ASME SBS-2023

Structures for Bulk Solids

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

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This code or standard was developed under procedures accredited as meeting the criteria for American National Standards. The standards committee that approved the code or standard was balanced to ensure that individuals from competent and concerned interests had an opportunity to participate. The proposed code or standard was made available for public review and comment, which provided an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

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FOREWORD

ASME was approached about developing a standard appropriate for structures for storage of bulk solids that operate at atmospheric pressure or very low internal gas pressure, where the primary loading of the structure was from storage of bulk solids versus gas or liquid pressure.

There was no comprehensive American standard for such metallic structures, and other standards for vessels or tanks for gas or liquid storage and containment did not have appropriate consideration of the loads and behavior of bulk solids. In some cases, these standards would not produce economical structures. Engineers designing bulk solids structures had to reference standards or references covering only certain aspects of the structures or loading, adapt portions of other codes and standards, or use various references, internal standards, or other sources.

ASME responded to this need for a recognized, more comprehensive standard by organizing a committee of knowledgeable parties. This included bulk solid structures users, manufacturers, fabricators, independent engineers, academics practicing in the field, and other appropriate interested parties, which became the Structures for Bulk Solids Committee.

A number of experts and knowledgeable interested parties have participated on the Committee over the development period, making important contributions leading to the inaugural Structures for Bulk Solids Standard. Some committee members have been active for the duration of the committee's operation; others participated and made significant contributions during their tenure with the committee. The efforts of all the contributing members and ASME Committee Secretaries and staff are appreciated and were important to bringing this Standard to publication.

While this Standard does include valuable information and requirements for designers, users, and fabricators of containers for storage of bulk solids that are within the scope of the Standard, it will not address every aspect of such structures and is not a replacement for education, experience, and the use of engineering judgment. The phrase "engineering judgment" refers to technical judgments made by designers experienced in the application of this Standard and referenced standards and knowledgeable about engineering principles involved in the design and function of such structures.

Reference and use of the Standard by appropriately trained engineers is part of the complete engineering design process and is not a substitute for such a process.

The Committee thanks ASME and the Board on Pressure Technology Codes and Standards for the longstanding support of the Committee during the development process.

This Standard was approved by the American National Standards Institute on May 30, 2023.

CORRESPONDENCE WITH THE SBS COMMITTEE

General. 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 Standard should be sent to the staff secretary noted on the committee's web page, accessible at https://go.asme.org/SBScommittee.

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

In addition, the committee may post errata on the committee web page. Errata become effective on the date posted. Users can register on the committee web page to receive e-mail notifications of posted errata.

This Standard is always open for comment, and the committee welcomes proposals for revisions. Such proposals should be as specific as possible, citing the paragraph number(s), 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 Standard

(4) to permit the 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 Standard.

(c) 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 Standard and the paragraph, figure, or table number(s)

(4) the edition(s) of the Standard to which the proposed case applies

(d) A case is effective for use when the public review process has been completed and it is approved by the cognizant supervisory board. Approved cases are posted on the committee web page.

Interpretations. Upon request, the committee will issue an interpretation of any requirement of this Standard. An interpretation can be issued only in response to a request submitted through the online Interpretation Submittal Form at https://go.asme.org/InterpretationRequest. Upon submitting the form, the inquirer will receive an automatic e-mail confirming receipt.

ASME does not act as a consultant for specific engineering problems or for the general application or understanding of the Standard 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 can track the status of their requests at https://go.asme.org/Interpretations.

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.

Interpretations are published in the ASME Interpretations Database at https://go.asme.org/Interpretations as they are issued.

Committee Meetings. The SBS Standards Committee regularly holds meetings that are open to the public. Persons wishing to attend any meeting should contact the secretary of the committee. Information on future committee meetings can be found on the committee web page at https://go.asme.org/SBScommittee.

Section 1
General Requirements

1-1 SCOPE

This Standard covers the requirements for vertical stationary containers used for the storage and processing of bulk solid materials at internal gage pressures not exceeding 15 psig (100 kPa) and external pressures, including wind pressure, not exceeding 1 psig (6.9 kPa) at temperatures up to 212°F (100°C).

1-1.1 General Requirements

This Standard contains requirements, prohibitions, and guidance for bulk solids containers, including materials of construction, solids-loading characteristics, design, fabrication, examination, testing, and overpressure protection. This Standard does not address all aspects of these elements. Those aspects that are not specifically addressed should not be considered prohibited, provided that activities not addressed are performed following recognized good engineering practices. Engineering practices shall be consistent with the philosophy of this Standard, and such judgments shall never be used to overrule the requirements or prohibitions of this Standard. Engineering requirements of this Standard, while considered necessary and adequate for safe design, generally take a simplified approach to the subject. A designer capable of applying a more rigorous analysis shall have the latitude to do so; however, the approach shall be documented in the engineering design and its validity accepted by the owner. The approach used shall provide details of design, construction, examination, inspection, and testing for the design conditions of Section 7, with calculations consistent with the design criteria of this Standard.

1-1.2 Jurisdictional Requirements

Laws or regulations issued by a municipality, state, provincial, federal, or other enforcement or regulatory body having jurisdiction at an installation may establish requirements for bulk solids containers within its jurisdiction. Such laws or regulations may require the use of this Standard for bulk solids containers or components outside its scope. These laws or regulations should be reviewed to determine size or service limitations of the coverage, which may be different than those given here.

1-1.3 Classes Not in Scope

The following classes of bulk solids containers are not included in the scope of this Standard:

(a) containers within the scope of the ASME Boiler and Pressure Vessel Code (BPVC).

(b) containers of noncircular cross section.

(c) containers with eccentric or side discharges or multiple discharge hoppers

(d) containers made from concrete, composite, thermoplastic, or nonmetallic materials. Acceptable metallic materials properties are given in Section 5. For materials not listed in Section 5, the mechanical properties from ASME BPVC, Section II, Part D shall be used.

(e) bulk solids containers used in transportation.

(f) containers that are integral parts of rotating or reciprocating mechanical devices where the primary design considerations and/or stresses are derived from the functional requirements of the device.

(g) containers whose primary function is the transport of material from one location to another within a system of which it is an integral part (e.g., piping, pneumatic, or other conveying systems).

(h) piping components such as the following:

(1) pipe, flanges, bolting, gaskets, valves, expansion joints, and fittings

(2) the pressure-containing parts of components such as strainers and devices that serve such purposes as mixing, separating, snubbing, distributing, and metering or controlling flow, provided that the pressure-containing parts of such components are generally recognized as piping components or accessories

(i) containers with an internal operating pressure exceeding 15 psig or subjected to an external pressure, including wind pressure, exceeding 1 psig (6.9 kPa).

(j) containers intended for human occupancy.

(k) containers where the principal cylindrical axis is not vertical.

(l) containers that contain substances declared lethal or highly toxic by the owner.

1-1.4 Bolted Containers Not Within Scope

Bolted metal containers storing agricultural products that satisfy all of the following criteria are not covered by this Standard:

(a) The container has a diameter less than or equal to 48 ft (14.6 m).

(b) The container has a cylindrical storage volume of less than 72,750 ft^3 (2 060 m^3).

(c) Complete cycling of the stored product in the container is less than three times annually.

(d) The container is isolated from public access or right of way.

(e) The manufacturer of the container provides a limited warranty on the container.

(f) The container is used only for the storage of owner-produced grain.

1-1.5 Pressure-Retaining Parts Within Scope

(a) Where external piping; other bulk solids containers; or mechanical devices such as pumps, mixers, or compressors are to be connected to the container, the applicability of this Standard shall terminate at the

(1) welded-end connection for the first circumferential joint for welded connections

(2) first threaded joint for screwed connections

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

(4) first sealing surface for proprietary connections or fittings

(b) Where non-product-containing or non-pressure-retaining parts are welded directly to either the internal or external product-containing or pressure-retaining surface of a container, this scope shall include the design, fabrication, testing, and material requirements established for non-product-containing or non-pressure-retaining part attachment by the applicable paragraphs of this Standard.

(c) The following are also within the scope of this Standard:

(1) product-containing or pressure-retaining covers for openings, such as manhole and hand hole covers

(2) the first sealing surface for proprietary fittings or components for which requirements are not provided by this Standard, such as gages, instruments, and nonmetallic components

1-1.6 Overpressure Protection

The scope of this Standard includes provisions for free air venting or pressure relief devices necessary to satisfy the requirements of this Standard.

1-1.7 Nondestructive Examination

All nondestructive examination (NDE) and associated acceptance standards beyond the requirements of this Standard shall be a matter of prior agreement between the manufacturer and owner or the owner's designated agent.

1-2 RESPONSIBILITIES

1-2.1 Owner's Responsibilities

The owner or the owner's designated agent shall establish the design requirements for bulk solids containers, considering factors associated with normal operation, conditions such as loading and unloading, and abnormal conditions that may become a governing design consideration. The owner or the owner's designated agent shall provide to the manufacturer a product container data sheet (see Nonmandatory Appendix B, Form B-1-1) that states all the design considerations for the container. Such considerations shall include but not be limited to the following:

(a) corrosion or abrasion allowances

(b) postweld heat treatment (PWHT) requirements beyond those of this Standard

(c) the applicable building code

(d) the characteristics of the stored product, including bulk density, particle size, flow characteristics, angle of repose, and other characteristics listed in part A of Form B-1-1

(e) the design operating conditions given in part B of Form B-1-1

1-2.2 Manufacturer's Responsibilities

The manufacturer of a bulk solids container, and any subcontractors used, shall comply with all applicable requirements of this Standard and shall ensure that all work done by others also complies.

1-3 FABRICATION METHODS

A bulk solids container may be designed and constructed using any combination of fabrication methods and material classes covered by this Standard, provided the requirements applying to each method and material are met.

1-4 ALTERNATIVE STRESS DESIGN BASIS

When the strength of any part cannot be computed, the design rules herein provide procedures for establishing the maximum allowable stress.

1-5 ITEMS NOT DESCRIBED

This Standard does not cover all details of design and construction. When complete details are not given, the manufacturer shall provide details of design and construction that meet or exceed the requirements of this Standard.

Section 2
References

The following is a list of publications referenced in this Standard. Unless otherwise specified, the latest edition shall apply.

29 CFR 1910.22. General Industry Standard. Code of Federal Regulations.
29 CFR 1910.106(b)(2)(v). Emergency Relief Venting. Code of Federal Regulations.
29 CFR 1910.272. Grain Handling Standard. Code of Federal Regulations.
29 CFR 1910.301. General Industry Standard, Subpart S. Code of Federal Regulations.
ACI 301. Specifications for Structural Concrete. American Concrete Institute.
ACI 318. Building Code Requirements for Structural Concrete and Commentary. American Concrete Institute.
AISC Steel Construction Manual. American Institute of Steel Construction.
ANSI/ASABE S433.1. Loads Exerted by Free-Flowing Grain on Bins. American National Standards Institute and American Society of Agricultural and Biological Engineers.
API Standard 650. Welded Steel Tanks for Oil Storage. American Petroleum Institute.
API Standard 2000. Venting Atmospheric and Low-Pressure Storage Tanks. American Petroleum Institute.
ASABE S412.2. Ladders, Cages, Walkways and Stairs. American Society of Agricultural and Biological Engineers.
ASCE-7. Minimum Design Loads and Associated Criteria for Buildings and Other Structures. American Society of Civil Engineers.
ASME B16.5. Pipe Flanges and Flanged Fittings: NPS ½ Through NPS 24, Metric/Inch Standard. The American Society of Mechanical Engineers.
ASME Boiler and Pressure Vessel Code, Section II. Materials. The American Society of Mechanical Engineers.
ASME Boiler and Pressure Vessel Code, Section III. Rules for Construction of Nuclear Facility Components. The American Society of Mechanical Engineers.
ASME Boiler and Pressure Vessel Code, Section V. Nondestructive Examination. The American Society of Mechanical Engineers.
ASME Boiler and Pressure Vessel Code, Section VIII, Division 1. Rules for Construction of Pressure Vessels. The American Society of Mechanical Engineers.
ASME Boiler and Pressure Vessel Code, Section IX. Welding, Brazing, and Fusing Qualifications. The American Society of Mechanical Engineers.
ASNT SNT-TC-1A. Personnnel Qualification and Certification in Nondestructive Testing. American Society for Nondestructive Testing.
ASTM 1226. Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts. American Society for Testing and Materials.
AWWA D102. Coating Steel Water-Storage Tanks. American Water Works Association.
AWWA D103. Factory-Coated Bolted Carbon Steel Tanks for Water Storage. American Water Works Association.
IBC 2009. International Building Code. International Code Council.
NFPA 68. Standard on Explosion Protection by Deflagration Venting. National Fire Protection Association.
NFPA 69. Standard on Explosion Prevention Systems. National Fire Protection Association.
NFPA 91. Standard for Exhaust Systems for Air Conveying of Materials. National Fire Protection Association.

Section 3
Definitions

3-1 GENERAL

Section 3 defines terms used in this Standard. In addition, some nomenclature and terminology used in the bulk solids industry and other ASME publications are defined.

3-2 DEFINITIONS FOR SECTION 5

bulk solid: a solid composed of many discrete and independent particles (also called *particulate solid*).

conical hopper: a hopper in which sloping sides converge towards a single point intended to produce axisymmetric (conical) flow of the solid.

container: a containment structure used to store particulate solids (e.g., silo, bunker, or bin).

cylindrical vertical-walled segment: the part of a container with vertical walls.

equivalent surface: level surface that contains the same volume of stored solid as the actual surface.

flat bottom: the internal base of a container that has an inclination greater than 85 deg to the vertical.

flow pattern: the form of flowing solid in the container when flow is well-established and the container is close to full.

fluidized solid: the state of a stored fine particulate solid when its bulk contains a high proportion of interstitial air (or other gas) and has a pressure gradient that supports the weight of the particles. The air may be introduced either by aeration or the filling process. A solid may be said to be partially fluidized when only part of the weight of particles is supported by the interstitial air pressure gradient.

free-flowing bulk solid: a bulk solid whose flowing behavior is not significantly affected by cohesion.

full condition: the condition in which the top surface of a stored solid is at the highest position possible under operating conditions. This is the assumed design condition for the container.

hopper: a container bottom with inclined walls.

normal pressure: force per unit area perpendicular to the wall of a container.

particulate solid: see *bulk solid*.

plane flow: a flow profile in a container with a slot outlet. The slot is parallel with two of the container walls, and its length is equal to the length of these walls.

pressure: force per unit area.

shallow hopper: any hopper not classified as either flat bottom or steep in which the full value of wall friction is not mobilized after filling the container.

shear stress: force per unit area acting on the wall of a container (vertical or inclined) in the direction of material movement (due to settlement or flow).

slenderness: the aspect ratio (height/diameter) of the vertical-walled segment of a container.

squat container: a container for which the aspect ratio (height/diameter) is greater than 0.4 but less than or equal to 1.0. However, if the container includes a hopper, it is considered squat if the aspect ratio is less than or equal to 0.4.

steep hopper: a hopper in which the full wall friction value is mobilized after filling the container.

transition: the intersection of the hopper and cylinder's vertical wall.

wedge hopper: a hopper in which the sloping sides converge in only one plane (with vertical ends) intended to produce plane flow in the stored solids.

