the number of devices, using design margins required by the competent authority, but in no case shall the design margin be based on ultimate strength required for design of the safety relief maximum allowable stress values for materials found in Section II, Part D applicable to this Section.

(2) Total stress induced in the tank vessel wall shall not exceed the maximum value allowed in 1-3.5.1(a)(1)(-b) of this Article when loads required by 1-3.5.1(a)(1) are transmitted into the tank vessel through the relief valve collision protection device.

(c) *Other Protective Devices Attached to Tank Vessels*. Tank vessel design for attachment and installation of other defined incident damage protection devices (not installed for protection of safety relief valves) to the tank vessel wall through vessel pads shall meet the requirements of 1-3.5.1(h) of this Modal Appendix.

(1) Design requirements for other defined incident damage protection devices, not protecting pressure relief devices, are beyond the scope of this Section and shall be established by the competent authority.

(2) Total stress induced in the tank vessel from transfer of loads through attachments of collision damage protection devices, not protecting pressure relief devices, shall not exceed the maximum value allowed in 1-3.5.1(a)(1)(-b) of this Article when loads required by 1-3.5.1(a)(1)(-b)(-3) are transmitted into the tank vessel through attachment of collision protection device.

1-3.5.6 ATTACHMENT REQUIREMENTS FOR SUPPORTING AND ANCHORING DEVICES

Design details of supporting and anchoring systems are beyond the scope of this Section, except that attachment to the tank vessel wall of support and anchoring devices, directly or through pads, shall conform to the requirements of 1-3.5.1(h) of this Modal Appendix. Total stresses in the tank vessel wall, including the stress induced therein by the transfer of loads specified in Figure 1-1.4 of this Modal Appendix shall not exceed the values specified by 1-3.5.1(a)(1)(-a) of this Article. Total stresses induced in the vessel wall by defined incident loads specified by 1-3.5.1(a)(1)(-b)(-2) of this Article shall not exceed the values specified in 1-3.5.1(a)(1)(-b).

1-3.6 FABRICATION AND EXAMINATION

1-3.6.1 TANK VESSEL JOINTS

(a) Except as required in (b) of this paragraph, tank vessel joints shall be designed, prepared, and welded according to those requirements of Parts TW and TF of this Section that are applicable to the material composition of the parts to be welded. All undercutting in tank wall material shall be repaired as specified therein.

(b) All longitudinal welds in the tank vessel shell shall be located in the upper half of the tank.

1-3.6.2 TESTING

(a) Inspections and Tests. Inspection of materials used in construction of the tank vessel shall be performed according to the requirements of Part TM of this Section. New tank vessels shall be pressure tested according to the requirements of Article TT-2 of this Section, except that test pressure for new tanks constructed to the rules of Article TF-6 of this Section shall be no less than required by the competent authority.

(b) Weld Testing and Inspection

(1) Each tank vessel constructed according to the requirements of Article TF-6 of this Section shall be subjected, after postweld heat treatment and hydrostatic tests, to a wet fluorescent magnetic particle inspection of all welds in, or on the tank shell and heads, inside and out. The inspection method shall conform to requirements of TE-240.5(a) and to Mandatory Appendix V of this Section, except that permanent magnets shall not be used.

(2) For tanks not described in (1) above and that are larger than 13 250 L (3,500 gal) and that are not fully radiographed, tests shall be made of all welds in or on the shell and heads both inside and outside by either the wet fluorescent magnetic particle method in accordance with Mandatory Appendix V of this Section, the liquid dye penetrant method in accordance with Mandatory Appendix VI of this Section, or ultrasonic testing in accordance with Mandatory Appendix IX of this Section, and in accordance with relevant paragraphs of Part TE of this Section.

(c) All defects discovered by the weld inspections required in (b) above shall be repaired, and the tank vessel shall again be postweld heat treated, if such heat treatment was previously performed, and the repaired area shall again be tested.

1-3.6.3 POSTWELD HEAT TREATMENT

Postweld heat treatment of tank vessels is required for tank vessels constructed to the rules of this Article under the following conditions:

(a) when required by the competent authority

(b) where required by 1-3.11.1 of this Article

(c) when tanks are constructed according to the rules of Article TF-6 of this Section

Postweld heat treatment of tank vessels shall be performed as required by Article TF-7 of this Section and 1-3.11.1 of this Article, where required.

1-3.7 SAFETY RELIEF DEVICES

Tanks constructed to the rules of this Article shall be equipped with pressure relief device(s) and shall conform to the requirements of Part TOP of this Section.

(a) Relief valves installed in tank vessels designed to the additional requirements of 1-3.11.1 of this Article shall meet the specifications for type, design, capacity, temperature range, and pressure settings applicable to the ladings as required by that Article.

(b) Pressure relief valves shall be designed constructed and marked for pressure not less than the tank vessel maximum allowable working pressure at the temperature expected to be encountered by the user, or the temperature required by the competent authority nor more than 110% of that value.

1-3.8 ASME NAMEPLATE REQUIREMENTS

Each tank vessel shall have an ASME nameplate made of stainless steel or other corrosion resisting metal conforming to marking and installation requirements of Part TS of this Section. If the tank vessel is insulated, a duplicate shall be installed on the outer jacket in accordance with the rules of Part TS and any relevant requirements of the competent authority. Nameplate markings for tank vessels designed to operate in a vacuum condition shall conform to 1-1.10 of this Modal Appendix.

1-3.9 JURISDICTIONAL MARKINGS AND CERTIFICATION

(a) Certification of compliance of the rules of this Section shall consist of completion and availability of documents according to the requirements of TS-3 of this Section.

(b) The competent authority shall provide its own rules for compliance certification of its regulations and requirements.

1-3.10 OPERATION, MAINTENANCE, AND INSPECTIONS

(a) Inspections and Tests. Except as otherwise required in (b) below, tank vessels constructed according to the rules of this Article shall be inspected and tested according to the most stringent requirements for types and intervals of in service inspections and tests required by 1-1.9 of this Modal Appendix, the competent authority, or the mandatory requirements of the National Board Inspection Code.

(b) Tank vessels constructed of materials listed in Table TM-130.2-6 of this Section shall receive internal inspections and pressure tests at intervals required by Table 1-1.9 for Category 331 tanks, as follows:

(1) Magnetic particle inspections described in 1-3.6.2(b)(1) of this Article shall be performed in accordance with publication P-26 (formerly TB-2) of the Compressed Gas Association.

(2) Pressure tests shall be performed according to the requirements of 1-1.9 of this Section, except that test pressure for new tanks constructed to the rules of Article TF-6 of this Section shall be no less than required by the competent authority.

(c) Inservice Repairs. Except as permitted in (d) below, defects discovered by inspections required in this paragraph shall be repaired according to the requirements in Part TP of this Section and the National Board Inspection Code.

(d) Alternative Method for Inservice Repair of Cracks Detected by Internal and External Inspections. The following alternative method applies only to tank vessels constructed of SA-517 material:

(1) Cracks discovered during the inservice testing required by (b)(1) may be repaired according to publication P-26 (formerly TB-2) of the Compressed Gas Association, provided the competent authority allows the repair and the conditions listed in (2) are met.

(2) Conditions required for alternative repair methods allowed by (1) above shall be as follows:

(-a) Welding procedures for repairs shall be qualified according to Part III, 2.5.3.2, "Welding Method 2" of the current National Board Inspection Code with the concurrence of an Authorized Inspector of a pressure vessel repair facility holding a current R stamp.

(-b) The repair welding procedure qualification shall include Charpy V-notch impact tests at a temperature no higher than the minimum design metal temperature marked on the tank vessel appropriate to procedure qualification test criteria for new construction of vessels of the same material specification and thickness, design pressure, design type, and operating conditions. The impact test acceptance criteria shall be in accordance with the minimum required value adopted either in the edition of the Code in effect when the vessel was built or in the edition of the Code in effect when the vessel is repaired.

(-c) The maximum depth of cracks allowed to be repaired according to this paragraph shall be no deeper than one-half of the tank vessel wall material at the location of any part of the crack.

(-d) No part of a crack to be repaired according to this paragraph shall be located in vessel wall material with construction thickness exceeding 14.7 mm (0.58 in.).

(-e) Tank vessels for which crack repair procedures described in this paragraph are allowable shall be limited to vessels that have transported anhydrous ammonia or liquefied petroleum gas or other petroleum ladings.

1-3.11 ADDITIONAL REQUIREMENTS

1-3.11.1 CONSTRUCTION REQUIREMENTS FOR CARGO TANK VESSELS USED TO TRANSPORT SPECIFIC HAZARDOUS MATERIALS

(a) Scope and General Requirements. Except where otherwise required in this paragraph, tank vessels used to transport the ladings listed in (1) below shall be constructed to all of the rules of this Modal Appendix pertaining to Category 331 tanks.

(1) This paragraph contains rules for the construction of highway tanks used for transportation of

(-a) anhydrous ammonia, carbon dioxide oxide refrigerated liquid, chlorine, nitrous oxide refrigerated liquid, and sulfur dioxide

(-b) other unspecified refrigerated liquids allowed by the competent authority to be transported in category 331 tanks

(2) Except as provided in (4) below or otherwise specified in this paragraph, tank vessels shall be designed and constructed, and be equipped with pressure relief valves, for the value of maximum allowable working pressure required by 1-3.3(b) of this Article, but in no case shall be less than the values listed as follows:

(-a) anhydrous ammonia: 18.3 bar (265 psi)

(-b) carbon dioxide oxide refrigerated liquid: 13.80 bar (200 psi), except as provided in (4) below

(-c) chlorine: 15.5 bar (225 psi)

(-d) nitrous oxide refrigerated liquid: 13.80 bar (200 psi)

(-e) sulfur dioxide: tank vessel capacity not more than 4 500 L (1,200 gal), 10.3 bar (150 psi)

(-f) sulfur dioxide: tank vessel capacity exceeding 4 500 L (1,200 gal), 8.62 bar (125 psi)

(-g) unspecified refrigerated liquids: maximum allowable working pressure and minimum required by competent authority

(3) Each cargo tank vessel used to transport ladings listed in (1) above, except tanks for transport of anhydrous ammonia, shall be covered with a suitable insulation of such thickness that the overall thermal conductance is not more than the conductance values listed in (-a) and (-b) below. Conductance values shall be measured at 15.6°C (60°F).

(-a) Except for additional restrictions in (d)(6) of this paragraph, the conductance required for insulation for tanks that are used to transport carbon dioxide refrigerated liquid, chlorine, or nitrous oxide refrigerated liquid shall be no greater than 1 600 J/m^2/°C differential (0.08 Btu/ft^2/°F/hr).

(-b) The conductance required for insulation for tanks that are used to transport sulfur dioxide shall be no greater than 1 500 J/m^2/°C (0.075 Btu/ft^2/°F/hr).

(-c) The conductance required for insulation for tanks that are used to transport other refrigerated liquids not otherwise specified shall be as required by the competent authority, or by the user. The competent authority or the user may require or specify temperature holding time and pressure rise criteria that will require more stringent insulation conductance specifications than required by (-b) or (-c) above.

(4) Where allowed by the competent authority, tank vessels used for transportation of refrigerated liquids may be designed for alternative values of maximum allowable

working pressure no lower than the minimum value of the pressure range for Category 331 tanks [see 1-3.3(b)(1)(-a)], provided

(-a) the tank is insulated according to the minimum requirements and criteria of (3)(-a) above

(-b) the alternative maximum allowable working pressure value is permitted by the competent authority

(-c) the tank vessel is constructed and marked for a minimum design metal temperature no higher than the coincident temperature of the lading at the alternative maximum allowable working pressure, according to the requirements of Article TM-2 of this Section, or in the alternative

(-d) the minimum design metal temperature is set by the competent authority (or the user) at a value equal to or higher than the vapor temperature of the lading at the least pressure allowed by 1-3.3(b)(1)(-a) of this Article, and the maximum allowable working pressure value is set by the competent authority (or the user) as equal to or incrementally higher than the vapor pressure at the minimum design metal temperature

(5) Relief valves shall be installed and located so that the cooling effect of the tank lading will not prevent the effective operation of the device. Pressure relief valves installed in insulated tanks that are designed for transport of refrigerated liquids, and that are equipped with manways, may be installed in protected locations to prevent obstruction or disablement of relief valves from icing, provided that the inlet port of the relief valve communicates with the vapor space of the vessel in its normal operating position through a pipe or tube of sufficient size to prevent restriction of flow or pressure drop below the full flow rating of the relief valve. Pipes or tubes that connect the vapor space of the tank vessel to the intake port of the relief valves shall be braced and connected and be of sufficient stiffness and strength to prevent damage from road vibration and shock, including leakage into the liquid space of the tank (see Nonmandatory Appendix B of this Section). Design of connecting pipes and tubes shall include a means to test for damage that results in leakage of liquid to the inlet port of the relief valve.

(b) Additional Requirements for Construction of Anhydrous Ammonia Cargo Tank Vessels. Cargo tank vessels used to transport anhydrous ammonia shall be designed and constructed to the rules of this Article and as required in this subparagraph.

(1) Tank vessels shall be constructed to the maximum allowable working pressure required by (a)(2)(-a) above.

(2) Tank vessels shall be constructed of steel. Use of copper, silver, zinc, or their alloys is prohibited.

(3) Tank vessels shall be postweld heat treated according to the requirements of 1-3.6.3 of this Article, but in no case at a metal temperature less than 566°C (1,050°F).

(4) Repair of cracks discovered by inspections required for continued service of tank vessels constructed of SA-517 shall be performed according to the rules in 1-3.10 of this Article.

(c) Additional Requirements for Construction of Carbon Dioxide Refrigerated Liquid Cargo Tank Vessels

(1) Except as provided in (2) below, tank vessels shall be constructed to the maximum allowable working pressure no less than the value required by (a)(2)(-b) above.

(2) Carbon dioxide refrigerated liquid tank vessels may be designed to an alternative maximum allowable working pressure no lower than the minimum value of the pressure range for Category 331 tanks required in 1-3.3(b)(1)(-a) of this Article provided the tank is constructed to requirements of (a)(4) above.

(3) Relief valves shall be installed and located so that the cooling effect of the tank lading will not prevent the effective operation of the device. One or more pressure control devices may be used in addition to the safety relief valves required by 1-3.7.

(d) Additional Requirements for Construction of Chlorine Cargo Tank Vessels

(1) Tank vessels shall be constructed to the maximum allowable working pressure value required by (a)(2)(-c) above.

(2) Material used to construct vessel shell, heads, the manway, and attachment and support pads shall be steel as follows:

(-a) Material shall conform to minimum requirements of specification SA-516 Grade 65 or 70, normalized, or specification SA-612 normalized.

(-b) Material plate impact specimens shall meet Charpy V-notch test requirements of SA-20.

(-c) Material plate impact test specimens shall meet the requirements of 1-3.4(a)(2) of this Article, except that the minimum impact shall be no less than 40 J (30 ft-lb) in the longitudinal direction, and 27 J (20 ft-lb) in transverse direction of final rolling of plate at an impact test temperature no warmer than −40°C (−40°F).

(3) Minimum thickness of vessel heads and shells and other pressure-retaining parts shall be no less than 15.9 mm (0.625 in.), including corrosion allowance, which shall be the smaller value of 20% of the construction thickness, or 2.5 mm (0.10 in.).

(4) Tank vessels shall have only one opening that shall be in the top of the tank vessel, and be fitted with a nozzle that is protected with a manway cover that conforms to the standard of The Chlorine Institute, Inc. drawing 103-4 dated September 1, 1971.

(5) Tank vessels shall be

(-a) fully radiographed according to the requirements of this Section

(-b) postweld heat treated as a unit after completion of all welding to the tank vessel wall, according to the requirements of 1-3.6.3 of this Article

(6) Tank insulation shall have a conductance no less than required in (a)(2)(-a) above, and be constructed of no less than 100 mm (4 in.) of corkboard, or 100 mm (4 in.) of polyurethane foam, or 50 mm (2 in.) of ceramic fiber/fiberglass of 6.4×10^{-8} kg/mm^3 (4 lb/ft^3) minimum density, covered by 50 mm (2 in.) minimum thickness of fiber.

(e) Additional Requirements for Construction of Nitrous Oxide Refrigerated Liquid Cargo Tank Vessels

(1) Except as provided in (2) below, tank vessels shall be constructed to the maximum allowable working pressure required by (a)(2)(-d) above.

(2) Nitrous oxide refrigerated liquid tank vessels may be designed to an alternative maximum allowable working pressure no lower than the minimum value of the pressure range for Category 331 tanks required in 1-3.3(b)(1)(-a) of this Article provided the tank is constructed to requirements of (a)(4) above.

(3) Relief valves shall be installed and located so that the cooling effect of the tank lading will not prevent the effective operation of the device. One or more pressure control devices may be used in addition to the safety relief valves required by 1-3.7 of this Article.

(4) Minimum thickness of shell, heads, and other pressure retention parts of tank vessels shall be the greatest of the values determined as follows:

(-a) Tank vessel wall thickness shall be no less than required to meet the stress and load requirements of 1-3.5.1, 1-3.5.5, and 1-3.5.6 of this Article.

(-b) Shells and heads of tanks excluding intermediate heads shall be constructed of 7.62 mm (0.30 in.) minimum SA-240 Type 304 stainless steel; or suitable steel of equivalent thickness, e_1, calculated as required by 1-3.11.2 of this Article, where the properties of SA-240 Type 304 stainless steel are specified in Section II. The properties of the actual material used, A_1 (percent elongation) and R_{m1} (minimum ultimate tensile strength), shall be determined from the specified properties of the actual material in Section II.

(f) Additional Requirements for Construction of Sulfur Dioxide Cargo Tank Vessels

(1) Tank vessels shall be designed and constructed to a maximum allowable working pressure equal to the value required by (a)(2)(-e) or (a)(2)(-f) above that is applicable to the tank vessel volume.

(2) Corrosion allowance of shell, heads, and other pressure retention parts of tank vessels shall be the smaller value of 20% of the construction thickness, or 2.5 mm (0.10 in.), and shall be exclusive of the greatest value of minimum thickness required in this subparagraph.

(3) Minimum thickness of shell, heads, and other pressure retention parts of tank vessels shall be the greatest of the values determined as follows:

(-a) Tank vessel wall thickness shall be no less than required to meet the stress and load requirements of 1-3.5.1, 1-3.5.5, and 1-3.5.6.

(-b) Shells and heads of tanks excluding intermediate heads shall be constructed of 6.35 mm (0.25 in.) minimum SA-240 Type 304 stainless steel; or suitable steel of equivalent thickness, e_1, calculated as required by 1-3.11.2 of this Article, where the properties of SA-240 Type 304 stainless steel are specified in Section II. The properties of the actual material used, A_1 (percent elongation) and R_{m1} (minimum ultimate tensile strength), shall be determined from the specified properties of the actual material in Section II.

(g) Additional Requirements for Construction of Refrigerated Liquid Cargo Tank Vessels Transporting Other Compressed Gases Not Specified Herein

(1) Tank vessel shall be insulated to the minimum requirements and performance criteria of (a)(3)(-c) above.

(2) Minimum design metal temperature and maximum allowable working pressure shall be determined as required in (a)(4) above.

(3) Relief valves shall be installed and located so that the cooling effect of the tank lading will not prevent the effective operation of the device. Where allowed by the competent authority, one or more pressure control devices may be used in addition to the safety relief valves required by 1-3.7.

1-3.11.2 EQUIVALENT MATERIAL THICKNESS

Where allowed in this Article, when a minimum thickness of a specified material is given, the equivalent thickness of the actual material used shall be determined according to Mandatory Appendix XIII, Method B.

ARTICLE 4
CATEGORY 338, VACUUM INSULATED CARGO TANKS FOR TRANSPORTING REFRIGERATED FLUIDS

1-4.1 SCOPE

(a) This Appendix provides the minimum requirements for design, construction, and continued service for vacuum insulated cargo tanks transporting refrigerated fluids. These requirements are in addition to all other applicable requirements of this Section. In addition, all requirements of the competent authority shall be met.

(b) Cargo tanks meeting the requirements of this Appendix shall be designated and stamped as T, Class 1, in accordance with the rules of this Section.

(c) For the purpose of this Modal Appendix, refrigerated fluids are listed in Table 1-4.1.

Table 1-4.1
Refrigerated Nontoxic Gases

Item and Group	Identification Number, Name, and Description [Note (1)]
3A	Asphyxiant Gases
	UN 1913 neon, refrigerated liquid
	UN 1951 argon, refrigerated liquid
	UN 1963 helium, refrigerated liquid
	UN 1970 krypton, refrigerated liquid
	UN 1977 nitrogen, refrigerated liquid
	UN 2187 carbon dioxide, refrigerated liquid
	UN 2591 xenon, refrigerated liquid
	UN 3136 trifluoromethane, refrigerated liquid
	UN 3158 gas, refrigerated liquid, NOS [Note (2)]
30	Oxidizing Gases
	UN 1003 air, refrigerated liquid
	UN 1073 oxygen, refrigerated liquid
	UN 2201 nitrous oxide, refrigerated liquid, oxidizing
	UN 3311 gas, refrigerated liquid, oxidizing, NOS [Note (2)]
3F	Flammable Gases
	UN 1038 ethylene, refrigerated liquid
	UN 1961 ethane, refrigerated liquid
	UN 1966 hydrogen, refrigerated liquid
	UN 1972 methane, refrigerated liquid; or natural gas, refrigerated liquid, with high methane content
	UN 3138 ethylene, acetylene, and propylene mixture, refrigerated liquid, containing at least 71.5% ethylene with not more than 22.5% acetylene and not more than 6% propylene
	UN 3312 gas, refrigerated liquid, Flammable, NOS [Note (2)]

NOTES:
(1) Identification (UN) number, name, and description according to UN Recommendations on Transport of Dangerous Goods, Modal Regulations
(2) NOS = Not otherwise specified

1-4.2 GENERAL REQUIREMENTS

(a) Each cargo tank shall consist of one or more suitably supported welded pressure vessels enclosed within an outer vacuum jacket with insulation between the inner vessel and outer shell or jacket and having piping, valves, supports, and other appurtenances. (See Nonmandatory Appendix E.)

(b) Design and construction details of the tank interior shall be such that collection and retention of cleaning materials or contaminants will not occur. To preclude the entrapment of foreign material, the design and construction of the tank must allow washing of all interior surfaces by the normal surging of the lading during transportation. The inner vessel shall be cleaned for the intended service.

(c) All applicable packaging requirements of the competent authority shall be met.

(d) The maximum allowable working pressure of the tank must be at least 1.74 bar gauge (25.3 psig) but not more than 34.5 bar gauge (500 psig).

(e) The material and the protection of the surfaces exposed to the atmosphere shall be suitable for the intended service surroundings.

(f) Thermal Conditions. The following thermal conditions shall be taken into account in the design and selection of materials:

(1) for the inner vessel and its associated equipment, the full range of temperature expected in normal operation

(2) for the outer jacket and equipment thereof [other than equipment covered in (1) above]

(-a) a minimum design metal temperature of −20°C (−4°F)

(-b) a maximum design temperature of 50°C (122°F)

If the jacket is designed for a lower temperature, it shall be marked on the nameplate.