3-3 DEFINITIONS FOR SECTION 6

butt weld: a weld placed in a groove between two abutting members. Grooves may be square, single, or double V-shaped, or single or double U-shaped.

double-welded butt joint: a joint between two abutting parts in approximately the same plane that is welded from both sides.

double-welded lap joint: a joint between two overlapping members in which the overlapping edges of both members are joined with fillet welds.

fillet weld: a weld of an approximately triangular cross section that joins two surfaces at approximately right angles, as in a lap or corner joint.

full-fillet weld: a fillet weld whose size is equal to the thickness of the thinner joined member.

roof, self-supported cone: a roof formed to approximate a right cone that is supported only at its periphery, without internal rafters or trusses.

roof, self-supporting dome: a roof formed to an approximate spherical surface that is supported only at its periphery, without internal rafters or trusses.

roof, self-supporting umbrella: a modified dome roof formed so that all horizontal sections are regular polygons with as many sides as there are roof plates. Each roof plate is rolled to a curved radius. The self-supporting umbrella roof is supported only at its periphery, without internal rafters or trusses.

roof, supported cone: a roof formed to approximate a right cone, where the roof plate rests on rafters arranged in a radial pattern. One end of the rafter is supported by the container shell, the other by a center ring. Rafters may be cold-formed shapes, rolled shapes, open web joists, or trusses. For small-diameter containers, integral parts of the roof sheet may be formed by flanging a radial edge of the sheet.

NOTE: See Figure 6-8.2.3-1, illustrations (c) and (d) for examples of typical roof-to-shell details.

single-welded butt joint with backing: a joint between two abutting parts welded from only one side using a strip bar or another suitable backing material.

single-welded lap joint: a joint between two overlapping members in which the overlapping edge of one member is welded with a fillet weld.

tack weld: a weld made to hold the parts of a weldment in proper alignment until the final weld can be made.

3-4 NOMENCLATURE

Symbols are defined within the paragraph in which they are used. If a symbol is used across paragraphs, reference is given to the paragraph in which it was originally defined.

Section 4
Materials

4-1 GENERAL

All materials to be incorporated into any container designed to meet the provisions of this Standard shall be new, with no visible damage or imperfections, and shall comply with all requirements of this Standard.

Certified materials are those listed by specification number in this Standard and may be used for fabrication of bulk solids containers.

Noncertified materials may be used if they are tested and found to comply with all physical, dimensional, and chemical requirements of materials that are acceptable for use under this Standard. A report showing the test results shall be provided when mill test reports are specified. The material certification may also use some alternate method if agreed to by the purchaser and material supplier. Material grades are given by ASME numbers, when available, which are generally interchangeable with ASTM numbers. Whenever ASME numbers are not available, the ASTM numbers are given.

This Standard also includes the Canadian Standards Association (CSA) nomenclature for Canadian grades of steel.

4-2 PLATES AND SHEETS

(a) General. Plate and sheet material furnished under this Standard shall conform to the applicable requirements of ASTM SA6/SA6M or ASTM A480/A480M.

(b) Carbon Steel Plates and Sheets. Carbon steel plate and sheet materials shall be open-hearth, electric-furnace, or basic-oxygen-process steel conforming to the specifications listed in Table 4-2-1. Plates and sheets may be provided by weight basis, with underrun permitted as specified in ASME SA-6/SA-6M or ASTM A924. For sheets ordered to weight as specified in ASME SA-568, no underrun is permitted.

(c) Stainless Steel Plates and Sheets. Stainless steel plate and sheet materials shall be made by any process that complies with ASME SA-240. If a specific type of melting is required by the purchaser, it shall be specified on the purchase order. ASME SA-240 covers chromium, chromium nickel, and chromium–manganese–nickel stainless steel; plate, sheet, and strip for pressure vessels; and general applications. Acceptable grades of stainless steel plate are listed in Table 4-2-1.

4-3 STRUCTURAL SHAPES

(a) Hot-Rolled Shapes. Hot-rolled carbon steel structural shapes for use under this Standard shall conform to the general requirements of ASME SA-6/SA-6M and the specifications for either ASME SA-36; ASTM A572, Grade 50; or ASTM A992.

(b) Tubular Shapes. Tubular steel structural shapes may be used for columns and other structural components. Carbon steel tubular structural members shall comply with one of the following specifications:

(1) Cold-formed square and rectangular carbon steel structural tubing shall comply with ASME SA-500.

(2) Hot-formed square and rectangular carbon steel tubing shall comply with ASME SA-501.

(c) Structural Tubing. Structural tubing with a circular cross section may be manufactured from plates conforming to any of the specifications permitted by subsection 4-4, provided the welding and other manufacturing processes comply with all sections of this Standard.

(d) Pipe. Carbon steel pipe may be used as tubular structural members provided it complies with ASME SA-139, Grade B; ASME SA-53, Type E or Type S, Grade B; ASME SA-106, Grade B; or API Spec 5L, Grade B.

(e) Stainless Steel Shapes. Stainless steel shapes shall conform to the material grades for plates listed under Table 4-2-1.

(f) Rods and Bars. Rods and bars used as cross-bracing or other miscellaneous components shall be from AISI 1010, AISI 1018, or AISI 1020. This type of rod and bar shall not be used for primary structural members.

4-4 CASTINGS AND FORGINGS

(a) Castings. Iron castings shall conform to ASME SA-48, Class 30. Steel castings shall conform to ASME SA-216, Grade WCB. ASTM A27/A27M Grades 35 through 65 are also acceptable.

(b) Forgings

(1) Forgings from plate and sheet materials shall conform to the plate and sheet materials permitted under subsection 4-2.

(2) Forgings from other than plate or sheet materials shall conform to ASME SA-668, Class E.

(c) Flanges. Carbon steel forged and rolled pipe flanges shall conform to ASME SA-181, Class 60; ASME SA-105; or materials listed in ASME B16.5.

4-5 FASTENERS AND ANCHOR RODS

(a) Table 4-5-1 lists fasteners recommended for use on bulk solids containers. Fasteners other than that listed may be used under agreement by both the fabricator and end user.

(b) Hot-dip galvanizing of fasteners shall conform to ASTM A153, Class C. Mechanical galvanizing of fasteners shall conform to ASTM B695, Class 50. Mechanical galvanizing is permitted for ASTM F3125, Grade A325; SAE J429, Grades 2, 5, 8, and 8.2; and SAE J995, Grade 8 fasteners, provided proper procedures are followed to prevent or eliminate hydrogen embrittlement. ASTM F835; ASTM F3125, Grade A490; SAE J429, Grade 8 or Grade 8.2; and SAE J995, Grade 8 high-strength fasteners shall not be hot-dip galvanized.

ASTM F3125, Grade A490 fasteners may be coated using only the permitted coatings in the provisions of ASTM F3125.

4-6 WELDING MATERIAL

Manual, shielded-metal, and arc-welding electrodes shall conform to applicable American Welding Society (AWS) or ASME BPVC, Section IX specifications for filler metal.

4-7 GASKETS AND SEALANTS

The container manufacturer shall use gaskets, sealants, or a combination of both in accordance with the following requirements:

(a) Gaskets

(1) When selecting gaskets, the manufacturer shall consider the operating parameters for the storage container, including but not limited to temperature, pressure, chemical compatibility, and purity of contents.

(2) Gasket material shall be of adequate compressive strength and resilience to obtain a leak-proof seal at all seams and joints.

(3) Gaskets constructed from elastomeric or polymer materials shall be resistant to weather, ozone, ultraviolet light, or other environmental conditions to which the container shall be exposed during operation. They shall not lose seal integrity due to local conditions, and they shall meet the physical requirements listed in Table 4-7-1.

(4) Gasket materials shall be compatible with container contents and not degrade or otherwise negatively impact product purity.

(b) Sealants

(1) Sealing material shall be generally flexible and capable of filling voids or irregular surfaces at joints where it is intended to be used.

(2) Sealing materials shall be selected for proper bonding to the surfaces being sealed.

(3) Sealants shall be suitable for the specified service conditions, including the following minimum considerations:

(-a) Resistance to Temperature. The sealant shall remain flexible when in continuous operation over a temperature range of -40°F to 170°F (-40°C to 77°C).

(-b) Weatherability

(-1) The sealant shall be resistant to hardening and cracking.

(-2) The sealant shall be essentially solid and contain no plasticizers or extenders that could cause shrinkage due to weathering.

(-3) The sealant shall be resistant to ozone and ultraviolet light.

(-4) The selected sealant shall be suitable for the anticipated chemical properties of the contents to be stored in the container and the external environment surrounding the container.

(c) Alternate Materials. Gasket and sealing materials meeting criteria other than those stated in (a) and (b) may be used by agreement between the fabricator and the end user.

4-8 CLADDING

Subject to agreement between the fabricator and end user, internal cladding may be used in a container for storage of bulk solids but only for corrosion and/or erosion protection or as a liner of the base structural wall. The thickness of the cladding shall not be included in the design thickness of the container's structural wall. The liner should be formed to fit the contours of the supporting hopper, where a hopper is present.

Such cladding shall only be fabricated from materials listed in Table 4-2-1 or from material meeting the requirements of ASME BPVC, Section II.

While cladding is allowed if agreed upon by the fabricator and end user, note this requires careful planning, the advice of experts, strict adherence to industry standards, or a combination of these stated methods. Weld overlay, hardfacing, or internal liners are also allowed. Refer to Nonmandatory Appendix A for further information.

Table 4-2-1
Materials

Material Specification	Grade	Thickness, *t*, Limits, in. (mm)	Minimum Yield Stress, ksi (MPa)	Minimum Tensile Stress, ksi (MPa)
ASME SA-36	...	...	36 (248)	58 (400)
ASME SA-240	304L	...	25 (172)	70 (483)
	304	...	30 (207)	75 (517)
	316L	...	25 (172)	70 (483)
	316 [Notes (1), (2)]	...	30 (207)	75 (517)
ASME SA-283	C	...	30 (207)	55 (379)
	D	...	33 (228)	60 (414)
ASME SA-285	C	...	30 (208)	55 (379)
ASME SA-516	55	≤8 (≤200)	30 (208)	55 (379)
	60	≤4 (≤100)	32 (221)	60 (414)
	65	≤4 (≤100)	35 (241)	65 (448)
	70	≤4 (≤100)	38 (262)	70 (483)
ASME-SA-572	42	≤6 (≤150)	42 (290)	60 (414)
	50	≤4 (≤100)	50 (345)	65 (448)
	55	≤2 (≤50)	55 (379)	70 (483)
	60 [Note (1)]	≤1$\frac{1}{2}$ (≤38)	60 (414)	75 (517)
	65 [Note (1)]	≤1$\frac{1}{2}$ (≤38)	65 (448)	80 (552)
ASME SA-573	58	≤1$\frac{1}{4}$ (≤32)	32 (221)	58 (400)
	65	≤1$\frac{1}{4}$ (≤32)	35 (241)	65 (448)
	70	≤1$\frac{1}{4}$ (≤32)	42 (290)	70 (483)
ASME SA-1011 [Note (3)]	30	...	30 (208)	49 (338)
	30	...	30 (208)	49 (338)
	33	...	33 (208)	52 (359)
	36	...	36 (248)	53 (365)
	40	...	40 (276)	55 (379)
	45	...	45 (310)	60 (414)
	50	...	50 (345)	65 (448)
	55	...	55 (379)	70 (483)
	60	...	60 (414)	75 (517)
	80 [Notes (1), (4)]	...	80 (552)	95 (655)
ASTM A653/A653M	33 [Note (5)]	...	33 (228)	45 (310)
	37 [Note (5)]	...	37 (255)	52 (359)
	40 [Note (5)]	...	40 (276)	55 (379)
	50 [Note (5)]	...	50 (345)	See notes
	40 [Note (6)]	...	40 (276)	50 (345)
	50 [Note (6)]	...	50 (345)	60 (414)
	55 [Note (6)]	...	55 (379)	70 (483)
ASTM A992	...	...	50 (345)	65 (448)

Table 4-2-1
Materials (Cont'd)

Material Specification	Grade	Thickness, *t*, Limits, in. (mm)	Minimum Yield Stress, ksi (MPa)	Minimum Tensile Stress, ksi (MPa)
CSA G40.21 [Note (2)]	38W [Notes (7)–(9)]	...	38 (262)	60 (414)
	38WT [Notes (7)–(9)]	...	38 (262)	60 (414)
	44W [Notes (7)–(10)]	...	44 (303)	65 (448)
	44WT [Notes (7)–(10)]	...	44 (303)	65 (448)
	50W [Notes (7)–(9), (11)]	...	50 (345)	65 (448)
	50WT [Note (5)]	≤2½ (≤64)	50 (345)	70 (483)
	50WT [Note (5)]	>2½ to ≤4 (>64 to ≤100)	46 (317)	70 (483)

NOTES:
(1) Caution is required when specifying this material for welded application. The fabricator shall provide weld procedures and qualification records to verify material properties in welds and heat-affected zones shall be comparable to the properties of the parent material.
(2) The W grades may be semi-killed or fully killed.
(3) Materials conforming to ASTM A1011 with a CS, DS, or UHSS designation shall not be used.
(4) No grade, type, or class material shall be used for which the ratio of published minimum yield strength to published minimum tensile strength exceeds 0.85.
(5) ASTM A653/A653M-listed grades are SS. Grade 50 shall be Class 1, Class 3, or Class 4 with tensile strength of 65 ksi (448 MPa), 70 ksi (483 MPa), or 60 ksi (414 MPa), respectively. All galvanizing shall comply with ASTM A924/A924M.
(6) ASTM A653-listed grades are HSLAS or HSLAS-F. Grade 50 shall be Class 1. All galvanizing shall comply with ASTM A924/A924M.
(7) Fully killed steel made to fine-grain practice shall be specified when required by the container designer.
(8) Elements added for grain refining or strengthening shall be restricted in accordance with Table 4-7-1.
(9) Plates shall have tensile strengths that are not more than 20 ksi (140 MPa) above the minimum strength specified for the grade.
(10) Grades 260W (38W) and 300W (44W) are acceptable for plate to a maximum thickness of 1 in. (25 mm) if semi-killed and 1½ in. (40 mm) if fully killed and made to fine-grain practice.
(11) Grade 350W (50W) is acceptable for plate to a maximum thickness of 1¾ in. (45 mm) and 4 in. (100 mm) if fully killed and made to fine-grain practice.

Table 4-5-1
Fastener Materials

Material Specification	Grade	Diameter, *d*, Limits, in. (mm)	Minimum Yield Stress, ksi (MPa)	Minimum Tensile Stress, ksi (MPa)
		Bolts		
API 12B	...	...	...	...
ASME SA-307	...	...	...	60 (414)
ASME SA-490/SA-490M	...	≥0.5 to ≤1 (≥12 to ≤25)	92 (634)	150 (1 034)
	...	>1 to ≤1.5 (>25 to ≤38)	81 (558)	150 (1 034)
ASME SA-193/SA-193M	Class 1	≤4 (≤100)	30 (207)	75 (517)
	B5	≤4 (≤100)	80 (552)	100 (690)
	B6	≤4 (≤100)	85 (586)	110 (758)
	B7	≤2.5 (≤64)	105 (724)	125 (862)
	B7	>2.5 to ≤4 (>64 to ≤100)	95 (655)	115 (793)
	B8	≤0.75 (≤19)	100 (690)	125 (862)
	B8	>0.75 to ≤1 (>19 to ≤25)	80 (552)	115 (793)
	B16	≤2.5 (≤64)	105 (724)	125 (862)
	B16	>2.5 to ≤4 (>64 to ≤100)	95 (655)	110 (758)
SAE J429	2	≥0.25 to ≤0.75 (≥6 to ≤19)	...	74 (510)
	2	>0.75 (>19)	...	60 (414)
	5	≥0.25 to ≤1 (≥6 to ≤25)	85 (586)	120 (827)
	5	>1.5 (>38)	74 (510)	105 (724)
	8	≥0.25 to ≤1.5 (≥6 to ≤38)	120 (827)	150 (1 034)
	8.2	≥0.25 to ≤1.5 (≥6 to ≤38)	120 (827)	150 (1 034)
ASTM A354	BD	≥0.25 to ≤4 (≥6 to ≤101)	130 (896)	150 (1 034)
ASTM A449	Type 1	≥0.25 to ≤1 (≥6 to ≤25)	92 (634)	120 (827)
		≥1.125 to ≤1.5 (≥6 to ≤25)	81 (558)	105 (724)
		>1.5 to ≤3 (>38 to ≤76)	58 (400)	90 (620)
ASTM F3125/F3125M	A325	≥0.5 to ≤1.5 (≥12 to ≤38)	92 (634)	120 (827)
	A490	≥0.5 to ≤1.5 (≥12 to ≤38)	130 (896)	150 (1 034)
ISO 898-1	10.9	≥0.25 to ≤1.5 (≥6 to ≤39)	120 (827)	150 (1 034)
		Nuts [Note (1)]		
API 12B	...	...	...	...
ASME SA-194	H	...	...	...
ASME SA-563/SA-563M	...	...	...	...
SAE J995	2, 5, 8	...	...	...
ISO 898-2	8, 10	...	...	...
		Anchor Rods		
ASTM 36	...	...	36 (248)	58 (400)
ASTM F1554	36	...	36 (248)	58 (400)
			55 (379)	75 (517)
		Socket Button or Countersunk Head Cap Screws		
ASTM F835	...	...	...	...

Table 4-5-1
Fastener Materials (Cont'd)

Material Specification	Grade	Diameter, *d*, Limits, in. (mm)	Minimum Yield Stress, ksi (MPa)	Minimum Tensile Stress, ksi (MPa)
Washers [Note (1)]				
ASTM F436	...	...	...	...
ASTM F844	...	...	...	...
Direction Tension Indicators				
ASTM F959	...	...	[Note (2)]	[Note (2)]

NOTES:
(1) Nuts and washers do not have stress values stated herein as they are intended to be matched to the bolt material.
(2) Refer to ASME SA-325 for the stress values for ASTM F959, Type 325 and to ASME SA-490 for the stress values for ASTM F959, Type 490.

Table 4-7-1
Physical Requirements for Gasket Material

Property	Requirement	Standard
Minimum tensile strength		
Initial	1,200 psi (8.3 MPa)	ASTM D412
After oven aging, as percentage of initial	70%	ASTM D573
After immersion in distilled water, as percentage of initial	60%	ASTM D471
Ultimate elongation		
Minimum value as percentage of initial length	175%	ASTM D412
After oven aging, as percentage of initial	70%	ASTM D573
Hardness		
Shore A value	75 ± 5	ASTM D2240
Change in Shore A value, after oven aging	7	ASTM D573
Compression		
Maximum percentage of original thickness, after oven aging	40%	ASTM D395
At low temperature, as maximum percentage of original	60%	ASTM D1229
Tear strength	160 lb/in. (28 kN/m)	...

Section 5
Loadings Imposed by Bulk Solids

5-1 INTRODUCTION

This Section covers the requirements for the minimum loading conditions to be used for the design of bulk solids storage containers covered by this Standard. Dead loads, live loads, and loads resulting from wind, snow, and seismic reactions shall be considered. Stored material shall be considered in container design, and the load reactions used for stored material shall be determined using the methods and requirements of this Section. The scope of this Standard covers only those material loading conditions that result in hoop tension and vertical compression in the container wall. Other loading conditions may exist, such as nonuniform loading due to eccentric filling or eccentric discharge due to outlets that do not align with the container symmetry axis. The resulting nonuniform loads will result in shell bending, which is beyond the scope of this Standard. The designer of the bulk solids storage container shall be responsible for recognizing when such conditions exist and shall not use this Standard to design containers subject to these conditions.

5-1.1 Geometrical Limitations

The following geometrical limitations apply to the design requirements for containers:

(a) The container shapes are limited to a cylindrical section that is circular in cross section and a converging hopper portion beneath the cylinder that is either a plane flow wedge (with vertical end walls) or a right circular cone. The geometry of the container shall be symmetrical.

(b) The following dimensional limitations apply (see Figure 5-1.1-1):

(1) $h_b/d_c < 10$

(2) $h_c/d_c < 5$

(3) $h_b < 300$ ft (90 m)

(4) $d_c < 200$ ft (60 m)

where

d_c = diameter of the container, ft (m)

h_c = height of vertical wall of the container, ft (m)

h_b = height from the discharge opening to the equivalent surface, ft (m)

(c) The cylinder–hopper transition lies in a single horizontal plane (see Figure 5-1.1-1).

(d) The container does not contain an internal structure.

5-1.2 Limitations on Stored Solids

The following limitations on the stored solids apply to the design rules for containers:

(a) Each container shall be designed for a defined range of bulk solids properties.

(b) The stored bulk solid shall be free flowing.

(c) Loads due to thermal effects are ignored.

5-1.3 Limitations on Filling and Discharge Arrangements

The following limitations on the filling and discharge arrangements apply to the design rules for containers:

(a) Filling and discharge are on the container symmetry axis.

(b) Filling involves only negligible inertia effects and impact loads.

(c) When a discharge device is used, the solids flow out of the container shall be uniform and symmetric.

(d) Dynamic loads due to falling bulk solids impact are not to be considered during container design.

5-1.4 Designs That Are Out of Scope

(a) The design of containers for reliable solids discharge is outside the scope of this Standard.

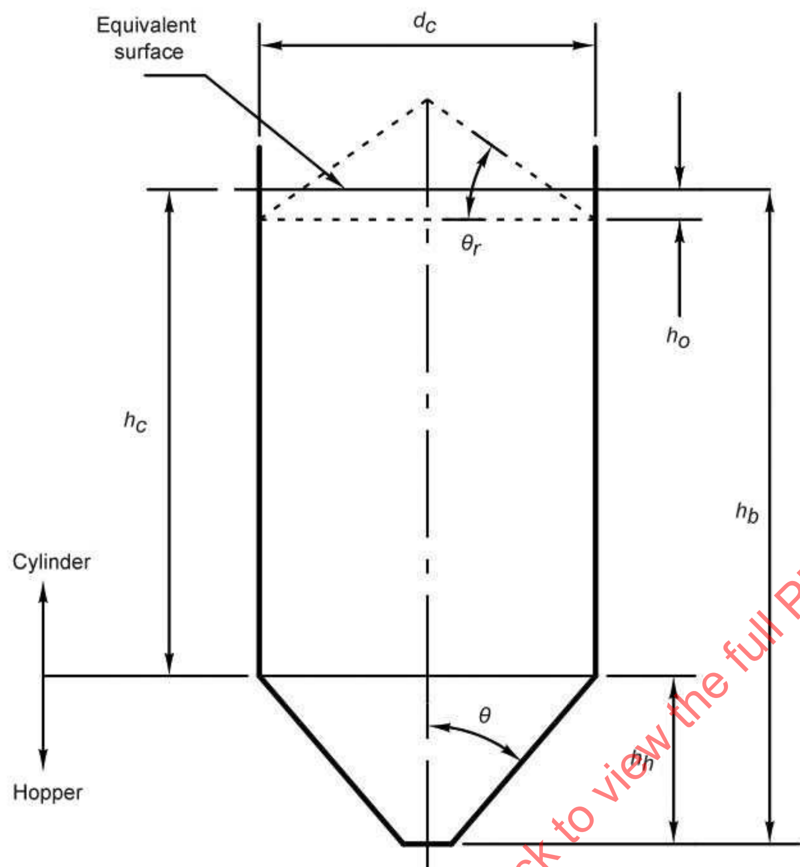
(b) The design of containers capable of withstanding quaking, shocks, honking, and pounding is outside the scope of this Standard. These phenomena are not well understood, so the use of this Standard does not guarantee that they will not occur or that the container will be adequate to resist them.

5-2 CALCULATING LOADINGS IMPOSED BY BULK SOLIDS

5-2.1 General

(a) The term "normal pressure" is used to denote a bulk solids load acting normal (i.e., perpendicular) to a container wall. It is an averaged effect due to the large number of individual particle contacts. Shear stresses act on the wall in the direction of material movement (due to settlement or flow) associated with the normal pressure. When the friction is fully mobilized, the shear stress is related to the normal pressure by the

Figure 5-1.1-1
Container Geometry Definitions



friction coefficient, μ. Smaller values of shear stress may still occur even when the friction is not fully mobilized.

(b) The normal pressures and shear stresses defined in this Standard are characteristic values for structural design, with the worst-case loads being selected by the designer as appropriate.

(c) Container geometries are divided into four categories based on the cylinder height-to-diameter ratio, h_c/d_c (see Figure 5-1.1-1), as shown in Table 5-2.1-1.

Table 5-2.1-1
Slenderness Category

Category	Slenderness Ratio, h_c/d_c
Slender	>2.0 to ≤5.0
Intermediate slenderness	>1.0 to ≤2.0
Squat	>0.4 to ≤1.0
	≤0.4, plus hopper
Retaining	≤0.4, flat bottom, i.e., no hopper

(d) The equations presented in this section are applicable for both U.S. Customary and SI units, provided consistent units are used.

5-2.2 Flow Patterns

Loads imposed on the container walls by the bulk solid are a function of the flow pattern that develops in the container and properties of the solid. The flow pattern also affects whether flow through a container will be reliable and meet the process requirements. Two primary flow patterns exist: funnel and mass flows. The characteristics of each are given in Nonmandatory Appendix A.

5-2.3 Design Classes

(a) The method used to determine the solids-imposed loads on a container is a function of the container's design class. Design classes are defined as follows:

Design Class	Description
1	Containers with capacity below 100 t (90 metric tonne)
2	All containers covered by this Standard that are not in Class 1

(b) A container with a capacity of less than 100 t may be treated as a design Class 2 container, with the more rigorous design Class 2 procedures applied.

5-2.4 Bulk Solids Properties

(a) Ranges of values of bulk solids properties to be used for loading calculations are the responsibility of the end user and shall be measured at expected handling conditions or obtained from other relevant data. Values must be interpreted appropriately for the load condition under consideration.

(b) Values of properties of well-known bulk solids are given in Nonmandatory Appendix D and may be used in lieu of those determined in (a) per agreement of all parties. Where the stored bulk solid cannot be clearly identified as similar to one of the descriptors in Nonmandatory Appendix B, the properties shall be determined as in (a).

(c) The upper characteristic bulk density, γ_u, shall be used in all calculations. This value shall be calculated at a pressure level corresponding to the maximum vertical pressure in the container.

(d) To determine the characteristic value of the lateral pressure ratio in a vertical walled container, K; the coefficient of wall friction, μ; and the effective angle of internal friction, δ, their mean values K_m, μ_m, and δ_m shall be multiplied and divided by appropriate modification factors. The following combinations shall be used:

$$K_u = K_m a_k \tag{5-1}$$

$$K_l = K_m / a_k \tag{5-2}$$

$$\mu_u = \mu_m a_\mu \tag{5-3}$$

$$\mu_l = \mu_m / a_\mu \tag{5-4}$$

$$\delta_u = \delta_m a_\delta \tag{5-5}$$

$$\delta_l = \delta_m / a_\delta \tag{5-6}$$

where

a_k, a_μ, a_δ = modification factors (The modification factors shall not be taken as less than 1.1, unless a smaller value can be justified by measurements of bulk solid properties.)
K_l = lower characteristic value of K
K_u = upper characteristic value of K
δ_l = lower characteristic value of δ
δ_u = upper characteristic value of δ
μ_l = lower characteristic value of μ
μ_u = upper characteristic value of μ

(1) If upper and lower characteristic values can be justified by measurement or other means, they may be used instead of the values noted in eqs. (5-1) through (5-6).

(2) In the absence of other information, a mean lateral pressure ratio in a vertical-walled container, K_m, of 0.45 may be used. A modification factor, a_k, of 1.2 shall be used for this case.

(3) For containers in design Class 1, the mean values of K_m, μ_m, and δ_m may be used for design in place of the range of values associated with the upper and lower characteristic values.

(4) Table 5-2.4-1 indicates which values shall be adopted for each of four typical load cases in design Class 2.

5-2.5 Calculation Procedure

(a) When determining loads, the designer shall assume that the bulk solid storage container is full.

(b) Loads on containers shall be expressed in terms of horizontal pressure, p_h, on the inner surface of the cylinder wall; normal pressure, p_n, on an inclined hopper wall; corresponding shear stresses on the walls, p_w and p_t, respectively; and vertical pressure, p_v, in the stored bulk solid.