1-4.3 MATERIALS

Materials of construction shall be as specified in 1-3.4. The jacket is not part of the pressure vessel. Cast materials are not permitted, except for valves.

(a) The jacket covering the insulation shall be of steel if the refrigerated fluid is to be transported by water or if it is oxygen or a flammable fluid.

(b) In choosing the materials for all parts of the cargo tank, consideration shall be given to avoidance of brittle fracture at the minimum design temperature, resistance to impact loads, and to hydrogen embrittlement and stress corrosion cracking if applicable. Nonmetallic materials may be used for the attachments and supports between the shell and jacket, provided their properties at the design pressure and minimum design temperature are proven to be suitable for the intended service.

(c) Any part of the tank, including fittings, gaskets, and piping, which may come in contact with the cryogenic fluid, shall be compatible with that cryogenic fluid.

(d) Valves, fittings, pumps, compressors, or controls made of aluminum or aluminum alloys with internal rubbing or abrading aluminum or aluminum alloy parts that may come in contact with oxygen or refrigerated fluid shall not be used on cargo tanks for oxygen service. Design of the pressure vessel interior and its internal fixtures shall also exclude any rubbing or abrading aluminum or aluminum alloy parts for oxygen service. Aluminum or aluminum alloy valves, pipe, or fittings external to the jacket that retain the oxygen lading during transportation shall not be used.

(e) Materials that may react with oxygen or oxygen-enriched atmospheres in a dangerous manner shall not be used in cargo tanks intended for the transport of cryogenic liquid having a boiling point of −198°C (−325°F) or colder.

1-4.4 DESIGN REQUIREMENTS (25)

Design of the inner vessel and outer jacket shall meet all applicable requirements of this Appendix and of Nonmandatory Appendix E.

(a) General

(1) In the event of an increase in at least one of the following parameters, the initial design process shall be repeated to take account of the modifications:

(-a) maximum allowable pressure

(-b) density of the fluid for which the vessel is designed

(-c) maximum tare weight of the inner vessel

(-d) nominal diameter of the inner vessel

(-e) an increase of more than 5% of the nominal length of the inner vessel

(2) Or if any change relative to the following parameters occurs, the initial design process shall be repeated to take account of the modifications:

(-a) the type or grade of material

(-b) the fundamental shape

(-c) the decrease in the minimum mechanical properties of the material being used

(-d) to the modification of the design of an assembly method concerning any part under stress, particularly as far as the support systems between the inner vessel and the outer jacket or the inner vessel itself or the protective frame, if any, are concerned

(b) Design Specification

(1) The following details shall be defined for the design of any cargo tank:

(-a) maximum allowable pressure

(-b) fluids intended to be contained

(-c) gross volume of the inner vessel

(-d) dimensions and allowable weight, taking characteristics of the vehicle into account

Table 1-4.4-1
Design Load Factors for Normal Operations in Specified Transportation Modes

Transportation Modes	Load Case	Load Factors				
		Forward, F_i	Backward, F_i	Up, F_j	Down, F_j	Lateral, F_k
Road and water	1	2.0	...	...	1.0	...
	2	...	2.0	...	1.0	...
	3	...	...	1.5	...	...
	4	...	...	...	2.0	...
	5	...	...	...	1.0	1.5

(-e) location of attachment points and loads allowable on these points

(-f) filling and emptying rate

(-g) range of ambient temperature

(-h) transportation mode

(2) A design document in the form of drawings with text, if any, shall be prepared, and it shall contain the information given above plus the following where applicable:

(-a) drawings with dimensions and thicknesses of the tank components

(-b) specification of all load bearing materials including grade, class, temper, testing, etc., as relevant

(-c) applicable material test certificates

(-d) calculations to verify compliance with this Part

(-e) design test program

(-f) nondestructive testing requirements

(-g) pressure test requirements

(-h) piping configuration including type, size, and location of all valves and relief devices

(-i) details of supports and attachments

(-j) diagram showing heat numbers and Charpy impact values of the plates used for the pressure vessel construction and their location on the pressure vessel

(c) *Design Analysis*. The pressure vessel shall be able to withstand safely the mechanical and thermal loads encountered during pressure test and normal operation. The static forces used shall be obtained as required in (1) and (2) below when the pressure vessel is fully supported within the vacuum jacket by structural members.

(1) The pressure vessel, its attachments, and supports shall be designed for the static forces obtained by multiplying the load factors applicable for the transportation modes given in Table 1-4.4-1 with the maximum weight imposed on the pressure vessel in addition to the design pressure. The maximum weight imposed on the inner vessel shall include the weights of the inner vessel, its fastenings and supports, maximum permissible content, piping, insulation, and any other item supported on the pressure vessel. Each load case shall be considered separately but all forces in a load case shall be considered acting simultaneously. The static forces obtained are equivalent to the dynamic loads experienced during normal operation of the cargo tank.

(2) The outer jacket, its attachments, and supports shall be designed for the static forces obtained by multiplying the load factors applicable for the transportation modes given in Table 1-4.4-1 with the maximum weight imposed on the outer jacket in addition to 2 bar (29 psi) external pressure. The maximum weight imposed on the outer jacket shall include the weights of the outer jacket, with all its enclosures including inner vessel filled to the maximum permissible capacity and the weights of all items fastened to or supported from/to the outer jacket such as piping, controls, cabinets, etc. Each load case shall be considered separately, but all forces in a load case shall be considered acting simultaneously. The static forces obtained are equivalent to the dynamic loads experienced during normal operation of the cargo tank.

(3) A cargo tank mounted on a motor vehicle frame must be supported to the frame by external cradles, load rings, or longitudinal members. If cradles are used, they must subtend at least 120 deg of the cargo tank circumference. The design calculations for the supports and load bearing tank or jacket, and the support attachments must include beam stress, shear stress, torsion stress, bending moment, and acceleration stress for the loaded vehicle as a unit. The effects of fatigue must also be considered in the calculations.

(4) Load rings in the jacket used for supporting the inner vessel shall be designed to carry the fully loaded inner vessel at the specified static and dynamic loadings and external pressure.

(d) *Fatigue Analysis*. The design shall take into account the effect of cyclic loads on the inner vessel and its attachments during normal conditions of operation from mechanical loads obtained from the load factors specified in Table 1-4.4-2 and design pressure. The minimum fatigue life shall meet the following requirements:

(1) 10^9 cycles for cyclic loads in Table 1-4.4-2

(2) 3×10^5 cycles for actual pressure cycles but in no case less than 10^5 cycles for full pressure cycles from 0 MPa (0 psi) to MAWP

Table 1-4.4-2
Factors for Fatigue Analysis

Transportation Modes	Load Case	Load Factors					
		Forward Cyclic, F_i	Backward Cyclic, F_i	Up Cyclic, F_j	Down Cyclic, F_j	Steady, F_j	Lateral Cyclic, F_k
Road and water	1	0.7	...	...	...	1.0	...
	2	...	0.7	...	...	1.0	...
	3	...	...	1.0	...	...	...
	4	...	...	...	1.0	1.0	...
	5	...	...	...	...	1.0	0.7

Fatigue life analysis shall be in accordance with Section VIII, Division 2, Part 5, 5.5. The Usage Factor shall not exceed 1.0. In fatigue evaluation of any item designed to withstand more than one load case, the maximum loadings in each direction from all applicable load cases shall be considered to act simultaneously in determining the magnitude of alternating stresses.

(e) Maximum Allowable Stresses

(1) The inner vessel shall be designed for the design pressure using the maximum allowable stress values given in Section II, Part D, for the materials used [see TM-130.2(b)].

(2) For the design loads specified in 1-4.4, the maximum allowable membrane stress values at any point in the vessel supports and in the vessel wall at support attachments shall not exceed the lesser of 33% of the specified minimum tensile strength and 67% of the specified minimum yield strength of the materials used (see Section II, Part D, Subpart 1, Tables U and Y-1). The local membrane plus bending stress shall not exceed 75% of the applicable yield strength. For austenitic stainless steels the 1% proof strength (determined by the 1% offset method), determined in accordance with the applicable material specification, may be used instead of the values in Section II, Part D, Subpart 1, Table Y-1, when acceptable to the jurisdictional authorities (e.g., 49 CFR 178.274).

When austenitic stainless steels are used, higher tensile strength, yield strength, or 1% proof strength values, and up to 115% of the minimum specified values in the applicable material standards may be used, provided these values are reported on the test report.

(3) For nonpressure parts, the enhanced tensile strength of the material at actual operating temperature may be substituted for the tensile strength at ambient temperature to the extent recognized by Section XII or EN 10028-7.

(f) Design Criteria

(1) Vessels and outer jackets shall be of a circular cross section.

(2) Vessel shall be designed and constructed to withstand a test pressure not be less than 1.3 times the MAWP. For shells with vacuum insulation, the test pressure shall not be less than 1.3 times the sum of the MAWP and 1 bar (14.5 psi). Except for an accessory vessel used for refrigerant (cooling and heating fluid) storage, the test pressure shall not be less than 3 bar (44 psi) gauge pressure.

(3) For metals exhibiting a clearly defined yield point or characterized by a guaranteed proof strength, the primary membrane stress, S, in the vessel shell shall not exceed $0.75R_e$ or $0.43R_m$, whichever is less, at the test pressure where

R_e = specified minimum yield strength, MPa (N/mm^2) (psi). [For austenitic stainless steel R_e may be determined by the 0.2% or the 1% offset method, as appropriate, see 1-4.4(e)(2).]

R_m = specified minimum tensile strength, MPa (N/mm^2) (psi)

(-a) The R_m and R_e values used in the design shall be the specified minimum values in accordance with the applicable national or international materials standards. For austenitic steels, the specified minimum R_e and R_m values in the applicable material standards may be increased by up to 15% when greater values are reported on the material inspection certificate (e.g., test report). See TF-410.3 for additional welding qualification requirements.

(-b) Steels that have an R_e/R_m ratio greater than 0.85 are not permitted for the construction of welded vessel shells. The values of R_e and R_m to be used in determining this ratio shall be the specified minimum values in the applicable material specification.

(-c) Steels used in the construction of vessels shall have an elongation at fracture, in percent, not less than $10{,}000/R_m$. The elongation shall not be less than 16% for fine grain steels and 20% for other steels. Aluminum and aluminum alloys used in the construction of vessels shall have an elongation at fracture, in percent, not less than

$10{,}000/6R_m$. The elongation shall not be less than 12% for aluminum and aluminum alloys.

NOTE: The unit to be used for R_m to compute the percent elongation shall be N/mm^2 (1 N/mm^2 = 1 MPa = 145 psi).

(-d) For sheet metal, the tensile test specimen shall be oriented at right angles (transverse) to the principal direction rolling. The elongation at fracture shall be measured on test specimens of rectangular cross section in accordance with ISO 6892:1998, Metallic Materials — Tensile Testing, using a 50 mm (2 in.) gauge length.

(g) Minimum Vessel Wall Thickness

(1) The minimum pressure vessel thickness shall be the greater of the following:

(-a) the minimum thickness determined in accordance with the requirements in (2) through (4) below

(-b) the minimum thickness determined in accordance with (c)(1)

(2) Vessels of not more than 1.80 m (71.0 in.) in diameter shall be not less than 5 mm (0.20 in.) thick in the Reference material [see (6) below], or shall be of equivalent thickness in the metal to be used. Vessels of more than 1.80 m (71.0 in.) in diameter shall be not less than 6 mm (0.24 in.) thick in the Reference material, or of equivalent thickness in the metal to be used.

(3) Vessels of vacuum-insulated tanks of not more than 1.80 m (71.0 in.) in diameter shall be not less than 3 mm (0.12 in.) thick in the Reference material [see (6) below] or of equivalent thickness in the metal to be used. Such vessels of more than 1.80 m (71.0 in.) in diameter shall be not less than 4 mm (0.16 in.) thick in the Reference material, or of equivalent thickness in the metal to be used.

(4) Vessels shall be not less than 3 mm (0.12 in.) thick regardless of the material of construction.

(5) For vacuum-insulated tanks, the aggregate thickness of the jacket and the vessel wall shall correspond to the minimum thickness prescribed in (2) above, and the thickness of the vessel wall shall not less than the minimum thickness prescribed in (3) above.

(6) Evacuated jackets for flammable fluids shall have a minimum thickness of 6 mm (0.24 in.) in the reference material.

(7) In no case shall the vessel wall and/or jacket thickness be less than that required by (1) through (6) above. The minimum thickness shall be exclusive of any corrosion allowance.

(8) The equivalent thickness of a material to the reference material thickness prescribed in (2), (3), and (6) above shall be determined according to Mandatory Appendix XIII, Reference Material and Equivalent Thickness.

(h) Surge Plates. The inner vessel shall be divided by surge plates to provide stability and limit dynamic loads to the requirements of (c) above, unless it is to be filled equal to or more than 80% of its capacity or nominally empty. The surge plate shall cover at least 70% of the cross-section of the vessel.

The volume between surge plates shall not exceed 10 500/s_g L (2,790/s_g gal) where

s_g = the specific gravity of the cryogenic fluid at 1 bar saturation (14.5 psig)

Surge plates and their attachments to the shell shall be designed to resist the stresses caused by a pressure evenly distributed across the area of the surge plate. The pressure is calculated by considering the mass of liquid between the plates decelerating at 2 g (Table 1-4.1).

1-4.5 FABRICATION AND EXAMINATION

(a) All welded joints in the pressure vessel shall meet the requirements of this Section, except that butt welds with one plate edge offset are not permitted [see Figure TW-130.5-1, illustration (k)].

(b) All longitudinal welds in the pressure vessel must be located so as not to intersect nozzles or supports other than load rings and stiffening rings.

(c) All inner vessel nozzle-to-shell and nozzle-to-head welds shall be full penetration welds.

(d) Provision for internal access shall be required for all cargo tanks transporting oxygen. Each inner vessel having an internal access shall be

(1) provided with means of entrance and exit through the jacket, or

(2) marked on its jacket to indicate the access location on the inner vessel.

A manhole with a bolted closure may not be located on the front head of the tank.

(e) The inlet to the liquid product discharge opening of each pressure vessel intended for flammable lading shall be at the bottom of the inner vessel.

(f) A tank for oxygen service shall be thoroughly cleaned in accordance with industry standards (e.g., CGA G-4.1, Cleaning Equipment for Oxygen Service) to remove foreign material that could react with the lading.

NOTE: The use of backing rings requires careful consideration of cleanliness, product drainage, and materials for safe application in oxygen service.

(g) All butt welds in the pressure vessel shell and heads subject to pressure shall be examined radiographically or ultrasonically for their full length in accordance with Article TE.

1-4.6 PRESSURE RELIEF DEVICES

(a) Every tank shall be provided with two independent pressure relief systems that are not connected in series, namely

(1) a primary system of one or more spring-loaded pressure relief valves and

(2) a secondary system of one or more frangible discs or pressure relief valves

(b) A competent authority may require stricter safeguards than those specified in this part.

(c) Capacity and Set Pressure of Pressure Relief Devices

(1) For the primary system, the pressure relief valves must have a set point not greater than 110% of the MAWP and be fully open at a pressure not exceeding 121% of the MAWP. These pressure relief valves must, after discharge, close at a pressure not lower than the MAWP and must remain closed at all lower pressures. The pressure relief valves should be of the type that will resist dynamic forces, including surge. The capacity for the pressure relief valves for the primary system shall provide for loss of vacuum and be sufficient so that the pressure inside the tank does not exceed 121% of the MAWP.

(2) For the secondary system, both the primary and secondary relieving devices, under complete fire engulfment at a coincident temperature not exceeding 427°C (800°F), shall be sufficient to limit the pressure in the tank to the test pressure.

(3) The required capacity of the relief devices shall be calculated in accordance with CGA S-1.2.

(d) Design and Construction. Each pressure relief valve and frangible disc holder must be designed and constructed for a pressure equal to or exceeding the tank's test pressure at the coldest temperature expected. Pressure relief devices must be either spring-loaded pressure relief valves or, for the secondary system, frangible discs. Pressure relief valves must be of a type that automatically opens and closes at predetermined pressures.

(e) Optional Pressure Relief Devices and Pressure Control Valves. In addition to the required pressure relief devices, a cargo tank in refrigerated liquid service may be equipped with one or both of the following:

(1) one or more pressure control valves set at a pressure below the tank's design pressure

(2) one or more frangible discs set to function at a pressure not less than the test pressure or more than 1.75 times the maximum allowable working pressure of the tank

(f) Type, Application, Testing, Marking, and Maintenance Requirements. Unless otherwise specified in this Section, the type, application, testing, marking, and maintenance requirements for pressure relief devices shall be as specified in CGA S-1.2.

(g) Maximum Filling Rate

(1) For a tank used in oxygen and flammable refrigerated fluid service, the maximum rate at which the tank is filled shall not exceed the liquid flow capacity of the primary pressure relief system, rated at a pressure not exceeding 121% of the tank's design pressure. This rate shall be included on the inner vessel plate.

(2) On a tank used in helium and atmospheric gas (except oxygen) refrigerated fluid service, the maximum rate at which the tank is filled shall not exceed the liquid flow capacity of the pressure relief valves, rated at the test pressure of the inner vessel. This rate shall be included on the inner vessel nameplate.

(h) Arrangement and Location of Pressure Relief Devices

(1) The discharge from any pressure relief system must be unobstructed to the outside of any protective housing in such a manner as to prevent impingement of gas upon the jacket or any structural part of the tank, or operating personnel. For oxygen and flammable refrigerated fluid service, the discharge must be directed upward.

(2) Each pressure relief valve shall be arranged or protected to prevent accumulation of foreign material between the relief valve and the atmospheric discharge opening in any relief piping. The arrangement must not impede the flow through the device.

(3) Each pressure relief valve shall be designed and located to minimize the possibility of tampering. If the pressure setting or adjustment is external to the valve, the valve shall be sealed.

(4) Each pressure relief device shall have direct communication with the vapor space of the inner vessel at the mid length.

(5) Each pressure relief device shall be installed and located so that the cooling effect of the contents during venting will not prevent the effective operation of the device.

(i) Connections

(1) Each connection to a pressure relief device must be of sufficient size to allow the required rate of discharge through the pressure relief device. The inlet connection must be not less than $\frac{1}{2}$ in. nominal pipe size.

(2) A shut-off valve may be installed in a pressure relief system only when the required relief capacity is provided at all times.

(j) Markings

(1) The flow capacity and rating shall be verified and marked by the Manufacturer of the safety relief valve in accordance with the requirements of Section XIII, 3.9.

(2) In addition, the markings shall comply with the applicable requirements of the competent authority.

1-4.7 ASME NAMEPLATE REQUIREMENTS (25)

(a) All applicable nameplate and stamping requirements of this Section shall be met [see 1-4.1(b)]. A duplicate nameplate [see TS-100.2(b)] for the inner vessel shall be installed on the outer jacket.

(b) The outer jacket is not required to be stamped with the Certification Mark with T Designator.

1-4.8 JURISDICTIONAL MARKINGS

Every cargo tank must be marked and labeled in accordance with the requirements of the competent authority.

1-4.9 OPERATION, MAINTENANCE, AND INSPECTION

(a) Cargo tanks shall be tested and inspected periodically at intervals required by the competent authority (for example, see 49 CFR, Part 180, Subpart E).

Vacuum jacketed cargo tanks used for dedicated transportation of refrigerated liquefied gases are exempted from the external inspection of the pressure vessel. Unless the pressure vessel is fitted with inspection openings on the pressure vessel, internal inspection of the pressure vessel is also not required.

(b) The periodic inspection and test shall include those inspections and tests for the intermediate periodic inspection, and an internal (unless exempted) and external examination.

(c) An exceptional inspection and test is necessary when a cargo tank shows evidence of damage or corroded areas, leakage, or other conditions that indicate a deficiency that could affect the integrity of the cargo tank: the tank has been in an accident and has been damaged to an extent that may adversely affect its retention capability; the tank has been out of service for a period of 1 yr or longer; or the tank has been modified from its original design specifications (see Article TP-2). The extent of the exceptional inspection and test shall depend on the amount of damage or deterioration of the cargo tank. It shall include at least the inspection and a pressure test. Pressure relief devices need not be tested or replaced unless there is reason to believe the relief devices have been affected by the damage or deterioration.

(d) The internal and external examinations shall ensure that

(1) the outside of the vacuum jacket and — if internal inspection is required — the inside of the pressure vessel is inspected for pitting, corrosion, or abrasions, dents, distortions, defects in welds or any other conditions, including leakage, that might render the cargo tank unsafe for transportation.

(2) the piping, valves, and gaskets are inspected for corroded areas, defects, and other conditions, including leakage, that might render the portable tank unsafe for filling, discharge, or transportation.

(3) devices for tightening manhole covers are operative and there is no leakage at manhole covers or gaskets.

(4) missing or loose bolts or nuts on any flanged connection or blank flange are replaced or tightened.

(5) all emergency devices and valves are free from corrosion, distortion, and any damage or defect that could prevent their normal operation. Remote closure devices and self closing stop-valves must be operated to demonstrate proper operation. Reclosable Pressure Relief devices shall be removed from the tank and tested separately unless they can be tested while installed on the cargo tank.

(6) required markings on the cargo tank are legible and in accordance with the applicable requirements

(e) The leakage test for cargo tanks used for refrigerated liquefied gas shall be performed at 90% of MAWP. During each leakage test the surface of all external uninsulated joints under pressure during transportation must be coated with a solution of soap and water or other material suitable for the purpose of detecting leaks. Alternately, helium mass spectrometer or ultrasonic leak detection with proper sensitivity may be used for leak testing. The pressure shall be held for a period of time sufficiently long to ensure detection of leaks, but in no case less than 5 min. During the test, relief devices may be removed, but all the closure fittings must be in place and the relief device openings plugged.

(f) Inspection personnel shall be qualified as required by Article TG-4.

(g) A cargo tank that fails a prescribed test or inspection shall be repaired and retested, or be removed from service. If scrapped, the ASME nameplate and jurisdictional nameplate shall be removed.

(h) Only manufacturing or repair facilities registered with the competent authority and accredited as required by Part TP may perform and certify repairs and alterations to the cargo tank. If required by the competent authority, the facility performing in-service testing and inspections shall be registered with the competent authority.

MODAL APPENDIX 2
RAIL TANK CARS

In course of preparation.

MODAL APPENDIX 3
PORTABLE TANKS

ARTICLE 1
PORTABLE TANKS FOR TRANSPORTING REFRIGERATED FLUIDS

3-1.1 SCOPE

(a) This Modal Appendix provides the minimum requirements for design, construction, and continued service for portable tanks transporting refrigerated fluids. These requirements are in addition to all other applicable requirements of this Section. In addition, all requirements of the competent authority shall be met.

(b) Portable tanks meeting the requirements of this Modal Appendix shall be designated and stamped as T, Class 1, in accordance with the rules of this Section.

(c) For the purpose of this Modal Appendix, cryogenic fluids are listed in Table 3-1.1.