(c) The design shall address the principal load cases that lead to different limit states for the container. These conditions include

(1) maximum normal pressure on the container's vertical wall

(2) maximum vertical shear stresses (traction) on the container's vertical wall

(3) the maximum load on the container's hopper

(d) The maximum loads shall be calculated using (c) in combination with the values for bulk solids properties defined in para. 5-2.4.

(e) The following procedure shall be used to determine the loads imposed on a container by bulk solids:

Step 1. Determine the container slenderness ratio (see para. 5-2.1).

Step 2. Obtain the flow properties of the bulk solids from the end user.

Step 3. Determine the design class (see para. 5-2.3).

Table 5-2.4-1
Values of Bulk Solid Properties to Be Used for Load Case for Design Class 2 Containers

Load Case	Application	Property Value to Be Used		
		Wall Friction Coefficient, μ	Lateral Pressure Ratio, K	Effective Angle of Internal Friction, δ
For the Cylinder Wall				
1	Maximum normal pressure on cylinder wall	Lower	Upper	N/A
2	Maximum frictional pressure on cylinder wall	Upper	Upper	N/A
3 and 4	Maximum vertical load on hopper	Lower	Lower	N/A
For the Hopper Wall				
3	Maximum hopper pressure for funnel flow or initial filling in mass flow	Lower value for hopper	N/A	N/A
4	Maximum hopper pressure for mass flow	Lower value for hopper	N/A	Upper

Step 4. Calculate the loads imposed by the bulk solids (see para. 5-2.6).

5-2.6 Design Loads

5-2.6.1 Loads on Vertical Container Walls

5-2.6.1.1 Slender Containers

(a) The symmetrical load on slender containers (see Figure 5-2.6.1.1-1) shall be calculated by eqs. (5-7) through (5-9).

(b) The values of normal pressure, $p_{he}(z)$; shear stress, $p_{we}(z)$; and vertical pressure, $p_{ve}(z)$, at any depth, z, in a vertical-walled cylinder segment shall be determined as follows:

$$p_{he}(z) = C_h p_{ho} Y_J(z) \tag{5-7}$$

$$p_{we}(z) = C_w \mu p_{ho} Y_J(z) \tag{5-8}$$

$$p_{ve}(z) = \frac{p_{ho} Y_J(z)}{K} \tag{5-9}$$

where

C_h = discharge factor for horizontal pressure
= 1.0 for containers in both design classes that are unloaded from the top (no flow within the stored solid)
= 1.15 for slender containers in design Class 2
= 2.0 for slender containers in design Class 1, where the mean value of the material properties K_m and μ_m has been used for design

C_w = discharge factor for wall frictional pressure
= 1.0 for containers in both design classes that are unloaded from the top (no flow within the stored solid)
= 1.10 for slender containers in design Class 2
= 1.40 for slender containers in design Class 1, where the mean values of the material properties, K_m and μ_m, have been used for design

h_o = value of z at the highest solid-to-wall contact point (see Figure 5-2.6.1.1-1) (This is the height of the equivalent cylinder of the cone of bulk material at the angle of repose.)
= $\frac{d_c}{6}\tan\theta_r$
  d_c = diameter of the container
  θ_r = angle of repose of the solid

K = characteristic value of the lateral pressure ratio for containers in design Class 2; see Table 5-2.4-1 for the appropriate value for the condition examined (The mean value, K_m, may be used for containers in design Class 1.)

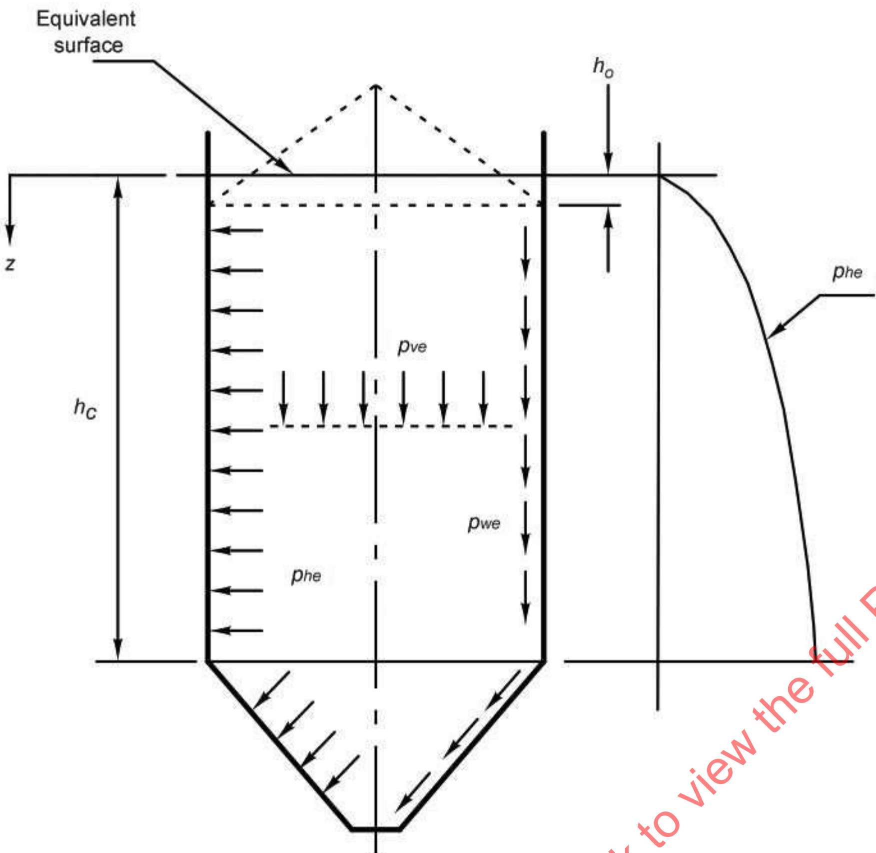
p_{ho} = normal pressure prior to application of discharge factor
= $\gamma_u K z_o$
  A = cross-sectional area of vertical-walled cylinder segment
  U = internal perimeter of vertical-walled cylinder segment
  z_o = Janssen characteristic depth
  = $\frac{1}{K\mu}\frac{A}{U}$
  γ_u = upper characteristic value of bulk density

$Y_J(z)$ = Janssen pressure depth variation function
= $1 - e^{-z/z_o}$

z = depth below equivalent surface (see Figure 5-2.6.1.1-1)

μ = characteristic value of the wall friction coefficient for containers in design Class 2; see Table 5-2.4-1 for the appropriate value for the load condition examined (The mean value, μ_m, may be used for containers in design Class 1.)

Figure 5-2.6.1.1-1
Symmetrical Pressures in the Cylinder Segment



(c) The resulting characteristic value of the vertical compressive force in the wall resulting from the traction force of the bulk solid, n_{zSk}, per unit length of the perimeter at any depth, z, shall be determined as follows:

$$n_{zSk} = \int_0^z p_{we}(z)dz = C_w \mu p_{ho}[z - z_o Y_J(z)] \quad (5\text{-}10)$$

(d) For containers in design Class 2, a uniform increase in the symmetrical load of eqs. (5-7) and (5-8) shall be included to account for accidental asymmetries in the filling and discharge processes. The resulting horizontal normal pressure, $p_{he,u}(z)$, and shear stress, $p_{we,u}(z)$, are as follows:

$$p_{he,u}(z) = p_{he}(z)(1 + 0.5C_{pe}) \quad (5\text{-}11)$$

$$p_{we,u}(z) = p_{we}(z)(1 + C_{pe}) \quad (5\text{-}12)$$

where

C_{pe} = load magnification factor
= $0.21(1 - e^{-1.5[(h_c/d_c) - 1]})$

5-2.6.1.2 Squat and Intermediate Slenderness Containers

(a) The symmetrical design load shall be calculated by eqs. (5-13) through (5-15).

(b) The values of normal pressure, $p_{he}(z)$; shear stress, $p_{we}(z)$; and vertical pressure, $p_{ve}(z)$, at any depth, z, in a vertical-walled cylinder segment shall be determined as follows:

$$p_{he}(z) = C_h p_{ho} Y_R(z) \quad (5\text{-}13)$$

$$p_{we}(z) = C_w \mu p_{ho} Y_R(z) \quad (5\text{-}14)$$

$$p_{ve}(z) = \gamma_u z_v \quad (5\text{-}15)$$

where

C_h = discharge factor for horizontal pressure
= 1.0 for containers in both design classes that are unloaded from the top (i.e., no flow within the stored solid)
= 1.0 for squat container in both design classes
= 1.0 + 0.15C_s for intermediate containers in design Class 2

C_s = slenderness adjustment factor
= h_c/d_c − 1.0, where h_c and d_c are as defined in para. 5-1.1(b)
= 2.0 for intermediate containers in design Class 1, where the mean values of the material properties, K_m and μ_m, have been used for design

C_w = discharge factor for wall frictional traction
= 1.0 for containers in both design classes that are unloaded from the top (i.e., no flow within the stored solid)
= 1.0 for squat container in both design classes
= 1.0 + 0.1C_s for intermediate containers in design Class 2
= 1.40 for intermediate containers in design Class 1, where the mean values of the material properties, K_m and μ_m, have been used for design

p_{ho} = normal pressure prior to application of discharge factor
= $\gamma_u K z_o$

- A = cross-sectional area of vertical-walled cylinder segment
- K = characteristic value of the lateral pressure ratio for containers in design Class 2 (See Table 5-2.4-1 for the appropriate value for the condition examined. The mean value, K_m, may be used for containers in design Class 1.)
- U = internal perimeter of vertical-walled cylinder segment
- z_o = Janssen characteristic depth = $\frac{1}{K\mu} \times \frac{A}{U}$

$Y_R(z)$ = squat silo pressure depth variation function
= $\left\{1 - \left[\left(\frac{z - h_o}{z_o - h_o}\right) + 1\right]^n\right\}$

- d_c = diameter of the container
- h_o = depth below the equivalent surface of the base of the top pile = $\frac{d_c}{6}\tan\theta_r$
- n = power relationship = $-(1 + \tan\theta_r)(1 - h_o/z_o)$
- θ_r = angle of repose of the solid

z = depth below equivalent surface (see Figure 5-2.6.1.2-1), defined as ≥h_o

z_v = depth measure used for vertical stress assessment in squat silos
= $h_o - \frac{1}{(n+1)}\left(z_o - h_o - \frac{(z + z_o - 2h_o)^{n+1}}{(z_o - h_o)^n}\right)$

γ_u = upper characteristic value of bulk density

μ = characteristic value of the wall friction coefficient for containers in design Class 2 (See Table 5-2.4-1 for the appropriate value for the load condition examined. The mean value, μ_m, may be used for containers in design Class 1.)

(c) The resulting characteristic value of the vertical compressive force in the wall resulting from the traction force of the bulk solid, n_{zSk}, per unit length of perimeter at any depth, z, shall be determined as follows:

$$n_{zSk} = \int_0^z p_{we}(z)dz = C_w \mu p_{ho}(z - z_v) \quad (5\text{-}16)$$

(d) For containers in design Class 2, a uniform increase in the symmetrical load of eqs. (5-13) and (5-14) shall be included to account for accidental asymmetries in the filling and discharge processes. The resulting horizontal normal pressure, $p_{he,u}(z)$, and shear stress, $p_{we,u}(z)$, are as follows:

$$p_{he,u}(z) = p_{he}(z)(1 + 0.5C_{pe}) \quad (5\text{-}17)$$

$$p_{we,u}(z) = p_{we}(z)(1 + C_{pe}) \quad (5\text{-}18)$$

where

C_{pe} = $0.21(1 - e^{-1.5[(h_c/d_c) - 1]})$ for $h_c/d_c > 1.2$
= larger of $0.14(h_c/d_c) - 1$ or 0 for $h_c/d_c \le 1.2$

5-2.6.1.3 Retaining Containers

(a) The normal pressure, $p_{he}(z)$, on a vertical wall at any depth, z_s, below the highest point at which the solid contacts the wall (see Figure 5-2.6.1.3-1) shall be determined as follows:

$$p_{he}(z) = \gamma_u K(1 + \sin\theta_r)z_S \quad (5\text{-}19)$$

where K, γ_u, and θ_r are as defined in para. 5-2.6.1.2(b).

(b) The characteristic value of the resulting compressive vertical force resulting from the traction force of the bulk solid, n_{zSk}, in the wall per unit length of container circumference at any depth, z_s, below the highest point of solid-to-wall contact shall be determined as follows:

Figure 5-2.6.1.2-1
Pressures in a Squat or Intermediate Slenderness Container

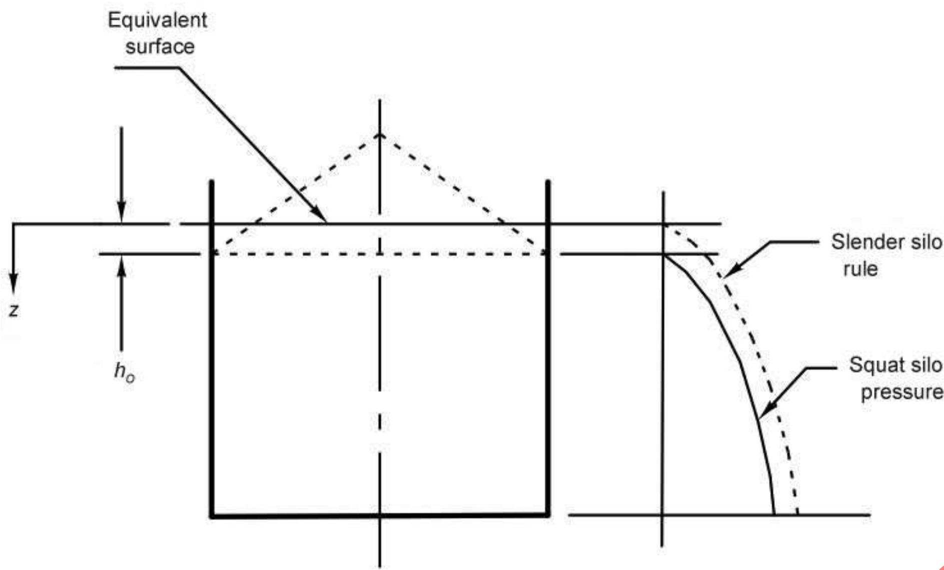
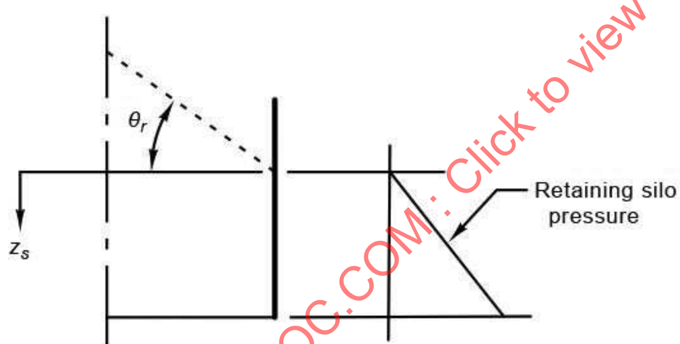


Figure 5-2.6.1.3-1
Pressures in a Retaining Container



$$n_{zSk} = \gamma_u \frac{\mu K}{2}(1 + \sin\theta_r) z_s^2 \quad (5\text{-}20)$$

where the nomenclature is as defined in (a) and para. 5-2.6.1.2(b).

5-2.6.2 Loads on Converging Hopper Walls

(a) Loads on the walls of hoppers shall be evaluated according to the angle of the hopper and the flow pattern of the solid. The following shall be used as a basis for determining the steepness of a hopper:

(1) A flat-bottom hopper shall have an inclination to the vertical θ greater than 85 deg.

(2) A shallow hopper shall be any hopper not classified as either flat bottom or steep.

(3) A steep hopper shall be any hopper that satisfies the following criterion (see Figure 5-2.6.2-1):

$$\tan\theta < \frac{(1 - K)}{2\mu} \quad (5\text{-}21)$$

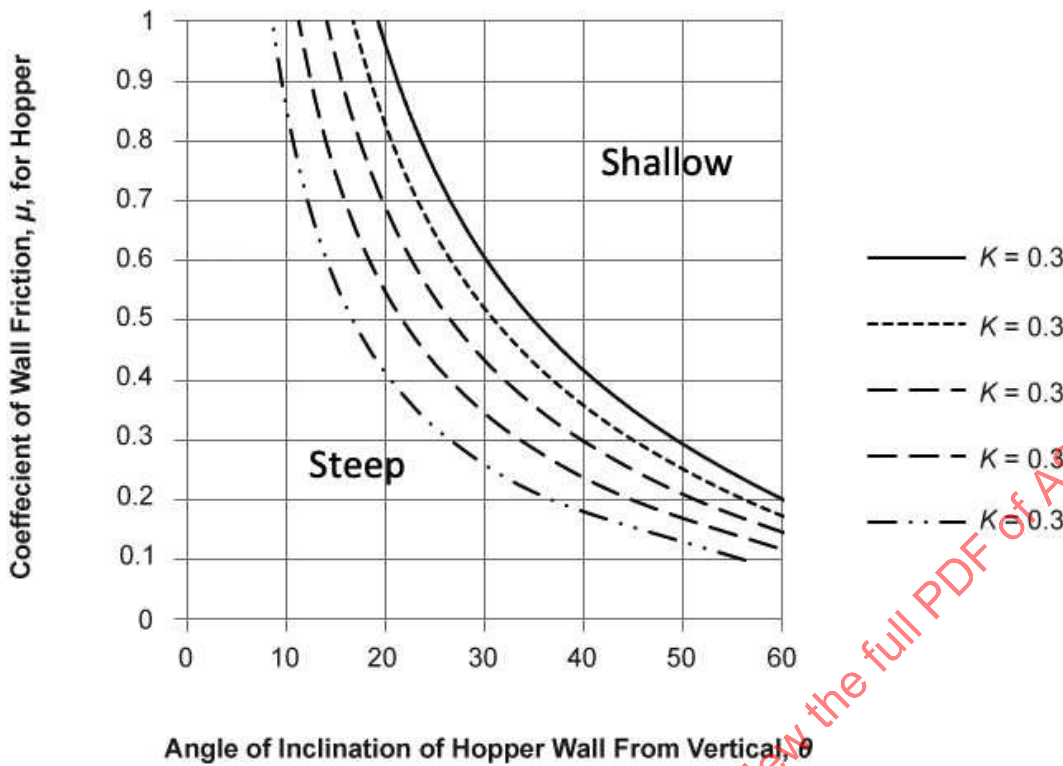
where

K = lower characteristic value of lateral pressure ratio on vertical walls

θ = hopper wall's angle of inclination from vertical (hopper half angle)

μ = lower characteristic value of the wall friction coefficient in hopper

Figure 5-2.6.2-1
Boundary Between Steep and Shallow Hoppers



(b) In a steep hopper, the pressures are governed by frictional sliding (fully mobilized friction) of the solid against the hopper wall. Hoppers that are too flat to fully develop wall friction (i.e., friction that is not fully mobilized) are termed "shallow" and have a larger hopper half angle θ. The pressure regime in the hopper is substantially affected by this difference (see Figure 5-2.6.2-2).

5-2.6.2.1 General Rules for Hopper Design. The mean vertical pressure, p_{vft}, (see Figure 5-2.6.2-2) at the transition between the vertical-walled cylinder segment and hopper or on the container bottom shall be determined as follows:

$$p_{vft} = C_b p_{ve} \tag{5-22}$$

where

C_b = bottom load magnifier to account for the possibility of larger loads being transferred to the hopper or container bottom from the vertical-walled segment
= 1.0 for containers in design Class 2
= 1.3 for containers in design Class 1 where the mean values of the material properties, K_m and μ_m, for the cylinder have been used for design

p_{ve} = vertical pressure calculated by eq. (5-9) or eq. (5-15) depending on the slenderness of the container, with the z coordinate equal to the height of the vertical wall, h_c (see Figure 5-1.1-1), and the values of solids properties that induce maximum hopper loading (see Table 5-2.4-1)

5-2.6.2.2 Hopper Design Loads. The values of normal pressure, $p_{ne}(x)$; shear stress, $p_{te}(x)$; and vertical pressure, $p_{ve}(x)$, at any height, x, above the hopper apex shall be determined as follows:

$$p_{ne}(x) = p_v(x) \tag{5-23}$$

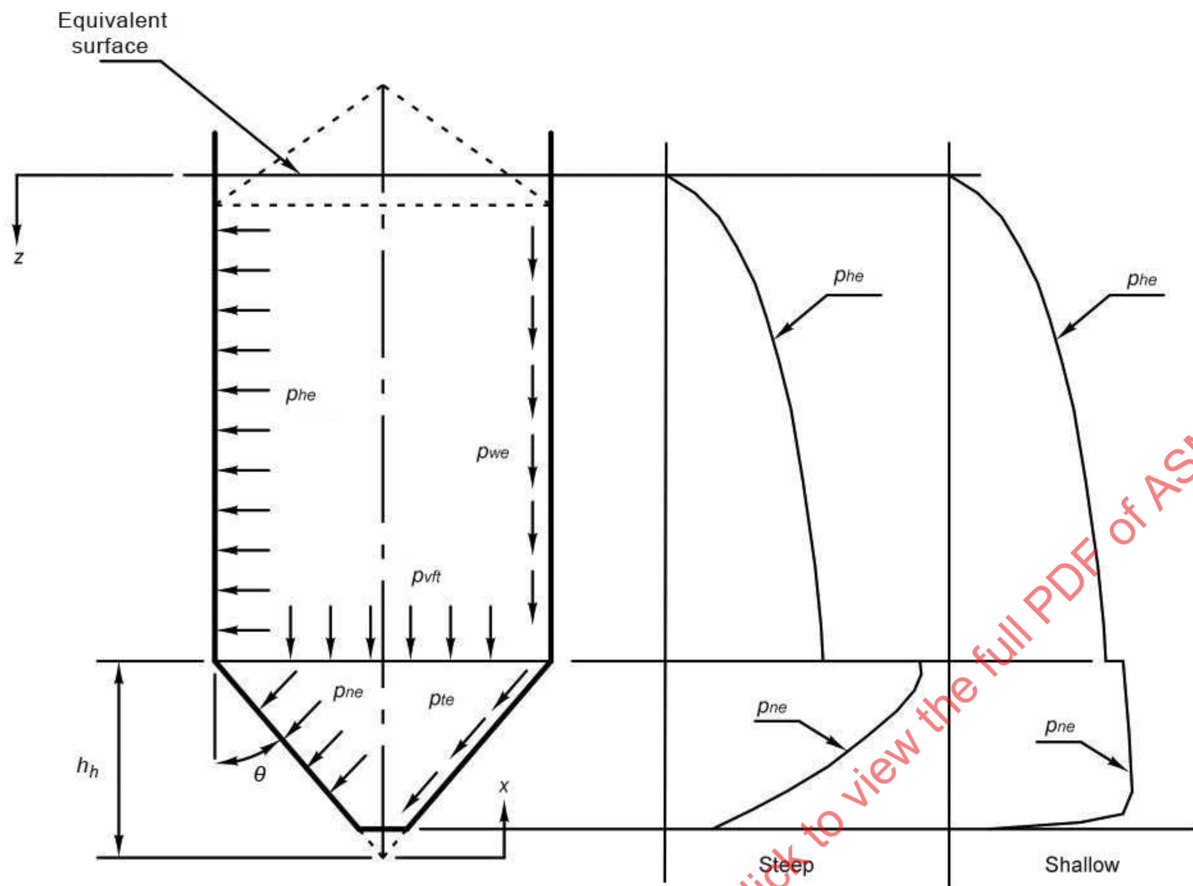
$$p_{te}(x) = \mu_{\text{eff}} p_v(x) \tag{5-24}$$

$$p_v(x) = \left(\frac{\gamma_u h_h}{n-1}\right)\left\{\left(\frac{x}{h_h}\right) - \left(\frac{x}{h_h}\right)^n\right\} + p_{vft}\left(\frac{x}{h_h}\right)^n \tag{5-25}$$

where

h_h = vertical height between the hopper apex and transition (see Figure 5-2.6.2-2)
n = power relationship

Figure 5-2.6.2-2
Distributions of Filling Pressures in Steep and Shallow Hoppers



$= S\mu_{eff}\cot\theta$

S = 1 for a plane flow hopper
= 2 for a conical hopper

θ = angle of inclination of hopper wall measured from vertical

p_{vft} = mean vertical pressure

x = vertical coordinate upward from hopper apex (see Figure 5-2.6.2-2)

γ_u = upper characteristic value of bulk density

μ_{eff} = effective or mobilized characteristic wall friction coefficient for the hopper. The determination of μ_{eff} shall take account of whether the hopper is steep or shallow (see paras. 5-2.6.2.2.1 and 5-2.6.2.2.2).

5-2.6.2.2.1 Loads on Steep Hoppers. For a steep hopper, μ_{eff} in eq. (5-24) shall be taken as μ where μ is the lower characteristic value of the wall friction coefficient in the hopper.

$$\mu_{eff} = \mu$$

$$n = S\mu_{eff}\cot\theta$$

5-2.6.2.2.2 Loads on Shallow Hoppers. In a shallow hopper, the wall friction is not fully mobilized. The mobilized or effective wall friction coefficient shall be determined as follows:

$$\mu_{eff} = \frac{(1 - K)}{2\tan\theta} \qquad (5\text{-}26)$$

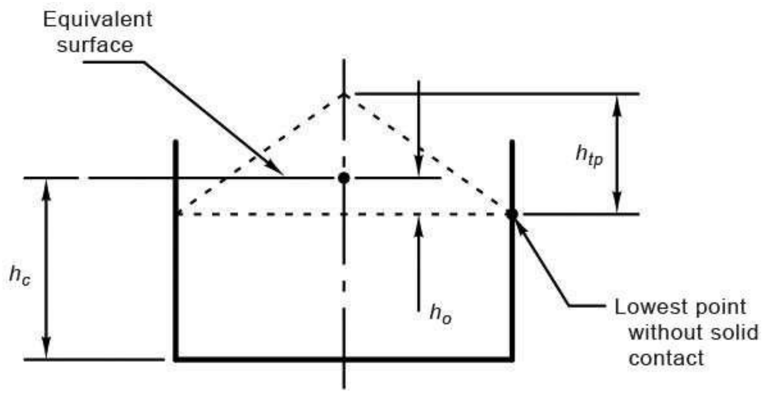
where

K = lower characteristic value of lateral pressure ratio for the vertical-walled segment, chosen for maximum hopper loading (see Table 5-2.4-1)

5-2.6.2.2.3 Loads on Flat-Bottom Containers

(a) Slender Containers. The vertical pressure, p_v, acting on the flat bottom (inclination θ > 85 deg) of a slender container may be taken as a uniform value, p_{vft}, which is obtained from eq. (5-22).

Figure 5-2.6.2.2.3-1
Pressures on the Bottom of a Squat or Intermediate Slenderness Container



(b) Squat and Intermediate Slenderness Containers

(1) The designer should consider the potential that pressures higher than those defined in eq. (5-22) may occur locally on the flat bottom of a squat or intermediate slenderness container.

(2) The vertical pressure, p_{vsq}, acting on the flat bottom of a squat or intermediate container may be taken as

$$p_{vsq} = p_{vb} + \Delta p_{sq}\left(\frac{2.0 - h_c/d_c}{2.0 - h_{tp}/d_c}\right) \tag{5-27}$$

where d_c and h_c are as defined in para. 5-1.1(b) and

h_{tp} = total height of the top pile, defined as the vertical distance from the lowest point on the wall that is not in contact with the stored solid to the highest stored particle (see Figure 5-2.6.2.2.3-1)

p_{vb} = uniform component of pressure, obtained from eq. (5-22) with $z = h_c$ and adopting characteristic values for the solids properties that induce maximum hopper loading (see Table 5-2.4-1)

Δp_{sq} = vertical pressure differential between two methods of vertical pressure determination
= $p_{vtp} - p_{vho}$

p_{vho} = vertical pressure at the base of the top pile, obtained from eq. (5-15) with $z = h_o$

p_{vtp} = vertical stack pressure of conical pile
= $\gamma_u h_{tp}$

γ_u = upper characteristic value of bulk density

NOTE: The method of eq. (5-27) provides a linear transition between the base pressure defined by the Janssen equation for a container that is just slender and the pressure for a condition where the bulk solids in the container are in the form of a heap.

(3) The value of p_{vsq} given by eq. (5-27) represents the vertical pressure near the center of the container floor. If the support of the floor slab is not uniform, a rational analysis should be used to determine the pressure variation.

5-2.6.2.3 Mass Flow Loads

(a) The hopper design loads described in para. 5-2.6.2.2 determine loads on a funnel flow hopper or a mass flow hopper that is filled from empty without bulk solids discharge. However, during discharge in mass flow (see Nonmandatory Appendix C for mass flow and funnel flow definitions), a very different pattern of hopper pressures develops from that described in para. 5-2.6.2.2. Specifically, high pressures develop near the transition of the vertical-walled segment and the hopper (see Figure 5-2.6.2.3-1).

(b) For containers in which potential mass flow can be defined per Figure 5-2.6.2.3-2 or Figure 5-2.6.2.3-3, the calculation procedure in (d) shall augment the loads calculated in para. 5-2.6.2.2.