3-1.2 DEFINITIONS

design pressure: the pressure used in pressure vessel design calculations required by this Section for determining the vessel thicknesses. This is equivalent of the MAWP as defined by TD-160 plus static head of lading. If the jacket is evacuated, the design pressure is the sum of the MAWP, 101 kPa (14.7 psia) jacket vacuum, and the static head of lading.

design type: one or more portable tanks that are made

(a) by the same manufacturer

(b) to the same engineering drawings and calculations, except for minor variations in piping that do not affect the lading retention capability of the portable tank

(c) of the same materials of construction except for minor non-stress-bearing parts

(d) to the same cross-sectional dimensions

(e) to a length varying by no more than 5%

(f) with the volume varying by no more than 5% (due to a change in length only)

(g) with insulation providing the same or better thermal performance

flammable gases: gases that at 20°C (68°F) and a standard pressure of 101 kPa (14.7 psi)

(a) are ignitable when in a mixture of 13% or less by volume with air, or

(b) have a flammable range with air of at least 12 percentage points regardless of the lower flammable limit. Flammability shall be determined by tests or by calculations in accordance with methods adopted by ISO (see ISO 10156).

NOTE: See Table 3-1.1 for examples of flammable gases.

jacket: either the outer shell or insulation cover.

periodic test pressure: the pressure at which the portable tank shall be tested at intervals specified by the competent authority.

portable tank for transporting refrigerated fluids: a multimodal tank having a capacity of more than 450 L (120 gal) used for the transport of substances listed in Table 3-1.1. The portable tank for transporting refrigerated fluids includes a shell fitted with service equipment and structural equipment. The tank shall be capable of being filled and discharged without the removal of its structural equipment. It shall possess stabilizing members external to the shell and shall be capable of being lifted full. It shall be designed primarily to be loaded onto a transport vehicle or ship and shall be equipped with skids, mountings, or accessories to facilitate mechanical handling. Road tank-vehicles, rail tank-wagons, nonmetallic tanks, and intermediate bulk containers (IBCs) are not considered to fall within the definition for portable tanks for transporting refrigerated fluids.

3-1.3 GENERAL REQUIREMENTS

(a) Each portable tank shall consist of one or more suitably supported welded pressure vessels enclosed within an outer jacket with insulation between the inner vessel and outer shell or jacket and having piping, valves, supports, and other appurtenances (see Nonmandatory Appendix E).

(b) Design and construction details of the tank interior shall be such that collection and retention of cleaning materials or contaminants will not occur. To preclude the entrapment of foreign material, the design and construction of the tank must allow washing of all interior

Table 3-1.1
Refrigerated Nontoxic Gases

Item and Group	Identification Number, Name, and Description [Note (1)]	
3A	**Asphyxiant Gases**	
	UN 1913	Neon, refrigerated liquid
	UN 1951	Argon, refrigerated liquid
	UN 1963	Helium, refrigerated liquid
	UN 1970	Krypton, refrigerated liquid
	UN 1977	Nitrogen, refrigerated liquid
	UN 2187	Carbon dioxide, refrigerated liquid
	UN 2591	Xenon, refrigerated liquid
	UN 3136	Trifluoromethane, refrigerated liquid
	UN 3158	Gas, refrigerated liquid, NOS
3O	**Oxidizing Gases**	
	UN 1003	Air, refrigerated liquid
	UN 1073	Oxygen, refrigerated liquid
	UN 2201	Nitrous oxide, refrigerated liquid, oxidizing
	UN 3311	Gas, refrigerated liquid, oxidizing, NOS
3F	**Flammable Gases**	
	UN 1038	Ethylene, refrigerated liquid
	UN 1961	Ethane, refrigerated liquid
	UN 1966	Hydrogen, refrigerated liquid
	UN 1972	Methane, refrigerated liquid; or natural gas, refrigerated liquid, with high methane content
	UN 3138	Ethylene, acetylene and propylene mixture, refrigerated liquid, containing at least 71.5% ethylene with not more than 22.5% acetylene and not more than 6% propylene
	UN 3312	Gas, refrigerated liquid, flammable, NOS

Legend:

NOS = Not otherwise specified.

NOTE: (1) Identification (UN) number, name, and description according to *UN Recommendations on Transport of Dangerous Goods – Model Regulations.*

surfaces by the normal surging of the lading during transportation.

(c) All applicable packaging requirements of the competent authority shall be met.

3-1.4 MATERIALS

(a) Materials of construction for the pressure vessel shall be those allowed by this Section. The jacket is not part of the pressure vessel. The jacket material may be of materials permitted in this Section or ASTM- or ISO-designated materials, provided they comply with the applicable requirements of the competent authority. Cast materials are not permitted, except for valves.

(b) The jacket covering the insulation shall be of steel.

(c) Nonmetallic materials may be used for the attachments and supports between the shell and jacket, provided their properties at the minimum design pressure and temperature are proven to be suitable for the intended service. In choosing the material, consideration shall be given to avoidance of brittle fracture at the minimum design temperature, resistance to impact loads and to hydrogen embrittlement and stress corrosion cracking.

(d) Any part of the tank, including fittings, gaskets, and piping, which may come into contact with the cryogenic fluid, shall be compatible with that cryogenic fluid.

(e) Materials that may react with oxygen or oxygen-enriched atmospheres in a dangerous manner shall not be used in portable tanks intended for the transport of cryogenic liquid having a boiling point of −198°C (−325°F) or colder.

Table 3-1.5-1
Design Load Factors for Normal Operations in Specified Transportation Modes

Transportation Modes	Load Case	Load Factors Forward, F_i	Backward, F_i	Up, F_i	Down, F_i	Lateral, F_k
Road and Water	1	2.0	...	...	1.0	...
	2	...	2.0	...	1.0	...
	3	...	...	1.0	...	...
	4	...	...	...	2.0	...
	5 [Note (1)]	...	...	...	1.0	1.0
	5A [Note (1)]	...	...	...	1.0	2.0
Rail Without Cushioning Devices [Note (2)]	1	4.0	...	...	1.0	...
	2	...	4.0	...	1.0	...
	3	...	...	2.0	...	...
	4	...	...	...	2.0	...
	5 [Note (1)]	...	...	...	1.0	2.0
	5A [Note (1)]	...	...	...	1.0	4.0
Rail With Cushioning Devices [Note (2)]	1	2.0	...	...	1.0	...
	2	...	2.0	...	1.0	...
	3	...	...	2.0	...	...
	4	...	...	...	2.0	...
	5	...	...	...	1.0	2.0

NOTES:
(1) Load case 5A shall be considered instead of load case 5, if the direction of travel is not known.
(2) The cushioning devices shall meet the requirements of 49 CFR 179.400-13.

(f) Aluminum and aluminum alloys that may come in contact with cryogenic oxygen by internal rubbing or abrading shall not be used. Aluminum or aluminum alloy valves, pipe, or fittings external to the jacket that retain the oxygen lading during transportation shall not be used.

(25) 3-1.5 DESIGN REQUIREMENTS

Design of the inner vessel and outer jacket shall meet all applicable requirements of this Appendix and of Nonmandatory Appendix E.

(a) Design Loads. The pressure vessel shall be able to withstand safely the mechanical and thermal loads encountered during pressure test and normal operation. The static forces used shall be obtained as specified in (1).

(1) In addition to the design pressure, the pressure vessel and its attachments shall be designed for the static forces obtained by multiplying the load factors applicable for the transportation modes given in Table 3-1.5-1 with the maximum weight imposed on the pressure vessel. The maximum weight imposed on the pressure vessel shall include the weight of the pressure vessel, its fastenings and supports, maximum permissible content, piping, insulation, and any other item supported on the pressure vessel. Each load case shall be considered separately, but all forces in a load case shall be considered acting simultaneously. The static forces obtained are equivalent to the dynamic loads experienced during normal operation of the transport vessel.

(b) Fatigue Analysis. The design shall take into account the effect of pressure, thermal and mechanical cyclic loads on the inner vessel and its attachments. During normal conditions of operation mechanical loads obtained from the load factors specified in Table 3-1.5-2 shall be used in the fatigue analysis. Fatigue life analysis shall be based on 10^9 cycles, in accordance with Section VIII, Division 2, Appendix 5. The Usage Factor shall not exceed 1.0.

In fatigue evaluation of any item designed to withstand more than one load case, the maximum loadings in each direction from all applicable load cases shall be considered to act simultaneously in determining the magnitude of alternating stresses.

(c) Maximum Allowable Stresses

(1) The inner vessel shall be designed for the design pressure using the maximum allowable stress values given in Section II, Part D, for the materials used [see TM-130.2(b)].

(2) For the design loads specified in 3-1.5, the maximum allowable membrane stress values at any point in the vessel supports and in the vessel wall at

Table 3-1.5-2
Factors for Fatigue Analysis in Specified Transportation Modes

Transportation Modes	Load Case	Load Factors					
		Forward Cyclic, F_i	Backward Cyclic, F_i	Up Cyclic, F_i	Down Cyclic, F_i	Down Steady, F_j	Lateral Cyclic, F_k
Road and Water	1	0.7	...	...	...	1.0	...
	2	...	0.7	...	...	1.0	...
	3	...	...	1.0	...	...	...
	4	...	...	...	1.0	1.0	...
	5	...	...	...	...	1.0	0.7
Rail Without Cushioning Devices [Note (1)]	1	4.0	...	...	...	1.0	...
	2	...	4.0	...	...	1.0	...
	3	...	...	1.0	...	...	...
	4	...	...	...	1.0	1.0	...
	5 [Note (2)]	...	...	...	...	1.0	1.0
	5A [Note (2)]	...	...	...	...	1.0	4.0
Rail With Cushioning Devices [Note (1)]	1	2.0	...	...	...	1.0	...
	2	...	2.0	...	...	1.0	...
	3	...	...	1.0	...	...	...
	4	...	...	...	1.0	1.0	...
	5 [Note (2)]	...	...	...	...	1.0	1.0
	5A [Note (2)]	...	...	...	...	1.0	2.0

NOTES:
(1) The cushioning devices shall meet the requirements of 49 CFR 179.400-13.
(2) Load case 5A shall be considered instead of load case 5, if the direction of travel is not known.

support attachments shall not exceed the lesser of 33% of the specified minimum tensile strength and 67% of the specified minimum yield strength of the materials used (see Section II, Part D, Subpart 1, Tables U and Y-1). The local membrane plus bending stress shall not exceed 75% of the applicable yield strength. For austenitic stainless steels the 1% proof strength (determined by the 1% offset method), determined in accordance with the applicable material specification, may be used instead of the values in Section II, Part D, Subpart 1, Table Y-1, when acceptable to the competent authority (e.g., 49 CFR 178.274).

(-a) When austenitic stainless steels are used, higher tensile strength and yield strength values [or 1% proof strength values, see (2)] may be used, provided these values are reported on the test report and do not exceed the specified minimum values by more than 15%.

(d) Design Criteria

(1) Vessels shall be of a circular cross-section.

(2) Vessel shall be designed and constructed to withstand a test pressure not less than 1.3 times the MAWP. For shells with vacuum insulation the test pressure shall be not less than 1.3 times the sum of the MAWP and 100 kPa (1 bar) (14.5 psi). In no case shall the test pressure be less than 300 kPa (3 bar) (43.5 psi) gauge pressure. See (e)(2) through (e)(7).

(3) For metals exhibiting a clearly defined yield point or characterized by a guaranteed proof strength, the primary membrane stress, S in the vessel shell shall not exceed $0.75R_e$ or $0.50R_m$, whichever is less, at the test pressure, where

R_e = specified minimum yield strength, MPa (N/mm^2) (psi). [For austenitic stainless steel R_e may be determined by the 0.2% or the 1% offset method, as appropriate, see (c)(2).]

R_m = specified minimum tensile strength, MPa (N/mm^2) (psi)

(-a) The R_m and R_e values used in the design shall be the specified minimum values in accordance with the applicable national or international materials standards. For austenitic steels, the specified minimum R_e and R_m values in the applicable material standards may be increased by up to 15% when greater values are reported on the material inspection certificate (e.g., test report). See TF-410.3 for additional welding qualification requirements.

(-b) Steels that have an R_e/R_m ratio greater than 0.85 are not permitted for the construction of welded vessel shells. The values of R_e and R_m to be used in determining this ratio shall be the specified minimum values in the applicable material specification.

(-c) Steels used in the construction of vessels shall have an elongation at fracture, in %, not less than 10 000/R_m. The elongation shall not be less than 16% for fine grain steels and 20% for other steels. Aluminum and aluminum alloys used in the construction of vessels shall have an elongation at fracture, in %, not less than 10 000/6R_m. The elongation shall not be less than 12% for aluminum and aluminum alloys.

NOTE: The unit to be used for R_m to compute the percent elongation shall be N/mm^2. (1 N/mm^2 = 1 MPa = 145 psi.)

(-d) For sheet metal, the tensile test specimen shall be oriented at right angles (transverse) to the principal direction of rolling. The elongation at fracture shall be measured on test specimens of rectangular cross section in accordance with ISO 6892: 1998, Metallic Materials — Tensile Testing, using a 50 mm (2 in.) gauge length.

(e) *Minimum Vessel Wall Thickness*

(1) The minimum vessel shell thickness shall be the greater of

(-a) the minimum thickness determined in accordance with the requirements in (2) through (7)

(-b) the minimum thickness determined in accordance with this Section, including the requirements of (d)

(2) Vessels of not more than 1.80 m (71 in.) in diameter shall be not less than 5 mm (0.197 in.) thick in the Reference steel [see (6)], or shall be of equivalent thickness in the metal to be used. Vessels of more than 1.80 m (71 in.) in diameter shall be not less than 6 mm (0.236 in.) thick in the Reference steel, or of equivalent thickness in the metal to be used.

(3) Vessels of vacuum-insulated tanks of not more than 1.80 m (71 in.) in diameter shall be not less than 3 mm (0.118 in.) thick in the Reference steel [see (6)] or of equivalent thickness in the metal to be used. Such vessels of more than 1.80 m (71 in.) in diameter shall be not less than 4 mm (0.158 in.) thick in the Reference steel, or of equivalent thickness in the metal to be used.

(4) For vacuum-insulated tanks, the aggregate thickness of the jacket and the vessel wall shall correspond to the minimum thickness prescribed in (2), and the thickness of the vessel shell shall be not less than the minimum thickness prescribed in (3).

(5) Vessels shall be not less than 3 mm (0.118 in.) thick regardless of the material of construction.

(6) The equivalent thickness of a material to the reference material thickness prescribed in (2), (3), and (4) above shall be determined according to Mandatory Appendix XIII.

(7) In no case shall the vessel wall thickness be less than that required by (1) through (5). All vessel parts shall have a minimum thickness as determined by (1) through (6). The thickness shall be exclusive of any corrosion allowance.

3-1.6 FABRICATION AND EXAMINATION

(a) All welded joints in the pressure vessel shall meet the requirements of this Section, except that butt welds with one plate edge offset are not permitted. [See Figure TW-130.5-1, sketch (k).]

(b) All longitudinal welds in the pressure vessel must be located so as not to intersect nozzles or supports other than load rings and stiffening rings.

(c) All inner vessel nozzle-to-shell and nozzle-to-head welds shall be full penetration welds.

(d) Bolted manholes or inspection openings are not required.

(e) The inlet to the liquid product discharge opening of each pressure vessel intended for flammable lading shall be at the bottom of the inner vessel.

(f) A tank for oxygen service shall be thoroughly cleaned in accordance with industry standards (e.g., CGA G-4.1, Cleaning Equipment for Oxygen Service) to remove foreign material that could react with the lading.

NOTE: The use of backing rings requires careful consideration of cleanliness, product drainage, and materials for safe application in oxygen service.

(g) All butt welds in the pressure vessel shell and heads subject to pressure shall be examined radiographically or ultrasonically for their full length in accordance with Part TE.

3-1.7 PRESSURE RELIEF DEVICES

(a) *Number of Pressure Relief Devices*

(1) Every tank shall be provided with not less than two independent spring-loaded reclosing pressure relief devices. The pressure relief devices shall open automatically at a pressure not less than the maximum allowable working pressure (MAWP) and be fully open at a pressure equal to 110% of the MAWP. These devices shall, after discharge, close at a pressure not less than 10% below MAWP, and shall remain closed at all lower pressures. The pressure relief devices shall be of the type that will resist dynamic forces, including surge.

(2) In the case of the loss of vacuum, an additional reclosing pressure relief device, set at no more than 110% of the MAWP, may be used, and the combined capacity of all pressure relief devices installed shall be sufficient so that the pressure (including accumulation) inside the vessel does not exceed 120% of the MAWP. For nonflammable refrigerated liquefied gases (except oxygen) and hydrogen, this capacity may be achieved by the use of rupture discs in parallel with the required safety relief

devices. Rupture discs shall rupture at a nominal pressure equal to the test pressure.

(3) Under the circumstances described in (1) and (2) above, together with complete fire engulfment, the combined capacity of all pressure relief devices shall be sufficient to limit the pressure in the tank to the test pressure.

(4) Pressure relief devices shall be designed to prevent the entry of foreign matter, the leakage of gas, and the development of any dangerous excess pressure.

(b) Capacity. The required capacity of the relief devices shall be calculated in accordance with CGA S-1.2 or ISO 21013-3:2006. The pressure relief system shall be sized so that the pressure drop during discharge does not cause the valve to reseat instantly.

(c) Type, Application, Testing, Marking, and Maintenance Requirements. Unless otherwise specified in this Section, the type, application, testing, marking, and maintenance requirements for pressure relief devices shall be as specified in CGA S-1.2.

(d) Maximum Filling Rate

(1) For a tank used in oxygen and flammable cryogenic service, the maximum rate at which the tank is filled shall not exceed the liquid flow capacity of the primary pressure relief system, rated at a pressure not exceeding 120% of the tank's design pressure. This rate shall be included on the inner vessel nameplate.

(2) On a tank used in helium and atmospheric gas (except oxygen) cryogenic liquid service, the maximum rate at which the tank is filled shall not exceed the liquid flow capacity of the pressure relief valves rated at test pressure for the inner vessel. This rate shall be included on the inner vessel nameplate.

(e) Arrangement and Location of Pressure Relief Devices

(1) The discharge from any pressure relief system must be unobstructed to the outside of any protective housing in such a manner as to prevent impingement of gas upon the jacket or any structural part of the tank or operating personnel. For oxygen and flammable cryogenic service, the discharge must be directed upward.

(2) Each pressure relief valve shall be arranged or protected to prevent accumulation of foreign material between the relief valve and the atmospheric discharge opening in any relief piping. The arrangement must not impede flow through the device.

(3) Each pressure relief valve shall be designed and located to minimize the possibility of tampering. If the pressure setting or adjustment is external to the valve, the valve shall be sealed.

(4) Each pressure relief device shall have direct communication with the vapor space of the inner vessel at the mid length of the top centerline.

(5) Each pressure relief device shall be installed and located so that the cooling effect of the contents during venting will not prevent the effective operation of the device.

(f) Markings

(1) The flow capacity and rating shall be verified and marked by the Manufacturer of the safety relief valve in accordance with the requirements of Section XIII, 3.9.

(2) In addition, the markings shall comply with the applicable requirements of the competent authority.

3-1.8 ASME NAMEPLATE REQUIREMENTS (25)

(a) All applicable nameplate and stamping requirements of this Section shall be met. A duplicate nameplate [see TS-100.2(b)] for the inner vessel shall be installed on the outer jacket, if any. [See 3-1.1(b).]

(b) The outer jacket is not required to be stamped with the Certification Mark with T Designator.

3-1.9 JURISDICTIONAL MARKINGS

(a) Every portable tank must be fitted with a corrosion-resistant metal nameplate, in addition to the ASME nameplate permanently attached to the portable tank in a conspicuous place and readily accessible for inspection. Any of the following items not required to be marked on the ASME nameplate shall be marked on this additional nameplate by stamping or by another equivalent method:

(1) country of manufacture

(2) UN approval

(3) country approval number

(4) alternative arrangements, "AA" [e.g., see 49 CFR 178.274(a)(3)]

(5) Manufacturer's name or mark

(6) Manufacturer's serial number

(7) Approval Agency (authorized body for the design approval)

(8) Owner's registration number

(9) year of manufacture

(10) pressure vessel code to which the shell is designed

(11) test pressure:____bar (psi) gauge

(12) MAWP _____bar (psi) gauge

(13) minimum design metal temperature range ______°C (°F) to ______°C (°F). (For portable tanks used for refrigerated liquefied gases, the minimum design temperature must be marked.)

(14) water capacity at 20°C (68°F) _____L (ft^3)

(15) water capacity of each compartment at 20°C (68°F) _____L

(16) initial pressure test date and witness identification

(17) MAWP for heating/cooling system ___bar (psi) gauge

(18) shell material(s) and material standard reference(s)

(19) equivalent thickness in reference steel _____mm (in.)

(20) lining material (when applicable)

(21) date and type of most recent periodic test(s). Month _____Year _____

(22) periodic test pressure: _____bar (psi) gauge

(23) stamp of approval agency that performed or witnessed the most recent test

(24) for portable tanks used for refrigerated liquefied gases: Either "thermally insulated" or "vacuum insulated" _____

(25) effectiveness of the insulation system (heat influx) _____watts (W)

(26) reference holding time _____days or hours and initial pressure _____ bar (kPa) gauge and degree of filling ______in kg (lb) for each refrigerated liquefied gas permitted for transportation

(b) The following information shall be marked either on the portable tank itself or on a metal plate firmly secured to the portable tank:

(1) name of the operator

(2) name of hazardous materials being transported and maximum mean bulk temperature [except for refrigerated liquefied gases, the name and temperature are only required when the maximum mean bulk temperature is higher than 50°C (122°F)]

(3) maximum permissible gross mass (MPGM) _____kg

(4) unladen (tare) mass _____kg

(5) maximum filling rate _____kg/h

(c) If a portable tank is designed and approved for handling in open seas operations, such as offshore oil exploration, in accordance with the IMDG Code, the words "OFFSHORE PORTABLE TANK" shall be marked on an identification plate.

(d) Transportation mode restrictions on the portable tank shall be marked on both sides of the portable tank in 10 cm (4 in.) high letters and on the nameplate.

(e) The next periodic inspection date (month and year) shall be marked in 75 mm (3 in.) high letters near the front, on the left-hand side of the tank.

3-1.10 OPERATION, MAINTENANCE, AND INSPECTION

(a) Portable tanks shall be tested and inspected periodically at intervals required by the competent authority (e.g., see 49 CFR, Part 180, Subpart G).

As a minimum, periodic inspections shall be performed at least once every 5 yr and an intermediate periodic inspection and test at least every 2.5 yr following the initial inspection and the last 5 yr periodic inspection and test.

(1) The intermediate periodic inspection and test shall include at least an internal and external examination of the portable tank and its fittings, a leakage test, and a test of the satisfactory operation of all service equipment.

(2) Portable tanks used for dedicated transportation of refrigerated liquefied gases that are not fitted with inspection openings are exempted from the internal inspection requirements.

(3) The periodic inspection and test shall include those inspections and tests for the intermediate periodic inspection, an internal (unless exempted) and external examination and, unless exempted, a pressure test as specified in this paragraph. The pressure test can be either hydrostatic or pneumatic using an inert gas, to a pressure of not less than 1.3 times the MAWP. The test shall be performed in accordance with Part TT of this Section. Reclosing pressure relief devices shall be removed from the tank and tested separately unless they can be tested while installed on the portable tank. Portable tanks used for the transportation of refrigerated liquified gases are exempt from the requirements for internal inspection and pressure test during the 5-yr periodic inspection and test, if the portable tanks were pressure tested to a minimum test pressure 1.3 times the MAWP using an inert gas before putting the portable tank into service initially and after any exceptional inspections and tests.