(c) It should be noted the boundary between the mass flow and funnel flow regimes in Figures 5-2.6.2.3-2 and 5-2.6.2.3-3 has been altered to allow mass flow under conditions that would, from a flow standpoint, display funnel flow. This boundary shift provides a more conservative load analysis when dealing with the potential for mass flow.

(d) The normal pressure, $p_{ne}(x)$, and frictional pressure, $p_{te}(x)$ (see Figure 5-2.6.2.3-3), at any point on the wall of a steep hopper during mass flow shall be determined as follows:

$$p_{ne}(x) = k_h p_v(x) \tag{5-28}$$

Figure 5-2.6.2.3-1
Discharge Pressures in a Steep Hopper

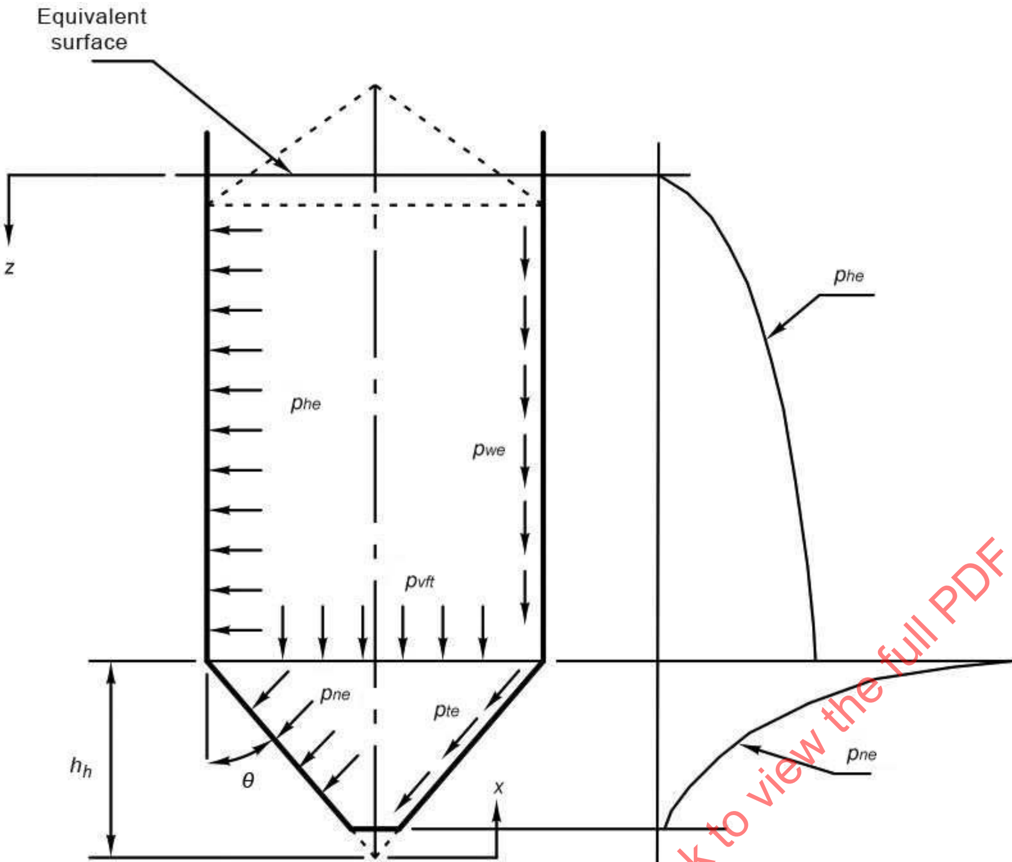


Figure 5-2.6.2.3-2
Conical Boundary Between Mass Flow and Funnel Flow for Pressure Calculations

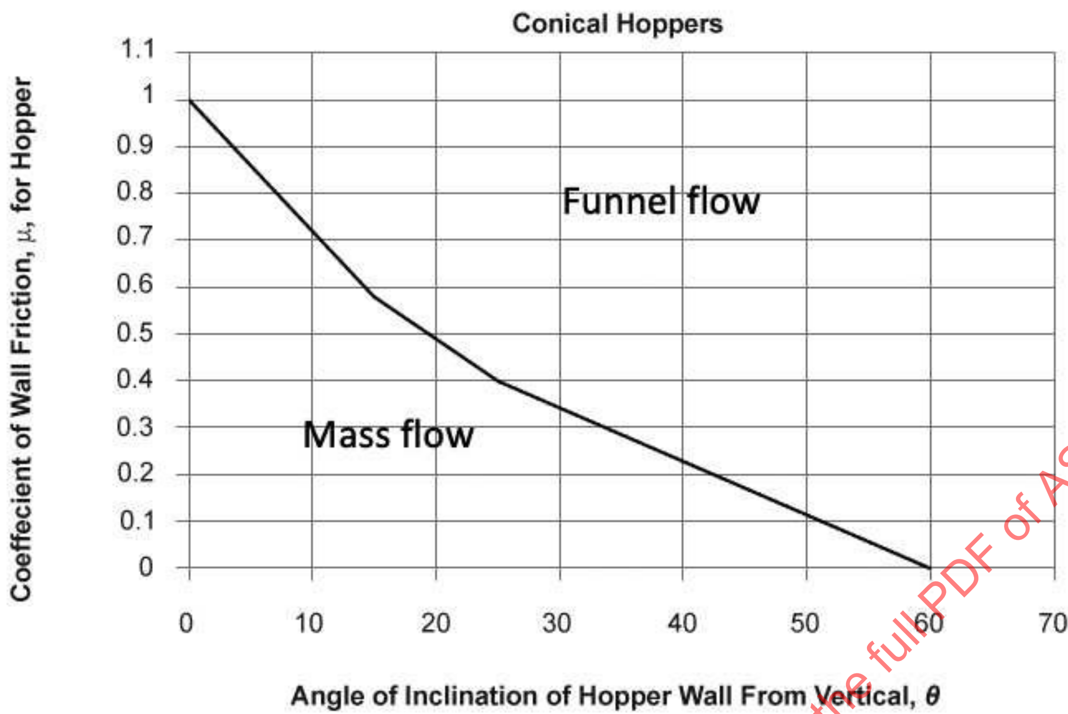
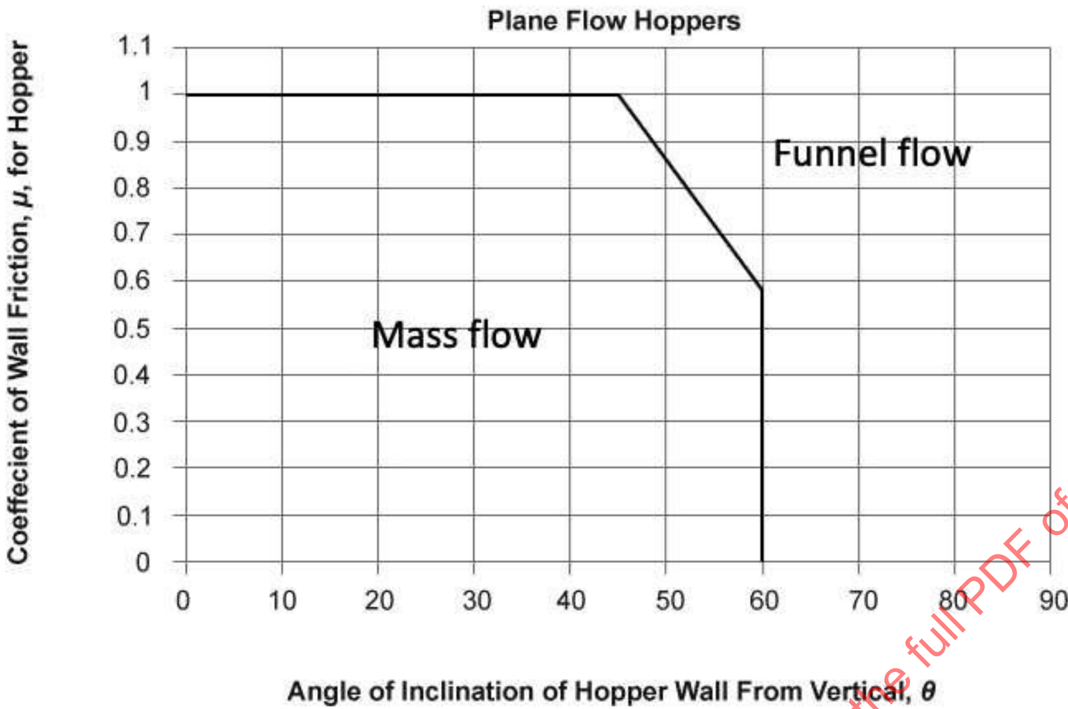


Figure 5-2.6.2.3-3
Plane Flow Boundary Between Mass and Funnel Flow for Pressure Calculations



$$p_{te}(x) = \mu k_h p_v(x) \tag{5-29}$$

where the nomenclature is as defined in (1) and (2).

(1) The vertical pressure, $p_v(x)$, is given by eq. (5-25) where

$$n = S[k_h(\mu \cot\theta + 1) - 1] \tag{5-30}$$

S = 2 for conical hoppers
= 1 for plane flow hoppers
θ = angle of inclination of hopper wall measured from the vertical

(2) The characteristic value of the lateral pressure ratio in hopper, k_h, shall be determined by either the theory of Walker, eq. (5-31), or the theory of Enstad, eq. (5-32). The designer should select the appropriate value to ensure the worst-case loads are applied to the container.

$$k_h = \frac{1 + \sin\delta\cos\varepsilon}{1 - \sin\delta\cos(2\theta + \varepsilon)} \tag{5-31}$$

$$\varepsilon = \phi' + \sin^{-1}\left(\frac{\sin\phi'}{\sin\delta}\right)$$

$$k_h = \left(\frac{1}{1 + \mu\cot\theta}\right)\left\{1 + 2\left[1 + \left(\frac{\sin\delta}{1 + \sin\delta}\right)\left(\frac{\cos\varepsilon\sin(\varepsilon - \theta)}{\sin\theta}\right)\right]\right\} \tag{5-32}$$

$$\varepsilon = \theta + \frac{1}{2}\left[\phi' + \sin^{-1}\left(\frac{\sin\phi'}{\sin\delta}\right)\right]$$

where

δ = upper characteristic value of the effective angle of internal friction
μ = lower characteristic value of the wall friction coefficient in the hopper
= tan ϕ'

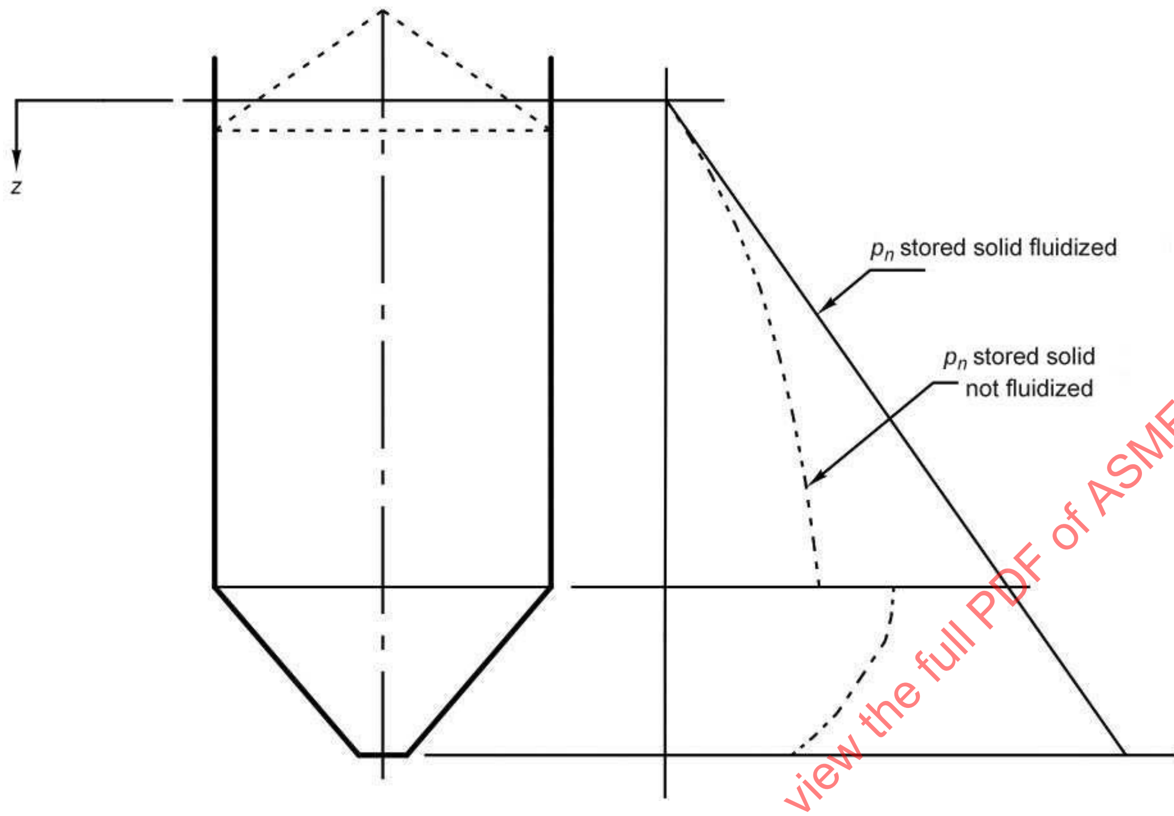
5-2.6.3 Containers Storing Solids With Entrained Air or Other Gas

5-2.6.3.1 General

(a) Containers in which it is possible for the stored solid to be fully or partially fluidized due to air entrainment shall be designed for the additional pressures that may arise due to fluidization and air pressure.

(b) Homogenizing fluidized containers and containers with a high filling velocity (see Figure 5-2.6.3.2-1) shall be designed for the following load cases:

Figure 5-2.6.3.2-1
Pressure for Container Storing Fluidized Solids



(1) the stored solid fluidized
(2) the stored solid not fluidized

5-2.6.3.2 Loads in Containers Containing Fluidized Solids

(a) The designer shall assume that the stored solid can become fluidized if the velocity of the rising surface of the stored solid exceeds 0.5 ft/min (0.15 m/min).

NOTE: The conditions under which a stored fine bulk solid can become fluidized depend on many factors and are not simple to define. The requirement in (a) provides a simple estimate of whether this may be an important design consideration. If there is doubt about the behavior of a stored solid, the designer should seek specialist advice.

(b) In homogenizing fluidized containers storing fine bulk solids that are being recirculated, the designer shall assume that the stored solid can become fluidized.