(4) An exceptional inspection and test is necessary when a portable tank shows evidence of damage or corroded areas, or leakage, or other conditions that indicate a deficiency that could affect the integrity of the portable tank.

(-a) The tank has been in an accident and has been damaged to an extent that may adversely affect its retention capability.

(-b) The tank has been out of service for a period of 1 yr or longer.

(-c) The tank has been modified from its original design specifications (see Article TP-2).

The extent of the exceptional inspection and test shall depend on the amount of damage or deterioration of the portable tank. It shall include at least the inspection and a pressure test according to (3). Pressure relief devices need not be tested or replaced unless there is reason to believe the relief devices have been affected by the damage or deterioration.

(b) The internal and external examinations shall ensure that

(1) the shell is inspected for pitting, corrosion, abrasions, dents, distortions, defects in welds or any other conditions, including leakage, that might render the portable tank unsafe for transportation.

(2) the piping, valves, and gaskets are inspected for corroded areas, defects, and other conditions, including leakage, that might render the portable tank unsafe for filling, discharge or transportation.

(3) devices for tightening manhole covers are operative and there is no leakage at manhole covers or gaskets.

(4) missing or loose bolts or nuts on any flanged connection or blank flange are replaced or tightened.

(5) all emergency devices and valves are free from corrosion, distortion, and any damage or defect that could prevent their normal operation. Remote closure devices and self-closing stop-valves must be operated to demonstrate proper operation.

(6) required markings on the portable tank are legible and in accordance with the applicable requirements.

(7) the framework, the supports, and the arrangements for lifting the portable tank are in satisfactory condition.

(c) The leakage test for portable tanks used for refrigerated liquefied gas shall be performed at 90% of MAWP. During each leakage test the surface of all external uninsulated joints under pressure during transportation must be coated with a solution of soap and water or other material suitable for the purpose of detecting leaks. The pressure shall be held for a period of time sufficiently long to ensure detection of leaks, but in no case less than 5 min. During the test, relief devices may be removed, but all the closure fittings must be in place and the relief device openings plugged.

(d) Inspection personnel shall be qualified as required by Article TG-4.

(e) A portable tank that fails a prescribed test or inspection shall be repaired and retested, or be removed from service.

(f) Only authorized manufacturing or repair facilities may perform and certify repairs and alterations. If required by the competent authority, the facilities performing in-service testing and inspection shall be registered with the competent authority.

MODAL APPENDIX 4 CATEGORY 106A500-X, 106A800-X, 110A500-W, 110A600-W, 110A800-W, 110A1000-W, AND 110A2000-W TON CONTAINERS

ARTICLE 1

4-1.1 SCOPE

This Modal Appendix provides the minimum requirements for the design, construction, and continued service of ton containers intended to transport compressed gases or liquids. These requirements are in addition to all other applicable requirements of this Section. In addition, all requirements of the competent authority shall be met.

Ton containers meeting the requirements of this Modal Appendix shall be designated and stamped as T, Class 1, in accordance with the rules of this Section.

For the purpose of this Modal Appendix, compressed gases and liquids are defined by the competent authority.

4-1.2 DEFINITIONS

A *ton container* is a cylindrical steel tank having a water capacity of more than 680 L (181 gal) but not more than 1 180 L (313 gal). It shall not possess stabilizing members external to the shell, and shall be capable of being rolled about its longitudinal axis with all openings protected within the heads. It shall be capable of being lifted filled with product. It shall be designed to be loaded onto a transport vehicle or container and so secured that it can be shipped by road, rail, or sea.

4-1.3 PHYSICAL SCOPE

4-1.3.1 INTERNAL PRESSURE

Internal pressure shall be in the range from full vacuum to 138 bar (2,000 psig).

4-1.3.2 MINIMUM DESIGN METAL TEMPERATURE (MDMT)

(a) For Category 106A tanks constructed of SA-285 Grade A material, the MDMT shall be −20°C (−4°F).

(b) For Category 110A tanks constructed of SA-516 Grade 70 material, the MDMT shall be −40°C (−40°F).

(c) The MDMT may be colder than −40°C (−40°F) if marked on the nameplate and the toughness requirements of Part TM are met.

4-1.3.3 MAXIMUM DESIGN TEMPERATURE

The maximum design temperature shall be 65°C (149°F).

4-1.4 GENERAL REQUIREMENTS

(a) Tanks shall not be insulated.

(b) All openings, including openings for valves, shall be in the heads. All service valves shall be protected by a detachable protective housing that shall not project beyond the end of the tank and shall be securely fastened to the tank head.

(c) Each tank shall have skirts at both ends, extending longitudinally outward from the tangent line of the head sufficiently to protect the valve protective bonnets and relief devices from mechanical damage. The outer end of each skirt shall be curved radially inward so that its diameter is at least 2 in. smaller than the outside diameter of the tank.

(d) Loading and unloading valves shall be made of metal not subject to rapid deterioration by lading and shall withstand tank test pressure without leakage.

Table 4-1.6.1-1
Minimum Thicknesses, Test Pressures, Start-to-Discharge or Burst Pressures, and Minimum Vapor-Tightness Pressures of Relief Devices

	Category						
Requirement	106A500-X	106A800-X	110A500-W	110A600-W	110A800-W	110A1000-W	110A2000-W
Min. required bursting pressure, psig	[Note (1)]	[Note (1)]	1,250	1,500	2,000	2,500	5,000
Min. required bursting pressure, MPa	[Note (1)]	[Note (1)]	8.6	10.3	13.8	17.2	34.5
Minimum thickness, shell, in.	$^{13}/_{32}$	$^{11}/_{16}$	$^{11}/_{32}$	$^{3}/_{8}$	$^{15}/_{32}$	$^{19}/_{32}$	$1^{1}/_{32}$
Minimum thickness, shell, mm	10.3	17.5	8.7	9.5	11.9	15.1	26.2
Test pressure, psig	500	800	500	600	800	1,000	2,000
Test pressure, MPa	3.5	5.5	3.5	4.1	5.5	6.9	13.8
Start-to-discharge or burst max., psi	375	600	375	450	600	700	1,500
Start-to-discharge or burst max., MPa	2.6	4.1	2.6	3.1	4.1	4.8	10.3
Vapor-tight, min., psig	300	480	300	360	480	650	[Note (2)]
Vapor-tight, min., MPa	2.1	3.3	2.1	2.5	3.3	4.5	[Note (2)]

NOTES:
(1) None specified.
(2) To be used only with frangible-disc devices. Vapor-tight pressure not applicable.

These valves shall be attached to one tank head. Provision shall be made for closing outlet connections of the valves.

(e) Threads for openings shall be National Gas Taper Threads (NGT), tapped to gage, clean cut, even, and without checks, or other threads approved by the competent authority.

(f) The use of backing rings is permitted on Category 110A tanks.[14]

4-1.5 MATERIALS

Steel plate material used to fabricate tanks must conform to the following specifications: SA-240/240M Type 304, 304L, 316, 316L, or 321; SA-285 Grade A, B, or C; SA-515/515M Grade 65 or 70; or SA-516/516M Grade 70.

Charpy impact testing is not required for Category 106A500-X and 106A800-X tanks constructed of SA-285 Grade A material and 110A500-W, 110A600-W, 110A800-W, 110A1000-W, and 110A2000-W tanks constructed of SA-516/516M Grade 70 material.

All appurtenances, including valves, fittings, and gaskets, shall be made of materials compatible with the gases and liquids to be transported.

4-1.6 DESIGN REQUIREMENTS

4-1.6.1 MINIMUM THICKNESSES, TEST PRESSURES, START-TO-DISCHARGE OR BURST PRESSURES, AND MINIMUM VAPOR-TIGHTNESS PRESSURES OF RELIEF DEVICES

See Table 4-1.6.1-1.

4-1.6.2 THICKNESS OF PLATES

(a) For Category 110A tanks, the wall thickness after forming of the cylindrical portion of the tank shall not be less than that specified in Table 4-1.6.1-1 nor less than that calculated by the formula

$$t = Pd/2SE$$

where

d = inside diameter, mm (in.)
E = welded joint efficiency
= 1.0 for fully radiographed Type No. 1 welded joints (see Table TW-130.4)

P = minimum required bursting pressure (from Table 4-1.6.1-1), MPa (psig)
S = minimum tensile strength of plate material, MPa (psi), as prescribed in Section II, Part D
t = minimum thickness of plate material after forming, mm (in.)

(b) For Category 106A tanks, the wall thickness of the cylindrical portion of the tank shall not be less than that specified in Table 4-1.6.1-1 and shall be such that at the tank test pressure, the maximum fiber stress in the wall of the tank will not exceed 108.6 MPa (15,750 psi) as calculated using the formula

$$S = p\left(1.3D^2 + 0.4d^2\right)/\left(D^2 - d^2\right)$$

where

D = outside diameter, mm (in.)
d = inside diameter, mm (in.)
p = tank test pressure, MPa (psig)
S = wall stress, MPa (psi)

(c) If plates are clad with material having tensile strength at least equal to that of the base material, the cladding may be considered to be a part of the base material when determining the required thickness. If cladding material does not have tensile strength at least equal to that of the base material, the base plate material alone shall meet the thickness requirements.

(d) Category 110A tanks shall have fusion-welded heads formed concave to the pressure. The heads shall be 2:1 semielliptical in form. They shall be of one piece, and hot formed in one heating cycle so as to provide a straight flange at least 40 mm ($1\frac{1}{2}$ in.) in length. The thickness shall not be less than that calculated by the formula

$$t = Pd/2SE$$

where symbols are as defined in (a) above.

(e) Category 106A tanks shall have hot-pressure welded (forge welded) heads, formed convex to pressure. Heads for forge welding must be torispherical, with an inside crown radius not greater than the inside diameter of the shell and inside corner radii. They must be one piece and hot formed in one heating cycle so as to provide a straight flange at least 2 in. long. The wall thickness of the heads after forming must be sufficient to meet the test requirements of 4-1.9 and provide for adequate threading of openings.

4-1.6.3 WELDING

Longitudinal (Category A) welds on both Category 106A and Category 110A tanks shall be fusion welded and of Type (1), (2), or (3) of Table TW-130.4. Head-to-shell joints shall be forge welded on Category 106A tanks. They shall be fusion welded and of Type (1), (2), or (3) of Table TW-130.4 on Category 110A tanks.

4-1.6.4 INTERNAL PRESSURE DESIGN FOR DIVISION 2.1 AND 2.2 GASES

Tanks intended for the transport of Division 2.1 and 2.2 gases (see 49 CFR 173.115) shall be designed for an internal pressure not less than the vapor pressure, at 50°C (122°F), of the gases to be transported.

4-1.6.5 INTERNAL PRESSURE DESIGN FOR DIVISION 2.3 GASES

Tanks intended for the transport of Division 2.3 gases (see 49 CFR 173.115) shall be designed for an internal pressure not less than the vapor pressure, at 65°C (149°F), of the gases to be transported.

4-1.6.6 VACUUM DESIGN

All tanks shall be designed and stamped for full vacuum.

4-1.6.7 FATIGUE DESIGN

Specific design analysis or testing to account for pressure cycling is not required for these tanks.

4-1.7 FABRICATION

After welding is complete, carbon steel tanks and all appurtenances welded thereto shall be postweld heat treated as a unit in accordance with Article TF-7.

Hot pressure welded (forge welded) joints shall be made using a procedure conforming to the requirements of Mandatory Appendix XIV. The heads must have a snug drive fit into the shell for forge welding.

After welding is complete, the longitudinal weld seam in Category 106A and 110A tanks shall be fully radiographically examined. The circumferential seams of Category 110A tanks 36 in. in diameter or greater shall be radiographically examined; circumferential seams of Category 110A tanks smaller than 36 in. in diameter need not be radiographically examined. Hot pressure welded (forge welded) circumferential weld seams of Category 106A tanks need not be radiographically examined.

4-1.8 PRESSURE RELIEF DEVICES

Unless otherwise directed by the competent authority for a specific commodity, each tank shall be provided with not less than three fusible plugs at each end. Each fusible plug shall function at a temperature not warmer than 79°C (175°F), and shall be vapor tight at a temperature not colder than 54°C (130°F).

Spring-loaded relief devices are neither required nor prohibited. If fitted, they shall meet the requirements of the competent authority.

All pressure relief devices shall vent unimpeded directly to the atmosphere. Unless prohibited by the competent authority, tanks shall be equipped with one or more relief devices made of metal not subject to rapid deterioration by the lading and screwed directly into tank heads, or attached to tank heads by other methods approved by the competent authority. The total discharge capacity shall be sufficient to prevent building up pressure in the tank in excess of 82.5% of the tank test pressure. When relief devices of the fusible plug type are used, the required discharge capacity shall be available in each head.

Pressure relief devices shall be set for start-to-discharge, and rupture disks shall burst at a pressure not exceeding that shown in Table 4-1.6.1-1.

4-1.9 TESTING

After postweld heat treatment, each tank shall be subjected to pressure testing in accordance with Table 4-1.6.1-1.

4-1.10 ASME NAMEPLATE REQUIREMENTS

All applicable nameplate and stamping requirements of this Section shall be met. In addition, the markings required under 4-1.11 shall be applied.

The nameplate shall be installed in such a manner as to avoid being damaged during normal transportation and to avoid corrosion between the nameplate and the tank. It shall be installed on the formed head at the valve end of the tank in such a manner that it is accessible for further stamping of information regarding periodic testing as required in 4-1.12.

4-1.11 MARKINGS REQUIRED BY THE COMPETENT AUTHORITY

In addition to the markings required by 4-1.10, the following shall be plainly and permanently stamped onto the ASME nameplate, onto a secondary nameplate, or onto the metal of the valve-end chime:

(a) jurisdictional specification number.
(b) material.
(c) Owner's or builder's identifying symbol and serial number.
(d) Inspector's official mark.
(e) date of original tank test (month and year; e.g., 1-2004 for January 2004). This should be so placed that dates of subsequent tests may be readily added.
(f) water capacity (kg and lb).
(g) tare weight (kg and lb).

4-1.12 OPERATION, MAINTENANCE, AND INSPECTION

Each tank shall undergo periodic inspection and testing at intervals not exceeding 5 yr, consisting of the following:

(a) external and internal visual examination in accordance with Part TT.
(b) inspection of each fusible plug removed from the tank for damage or deterioration, and replacement if necessary
(c) hydrostatic pressure testing in accordance with Part TT (the hydrostatic pressure test may be waived for tanks in dedicated service for noncorrosive refrigerant gases)
(d) upon completion of the periodic inspection and test, the date of the inspection and retest and the Inspector's mark shall be stamped onto the ASME nameplate, onto a secondary nameplate, or onto the metal of the valve-end skirt extension
(e) upon completion of the periodic inspection and test, a written record shall be prepared and retained by the Owner or user of the tank for a period of at least 15 yr

MANDATORY APPENDIX I
QUALITY CONTROL SYSTEM

(25) I-1 GENERAL

A Manufacturer, Repair or Relief Valve Recertification Organization holding or applying for a Certificate of Authorization shall demonstrate a quality control program that meets ASME CA-1 and establishes that all Code requirements, including material, design, fabrication, examination (by the Manufacturer, Repair, and Relief Valve Recertification Organization), and for vessels and vessel parts, inspection (by the Inspector), will be met. Provided that Code requirements are suitably identified, the system may include provisions for satisfying any requirements by the Manufacturer, 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 or vessel parts may make changes in parts of the system that do not affect the Code requirements without securing acceptance by the Inspector.

The system that the Manufacturer uses to meet the requirements of this Section must be one suitable for the Manufacturer's own circumstances. The necessary scope and detail of the system shall depend on the complexity of the work[15] performed and on the size and complexity of the Manufacturer's organization.[16] A written description of the system the Manufacturer will use to produce a Code item shall be available for review. Depending upon the circumstances, the description may be brief or voluminous.

The written description may contain information of a proprietary nature relating to the Manufacturers or processes. Therefore, the Code does not require any distribution of this information except for the Inspector, ASME Designee, or an ASME-designated organization as covered by I-16(c) and Section XIII, Mandatory Appendix III, III-2.13. 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 upon completion of the evaluation.

I-2 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 that should be covered in the written description of the Quality Control System and that is equally applicable to both shop and field work.

I-3 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 initiate, recommend, and provide solutions.

I-4 ORGANIZATION

An organization chart showing the relationships among management and engineering, purchasing, manufacturing, 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 right to establish, and from time to time, to alter, whatever form of organization the Manufacturer considers appropriate for its Code work.

I-5 DRAWINGS, DESIGN CALCULATIONS, AND SPECIFICATION CONTROL

The Manufacturer's or Assembler's Quality Control System shall provide procedures that will ensure 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.

For Manufacturers or Assemblers of parts who do not perform or assume any design responsibility for the parts they manufacture, the Quality Control System need only describe how design documents, including specifications, drawings, and sketches, that are received from the purchaser of the part are controlled, and how the parts are controlled while in the custody of the parts Manufacturer or Assembler.

I-6 MATERIAL CONTROL

The Manufacturer shall include a system of receiving control that will ensure that the material received is properly identified and has documentation including required Certificates of Compliance or Material Test Reports to satisfy Code requirements as ordered. The required Certificates of Compliance or Material Test Reports may be electronically transmitted from the material Manufacturer or Supplier to the Certificate Holder. The material control system shall ensure that only the intended material is used in Code construction.

I-7 EXAMINATION AND INSPECTION PROGRAM

The Manufacturer's Quality Control System shall describe the fabrication operations, including examinations, sufficiently to permit the Inspector, ASME Designee, or an ASME-designated organization to determine at what stages specific inspections are to be performed.

I-8 CORRECTION OF NONCONFORMITIES

There shall be a system agreed upon with the Inspector for correction of nonconformities. A nonconformity is any condition that does not comply with the applicable rules of this Section. Nonconformities must be corrected or eliminated in some way before the completed component can be considered to comply with this Section.

I-9 WELDING

The Quality Control System shall include provisions for indicating that welding conforms to requirements of Section IX as supplemented by this Section. Manufacturers intending to use AWS Standard Welding Procedures shall describe control measures used to ensure that welding meets the requirements of this Section and Section IX.

I-10 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 Section.

(25) ## I-11 HEAT TREATMENT

The Quality Control System shall provide controls to ensure that heat treatments as required by the rules of this Section are applied. Means shall be indicated by which the Inspector, ASME Designee, or an ASME-designated organization can verify that these Code heat treatment requirements are met. This may be by review of furnace time-temperature records or by other methods as appropriate.

I-12 CALIBRATION OF MEASUREMENT AND TEST EQUIPMENT

The Manufacturer shall have a system for the calibration of examination, measuring, and test equipment used in fulfillment of requirements of this Section.

I-13 RECORDS RETENTION

The Manufacturer shall have a system for the maintenance of radiographs and Manufacturer's Data Reports as required by this Section.

I-14 CERTIFICATION

(a) Methods other than written signature may be used for indicating certifications, authorizations, and approvals where allowed and as described elsewhere in this Section.

(b) Where other methods are employed, controls and safeguards must be provided and described in the Manufacturer's Quality Control System to ensure the integrity of the certification, authorization, and approval.

I-15 SAMPLE FORMS

The forms used in the 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.

I-16 INSPECTION OF VESSELS AND VESSEL PARTS (25)

(a) Inspection of vessels and vessel parts shall be by the Inspector as defined in Article TG-4.

(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 all drawings, calculations, specifications, procedures, process sheets, repair procedures, records, test results, and any other documents as necessary for the Inspector to perform the Inspector's duties in accordance with this Section. The Manufacturer may provide such access either to the Manufacturer's own files of such documents or by providing copies to the Inspector.

MANDATORY APPENDIX II
SPECIAL COMMODITIES

In course of preparation.

MANDATORY APPENDIX III DEFINITIONS FOR TRANSPORT TANKS

III-1 INTRODUCTION

This Mandatory Appendix defines the terminology used in this Section. Definitions relating to specific types of transport tanks may be found in one of the Modal Appendices.

(25) III-2 DEFINITIONS

bar: 1 bar = 100 kPa (14.5 psi).

C: Celsius or Centigrade.

cargo tank: a bulk packaging that

(a) is a tank intended primarily for the carriage of liquids or gases and includes appurtenances, reinforcements, fittings, and closures.

(b) is permanently attached to or forms a part of a motor vehicle, or is not permanently attached to a motor vehicle but which, by reason of its size, construction, or attachment to a motor vehicle is loaded or unloaded without being removed from the motor vehicle.

(c) is not fabricated under a specification for cylinders, portable tanks, tank cars, or multiunit tank car tanks.

cargo tank motor vehicle (CTMV): a motor vehicle with one or more cargo tanks permanently attached to or forming an integral part of the motor vehicle.

Certificate of Authorization: a document issued by the Society that authorizes the use of the ASME Certification Mark and appropriate Designator for a specified time and for a specified scope of activity.

Certification Designator: the symbol used in conjunction with the Certification Mark for the scope of activity described in a Manufacturer's Certificate of Authorization.

Certification Mark: an ASME symbol identifying a product as meeting Code requirements.

Certification Mark Stamp: a stamp issued by the Society for use in impressing the Certification Mark.

competent authority (CA): a national agency responsible under its national law for the control or regulation of a particular aspect of the transportation of hazardous materials (dangerous goods). The Appropriate Authority, as used in the ICAO Technical Instructions (see Sec. 171.7), has the same meaning as competent authority. For example, the U.S. Department of Transportation's Associate Administrator of Hazardous Materials Safety is the competent authority for the United States.

dangerous goods: substances or articles classified and subject to the *United Nations Recommendations on the Transport of Dangerous Goods: Model Regulations*. Included in this definition are hazardous materials that are subject to the requirements of the U.S. Department of Transportation.

Designator: see *Certification Designator*.

DOT or Department: U.S. Department of Transportation.

F: Fahrenheit.

fine-grain practice: a steelmaking practice that is intended to produce a killed steel that is capable of meeting the requirements for fine austenitic grain size.

fusible element: a nonreclosing pressure relief device that is thermally activated and that provides protection against excessive pressure buildup in the portable tank developed by exposure to heat, such as from a fire.

gas: a material that has a vapor pressure greater than 300 kPa (43.5 psia) at 50°C (122°F) or is completely gaseous at 20°C (68°F) at a standard pressure of 101.3 kPa (14.7 psia).

hazardous material: a substance or material that has been determined by the Secretary of Transportation to be capable of posing an unreasonable risk to health, safety, and property when transported in commerce, and that has been so designated. The term includes but is not limited to hazardous substances, hazardous wastes, marine pollutants, and elevated-temperature materials as defined in CFR, Title 49.

IMO: International Maritime Organization.

intermodal container: a freight container designed and constructed to permit it to be used interchangeably in two or more modes of transport.

intermodal (IM) portable tank: a specific class of portable tanks designed primarily for international intermodal use.

international transportation: transportation

(a) between any place in the United States and any place in a foreign country.