(c) The pressure on the container walls, p_n, from fluidized solids (see Figure 5-2.6.3.2-1) shall be calculated as follows:

$$p_n = \gamma_f z \tag{5-33}$$

where z is as defined in para. 5-2.6.1.1(b) and

γ_f = fluidized bulk density
= $0.8\gamma_{\min}$
$\gamma_{\min}$ = minimum or loose-fill bulk density of the solid

(d) The design pressures shall be evaluated with no frictional pressure on the cylinder or hopper wall, where such loads would reduce the design load of any component.

Section 6
Design

6-1 SCOPE

The provisions of this Section are based on allowable stress design (ASD).

This Standard does not contain all rules to cover all details of design and construction. Where complete details are not given, it is intended that the manufacturer, subject to the acceptance by the owner, shall provide details of design and construction that will not exceed the allowable stress of this Standard and do not violate any other requirements stated herein. All such designs shall follow good engineering and industry-recognized practices.

6-2 INFORMATION TO BE FURNISHED BY THE PURCHASER

The purchaser shall specify all applicable jurisdictional regulations and furnish all requirements that may affect the design and construction of the container. Information to be furnished by the purchaser shall be specified on Form B-1-1 (see Nonmandatory Appendix B).

6-3 WELDED JOINTS

6-3.1 Weld Size

The size of a groove weld shall be based on the joint penetration.

The size of a fillet weld shall be based on the perpendicular distance from the hypotenuse of the triangle formed by the two legs of the fillet weld to the root of the fillet weld.

6-3.2 Restrictions on Welded Joints

(a) Tack welds shall not be considered to have any strength value in the finished structure.

(b) The minimum fillet weld sizes shall be as shown in Table 6-3.2-1, except that the weld size need not exceed the thickness of the thinner part joined, unless a larger size is required by calculated stresses.

(c) Single-welded lap joints are permissible only on fully supported flat bottom and roof plates.

(d) Lap-welded joints shall be lapped at least 5 times the nominal thickness of the thinner plate joined. In double-welded lap joints, the lap need not exceed 2 in. (50 mm). In single-welded lap joints, the lap need not exceed 1 in. (25 mm).

(e) Roof plate and shell-to-bottom fillet weld legs greater than 0.25 in. (6 mm) shall be multipass.

(f) All attachments to the exterior of the container shall be completely seal welded. Intermittent welding is not permitted except for intermediate wind stiffeners.

(g) Except for roofs, permanent joint backing strips are permitted only with the approval of the purchaser.

6-3.3 Typical Joints

6-3.3.1 General

(a) Typical joints are shown in Figures 6-3.3.1-1 and 6-3.3.1-2.

(b) The top surfaces of bottom welds such as butt-welded annular plates shall be ground flush where they contact the bottom of the shell, insert plates, or reinforcing plates.

6-3.3.2 Vertical Shell Joints

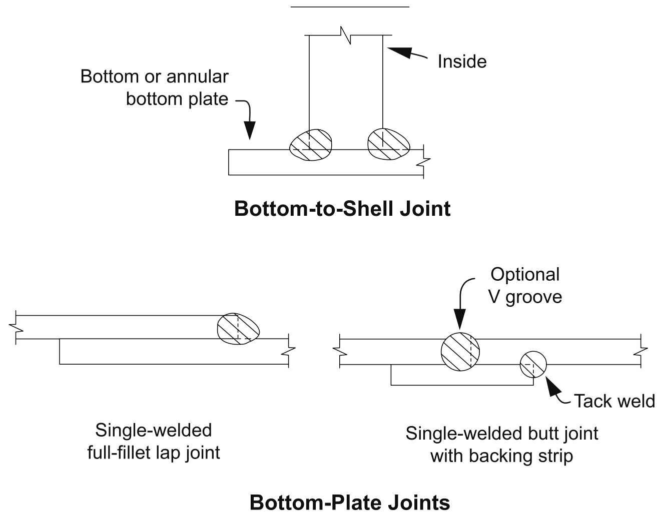
(a) Vertical shell joints shall be butt joints with complete penetration and fusion attained by double welding or other means that will provide the same quality of deposited weld metal on the inside and outside weld surfaces.

(b) Vertical joints in adjacent shell courses shall not be aligned but shall be offset from each other a minimum distance of the greater of $5t$ or 3 in. (75 mm), where t is the plate thickness of the thicker course at the offset point.

Table 6-3.2-1
Minimum Fillet Weld Sizes

Thickness of Thinner Part Joined, in. (mm)	Minimum Size of Fillet Weld, in. (mm)
≤0.5 (≤13)	0.1875 (5)
>0.5 to 0.75 (>13 to 19)	0.25 (6)
>0.75 to 1.5 (>19 to 38)	0.3125 (8)
>1.5 to 2.25 (>38 to 57)	0.375 (10)

Figure 6-3.3.1-1
Typical Bottom Joints



GENERAL NOTES:
(a) The illustrations are from API Standard 650, Welded Tanks for Oil Storage (2020, 13th ed.), Figure 5.3a. Reproduced courtesy of the American Petroleum Institute.
(b) Joint details shown are for flat-bottom containers resting on grade and are not applicable to containers with suspended conical bottoms.

6-3.3.3 Horizontal Shell Joints

(a) Horizontal shell joints shall have complete penetration and fusion attained by double welding or other means that will provide the same quality of deposited weld metal on the inside and outside weld surfaces.

(b) Top angles may be attached to the top course by a double-welded lap joint (see Figure 6-8.2.3-1).

6-3.3.4 Hopper to Shell Joints. The hopper-to-shell joint shall be a full-penetration groove weld, a full-penetration double fillet weld, or alternative weld details that develop full design strength of the connected steel. The design, fabrication, and inspection methods shall be aligned.

6-3.3.5 Conical Hopper Joints. Conical hoppers shall be assembled utilizing butt welds with complete penetration and fusion attained by double welding or other means that will provide the same quality of deposited weld metal on the inside and outside weld surfaces. Horizontal joints may be a double-welded single-lap detail.

6-3.3.6 Roof and Top-Angle Joints

(a) Roof plates shall at minimum be welded on the top side with a continuous full-fillet weld. Butt welds are also permitted.

(b) Roof plates shall be attached to the shell or top angle of the container with a continuous fillet weld on the exterior. Additional internal welds are permitted by agreement between the manufacturer and purchaser.

(c) Except as noted in (d), containers shall be provided with top angles not less than the sizes given in Table 6-3.3.6-1.

(d) Closed-top containers meeting the minimum shell and roof participation area as referenced in Figure 6-8.2.3-1 do not require a top angle. The roof-to-shell weld may be a corner-to-corner butt weld, or the roof plate may overlap the shell and be attached with an overhead fillet weld.

6-4 DESIGN CONSIDERATIONS

6-4.1 Loads

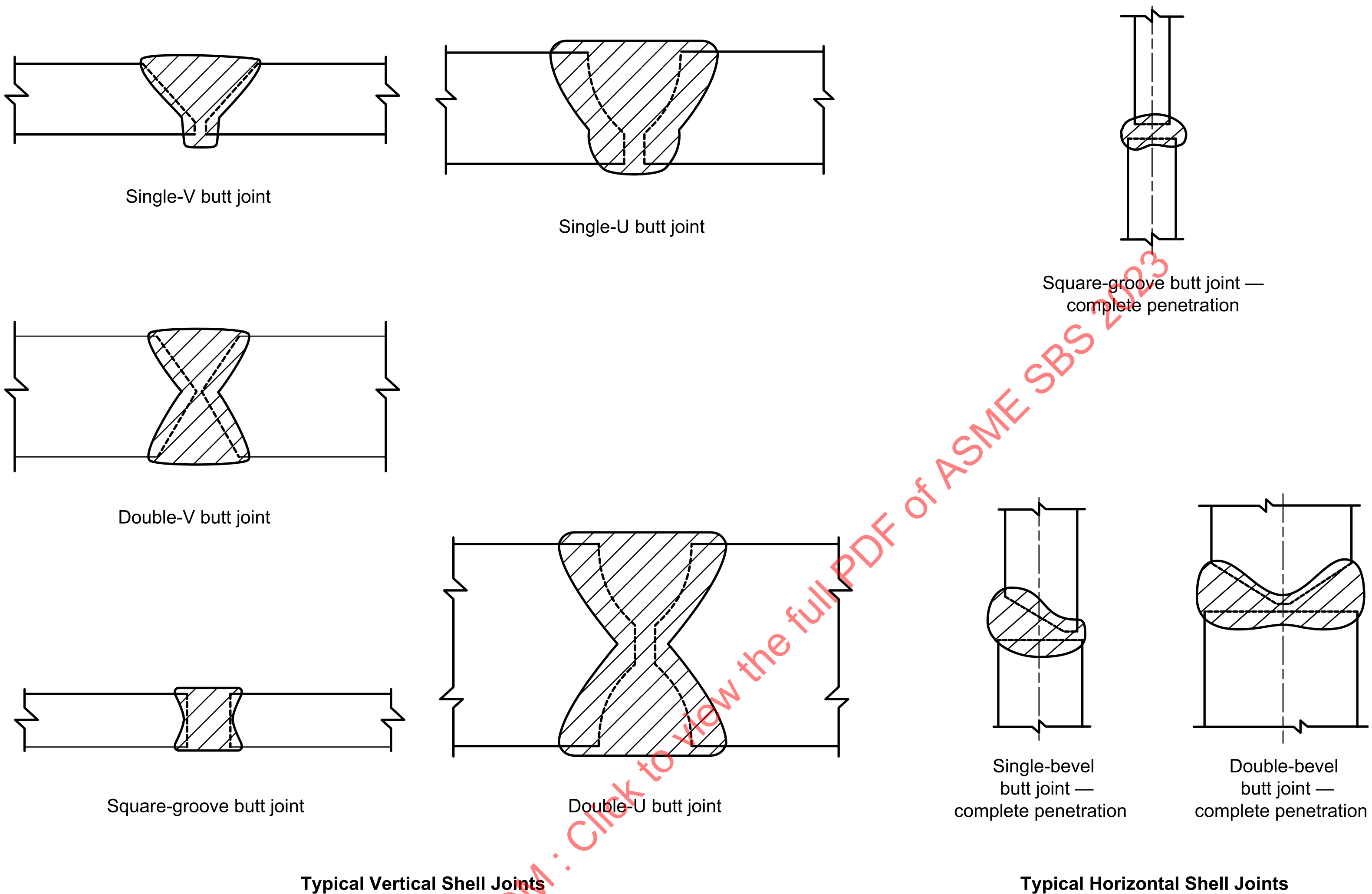
The container shall be designed (allowable stress basis only) for the loads and load combinations given in ASCE-7, IBC, or an applicable local building code, subject to the following qualifications:

(a) *Dead Load, D_L.* The dead load equals the self-weight of the container plus the self-weight of attached components.

(b) *Bulk Solids Load, H_b.* Loads in the container should be calculated per Section 5. Note that loads due to pressure of bulk materials are included in the ASCE-7/ASD load combinations with a load factor of 1.0. Supporting structures (skirts, column supports, lugs, etc.) for containers with elevated bottoms shall be designed using the entire mass of the stored product.

(c) *Design External Pressure, p_e.* Design external pressure is the pressure created from a vacuum condition.

Figure 6-3.3.1-2
Typical Horizontal and Vertical Shell Joints



GENERAL NOTE: The illustrations are from API Standard 650, Welded Tanks for Oil Storage (2020, 13th ed.), Figures 5.1, 5.2, and 5.3a. Reproduced courtesy of the American Petroleum Institute.

Table 6-3.3.6-1
Minimum Top Angle Sizes

Container Diameter, *D*, ft (m)	Minimum Top Angle Size, in. (mm)
>12 to ≤35 (>3.5 to ≤10.5)	2 × 2 × 0.1875 (50 × 50 × 5)
>35 to ≤60 (>10.5 to ≤18)	2 × 2 × 0.25 (50 × 50 × 6)
>60 (>18)	3 × 3 × 0.375 (75 × 75 × 10)

(d) Design Internal Pressure, p_i. Design internal pressure is the pressure from pneumatic fill or gas injection.

(e) Minimum Roof Live Load, L_r. The minimum roof live load shall not be below 15 psf (0.72 kPa) on the projected area of the roof.

(f) Seismic Loads, E_L. For seismic calculations, the weight of the structure shall include the dead load of the structure as well as the effective weight of the container contents. Effective mass, *E*, shall be included with seismic loads.

(g) Snow, S_L. Load from snow on projected area of the roof.

(h) Wind, W_L. For case containers with conical roofs or other container components and configurations for which wind pressure coefficients are not provided by the referenced building codes, the designer shall take a rational approach, considering other information, codes, and references.

(i) Live Load, L_L. Live loads include loads imparted to the container from attached components and ancillary equipment other than the self-weight of the equipment. Per para. 6-4.3, the purchaser shall state the magnitude and direction of any external loads for which the container shell and roof must be designed. The self-weight of the equipment and accessories is included with the dead load, D_L.

6-4.2 Special Provisions for Stored Contents With Earthquake Load

For containers where the stored material is in direct contact with a concrete foundation, the earthquake-overturning moment may be computed using the weight of the container plus 80% of its contents. For suspended hopper-bottomed containers, 100% of the contents shall be used.

6-4.3 Design Factors

The purchaser shall state on Form B-1-1 all applicable design parameters, including, but not limited to, the design metal temperature, maximum design temperature, seismic factors, product bulk density, coefficient of wall friction, effective angle of internal friction, and the lateral-to-vertical product pressure ratio.

6-4.4 External Loads

The purchaser shall state the magnitude and direction of any external loads for which the container shell and roof must be designed.

6-5 SPECIAL CONSIDERATIONS

6-5.1 Adequacy of Foundation Support

The selection of the container site and the design and construction of the foundation shall be given careful consideration to ensure adequate support of the container loads and operational limits of the container. The adequacy of the foundation is the responsibility of the purchaser.

6-5.2 Wear and Corrosion Allowance

6-5.2.1 Purchaser Specification. The purchaser shall specify on Form B-1-1 the wear and corrosion allowances for all components of the container. The wear allowance should take proper account of the abrasion potential of the stored product on the internal surfaces of the container.

6-5.2.2 Application of Wear and Corrosion Allowance. The wear and corrosion allowances specified by the purchaser shall be added to the greater of either the required thickness determined by design or to the minimum specified thickness.

6-5.2.3 Corrosion Allowance on Anchor Rods. A corrosion allowance of 0.25 in. (6 mm) for anchor rods shall be added to the nominal diameter. A corrosion allowance is not required for anchor rods that have corrosion-prevention coatings or plating.