(b) between places in the United States through a foreign country.

(c) between places in one or more foreign countries through the United States.

liquid: a material, other than an elevated-temperature material, with a melting point or initial melting point of 20°C (68°F) or lower at a standard pressure of 101.3 kPa (14.7 psia). A viscous material for which a specific melting point cannot be determined must be subjected to the procedures specified in ASTM D4359, Standard Test Method for Determining Whether a Material is Liquid or Solid.

Manufacturer: an organization in possession of an ASME Certificate of Authorization to apply the Certification Mark.

Material Test Report: a document in which the results of tests, examinations, repairs, or treatments required by the material specification to be reported are recorded, including those of any supplementary requirements or other requirements stated in the order for the material. This document may be combined with a certificate of compliance as a single document. When preparing a Material Test Report, a material Manufacturer may transcribe data produced by other organizations, provided the material Manufacturer accepts responsibility for the accuracy and authenticity of the data.

mode: any of the following transportation methods: rail, highway, air, or water.

relief valve recertification organization: an organization authorized by the competent authority to repair or alter relief valves (e.g., NB "VR" certificate holders).

repair organization: an organization authorized by the competent authority to repair or alter transport tanks (e.g., NB "R" certificate holders).

SCF (standard cubic foot): one cubic foot of gas measured at 60°F and 14.7 psia.

service equipment: measuring instruments and filling, discharge, venting, safety, heating, cooling, and insulating devices.

solid: a material that is neither a gas or a liquid.

UN: United Nations.

UN Hazard Classification: the classification of Dangerous Goods into Classes 2 through 6 meeting the criteria of Part 2 of the UN Recommendations on the Transport of Dangerous Goods.

UN Recommendations: the UN Recommendations on the Transport of Dangerous Goods: Model Regulations.

MANDATORY APPENDIX IV
ROUNDED INDICATION CHARTS, ACCEPTANCE STANDARDS FOR RADIOGRAPHICALLY DETERMINED ROUNDED INDICATIONS IN WELDS

IV-1 APPLICABILITY OF THESE STANDARDS

These standards are applicable to the materials permitted by this Section.

IV-2 TERMINOLOGY

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.

rounded indications: indications with a maximum length of three times the width or less on the radiograph. 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 imperfection in the weld, such as porosity, slag, or tungsten.

thickness, 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.

IV-3 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 IV-3 for examples.) Only those rounded indications that exceed the following dimensions shall be considered relevant:

(1) $\frac{1}{10}t$ for t less than 3.2 mm ($\frac{1}{8}$ in.)

(2) 0.4 mm ($\frac{1}{64}$ in.) for t from 3.2 mm to 6 mm ($\frac{1}{8}$ in. to $\frac{1}{4}$ in.), incl.

(3) 0.8 mm ($\frac{1}{32}$ in.) for t greater than 6 mm to 51 mm ($\frac{1}{4}$ in. to 2 in.), incl.

(4) 1.6 mm ($\frac{1}{16}$ in.) for t greater than 51 mm (2 in.)

(c) Maximum Size of Rounded Indication. (See Table IV-3 for examples.) The maximum permissible size of any indication shall be $\frac{1}{4}t$, or 4 mm ($\frac{5}{32}$ in.), whichever is smaller; except that an isolated indication separated from an adjacent indication by 25 mm (1 in.) or more may be $\frac{1}{3}t$, or 6 mm ($\frac{1}{4}$ in.), whichever is less. For t greater than 51 mm (2 in.) the maximum permissible size of an isolated indication shall be increased to 10 mm ($\frac{3}{8}$ in.).

(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 Figure IV-3-1. The length of groups of aligned rounded indications and the spacing between the groups shall meet the requirements of Figure IV-3-2.

(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 Indication Charts. The rounded indications characterized as imperfections shall not exceed that shown in the charts. The charts in Figures IV-3-3 through IV-3-8 illustrate various types of assorted, randomly dispersed and clustered rounded indications for different weld thicknesses greater than 3.2 mm ($\frac{1}{8}$ in.). These charts represent the maximum acceptable concentration limits for rounded indications. The charts for each thickness range represent full-scale 152 mm (6 in.) 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.

(g) Weld Thickness, t, Less Than 3.2 mm ($\frac{1}{8}$ in.). For t less than 3.2 mm ($\frac{1}{8}$ in.), the maximum number of rounded indications shall not exceed 12 in a 152 mm (6 in.) length of weld. A proportionally fewer number of indications shall be permitted in welds less than 152 mm (6 in.) in length.

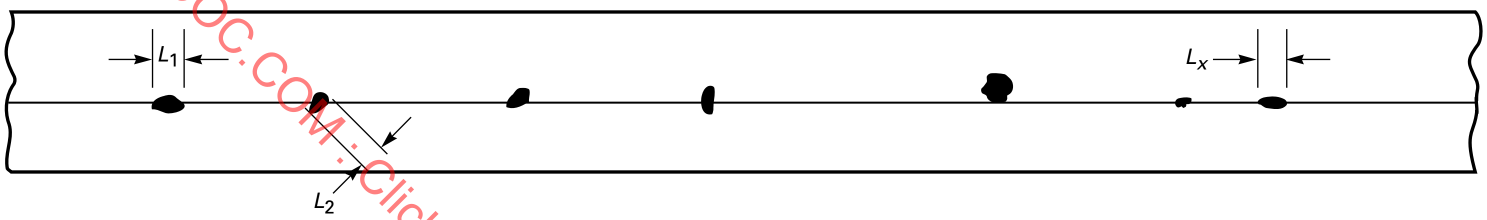
(h) Clustered Indications. The illustrations for clustered indications show up to four times as many indications in a local area, as that shown in the illustrations for random indications. The length of an acceptable cluster shall not exceed the lesser of 25 mm (1 in.) or $2t$. Where more than one cluster is present, the sum of the lengths of the clusters shall not exceed 25 mm (1 in.) in a 152 mm (6 in.) length weld.

Table IV-3
Acceptable Rounded Indications

SI Units			
	Maximum Size of Acceptable Rounded Indication, mm		Maximum Size of Nonrelevant Indication, mm
Thickness *t*, mm	Random	Isolated	
Less than 3	$\frac{1}{4}t$	$\frac{1}{3}t$	$\frac{1}{10}t$
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
10	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
19.0 to 50 , incl.	3.96	6.35	0.79
Over 50	3.96	9.53	1.60
U.S. Customary Units			
	Maximum Size of Acceptable Rounded Indication, in.		Maximum Size of Nonrelevant Indication, in.
Thickness *t*, in.	Random	Isolated	
Less than $\frac{1}{8}$	$\frac{1}{4}t$	$\frac{1}{3}t$	$\frac{1}{10}t$
$\frac{1}{8}$	0.031	0.042	0.015
$\frac{3}{16}$	0.047	0.063	0.015
$\frac{1}{4}$	0.063	0.083	0.015
$\frac{5}{16}$	0.078	0.104	0.031
$\frac{3}{8}$	0.091	0.125	0.031
$\frac{7}{16}$	0.109	0.146	0.031
$\frac{1}{2}$	0.125	0.168	0.031
$\frac{9}{16}$	0.142	0.188	0.031
$\frac{5}{8}$	0.156	0.210	0.031
$\frac{11}{16}$	0.156	0.230	0.031
$\frac{3}{4}$ to 2, incl.	0.156	0.250	0.031
Over 2	0.156	0.375	0.063

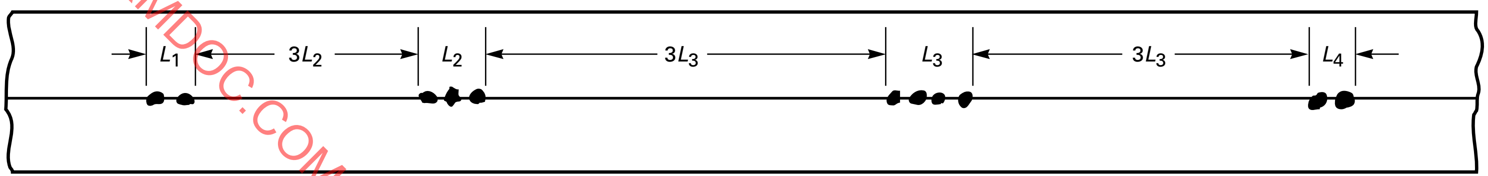
GENERAL NOTE: This table contains examples only.

Figure IV-3-1
Aligned Rounded Indications



GENERAL NOTE: Sum of L_1 to L_x shall be less than t in a length of $12t$.

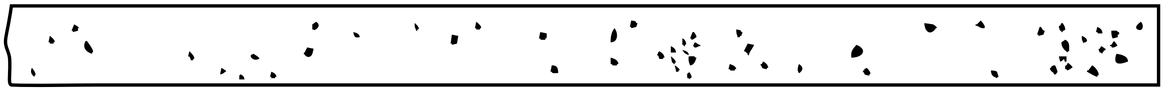
Figure IV-3-2
Groups of Aligned Rounded Indications



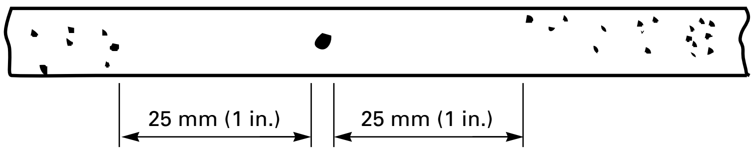
Maximum Group Length	Minimum Group Spacing
L = 6 mm ($\frac{1}{4}$ in.) for t less than 19 mm ($\frac{3}{4}$ in.) L = $\frac{1}{3}$ t for t 19 mm ($\frac{3}{4}$ in.) to 57 mm ($2\frac{1}{4}$ in.) L = 19 mm ($\frac{3}{4}$ in.) for t greater than 57 mm ($2\frac{1}{4}$ in.)	3L where L is the length of the longest adjacent group being evaluated.

GENERAL NOTE: Sum of the group lengths shall be less than t in a length of 12t.

Figure IV-3-3
Charts for *t* Equal to 3.2 mm to 6.4 mm ($^1/_8$ in. to $^1/_4$ in.), Inclusive



(a) Random Rounded Indications [See Note (1)]



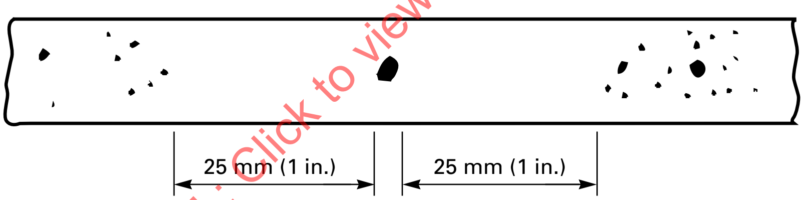
(b) Isolated Indication [See Note (2)]

(c) Cluster

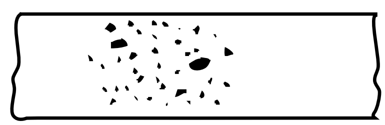
NOTES:
(1) Typical concentration and size permitted in any 152 mm (6 in.) length of weld.
(2) Maximum size per Table IV-3.

Figure IV-3-4
Charts for *t* Over 6.4 mm to 9.5 mm ($^1/_4$ in. to $^3/_8$ in.), Inclusive

(a) Random Rounded Indications [See Note (1)]



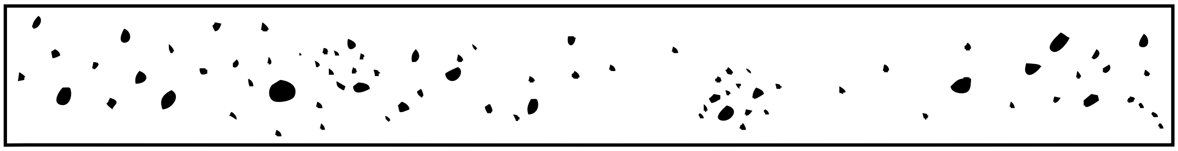
(b) Isolated Indication [See Note (2)]



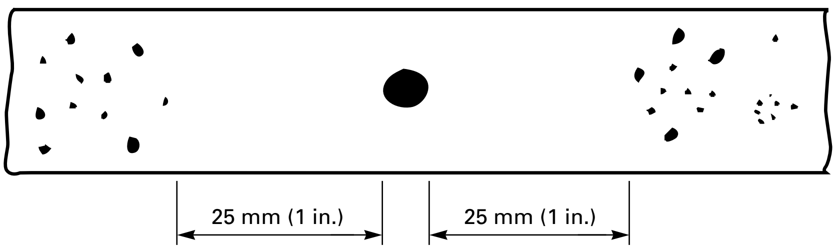
(c) Cluster

NOTES:
(1) Typical concentration and size permitted in any 152 mm (6 in.) length of weld.
(2) Maximum size per Table IV-3.

Figure IV-3-5
Charts for *t* Over 9.5 mm to 19 mm ($^3/_8$ in. to $^3/_4$ in.), Inclusive



(a) Random Rounded Indications [See Note (1)]



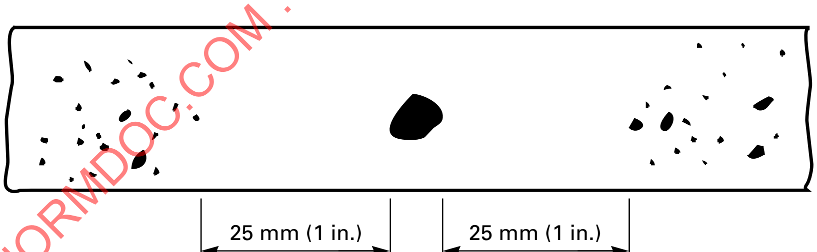
(b) Isolated Indication [See Note (2)]

(c) Cluster

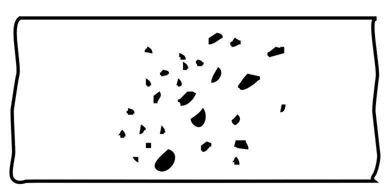
NOTES:
(1) Typical concentration and size permitted in any 152 mm (6 in.) length of weld.
(2) Maximum size per Table IV-3.

Figure IV-3-6
Charts for *t* Over 19 mm to 50 mm ($^3/_4$ in. to 2 in.), Inclusive

(a) Random Rounded Indications [See Note (1)]



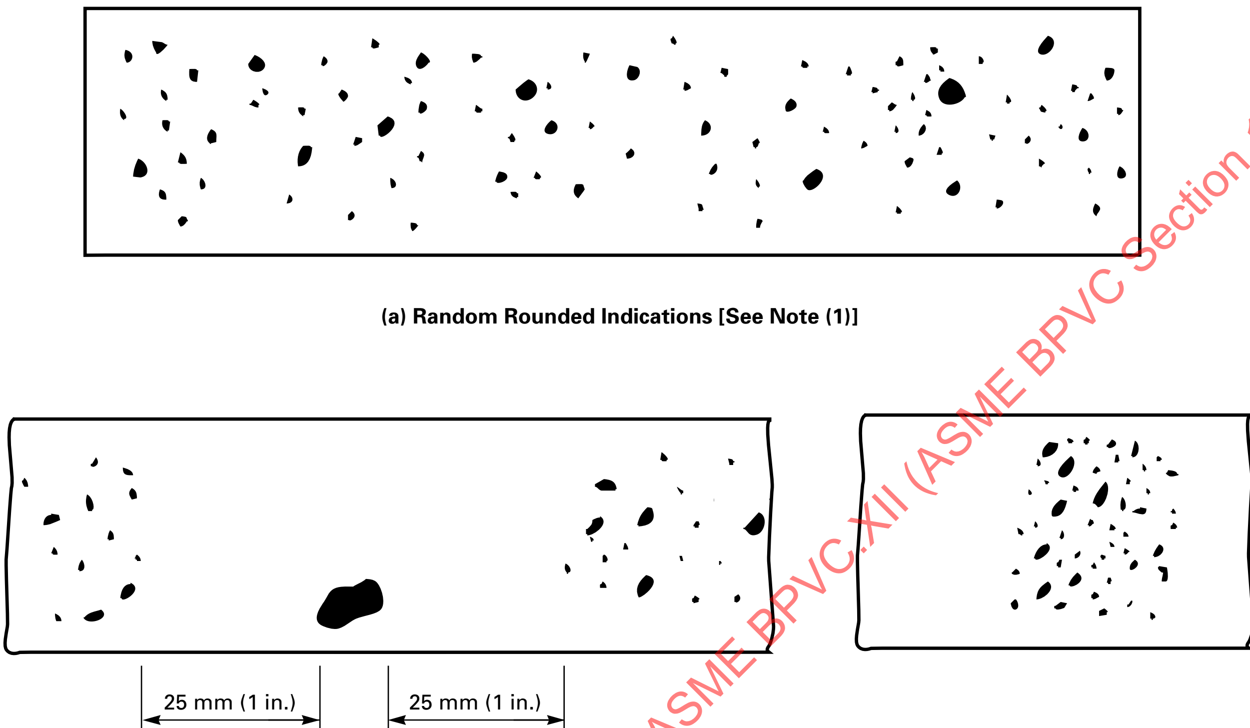
(b) Isolated Indication [See Note (2)]



(c) Cluster

NOTES:
(1) Typical concentration and size permitted in any 152 mm (6 in.) length of weld.
(2) Maximum size per Table IV-3.

Figure IV-3-7
Charts for *t* Over 50 mm to 100 mm (2 in. to 4 in.), Inclusive



(a) Random Rounded Indications [See Note (1)]

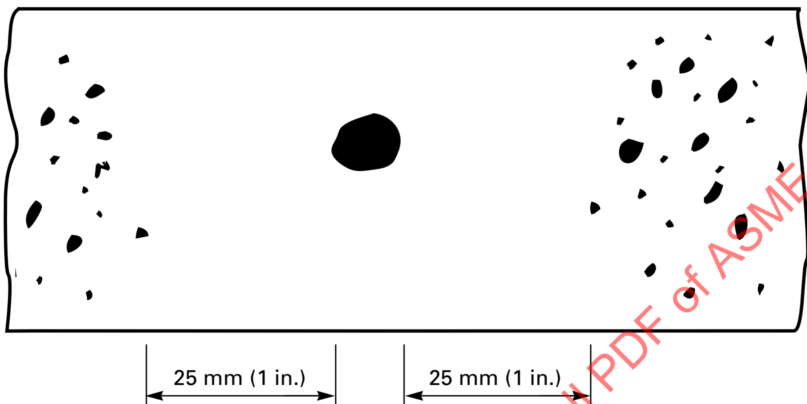
(b) Isolated Indication [See Note (2)]

(c) Cluster

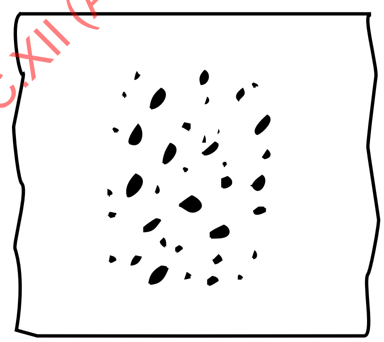
NOTES:
(1) Typical concentration and size permitted in any 152 mm (6 in.) length of weld.
(2) Maximum size per Table IV-3.

Figure IV-3-8
Charts for *t* Over 100 mm (4 in.)

(a) Random Rounded Indications [See Note (1)]



(b) Isolated Indication [See Note (2)]



(c) Cluster

NOTES:
(1) Typical concentration and size permitted in any 152 mm (6 in.) length of weld.
(2) Maximum size per Table IV-3.

MANDATORY APPENDIX V
METHODS FOR MAGNETIC PARTICLE EXAMINATION (MT)

V-1 SCOPE

(a) This Appendix provides for procedures that shall be followed whenever magnetic particle examination is specified in this Section.

(b) Section V, Article 7 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 Section V, Article 1, T-150.

(25) V-2 CERTIFICATION OF COMPETENCY FOR NONDESTRUCTIVE EXAMINATION PERSONNEL

The Manufacturer shall certify that each magnetic particle examiner meets the following requirements:

(a) The examiner has vision, with correction if necessary, to enable the examiner to read a Jaeger Type No. 2 Standard Chart at a distance of not less than 305 mm (12 in.), and is capable of distinguishing and differentiating contrast between colors used. These requirements shall be checked annually.

(b) The examiner is competent in the techniques of the magnetic particle examination method for which the examiner is certified, including making the examination and interpreting and evaluating the results, except that where the examination method consists of more than one operation, the examiner may be certified as being qualified only for one or more of these operations.

V-3 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 1.5 mm ($^1/_{16}$ in.) 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.

(c) Any questionable or doubtful indications shall be reexamined to determine whether or not they are relevant.

V-4 ACCEPTANCE STANDARDS

These acceptance standards shall apply unless other more restrictive standards are specified for specific materials or applications within this Section.

All surfaces to be examined shall be free of

(a) relevant linear indications

(b) relevant rounded indications greater than 5 mm ($^3/_{16}$ in.)

(c) four or more relevant rounded indications in a line separated by 1.5 mm ($^1/_{16}$ in.) or less, edge to edge

V-5 REPAIR REQUIREMENTS

The defect shall be removed or reduced to an imperfection of acceptable size. 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.

(a) Treatment of Indications Believed Nonrelevant. Any indication that 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.

(b) Examination of Areas From Which Imperfections 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 it has been removed or reduced to an acceptably sized imperfection.

(c) 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.

MANDATORY APPENDIX VI
METHODS FOR LIQUID-PENETRANT EXAMINATION (PT)

VI-1 SCOPE

(a) This Mandatory Appendix describes methods that shall be employed whenever liquid-penetrant examination is specified in this Section.[17]

(b) Section V, Article 6 shall be applied for detail requirements in methods, procedures, and qualifications, unless specified within this Appendix.

(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 Section V, Article 1, T-150.

(25) ## VI-2 CERTIFICATION OF COMPETENCY OF NONDESTRUCTIVE EXAMINATION PERSONNEL

The manufacturer shall certify that each liquid-penetrant examiner meets the following requirements:

(a) The examiner has vision, with correction if necessary, to enable the examiner to read a Jaeger Type No. 2 Standard Chart at a distance of not less than 12 in. (305 mm), and is capable of distinguishing and differentiating contrast between colors used. These requirements shall be checked annually.

(b) The examiner is competent in the techniques of the liquid-penetrant 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, the examiner may be certified as being qualified only for one or more of these operations.

VI-3 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 1.5 mm ($^1/_{16}$ in.) 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.

VI-4 ACCEPTANCE STANDARDS

These acceptance standards shall apply unless other more restrictive standards are specified for specific materials or applications within this Section.

All surfaces to be examined shall be free of

(a) relevant linear indications

(b) relevant rounded indications greater than 5 mm ($^3/_{16}$ in.)

(c) four or more relevant rounded indications in a line separated by 1.5 mm ($^1/_{16}$ in.) or less (edge to edge)

VI-5 REPAIR REQUIREMENTS

Unacceptable imperfections shall be repaired and reexamination made to ensure removal or reduction to an acceptable size. Whenever an imperfection is repaired 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 repair of an imperfection, the area shall be cleaned and welding performed in accordance with a qualified welding procedure.

(a) Treatment of Indications Believed Nonrelevant. Any indication that 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.

(b) 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 it has been removed or reduced to an acceptably sized imperfection.

(c) 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.

MANDATORY APPENDIX VIII
LOW PRESSURE TANK DESIGN

VIII-1 SCOPE

This Mandatory Appendix provides requirements for transport tanks with design pressures and temperatures less than 1.03 bar (15 psi) and 260°C (500°F) for tanks of circular and noncircular cross section.

VIII-2 DESIGN REQUIREMENTS

(a) General. The loads and operating conditions for low pressure transport tanks shall be as specified in the appropriate modal appendix applicable to the tank service. The operating conditions to be checked in design will always include one in which the tank is fully loaded under maximum internal pressure supported as a static object by its normal underpinnings. Design stresses shall be as specified in Section II, Part D. These rules apply when the tank cross sectional area divided by the product of tank perimeter times minimum shell thickness is between 3 and 120 for aluminum and 5 and 160 for steel. Configurations of tank shapes shall be limited to ratios of maximum width (height) to minimum height (width) no greater than 2.5. Design for defined incident loadings is covered in the applicable modal appendix.

(b) Nomenclature. The terms not defined here are uniquely defined in the sections in which they are first used.

A = tank cross sectional area
a = half of tank minor overall dimension (for example, half minor diameter of an elliptical tank)
a' = half of tank minor overall dimension for bulged rectangular tanks
b = half of tank major overall dimension (for example, half of major diameter of an elliptical tank)
b' = half of tank major overall dimension for bulged rectangular tanks
B_1 = effective shell breadth where shell is in tension and baffle is in compression ($50t_s$ each side of stiffener)
B_2 = effective breadth where shell is in compression and baffle is in tension ($20t_s$ on each side of stiffener)
c_n = moment coefficient for circumferential shell moment at location n
F_b = membrane force in bottom of tank
F_s = membrane force in side of tank
H = effective height of baffle where baffle is in compression and shell is in tension; $H = 80K_1t_b$
h = effective height of baffle where baffle is in tension and shell is in compression $h = 120K_1t_b$
I_1 = section moment of inertia where shell is in tension
I_2 = section moment of inertia when shell is in compression
k = ratio of corner radius of rectangular or bulged tank to half of minor overall dimension, $k = r/a$
K_1 = effective height factor for baffle material; K_1 = 1.67 for steel and 1.00 for aluminum
L_a = head radius of curvature in short direction (minimum)
L_b = head radius of curvature in long direction (maximum)
L_{trib} = tributary tank length associated with a particular shell/stiffener combination
M_n = circumferential bending moment in tank at location n
M_{bot} = maximum bending moment in tank bottom
M_{side} = maximum bending moment in tank side
n = location of bending moment on a non-circular tank shell as noted on Figure VIII-2-2
P = design pressure at bottom of tank including static head of contents
q = area coefficient for bulged rectangular tanks
R_1 = radius normal to minor axis for bulged rectangular tanks
R_2 = radius normal to major axis for bulged rectangular tanks
r = corner radius of rectangular type tank with rounded corners
r' = corner radius of bulged rectangular type tank
S_a = head stress in short direction (maximum)
S_b = head stress in long direction (minimum)
S_{bbbot} = bending stress in baffle/head at bottom
S_{bbot} = total stress in baffle/head at bottom = $S_{\text{mbot}} + S_{\text{bbbot}}$
S_{bbside} = bending stress in baffle/head at side
S_{bsbot} = bending stress in tank shell at bottom
S_{bside} = total stress in baffle/head at side = $S_{\text{sbot}} + S_{\text{bbside}}$
S_{bsside} = bending stress in tank shell at side
S_{mbot} = membrane stress in tank bottom

S_{mside} = membrane stress in tank side
S_{sbot} = total stress in tank shell at bottom = S_{mbot} + S_{bsbot}
S_{sside} = total stress in tank shell at side = S_{mside} + S_{bsside}
t_b = baffle thickness less corrosion allowance
t_h = head thickness less corrosion allowance
t_s = tank shell thickness less corrosion allowance
X = neutral axis distance from shell where shell is in tension
x = neutral axis distance from shell where shell is in compression
Z_{1b} = section modulus of baffle where shell is in tension
Z_{1s} = section modulus of shell where shell is in tension
Z_{2b} = section modulus of baffle where shell is in compression
Z_{2s} = section modulus of shell where shell is in compression

(c) Design Pressure. For cylindrical tanks and heads for cylindrical transport tanks, the internal pressure design equations shall be those of such tanks subject to pressures over 15 psi as noted in Articles TD-3 and TD-5. For noncylindrical transport tanks, the pressure design equations shall be as specified in Figures VIII-2-1, VIII-2-2, and VIII-2-3 of this Appendix and will apply to loads tributary to the heads, bulkheads, stiffeners, or internal baffles installed in the tanks. The membrane stresses due to pressure are taken by the tank shell, and the bending moments are taken by a portion of the shell acting in conjunction with baffles, bulkheads, heads, and internal or external stiffeners to form a girder [see (d) below]. The longitudinal stresses due to internal pressure and bending between supports in noncylindrical tanks are assumed to be membrane stresses alone. The design pressure for the tank shall be the MAWP plus the static head at the bottom of the tank. The hydrostatic test pressure for the tank shall be 1.50 times the design pressure. The maximum spacing of heads, bulkheads, stiffeners, and baffles for any noncylindrical tank shall not exceed 1 500 mm (60 in.). The following weld joint efficiencies shall be permitted:

(1) For longitudinal shell welds within 6 times the shell thickness of calculated circumferential bending moment points, use 70% of the allowable weld design stress. For aluminum, the allowable design stress at welds is for the O temper.

(2) For circumferential welds, the lower of 70% or the O temper allowable stress shall be used. For noncylindrical vessels, the head stresses are as follows: in the short direction, $S_a = P/[t_h\,(1/L_a + L_a/L_b^2)]$, and in the long direction, $S_b = S_aL_a/L_b$.

For heads of low pressure tanks, the knuckle radius shall be the greater of 12.7 mm (0.5 in.) or 3 times the nominal thickness of the plate from which the head was formed. Stuffed (inserted) heads and baffles are allowed and may be attached to shells with a suitable fillet weld. Notwithstanding the rules and procedures outlined above, the thicknesses of tank shells, heads, bulkheads, and baffles shall not be lower than indicated in the applicable modal appendix for the particular tank specification.

(d) Shell and Stiffener Properties. Shell and stiffener properties shall be determined by the following procedures and are illustrated in Figure VIII-2-4:

(1) A shell/baffle combination acts as a girder in bending with section properties determined by whether the shell is in tension or compression due to bending moment using values noted in (b) above.

(2) A shell/stiffener combination has section properties calculated with the stiffener and associated shell as an effective tee section using an effective breadth beyond the stiffener of $20t_s$ on each side where the shell is in compression and $50t_s$ on each side where the shell is in tension. The effective baffle depth is given in Figure VIII-2-4 for where the baffle is in compression or tension.

(3) For membrane stresses use Pa/t_s for top and bottom and Pb/t_s for sides, both in tension.

(e) Openings. Openings in low pressure cylindrical transport tanks shall be reinforced as required for pressure tanks taking into consideration the lower pressures. Noncylindrical transport tanks shall have openings located preferably outside the effective shell width on each side of baffles, bulkheads, or stiffeners (stiffening elements) used in determining the section properties for circumferential tank wall stresses. The openings need not be reinforced unless the tributary membrane stress calculated by deducting the shell cut away by the opening from the shell tributary to the stiffening element exceeds the allowable stress for the shell material.

(f) Special Design Details. Pressure-retaining heads and bulkheads in low pressure transport tanks can be inserted into the tank shell and fillet welded from one side, and each such pressure-retaining part may have a formed flange providing a faying surface to the shell. The single fillet weld shall be made on the end of the formed flange. Heads, bulkheads, baffles, and non-pressure-retaining elements can be installed without formed flanges but such tanks shall require an annual inspection of the shell welds to them to verify their integrity if made from one side only. Circumferential shell welds in noncircular tanks with shell plates running longitudinally shall be staggered so that no more than one-third of the circumference of the tank contains a circumferential weld seam located within 8 times the thickness longitudinally of another circumferential weld seam. The one-third circumference containing a weld seam need not be continuous but may be made up of several sections spaced at least 100 times the shell thickness apart circumferentially.

(g) Proof Testing. Proof testing of low pressure transport tanks, in accordance with Part TT, is permitted if not calculable by the rules in this Appendix.

(h) Minimum Thickness Requirements. Minimum thickness requirements are stated in the applicable Modal Appendices.

VIII-3 FABRICATION AND WELDING

(a) Piping, Valves, Openings, and Covers. Piping, valves, openings, and covers shall be designed to meet their individual pressure requirements. Piping shall be supported at intervals not exceeding 24 times the pipe diameter. Access openings and covers shall be designed for resisting 36 psig test pressures and can also be designed to withstand defined incident loads at the option of the manufacturer.

(b) Fabrication Requirements. Low pressure transport tanks shall be fabricated using practices applicable to pressure tanks under the applicable modal appendix. Welding procedures shall be qualified, and materials and weld filler metal shall be as required for pressure tanks under the applicable modal appendix. Since noncircular tanks have significant shell bending stresses that differ markedly at different points on the tank circumference, longitudinal shell welds in those tanks shall be located in areas where shell bending stresses are less than 50% of maximum, and welds made from one side shall be made so that side is the one subject to compressive flexural stresses. Forming of materials shall be done to avoid sharp blows, peening type deformations, and excessive work hardening of local areas. Knuckle inside radii shall be more than 3 times the original plate thickness before forming. Where heat-treated material is fabricated into tanks, the forming, assembly, and welding processes used shall be as required elsewhere in this Code for the particular materials used.

(c) Inspection Requirements. Low pressure transport tanks shall be considered as Class 3 vessels per TG-430 and are subject to inspection by manufacturers, tank owners, and inspection agencies to a level commensurate with the service expected of the tank and the public danger associated with the tank contents escaping or reacting with the outside atmosphere.

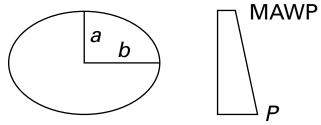
(d) Safety Devices. All low pressure transport tanks shall have relief devices to ensure that design pressures are not exceeded in the transport condition as well as in the loading and unloading conditions.

(e) Examination Requirements. All examinations of low pressure transport tanks shall be in accordance with Part TE and any additional requirements of the applicable modal appendix.

(f) Pressure Test Requirements. Low pressure transport tanks shall be pressure tested according to the test requirements of Article TT-2 and the additional requirements of the applicable modal appendix.

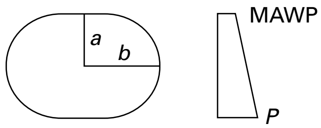
Figure VIII-2-1
Types of Tanks: Design Moments and Bending Stresses

(a) **Elliptical**



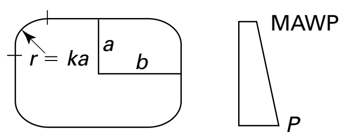
Use elliptical coefficients.

(b) **Obround**



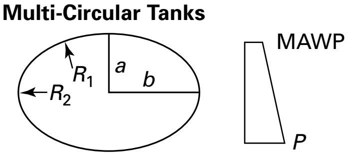
Use obround coefficients.

(c) **Rectangular With Radius Corners**



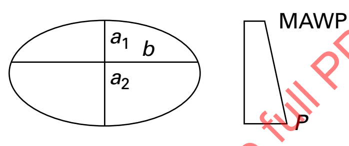
Use rectangular with radius corner coefficients.

(d) **Multi-Circular Tanks**



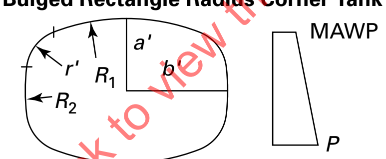
Use elliptical coefficients.

(e) **Double Elliptical Tanks**



Use elliptical tank coefficients using a_{top}/b for top moment and $(a_{top} + a_{bot})/2b$ for bottom and side moments.

(f) **Bulged Rectangle Radius Corner Tank**



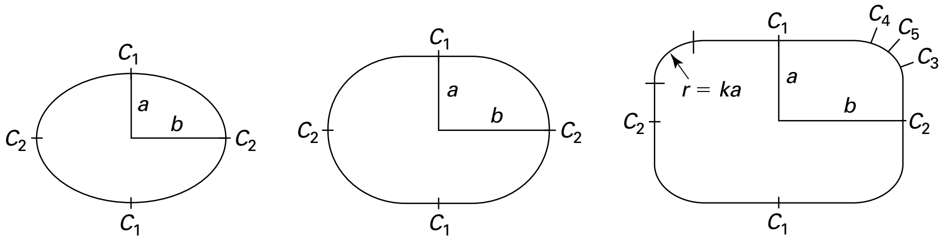
Design as Case (c), but using adjusted a and b as follows:

$$q = \sqrt{\frac{A}{(2 \cdot a') \cdot (2 \cdot b') - r'^2 \cdot (4 - \pi)}}$$

$$a = q \cdot a' \qquad b = q \cdot b' \qquad r = q \cdot r'$$

Use design pressure based on full tank depth.

Figure VIII-2-2
Bending Moments in Noncircular Shells

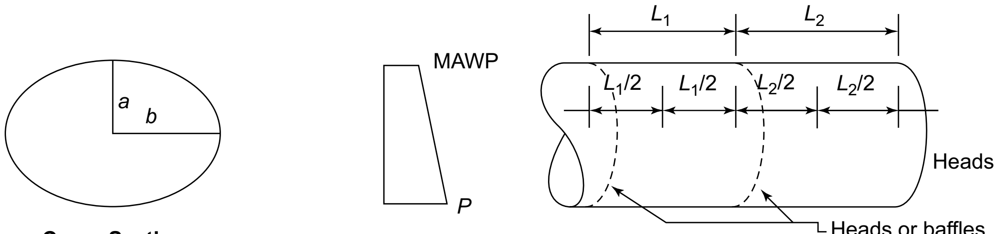


Ellipse   Obround   Rectangle With Rounded Corners

Shape	Coefficient	*a/b* = 1.0	*a/b* = 0.9	*a/b* = 0.8	*a/b* = 0.7	*a/b* = 0.6	*a/b* = 0.5	*a/b* = 0.4
Ellipse	c_1	0	−0.057	−0.133	−0.237	−0.391	−0.629	−1.049
Ellipse	c_2	0	0.060	0.148	0.283	0.498	0.870	1.576
Obround	c_1	0	−0.072	−0.166	−0.293	−0.476	−0.759	−1.247
Obround	c_2	0	0.045	0.116	0.227	0.413	0.741	1.378
Rectangle k = 1.0	c_1	−0.050	−0.123	−0.218	−0.347	−0.534	−0.824	−1.323
Rectangle k = 1.0	c_2	−0.050	−0.005	0.064	0.173	0.355	0.676	1.302
Rectangle k = 1.0	c_3	−0.030	0.015	0.084	0.193	0.375	0.696	1.322
Rectangle k = 1.0	c_4	−0.030	−0.074	−0.116	−0.150	−0.159	−0.104	0.122
Rectangle k = 1.0	c_5	0.036	0.062	0.118	0.218	0.393	0.709	1.331
Rectangle k = 0.6	c_1	−0.091	−0.164	−0.261	−0.393	−0.584	−0.880	−1.390
Rectangle k = 0.6	c_2	−0.091	−0.047	0.020	0.127	0.305	0.620	1.235
Rectangle k = 0.6	c_3	−0.011	0.033	0.100	0.207	0.385	0.700	1.315
Rectangle k = 0.6	c_4	−0.011	−0.034	−0.050	−0.050	−0.015	0.100	0.415
Rectangle k = 0.6	c_5	0.088	0.116	0.168	0.262	0.468	0.734	1.340
Rectangle k = 0.4	c_1	−0.124	−0.198	−0.296	−0.431	−0.625	−0.928	−1.449
Rectangle k = 0.4	c_2	−0.124	−0.081	−0.015	0.090	0.264	0.572	1.176
Rectangle k = 0.4	c_3	0.056	0.099	0.165	0.270	0.444	0.752	1.356
Rectangle k = 0.4	c_4	0.056	0.055	0.065	0.098	0.177	0.352	0.756
Rectangle k = 0.4	c_5	0.156	0.187	0.241	0.335	0.498	0.796	1.390
Rectangle k = 0.2	c_1	−0.149	−0.224	−0.324	−0.460	−0.659	−0.968	−1.499
Rectangle k = 0.2	c_2	−0.149	−0.107	−0.042	0.060	0.230	0.532	1.126
Rectangle k = 0.2	c_3	0.171	0.213	0.278	0.380	0.550	0.852	1.446
Rectangle k = 0.2	c_4	0.171	0.191	0.228	0.294	0.417	0.652	1.146
Rectangle k = 0.2	c_5	0.237	0.273	0.332	0.427	0.591	0.886	1.473
Rectangle k = 0.0	c_1	−0.167	−0.243	−0.344	−0.483	−0.685	−1.000	−1.542
Rectangle k = 0.0	c_2	−0.167	−0.126	−0.063	0.037	0.204	0.500	1.083
Rectangle k = 0.0	c_3	0.333	0.374	0.438	0.537	0.704	1.000	1.583
Rectangle k = 0.0	c_4, c_5	0.333	0.374	0.438	0.537	0.704	1.000	1.583

GENERAL NOTES:
(a) Maximum values are underlined.
(b) Moment at point n is $M_n = C_n a^2 PL_{trib}$, where C_n is a coefficient from Figure VIII-2-2 and P is the design pressure (at bottom of tank).

Figure VIII-2-3
Noncircular Cargo Tank Structural Properties



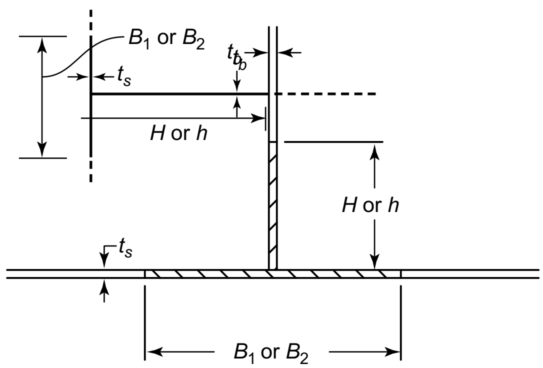
Cross Section

Elevation

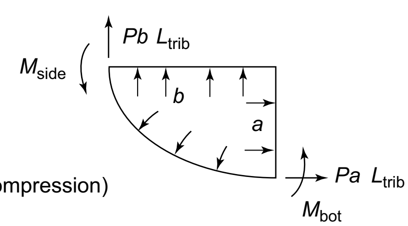
Tributary Lengths: For end head $L_{trib} = L_2/2$. See definition of L in TD-400.1 for further clarification and application.

For interior $L_{trib} = (L_1 + L_2)/2$

Stiffener Diagram



GENERAL NOTE: For a typical noncircular tank with an interior baffle (elliptical as an example), the stresses are determined as follows:



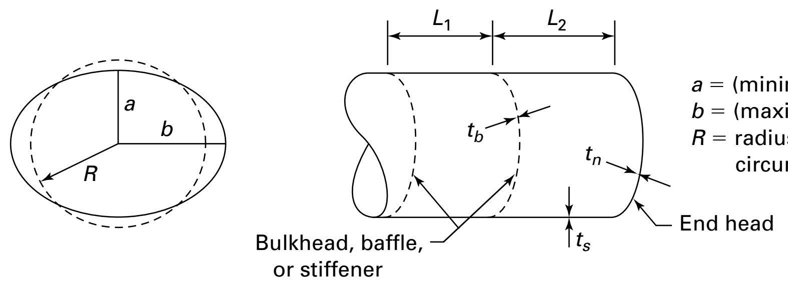
(a) Membrane stress: $S_{mbot} = Pa/t_s$ (tension) $S_{mside} = Pb/t_s$ (tension)

(b) Bending stress: $S_{bsbot} = M_{bot}/Z_{1s}$ (shell tension) $S_{bbbot} = M_{bot}/Z_{1b}$ (baffle compression)

$S_{bsside} = M_{side}/Z_{2s}$ (shell compression) $S_{bbside} = M_{side}/Z_{2b}$ (baffle tension)

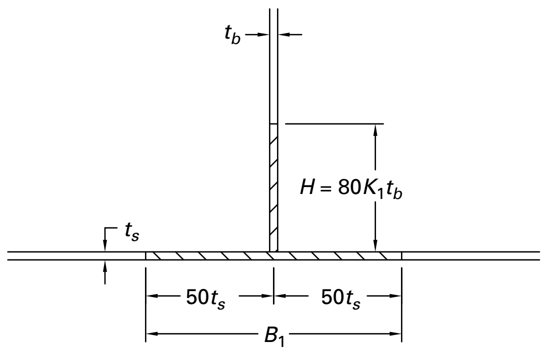
(c) Combine membrane and bending stresses to obtain total stress.

Figure VIII-2-4
Noncircular Tank



a = (minimum diameter)/2
b = (maximum diameter)/2
R = radius of cylinder tank of same circumference as noncircular tank

(a) Where bending moment causes compression in the baffle, use the following effective stiffener section:



effective breadth = $100t_s$

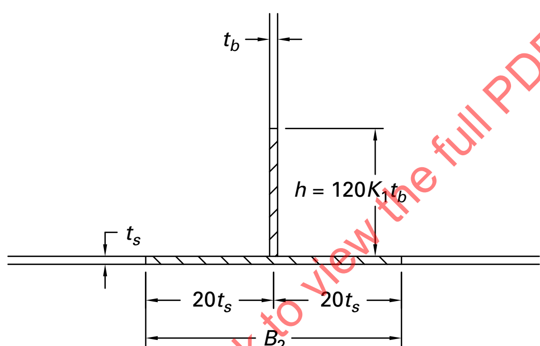
$$I_1 = B_1 t_s X^2 + H t_b \left[\frac{H^2}{12} + \left(\frac{H}{2} - X\right)^2\right]$$

$$X = H^2 t_b / [2(B_1 t_s + H t_b)]$$

$$Z_{1b} = I_1/(H - X)$$

$$Z_{1s} = I_1/X$$

(b) Where bending moment causes tension in the baffle, use the following effective stiffener section:



effective breadth = $40t_s$

$$I_2 = B_2 t_s x^2 + h t_b \left[\frac{h^2}{12} + \left(\frac{h}{2} - x\right)^2\right]$$

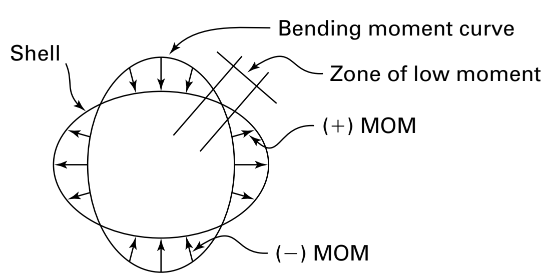
$$x = h^2 t_b / [2(B_2 t_s + h t_b)]$$

$$Z_{2b} = I_2/(h - x)$$

$$Z_{2s} = I_2/x$$

(c) For end heads, effective breadth is half that of interior locations. Tributary length for ends is $L_2/2$ and for interior is $(L_1 + L_2)/2$. See definition of L in TD-400.1 for further clarification and application.

(d) For heads or internal bulkheads, membrane stress due to pressure should be added algebraically to baffle stress. Bending moment varies around shell from positive to negative with 4 areas of high moment and 4 areas of low moment.



MANDATORY APPENDIX IX ULTRASONIC EXAMINATION OF WELDS (UT)

IX-1 SCOPE

(a) This Appendix describes methods that shall be employed when ultrasonic examination of welds is specified in this Section.

(b) Section V, Article 5 shall be applied for detail requirements in methods, procedures, and qualifications, unless otherwise specified in this Appendix.

(c) Ultrasonic examination shall be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirements of Section V, Article 1, T-150.

IX-2 CERTIFICATION OF COMPETENCE OF NONDESTRUCTIVE EXAMINER

The Manufacturer shall certify that personnel performing and evaluating ultrasonic examinations required by this Section have been qualified and certified in accordance with their employer's written practice. SNT-TC-1A[18] 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) [18] or CP-189[18] 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 Mandatory Appendix I).

IX-3 ACCEPTANCE/REJECTION STANDARDS

These standards shall apply unless other standards are specified for specific applications within this Section.

Imperfections that produce a response 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).

(a) Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

(b) Other imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths that exceed

(1) 6 mm ($^1\!/_4$ in.) for t up to 19 mm ($^3\!/_4$ in.)

(2) $^1\!/_3t$ for t from 19 mm ($^3\!/_4$ in.) to 57 mm ($2^1\!/_4$ in.)

(3) 19 mm ($^3\!/_4$ in.) for t over 57 mm ($2^1\!/_4$ in.)

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.

IX-4 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, response level, dimensions, depth below the surface, and classification.

MANDATORY APPENDIX X
EXAMINATION OF STEEL CASTINGS

X-1 SCOPE

This Mandatory Appendix covers examination requirements that shall be observed for all steel castings to which a 100% quality factor is to be applied in accordance with TM-190(a)(5). Except for fluids defined in TW-100.1(a), steel castings made to an accepted standard, such as ASME B16.5, are not required to comply with the provisions of this Appendix (see Table TG-130).

(25) ## X-2 EXAMINATION TECHNIQUES

Examination techniques shall be carried out in accordance with the following:

(a) Magnetic particle examinations shall be per Mandatory Appendix V, except that acceptance standards shall be as given in X-3(a)(3) of this Appendix.

(b) Liquid-penetrant examinations shall be per Mandatory Appendix VI, except that acceptance standards shall be as given in X-3(a)(4) of this Appendix.

(c) Radiographic examinations shall be per Section V, Article 2 with acceptance standards as given in X-3(a)(1) or X-3(b)(3) of this Appendix.

(1) A written radiographic examination procedure is not required. Demonstration of density and image quality indicator (IQI) image requirements on production or technique radiographs shall be considered satisfactory evidence of compliance with Section V, Article 2.

(2) The requirements of Section V, Article 2, T-285 are to be used only as a guide. Final acceptance of radiographs shall be based on the ability to see the prescribed IQI image and the specified hole or the designated wire or a wire IQI.

(d) Ultrasonic examinations shall be per Section V, Article 5 with acceptance standards as given in X-3(b)(3) of this Appendix.

X-3 EXAMINATION REQUIREMENTS

All steel castings shall be examined in accordance with (a) or (b) as applicable.

(a) All castings having a maximum body thickness less than 114 mm $(4\frac{1}{2}$ in.) shall be examined as follows:

(1) All critical sections[3] shall be radiographed. For castings having radiographed thicknesses up to 50 mm (2 in.), the radiographs shall be compared to those in ASTM E446, *Standard Reference Radiographs for Steel Castings Up to 50 mm (2 in.) in Thickness*. The maximum acceptable severity levels for imperfections shall be as specified as follows:

Imperfection Category	Maximum Severity Level — Thicknesses <1 in.	Maximum Severity Level — Thicknesses 1 in. to <2 in.
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

For castings having radiographed thicknesses from 50 mm to 114 mm (2 in. to $4\frac{1}{2}$ in.), the radiographs shall be compared to those in ASTM E186, *Standard Reference Radiographs for Heavy-Walled [50 mm to 114 mm (2 in. to $4\frac{1}{2}$ in.)] Steel Castings*. The maximum acceptable severity levels for imperfections shall be as follows:

Imperfection Category	Maximum Severity Level
A — Gas porosity	2
B — Sand and slag inclusions	2
C — Shrinkage	...
Type 1	1
Type 2	2
Type 3	3
D — Cracks	0
E — Hot tear	0
F — Inserts	0

(2) All surfaces including machined gasket seating surfaces shall be examined by the magnetic particle or the liquid-penetrant method. When the casting specification requires heat treatment, these examinations shall be conducted after that heat treatment.

(3) Surface indications determined by magnetic particle examination shall be compared with those indicated in ASTM E125, *Standard Reference Photographs for Magnetic Particle Indications on Ferrous Castings*, and shall be removed if they exceed the following limits:

Type		Degree
I.	Linear discontinuities (hot tears and cracks)	All
II.	Shrinkage	2
III.	Inclusions	3
IV.	Chills and chaplets	1
V.	Porosity	1

(4) Surface indications determined by liquid-penetrant examination are unacceptable if they exceed the following limits:

(-a) all cracks and hot tears

(-b) any group of more than six linear indications other than those in (a) in any rectangular area of 38 mm × 150 mm ($1\frac{1}{2}$ in. × 6 in.) or less, or any circular area having a diameter of 89 mm ($3\frac{1}{2}$ in.) or less, these areas being taken in the most unfavorable location relative to the indications being evaluated

(-c) other linear indications more than 6 mm ($\frac{1}{4}$ in.) long for thicknesses up to 19 mm ($\frac{3}{4}$ in.) inclusive, more than one-third of the thickness in length for thicknesses from 19 mm to 57 mm ($\frac{3}{4}$ in. to $2\frac{1}{4}$ in.), and more than 19 mm ($\frac{3}{4}$ in.) long for thicknesses over 57 mm ($2\frac{1}{4}$ in.) (aligned acceptable imperfections separated from one another by a distance equal to the length of the longer imperfection are acceptable)

(-d) all indications of nonlinear imperfections that have any dimension exceeding 5 mm ($\frac{3}{16}$ in.)

(5) When more than one casting of a particular design is produced, each of the first five shall be examined to the full extent prescribed herein. When more than five castings are being produced, examinations as prescribed shall be performed on the first five and on one additional casting for each additional five castings produced. If any of these additional castings proves to be unacceptable, each of the remaining four castings of that group shall be examined fully.

(b) All castings having maximum body thickness 114 mm ($4\frac{1}{2}$ in.) and greater and castings of lesser thickness that are intended for severe service applications[19] shall be examined as follows:

(1) Each casting shall be subjected to 100% visual examination and to complete surface examination by either the magnetic particle or the liquid-penetrant method. When the casting specification requires heat treatment, these examinations shall be conducted after that heat treatment. Acceptability limits for surface imperfections shall be as given in (a)(3) and (a)(4).

(2) All parts of castings up to 300 mm (12 in.) in thickness shall be subjected to radiographic examination and the radiographs compared to those given in ASTM E280, *Standard Reference Radiographs for Heavy-Walled* [114 mm to 300 mm ($4\frac{1}{2}$ in. to 12 in.)] *Steel Castings*. The maximum acceptable severity levels for imperfections shall be as follows:

Imperfection Category	Maximum Severity Level
A — Gas porosity	2
B — Sand and slag inclusions	2
C — Shrinkage	...
Type 1	2
Type 2	2
Type 3	2
D — Cracks	0
E — Hot tears	0
F — Inserts	0

(3) For castings having a maximum thickness in excess of 300 mm (12 in.), all thicknesses that are less than 300 mm (12 in.) shall be examined radiographically in accordance with the preceding paragraph. All parts of such castings having thicknesses in excess of 300 mm (12 in.) shall be examined ultrasonically in accordance with Section V, Article 5. Any imperfections that do not produce indications exceeding 20% of the straight beam back reflection or do not reduce the height of the back reflection by more than 30% during a total movement of the transducer of 50 mm (2 in.) in any direction shall be considered acceptable. Imperfections exceeding these limits shall be repaired unless proved to be acceptable by other examination methods.

X-4 REPAIRS

(a) Whenever an imperfection is repaired, the excavated areas shall be examined by the magnetic particle or liquid-penetrant method to ensure it has been removed or reduced to an acceptable size.

(b) Whenever a surface imperfection is repaired by removing less than 5% of the intended thickness of metal at that location, welding need not be employed in making repairs. Where this is the case, the excavated area shall be blended into the surrounding surface so as to avoid any sharp contours.

(c) Castings of nonweldable materials (see TM-150.1) that contain imperfections in excess of acceptable limits as given in X-3 shall be rejected.

(d) For any type of defect, if the repair will entail removal of more than 75% of the thickness or a length in any direction of 150 mm (6 in.) or more, approval of the purchaser of the casting shall be obtained prior to making repairs.

(e) The finished surface of all repair welds shall be examined by the magnetic particle or liquid-penetrant method. When subsequent heat treatment is required, this examination of the repaired area shall be conducted after heat treatment.

(f) Except as provided in (1) and (2), all weld repairs shall be examined by radiography.

(1) Where the depth of repair is less than 25 mm (1 in.) or 20% of the section thickness, whichever is the lesser, and where the repaired section cannot be radiographed effectively, the first layer of each 6 mm ($^1/_4$ in.) thickness of deposited weld metal shall be examined by the magnetic particle or the liquid-penetrant method.

(2) Weld repairs that are made as a result of ultrasonic examination shall be reexamined by the same method when completed.

(g) When repair welding is done after the casting has been heat treated and when required by either the rules of this Section or the requirements of the casting specification, the repaired casting shall be postweld heat treated.

(h) All welding shall be performed using procedure qualifications in accordance with Section IX. The procedure qualification shall be performed on a test specimen of the same P-Number and same group as the production casting. The test specimen shall be subjected to the same heat treatment both before and after welding as will be applied to the production casting. All welders and operators performing this welding shall be qualified in accordance with Section IX.

X-5 IDENTIFICATION AND MARKING

Each casting shall be marked with the Manufacturer's name and casting identification, including the applicable casting quality factor and material identification. The Manufacturer shall furnish reports of the chemical and mechanical properties and certification that each casting conforms to all applicable requirements of this Appendix. The certification for castings for lethal service shall indicate the nature, location, and extent of any repairs.

MANDATORY APPENDIX XI
ADHESIVE ATTACHMENT OF NAMEPLATES

XI-1 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 0.13 mm (0.005 in.) and which are protected with a moisture-stable liner

(b) The nameplate has a nominal thickness not less than 0.5 mm (0.020 in.)

(c) use for vessels with design temperatures within the range of −40°C to 149°C (−40°F to 300°F), inclusive

(d) application to clean, bare metal surfaces, with attention being given to removal of antiweld spatter compound that may contain silicone

(e) use of prequalified application procedures as outlined in XI-2

(f) use of the preapplied adhesive within an interval of 2 yr after adhesive application

XI-2 NAMEPLATE APPLICATION PROCEDURE QUALIFICATION

(a) The Manufacturer's Quality Control System (see TG-320) 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°C (−40°F) 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) × 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 (see TG-130):

(1) Width of nameplate test strip shall be not less than 25 mm (1 in.).

(2) Nameplates shall have an average adhesion of not less than 1.4 N/mm (8 lb/in.) of width after all exposure conditions, including low temperature.

(d) Any change in (b) shall require requalification.

(e) Each lot or package of nameplates shall be identified with the adhesive application date.

MANDATORY APPENDIX XII
STANDARD UNITS FOR USE IN EQUATIONS

Table XII-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.^{2})	cubic millimeters (mm^2)
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 ($\mathrm{ksi}\sqrt{\mathrm{in.}}$)	MPa square root meters ($\mathrm{MPa}\sqrt{\mathrm{m}}$)
Angle	degrees or radians	degrees or radians
Boiler capacity	Btu/hr	watts (W)

MANDATORY APPENDIX XIII
REFERENCE MATERIAL AND EQUIVALENT THICKNESS

XIII-1 INTRODUCTION

The equivalent thickness shall be calculated using Method A or Method B, depending on how the minimum thickness is specified by the competent authority. If the value of v is not specified, use v = 0.3.

XIII-2 METHOD A

The required minimum equivalent thickness shall be calculated as follows:

(SI Units)

$$e_1 = \frac{1\,300 e_0}{\sqrt[3]{P_{m1} R_{m1} A_1}}$$

(U.S. Customary Units)

$$e_1 = \frac{35{,}896 e_0}{\sqrt[3]{P_{m1} R_{m1} A_1}}$$

where

A_1 = specified minimum elongation at fracture of the material to be used, in accordance with the applicable national or international standard, %
E_1 = modulus of elasticity of the actual material to be used, MPa (psi)
e_1 = required minimum thickness of the actual material to be used, mm (in.)
e_0 = minimum required thickness of the Reference Material specified, mm (in.)
P_{m1} = $E_1(1/v_1)^2 / \left[(1/v_1)^2 - 1\right]$
R_{m1} = specified minimum tensile strength of the actual material to be used, MPa (psi). Where a minimum and maximum are specified for tensile strength in specifications, the actual value indicated in the material test results may be used up to the maximum allowed by the specifications.
v_1 = Poisson's ratio of the actual material to be used

The thicknesses e_0 and e_1 shall be exclusive of any allowances for chemical or physical actions that can influence the thicknesses, e.g., corrosion, erosion, and forming (thinning).

NOTE: For hazardous materials tanks for which a minimum reference material thickness of 8 mm (0.315 in.) or higher is specified by competent authorities or Modal Appendices, the required thickness is based on a shell diameter of 1.8 m. When the shell has a diameter of more than 1.8 m, the equivalent minimum thickness obtained from the conversion equations shall be multiplied by $d_1/1.8$, where d_1 is the actual diameter of the shell in meters but not less than 1.8 m, to obtain the minimum required thickness.

XIII-2.1 EXAMPLE 1

Specified minimum thickness is 6 mm in Reference Material. What is the required thickness for SA-240 Type 304 material?

A_1 = 40%
e_0 = 6 mm (0.236 in.)
E_1 = 190 344.8 MPa (27.6 × 10^6 psi)
R_{m1} = 515 MPa (75,000 psi) from Section II, Part A, for SA-240 Type 304
v_1 = 0.305

(SI Units)

$$P_{m1} = \frac{190\,344.8\left(\frac{1}{0.305}\right)^2}{\left(\frac{1}{0.305}\right)^2 - 1} = 209\,868 \text{ MPa}$$

$$e_1 = \frac{1\,300(6)}{\sqrt[3]{(209\,868)\ (515)\ (40)}} = 4.79 \text{ mm}$$

(U.S. Customary Units)

$$P_{m1} = \frac{27.6 \times 10^6\left(\frac{1}{0.305}\right)^2}{\left(\frac{1}{0.305}\right)^2 - 1} = 30.43 \times 10^6 \text{ psi}$$

$$e_1 = \frac{35{,}896(0.236)}{\sqrt[3]{\left(30.43 \times 10^6\right)\left(75{,}000\right)\left(40\right)}} = 0.188 \text{ in.}$$

XIII-2.2 EXAMPLE 2

Specified minimum thickness is 3 mm in Reference Material (e_0 = 3 mm = 0.118 in.). What is the required minimum thickness for SB-209 6061-T6?

From Section II, Part B, SB-209 alloy 6061 is heat treatable. Therefore, R_{m1} = 290 MPa (42,000 psi) and A_1 = 35% if the welded vessel is heat treated to T6 temper. If the welded vessel is not heat treated to T6 temper, R_{m1} = 207 MPa (30,000 psi) and A_1 = 16%, which are the values for O temper. E_1 = 68 965.5 MPa (10 × 10^6 psi) and v_1 = 0.332.

For a welded vessel heat treated to T6 temper:

(SI Units)

$$P_{m1} = \frac{68\,965.5\left(\frac{1}{0.332}\right)^2}{\left(\frac{1}{0.332}\right)^2 - 1} = 77\,509 \text{ MPa}$$

$$e_1 = \frac{1\,300(3)}{\sqrt[3]{(77\,509)(290)(35)}} = 4.22 \text{ mm}$$

(U.S. Customary Units)

$$P_{m1} = 77{,}509 \times 145 = 11.238805 \times 10^6 \text{ psi}$$

$$e_1 = \frac{35{,}896(0.118)}{\sqrt[3]{\left(11.238805 \times 10^6\right)\left(42{,}000\right)\left(35\right)}} = 0.166 \text{ in.}$$

For a welded vessel not heat treated to T6 temper:

(SI Units)

$$e_1 = \frac{1\,300(3)}{\sqrt[3]{(77\,509)(207)(16)}} = 6.14 \text{ mm}$$

(U.S. Customary Units)

$$e_1 = \frac{35{,}896(0.118)}{\sqrt[3]{\left(11.238805 \times 10^6\right)\left(30{,}000\right)\left(16\right)}} = 0.242 \text{ in.}$$

XIII-3 METHOD B, EQUIVALENT THICKNESS

Where a material and its minimum required thickness are specified, the minimum required thickness of any other material shall be calculated as follows:

$$e_1 = e_s\left(\frac{P_{ms}R_{ms}A_s}{P_{m1}R_{m1}A_1}\right)^{1/3}$$

where

A_1 = specified minimum elongation at fracture of the material to be used, in accordance with the applicable national or international standard, %
A_s = specified minimum elongation at fracture of the specified material, in accordance with the applicable national or international standard, %
E_1 = modulus of elasticity of material to be used, MPa (psi)
E_s = modulus of elasticity of specified material, MPa (psi)
e_1 = required minimum thickness of the actual material to be used, mm (in.)
e_s = minimum required thickness of the specified material, mm (in.)
P_{m1} = $E_1\,(1/v_1)^2/[(1/v_1)^2 - 1]$
P_{ms} = $E_s\,(1/v_s)^2/[(1/v_s)^2 - 1]$
R_{m1} = specified minimum tensile strength of the actual material to be used, in accordance with the applicable national or international standard, MPa (psi).
R_{ms} = specified minimum tensile strength of the specified material, in accordance with the applicable national or international standard, MPa (psi). Where a minimum and maximum are specified for tensile strength in specifications, the actual value indicated in the material test results may be used up to the maximum allowed by the specifications.
v_1 = Poisson's ratio of material to be used
v_s = Poisson's ratio of specified material

The thicknesses e_o and e_1 shall be exclusive of any allowances for chemical or physical actions that can influence the thicknesses, e.g., corrosion, erosion, and forming (thinning).

MANDATORY APPENDIX XIV
HOT PRESSURE WELDED JOINT FOR HEAD-TO-SHELL WELDS OF TON CONTAINERS

XIV-1 GENERAL

The ton container and its head and shell are described in Modal Appendix 4. The head-to-shell weld of a ton container that is made using hot pressure welding (commercially known as forge welding) shall meet the following requirements in addition to the requirements of Modal Appendix 4.

XIV-2 DESIGN

The heads shall be convex to the pressure. They shall be torispherical, with an inside radius not greater than the inside diameter of the shell. They shall be made of one piece and hot formed so as to provide a straight flange at least 2 in. in length. The thickness of the heads after forming shall be not less than $^{11}/_{16}$ in., nor greater than $^{7}/_{8}$ in. The heads shall fit snugly when inserted into the shell.

XIV-3 MATERIALS

The material for the shell and heads of the container shall be ASME SA-285 Grade A steel.

XIV-4 FABRICATION

The head and shell surfaces to be joined shall be cleaned before assembly as required by the WPS. Before hot pressure welding, the head and shell shall be joined at the open-end interface of the head and shell with an intermittent or continuous weld made by arc welding, following a WPS that has been qualified in accordance with ASME Section IX. Electric induction shall be used to heat the assembled head and shell in the region where the hot pressure weld is to be made to between 1 260°C (2,300°F) and 1 340°C (2,450°F). The container shall be rotated during the entire heating and forging operation. Pressure welding and crimping of each head as shown in Modal Appendix 4 shall be accomplished by rolling of the joint between pressure rollers in one continuous heating and forming cycle. The straight flanges of the heads shall be crimped radially inward at least 1 in. toward the centerline of the container during forming. The completed weld shall be allowed to cool in still air. The completed vessel shall be heat treated at 1,150°F ± 50°F for 1 hr.

The combined thickness of each weld after forge welding shall be an average of $^{15}/_{16}$ in. ±$^{1}/_{8}$ in. around the circumference.

XIV-5 ESSENTIAL VARIABLES FOR PROCEDURE QUALIFICATION

The welding procedure qualification test shall be a lap joint configuration that duplicates the joint configuration to be used in production. Requalification of the WPS is required if the production joint exceeds the following from that qualified:

(a) a change in thickness of either member greater than 10%

(b) an increase in the gap between parts prior to forging

(c) a change in the overlap length of the parts greater than 10%

(d) a change in the starting diameter of either cylinder greater than 10%

(e) a decrease in the percentage of reduction in the thickness of the sum of the members being joined by more than 10%

(f) a decrease in the length of the forged portion of the joint (i.e., upset length)

(g) the deletion, or reduction in the frequency or length, of tack welding of parts prior to forging

(h) addition, deletion, or a change in the nature of the atmosphere around the parts being joined (air, inert gas, reducing gas, etc.) during welding

(i) a change in the type or model of the welding equipment, in the major dimensions of the parts used for forging, or in the method of applying forging force (mechanical, hydraulic, etc.)

(j) deletion of PWHT

XIV-6 PROCEDURE QUALIFICATION TESTING

The test coupon shall consist of a head and shell production part that has been heat treated. The joint shall be assembled and welded as described in XIV-4. Two specimens of the weld approximately 2 in. wide, cut transverse to the weld length, shall be removed at four locations approximately 90 deg apart around the joint.

(a) One sample from each location shall be polished and etched to reveal the bond line. The bond line shall be free of cracks and shall be of a length such that when the measured cumulative lengths of lack of bond and slag are subtracted, at least $1\frac{1}{4}$ in. of cumulative bonding exists. The length of the bond line shall be recorded and any flaws observed shall be characterized, measured, and reported.

(b) The remaining four samples shall be wedged open at one end and a cold chisel inserted into the opening. The chisel shall be hammered into the opening in an attempt to separate the members along the bond line. If the members fail along the bond line, the test shall be considered to have been failed.

XIV-7 WELDING OPERATOR QUALIFICATION

A welding operator who welds a procedure qualification test coupon that passes the testing required by XIV-6 is qualified to operate the type or model of welding equipment and the method of applying forging force (mechanical, hydraulic, etc.) used during the test. Other welding operators shall weld a test coupon as required by XIV-6. The coupon shall be tested as required by XIV-6(b). A successful test shall qualify that operator to operate the type or model of welding equipment and the method of applying forging force (mechanical, hydraulic, etc.) used during the test.

MANDATORY APPENDIX XV RULES FOR MASS PRODUCTION OF PRESSURE VESSELS

XV-1 INTRODUCTION

This Appendix provides detailed requirements for the mass production of T-stamped pressure vessels at a rate of production that makes it impracticable for the Inspector (see TG-410) to perform the duties normally assigned under TG-330. The provisions of this Appendix allow the Manufacturer to assume responsibility for carrying out some of the Inspector's normally assigned duties by the development, acceptance, and implementation of a detailed inspection and quality control procedure as described in XV-4. The objective of such a procedure is to ensure that Code compliance and pressure integrity of mass-produced pressure vessels remain essentially identical to vessels constructed under TG-330. The Inspector must be satisfied that the inspection and quality control procedure and the Quality Control System are being fully implemented, and completed vessels meet the applicable requirements of this Section.[20]

XV-2 SCOPE

This Appendix provides rules allowing the Manufacturer of mass-produced T-stamped pressure vessels to assume responsibility for carrying out some of the Inspector's duties normally assigned under TG-330, in addition to the responsibilities normally assigned to the Manufacturer in TG-320. A mass-production program for pressure vessel fabrication may be implemented when the requirements of this Appendix are met.

XV-3 GENERAL

(a) Mass production is defined as the construction of multiple pressure vessels at a rate of production that makes it impracticable for the Inspector to perform all of the duties normally assigned under TG-330. The Inspector and/or the Authorized Inspection Agency (AIA) shall determine the acceptability of applying the mass-production inspection and quality control procedure to the construction of any vessel or series of vessels.

(b) Construction of two or more pressure vessels per shift at a rate of production that affords the Inspector sufficient opportunity to perform the required duties given in TG-330 does not qualify for mass production.

(c) Pressure vessels constructed under this Appendix shall be identical, except for differences in fitting sizes and locations, shell lengths, and the location and configuration of nonpressure attachments.

(d) The design and construction of pressure vessels fabricated under this Appendix shall be reviewed and accepted by the Inspector in accordance with the Certificate Holder's Quality Control System (see Mandatory Appendix I, I-5).

(e) There is no size limitation on mass-produced pressure vessels.

(f) Mass-produced pressure vessels meeting both (c) above and the incremental requirements of TE-230.1(b)(3) may be used to establish the 15 m (50 ft) linear weld increment requirements for spot radiography.

XV-4 QUALITY CONTROL PROCEDURES (25)

(a) The Manufacturer and the Authorized Inspection Agency (AIA) of record shall collaborate on the preparation of a detailed inspection and quality control procedure describing how some of the duties of the Inspector will be assumed by the Manufacturer. The inspection and quality control procedure, along with the Quality Control System Manual, shall be submitted to the AIA of record for review and acceptance in writing prior to implementation. The AIA of record shall submit the accepted inspection and quality control procedure and the Quality Control System Manual to the competent authority (see TG-300), and to an ASME Designee for review and acceptance. The final approved version of the inspection and quality control procedure shall be included in the Manufacturer's written Quality Control System (see Mandatory Appendix I, I-1).

(b) The inspection and quality control procedure shall be implemented at the location of the Manufacturer named on the Certificate of Authorization. An Inspector employed and designated by the AIA of record shall be assigned at each Manufacturer's location where mass production of pressure vessels is being performed. The assigned Inspector shall perform the required duties, including verification and oversight of implementation of the inspection and quality control procedure, as stated in (c) below. A minimum of one full-time (40 h per week) Inspector shall be present during mass production operations to perform the required duties. The

Inspector shall be present at all times during mass production operations when operating less than 40 h per week. When multiple-shift mass production operations are taking place, the required Inspector presence beyond the full-time requirement shall be a matter of agreement between the AIA of record and the Manufacturer, as set forth in the accepted inspection and quality control procedure. Manufacturing personnel who implement the inspection and quality control procedure shall be trained and qualified for their assigned duties in accordance with the Manufacturer's Quality Control System. All training and qualification documentation shall be maintained in accordance with the Manufacturer's Quality Control System.

(c) The Inspector shall perform all duties specifically assigned, and any necessary intermittent and unannounced in-process inspections and other inspection activities, required to ensure pressure vessels have been designed and constructed in accordance with the requirements of this Section prior to applying the Certification Mark. The Inspector's duties shall, as a minimum, include verifying that

(1) the Manufacturer has a valid Certificate of Authorization (see TG-320) and is working to a Quality Control System (see Mandatory Appendix I)

(2) the applicable design calculations are available (see TG-320 and Mandatory Appendix I, I-5)

(3) materials used in the construction of the vessel comply with the requirements of Part TM and Mandatory Appendix I, I-6

(4) all welding and brazing procedures have been qualified (see Mandatory Appendix I, I-9 and TF-210.2)

(5) all welders, welding operators, brazers, and brazing operators have been qualified (see Mandatory Appendix I, I-9 and TF-210)

(6) the heat treatments, including PWHT, have been performed (see Article TF-7 and Mandatory Appendix I, I-11)

(7) material imperfections repaired by welding were acceptably repaired (see Mandatory Appendix I, I-8 and TF-110.3)

(8) required volumetric nondestructive examinations, impact tests, and other tests have been performed and that the results are acceptable (see Article TM-2, Article TT-2, and TE-230.1)

(9) the inspection and quality control procedure is being implemented effectively, by monitoring all aspects of its implementation completely each calendar year

(10) the vessel is in compliance with all the provisions of this Section, to the best of the Inspector's knowledge and belief, prior to signing the Certificate of Inspection on the Manufacturer's Data Report

(d) In addition to the responsibilities of the Manufacturer found in TG-320, the Manufacturer is responsible for the following duties, as provided in the inspection and quality control procedure described in (a) above:

(1) verifying that weld defects were acceptably repaired (see TE-250.2)

(2) making a visual examination of the vessel to confirm that the material identification numbers have been properly transferred (see TM-140)

(3) making a visual examination of the vessel to confirm that there are no material or dimensional defects (see TG-420; Mandatory Appendix I, I-16; and Article TP-4)

(4) verifying that required surface nondestructive examinations and other tests have been performed and that the results are acceptable (see Mandatory Appendix I, I-10)

(5) performing internal and external examinations, and verifying that the hydrostatic or pneumatic tests have been performed (see Article TT-2)

(6) verifying that the required marking is provided (see Article TS-1) and that any nameplate has been attached to the proper vessel

(e) When the Manufacturer wishes to make changes to the accepted inspection and quality control procedure affecting compliance with the requirements of this Section, the changes shall be subjected to review and acceptance prior to implementation by all parties required for a joint review, including the AIA of record, the competent authority, and an ASME Designee. The AIA of record shall forward the accepted revisions to the inspection and quality control procedure to the competent authority and the ASME Designee for their written acceptance.

XV-5 DATA REPORTS

(a) Form T-1A, Form T-1B, or Form T-1C, prepared by the Manufacturer for pressure vessels constructed under a mass-production program, shall include under "Remarks" the statement: "Constructed under the provisions of Mandatory Appendix XV." The Data Reports shall be certified by the Manufacturer and Inspector when the completed vessels are found to be in compliance with the requirements of this Section.

(b) Same-day construction of identical mass-produced pressure vessels may be reported on a single Form T-1A, Form T-1B, or Form T-1C when the requirements of Article TS-3 are met.

XV-6 PNEUMATIC TESTING[21]

Mass-produced pressure vessels that otherwise qualify for exemption from impact testing per TM-210 may be pneumatically tested as follows, in lieu of the hydrostatic test requirements of TT-210(a):

(a) The pneumatic testing shall comply with TT-210(b).

(b) The maximum allowable working pressure to be stamped on the vessel shall not exceed 3.5 MPa (500 psig).

(c) Materials used for pressure-retaining portions of the vessel, and for nonpressure parts attached to pressure parts by welds having a throat thickness greater than 6 mm ($^1/_4$ in.), shall be restricted to those listed in the notes of Figure TM-240.1-1.

(d) The following thickness limitations apply:

(1) For butt joints, the nominal thickness at the thickest welded joint shall not exceed 13 mm ($^1/_2$ in.).

(2) For corner joints or lap welds, the thinner of the two parts joined shall not exceed 13 mm ($^1/_2$ in.).

(3) ASME B16.5 ferritic steel flanges used at design metal temperatures no colder than −29 °C (−20°F) may be used without thickness limitation.

(e) The minimum metal temperature during the pneumatic test shall be maintained at least 18°C (30°F) above that given in Figure TM-240.1-1 for the governing material classification and thickness combination in TM-240.1.

(f) The TE-240.1 NDE requirements are not applicable for mass-produced pressure vessels.

(g) The pneumatic test pressure shall be at least equal to 1.3 times the maximum allowable working pressure to be stamped on the vessel, multiplied by the lowest ratio (for the materials of which the vessel is constructed) of the stress value *S* for the test temperature of the vessel to the stress value *S* for the design temperature (see TD-150). In no case shall the pneumatic test pressure exceed 1.3 times the basis for calculated test pressure by more than 10%. The pressure in the vessel shall be gradually increased to not more than one-half of the test pressure. Thereafter, the test pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached. Then the pressure shall be reduced to a value equal to the test pressure divided by 1.3 and held for a sufficient time to permit inspection of the vessel. This inspection may be performed as a separate test. The visual inspection of the vessel at the required test pressure divided by 1.3 may be waived, provided

(1) a suitable gas leak test is applied

(2) substitution of the gas leak test is by agreement reached between Manufacturer and Inspector

(3) all welded seams that will be hidden by assembly are given a visual examination for workmanship prior to assembly

XV-7 HYDROSTATIC TESTING

Single-chamber pressure vessels constructed by a Manufacturer under the provisions of this Appendix may be pressure tested separately from their removable covers in a test fixture, and the corresponding bolted blind flange closures pressure tested only on a quality control basis, provided all of the following requirements are met:

(a) Only one end of the pressure vessel may consist of a bolted flat blind flange closure. The bolted flat blind flange closure and attachment flange shall comply with the following requirements:

(1) All requirements of ASME B16.5 for bolted flanges shall be met.

(2) As an alternative to (1), a fabricated flat blind flange may be used, provided it is dimensionally identical to an ASME B16.5 flange or designed in accordance with Section VIII, Division 1, Mandatory Appendix 2 and Article TD-5. A flange dimensionally identical to ASME B16.5 shall use the pressure–temperature rating for the flange construction material and class. A cover and flange designed in accordance with Section VIII, Division 1, Mandatory Appendix 2 and Article TD-5 shall be designed to 1.14 times the vessel MAWP at the design temperature. The vessel shell shall not exceed 760 mm (30 in.) outside diameter. In addition, the ASME B16.5 surface finish and machining requirements shall be met.

(3) The MAWP of the vessel shall not exceed 3.45 MPa (500 psi), and the maximum design temperature shall not exceed 343°C (650°F).

(4) No welding shall be permitted on the flat blind flanges.

(b) The pressure vessel with open end shall be tested in a fixture that will permit achieving the test pressure required by Article TT-2. The vessel shall be mounted to the test fixture in such a manner that the structural integrity and leak tightness of the body flange is established.

(c) One out of every 200 vessels, which selected at random from each day's production, shall be pressure tested per Article TT-2, with its removable cover, service gasket, and service bolting installed. If this quality control vessel fails the test, then all vessels produced in that day's production shall be tested. All vessels in the subject production lot shall consist of identical vessels and design conditions.

(d) The test fixture shall be designed such that the stress developed in the vessel during the hydrostatic test using the test fixture is the same as the stress developed in the vessel when tested with its removable cover.

MANDATORY APPENDIX XVI
LOCAL THIN AREAS IN CYLINDRICAL SHELLS AND IN SPHERICAL SEGMENTS OF SHELLS

XVI-1 SCOPE

The rules of this Appendix permit acceptable local thin areas (LTAs) in cylindrical shells or spherical segments of shells (such as spherical vessel, hemispherical heads, and the spherical portion of torispherical and ellipsoidal heads) under internal pressure to be less than the thickness required by TD-100.1. Local thin areas on the inside or outside of cylindrical shells or spherical segments of shells designed for internal pressure are acceptable, provided they meet the requirements in this Appendix.

XVI-2 GENERAL REQUIREMENTS

(a) The Manufacturer shall maintain records of the calculations and the location and extent of all LTAs that are evaluated using this Appendix, and provide such information to the purchaser, User, or the User's designated agent if requested. This information shall be documented in the design calculations made to meet the requirements of this Appendix.

(b) The provisions of this Appendix do not apply to corrosion-resistant linings or overlays.

(c) All other applicable requirements of this Section shall be met.

XVI-3 NOMENCLATURE

C = projected circumferential length of LTA in a cylindrical shell, in.
D = per TD-310
D_L = maximum dimension of LTA in a spherical segment, in.
K_o = factor from Table TD-430
L = projected axial length of LTA in a cylindrical shell, in.
LTA = local thin area
R = inside radius for cylindrical shell or spherical segment, in.
= K_oD for ellipsoidal heads
t = required thickness per Article TD-3, but not less than thickness requirements of TD-100.1, in.
t_L = minimum thickness of LTA, in.
θ = see Figure XVI-3-1

XVI-4 SINGLE LOCAL THIN AREAS IN CYLINDRICAL SHELLS

(a) Single LTA shall satisfy the following equations:

$$\frac{t_L}{t} \geq 0.9 \tag{1}$$

$$L \leq \sqrt{Rt} \tag{2}$$

$$C \leq 2\sqrt{Rt} \tag{3}$$

$$t - t_L \leq {}^3/_{16} \text{ in.} \tag{4}$$

(b) Any edge of an LTA shall not be closer than $2.5\sqrt{Rt}$ from a structural discontinuity such as a head or stiffener.

(c) For openings meeting TD-600.3(c), the minimum axial distance between the edge of the LTA and the center of the opening shall be equal to or greater than the inside diameter of the opening plus $\sqrt{Rt}$.

(d) For openings not meeting TD-600.3(c), the minimum axial distance between the edge of the LTA and the reinforcement limit of the opening shall be equal to or greater than $\sqrt{Rt}$.

(e) The blend between the LTA and the thicker surface shall be with a taper length not less than three times the LTA depth, as shown in Figure XVI-3-1, sketch (b). The minimum bottom blend radius shall be equal to or greater than two times the LTA depth, as shown in Figure XVI-3-1, sketch (b).

(f) The longitudinal stresses on the LTA from mechanical loads other than internal pressure shall not exceed $0.3S$.

(g) The thickness at the LTA shall meet the requirements of TD-400 as applicable.

XVI-5 MULTIPLE LOCAL THIN AREAS IN CYLINDRICAL SHELLS

(a) A pair of local areas with finished axial length, L_1 and L_2 [see Figure XVI-3-1, sketch (c)] are acceptable if the individual LTA satisfies the requirements of XVI-4 and one of the following two conditions is met:

(1) When $\theta \leq 45$ deg, the minimum axial separation [see Figure XVI-3-1, sketch (c)] shall be the greater of

$$\frac{(1.0 + 1.5\cos\theta)(L_1 + L_2)}{2} \text{ or } 2t$$

(2) When $\theta > 45$ deg, both of the following shall be met:

(-a) The minimum axial separation shall be equal to or greater than

$$\frac{2.91\cos\theta(L_1 + L_2)}{2}$$

(-b) The minimum circumferential separation shall be equal to or greater than $2t$.

(b) Multiple pairs of LTA are acceptable, provided all pairs meet the rules of a single pair specified in (a) above.

(c) Multiple local thin areas may be combined as a single LTA. The resultant single LTA is acceptable if it satisfies the rules of XVI-4.

XVI-6 SINGLE LOCAL THIN AREAS IN SPHERICAL SEGMENTS OF SHELLS

(a) The single LTA shall satisfy the following equations:

$$\frac{t_L}{t} \geq 0.9 \quad (5)$$

$$D_L \leq \sqrt{Rt} \quad (6)$$

$$t - t_L \leq {}^3\!/_{16}\text{ in.} \quad (7)$$

(b) For openings meeting TD-600.3(c), the minimum distance between the edge of the LTA and the center of the opening shall be equal to or greater than the inside diameter of the opening plus $\sqrt{Rt}$.

(c) For openings not meeting TD-600.3(c), the minimum distance between the edge of the LTA and the reinforcement limit of the opening shall be equal to or greater than $\sqrt{Rt}$.

(d) The edges of an LTA shall not be closer than $2.5\sqrt{Rt}$ from a structural discontinuity.

(e) A constant thickness junction between head and cylindrical shell is not considered to be a structural discontinuity for LTA rules.

(f) The blend between the LTA and the thicker surface shall be with a taper length not less than three times the LTA depth. The minimum bottom blend radius shall be equal to or greater than two times the LTA depth. The blend requirements are shown in Figure XVI-3-1, sketch (b).

(g) The LTA for a torispherical head must lie entirely within the spherical portion of the head. See Figure XVI-6-1.

(h) The LTA for an ellipsoidal head must lie entirely within a circle, the center of which coincides with the axis of the vessel and the diameter of which is equal to 80% of the shell inside diameter. See Figure XVI-6-2.

(i) The LTA for a hemispherical head is acceptable within any portion of the head, except as limited by (d) above. See Figure XVI-6-3.

(j) The thickness at the LTA shall meet the requirements of TD-310, as applicable.

(k) The provisions of this Appendix do not apply to the torus portion of either a torispherical or ellipsoidal head, to flat heads, or to conical heads.

XVI-7 MULTIPLE LOCAL THIN AREAS IN SPHERICAL SEGMENTS OF SHELLS

(a) Multiple LTAs may be combined and evaluated as a single LTA. The encompassed areas of the combined LTAs shall be within the D_L dimension.

(b) Each LTA in the encompassed area shall meet the rules of XVI-6.

(c) Multiple LTAs may be treated as single LTAs, provided their edges are no closer than $2.5\sqrt{Rt}$.

XVI-8 DATA REPORTS

When all the requirements of this Section and supplemental requirements of this Appendix have been met, the following notation shall be entered on the Manufacturer's Data Report under "Remarks": "Constructed in Conformance With Appendix XVI, Local Thin Areas in Cylindrical Shells and in Spherical Segments of Shells."

Figure XVI-3-1
Nomenclature

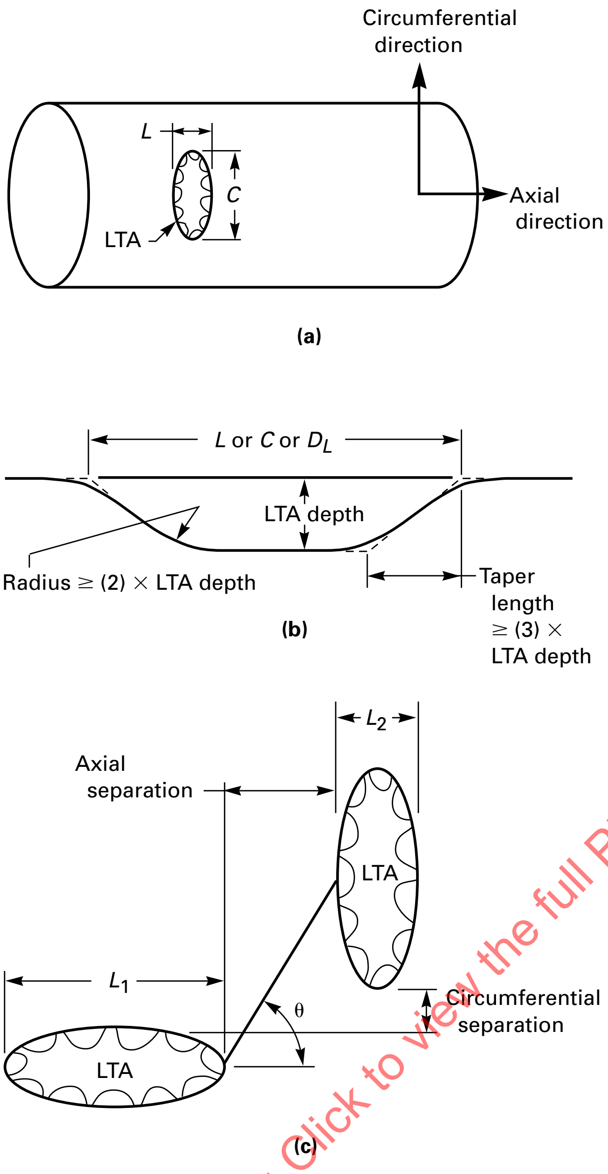


Figure XVI-6-1
Limits for Torispherical Head

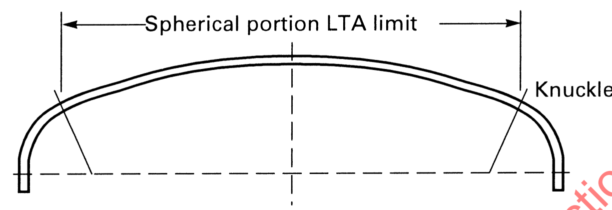


Figure XVI-6-2
Limits for Ellipsoidal Head

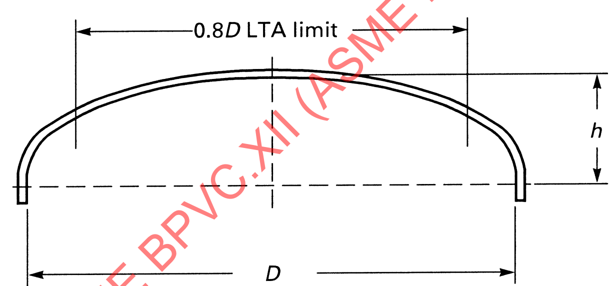
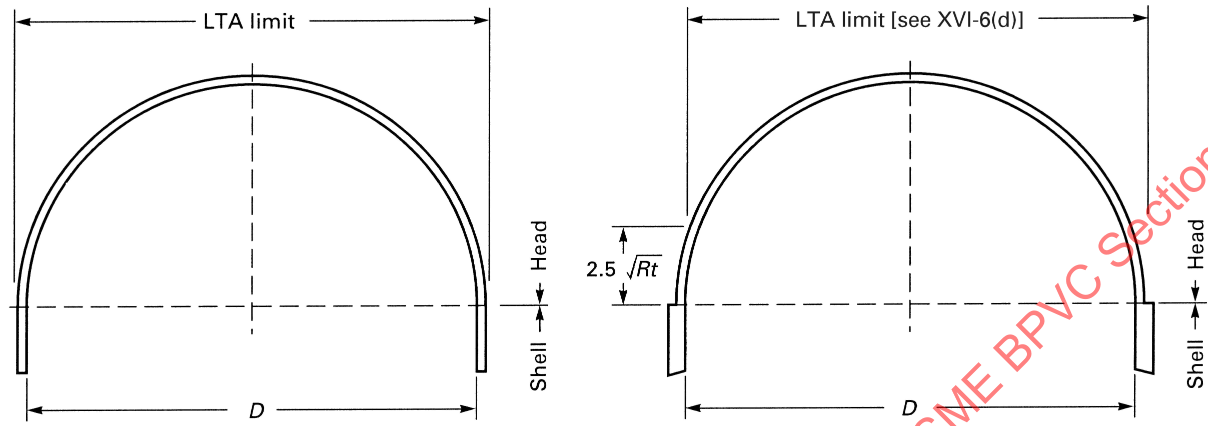


Figure XVI-6-3
Limits for Hemispherical Head



(a) Constant Thickness Junction

(b) Nonconstant Thickness Junction