6-5.2.4 Wear and Corrosion Allowances on Internal Surfaces. For internal structural members, except for channel and wide-flange webs, the wear and corrosion allowances shall be added to the total thickness, unless otherwise specified.

6-5.3 Annular Bearing Plates

When the bottom shell course thickness, excluding any wear and corrosion allowance, is equal to or greater than 0.75 in. (19 mm), a complete penetration butt-welded annular bearing plate shall be used under the bottom shell course that rests on the concrete foundation. The minimum annular bearing plate thickness is given in Table 6-5.3-1.

The width of the annular plate, measured from the inside edge of the shell to the edge of the plate in the remainder of the bottom, shall be adequate to support the vertical static pressure on top of it in case of foundation settlement. The minimum width of the annular plate shall be 24 in. (600 mm), and sufficient bearing area shall be provided utilizing the concrete bearing provisions of

Table 6-5.3-1
Annular Bearing Plate Thickness

Lowest Course Plate Thickness, *t*, in. (mm) [Note (1)]	Minimum Annular Plate Thickness, in. (mm)
≤1.25 (≤32)	0.25 (6 mm)
>1.25 to ≤1.5 (>32 to ≤38)	0.3125 (8 mm)
>1.5 to ≤1.75 (>38 to ≤45)	1.0325 (9 mm)

NOTE: (1) Excludes wear and corrosion allowances.

para. 6-5.4. Annular plate projection outside the shell shall be at least 2 in. (50 mm).

6-5.4 Concrete Bearing Provisions

Proper provision shall be made to transfer vertical forces and moments to the foundation.

Permissible bearing stress on concrete foundations under annular bearing plates, base flanges, stiffening member bases, and column bases may be determined by the provisions of ACI 318. Note that this Standard is based on the allowable stress method. ACI 318 is based on an ultimate strength approach; therefore, all load factor provisions of ACI 318 shall be applied to loads determined from this Standard.

As an alternate provision, the allowable load limit due to the limit strength of concrete crushing may be taken as follows:

(a) Over the full area of a concrete support

$$P_p = \frac{0.85 f_c A_1}{2.5}$$

(b) Less than the full area of a concrete support

$$P_p = \frac{0.85 f_c A_1 \times \sqrt{\frac{A_2}{A_1}}}{2.5}$$

where

A_1 = area of steel concentrically bearing on a concrete support, in.^{2}

A_2 = maximum area of the portion of the supporting surface that is geometrically similar to and concentric with the loaded area, in.^{2}

f_c = specified minimum compressive strength of concrete, kip/in.^{2}

P_p = allowable load, kips

NOTE: The square root of A_2/A_1 shall be less than or equal to 2.

6-6 SHELL DESIGN OF WELDED AND SMOOTH-WALL BOLTED CONTAINERS

6-6.1 General

The required shell plate thickness, *t*, is the thickness at the point of consideration and shall be the greater of the design shell thickness based on loads defined in subsection 6-4, excluding any wear and corrosion allowances, or the minimum plate thickness listed in Table 6-6.1.2-1.

6-6.1.1 Toughness Requirements. The thickness and design metal temperature of all container shell plates, shell insert plates, annular bottom plates welded to the shell, plates used for manhole and nozzle necks, plate-ring shell-nozzle flanges, blind flanges, and manhole covers shall conform to the requirements of Section 5.

6-6.1.2 Minimum Thickness. The minimum thickness for any part of a welded container shell shall be per Table 6-6.1.2-1.

6-6.2 Allowable Design Stresses

6-6.2.1 Design Tensile Stress for Plates. The list of permissible materials for fabrication is found in Section 4. The net plate thickness (the actual thickness less the wear and corrosion allowances) shall be used in the calculation. The design tensile stress, S_d, shall not exceed the value given by

Table 6-6.1.2-1
Minimum Shell Plate Thickness for Welded Containers

Nominal Diameter, d_c, of Container Shell, ft (m) [Note (1)]	Nominal Container Shell Height, *H*, ft (m)	Nominal Shell Thickness, in. (mm) [Note (2)]
≤14 (≤4.3)	All	0.1345 (3.41)
>14 to ≤20 (>4.3 to ≤6.1)	All	0.1793 (4.55)
>20 to ≤50 (>6.1 to ≤15.2)	≤48 (≤14.6)	0.1793 (4.55)
	>48 (>14.6)	0.25 (6.35)
>50 to ≤120 (>15.2 to ≤36.6)	All	0.25 (6.35)
>120 to ≤200 (>36.6 to ≤61.0)	All	0.3125 (7.94)
>200 (>61.0)	All	0.375 (9.52)

NOTES:
(1) Unless otherwise specified by the purchaser, the nominal container diameter for welded containers shall be the centerline diameter of the bottom shell course.
(2) Nominal plate thickness refers to the container shell as constructed. The thicknesses specified are based on erection requirements.

$$S_d = \min(0.67F_y,\ 0.4F_u)$$

where

F_u = ultimate tensile strength, psi
F_y = yield stress, psi

See subsection 6-12 for the design stress for bolted joints.

6-6.2.2 Design Tensile Stress for Rolled Sections. For nonplate hot-rolled structural shapes, design stresses shall conform to the allowable working stresses in the latest edition of AISC 360. The ASD provisions of the specification shall be used for determination of allowable working stresses and member capacities.

6-6.3 Shell Plate Thickness for Welded and Smooth-Wall Bolted Containers

6-6.3.1 General. The required shell plate thickness (excluding any specified wear and corrosion allowances) is the greater of the thickness required to resist the maximum normal product pressure, p_{he}, acting on the container shell and the thickness required to resist the vertical compressive force per unit circumference, nz, in the container wall.

The course plate thickness for the given container height must satisfy the allowable stress requirement for the hoop stress caused by the product pressure combined with the vertical compressive force, since this condition is more demanding than each acting alone. It shall also satisfy the limitation for vertical compressive force that may cause instability in the wall (see para. 6-6.4).

The normal product pressure, p_{he}, and vertical compressive force per unit circumference, n_z, at every level in the container shall be obtained from Section 5. At every depth, z, below the equivalent surface, the acting stress shall be determined using the equations in paras. 6-6.3.2 through 6-6.3.4.

6-6.3.2 Hoop Stress. The membrane hoop stress due to product pressure shall be determined at every level in the container.

The hoop stress for the normal product pressure at the depth, z, below the equivalent surface is calculated as follows:

(U.S. Customary Units)

$$S_h = (p_{he} + 144p_i)R/12t$$

(SI Units)

$$S_h = (p_{he} + p_i)R/t$$

where

p_{he} = normal product pressure at the depth, z, lbf/ft^2 (kPa)
p_i = design supplemental pressure, psi (kPa)
R = container radius, ft (m)
S_h = hoop membrane stress, psi (MPa)
t = shell thickness, in. (mm)

6-6.3.3 Vertical Stress. The total vertical force per unit circumference, $n_{z,\text{total}}$, at any depth, z, below the equivalent surface shall be the sum of the force per unit circumference, $n_{z,\text{total}}$, calculated per para. 6-4.1 acting on the shell at that level.

The vertical stress in the shell at any depth, z, shall be calculated as

$$S_z = n_{z,\text{total}}/tU$$

where

$n_{z,\text{total}}$ = total vertical force per unit circumference, lb/ft (kN/m)
S_z = vertical stress, psi (MPa)
t = thickness of the point in the container shell under consideration, in. (mm)
U = factor for the units
= 12 for U.S. Customary units
= 1 for SI units
z = depth below the equivalent surface (see para. 5-2.6.1.1)

6-6.3.4 Limitation on the Total Allowable Stress. The combination of hoop stress, S_h, and vertical compressive stress, S_z, at any depth, z, below the equivalent surface shall be less than or equal to the design stress, S_d, considering the joint efficiency factor, E.

$$S_h/E + S_z \leq S_{dt}$$

where

E = joint efficiency factor (For welded joint efficiency, see Table 7-2.2.6-1; for smooth walled bolted joint efficiency, see subsection 6-12.)
S_d = design stress, psi (MPa)

6-6.4 Shell Stability Under Vertical Compression

6-6.4.1 General. Cylindrical shell containers are subjected to axial compression from dead load, live load, frictional drag loads from product, and reactions from wind or seismic forces. The allowable compressive stress for cylindrical shells shall be determined from para. 6-6.4.2 or para. 6-6.4.3, as appropriate.

6-6.4.2 Smooth Cylindrical Shells Without Longitudinal Stiffeners

(a) Empty Container or Portions of Container Not in Contact With the Stored Product. For all values of R_i/t

(U.S. Customary Units)

$$S_e = \left[\frac{15{,}300}{0.8 + (R_i/350t)^2}\right]$$

(SI Units)

$$S_e = \left[\frac{106}{0.8 + (R_i/350t)^2}\right]$$

where

R_i = inside shell radius, in. (mm)
S_e = maximum allowable longitudinal compressive stress, psi (MPa)
t = shell thickness, in. (mm)

(b) Portions of the Container in Contact With the Stored Product. The pressure of granular material against the wall of a container will increase the buckling strength in vertical compression. The increased buckling strength due to pressure at any level depends on the relative pressure, p^*, which must be derived from the value of filling pressure, p_{hf}, at the same level, calculated per Section 6.

$$p_{hf} = \frac{p_{he}}{144Ch}$$

where p_{he} and C_h are taken from para. 5-2.6.1.1(b) or para. 5-2.6.1.2(b) as appropriate.

The relative pressure, p^*, is then calculated as follows:

(U.S. Customary Units)

$$p^* = \frac{p_{hf}}{18.2 \times 10^6}\left(\frac{R_i}{t}\right)^2$$

(SI Units)

$$p^* = \frac{p_{hf}}{125 \times 10^3}\left(\frac{R_i}{t}\right)^2$$

The increase in buckling strength due to internal pressure is calculated as follows:

(U.S. Customary Units)

$$\Delta S_e = 18.2 \times 10^6\left[\frac{0.5p^*}{(1 + p^*)^{0.8}}\right]\left[\frac{t}{R_i}\right]$$

(SI Units)

$$\Delta S_e = 125 \times 10^3\left[\frac{0.5p^*}{(1 + p^*)^{0.8}}\right]\left[\frac{t}{R_i}\right]$$

where

p_{hf} = filling pressure, psi (MPa)
R_i = inside shell radius, in. (mm)
t = shell thickness, in. (mm)
ΔS_e = maximum allowable increase in longitudinal compressive stress, psi (MPa)

6-6.4.3 Longitudinally Stiffened Smooth Cylindrical Shells. In cases where the allowable strength of an unstiffened container shell is not sufficient to resist the calculated vertical compressive loads, consideration should be given to designing a longitudinally stiffened shell. In a longitudinally stiffened shell, the total vertical strength is derived from a combination of the vertical compressive strength of the stiffener and a portion of the shell on either side of the stiffener. The horizontal spacing of vertical stiffeners, b, shall be limited to the lesser of the following:

(U.S. Customary Units)

$$b \le 4.08\left(Fy_{\text{cyl}}\right)^{0.5} \times t$$

$$b \le 75 \text{ in.}$$

(SI Units)

$$b \le 1.55\left(Fy_{\text{cyl}}\right)^{0.5} \times t$$

$$b \le 1\,900 \text{ mm}$$

where

Fy_{cyl} = yield strength of the container wall material, psi (MPa)
t = shell thickness, in. (mm)

The portion of the shell extending on either side of the bolt or weld line that attaches the stiffener to the shell can be considered a contributor to the strength of the vertical stiffener. The contributing shell width on either side of the stiffener attachment shall be calculated as follows:

$$w_{\text{shell}} = 0.76(R_i t_s)^{0.5} \le 16t_s$$

where w_{shell}, R_i, and ts are expressed in consistent units (either inches or millimeters), and R_i is as defined in para. 6-6.4.2. The contributing shell width may not exceed the width between the vertical stiffeners.

Since the yield strength of the container walls, Fy_{cyl}, may differ from the yield strength of the stiffener, Fy_{stiff}, the total contributing width of the container wall shall be reduced by the adjustment factor C_{adj}, where $C_{\text{adj}} = Fy_{\text{cyl}}/Fy_{\text{stiff}} < 1.0$.

Vertical stiffeners shall be designed per AISC 360 for columns in compression.

Stiffeners should be attached to the cylinder with the strong axis (X-axis in general terminology) parallel to the cylinder. For stiffeners fabricated of hot-rolled W sections (I beams), the flange should be attached to the shell wall.

The stiffener shall be attached to the shell by bolting or welding, at vertical increments not exceeding 12 in. (305 mm). For bolted attachments, stiffeners shall be attached using a minimum of two rows of fasteners, unless the stiffener gage dimensions allow for only one row. For welded attachments, welds shall be placed on both sides of the stiffener.

A stiffener shall be designed as a compression member with a minimum effective length, KL_{ul}, where K = 1.0 and L_{ul} = the unbraced length. The buckling strength shall be assessed for buckling, both at right angles to the shell wall and parallel to the shell wall, using the radius of gyration, r, for bending about the appropriate axis. Consistent units should be used for L_{ul} and r (either inches or millimeters). For buckling parallel to the shell, the stiffener length, L_{ul}, shall be taken as the vertical spacing of the stiffener attachments to the shell.

For external stiffeners or for internal stiffeners that are not in the product zone, for calculation of buckling strength at right angles to the shell, the stiffener length, L_{ul}, shall be the shell height between nodal braces. For internal stiffeners in the product zone for calculation of buckling strength, the stiffener length, L_{ul}, shall be the shell height between adjacent rings at the level under consideration, with K = 2.0. Alternately, if nodal bracing is considered, the stiffener length, L_{ul}, shall be the shell height between nodal braces, with K = 1.0.

When considering nodal bracing for stiffeners, the lateral force developed in each stiffener shall be 0.01P or 1% of the total axial design load of each stiffener. Nodal bracing can be provided by assembly flanges (chimes of bolted flanged panel tanks), sheet overlaps, rolled angles, the hopper compression region (springline), roof eaves, or other stabilizing rings designed to resist the lateral compression or tension forces due to out-of-plane bending of the stiffener. When nodal bracing is used, the braces shall be equally spaced along the stiffener length. If equal spacing of nodal bracing is not practical, the unbraced stiffener length used for design shall be the largest nodal bracing spacing possible. Nodal bracing shall be designed as a continuous circumferential ring loaded with equal radial forces equally spaced (assuming equal stiffener spacing), considering both compression loads from inward lateral forces and tension loads from outward lateral forces. See para. 6-8.7 for compression/tension ring design, where Q is the calculated lateral (radial) force applied to the nodal brace from each column. Nodal bracing must be considered for any bolted container when shell rings exceed 120 in. (3 050 mm) in height. Nodal bracing shall be used for any construction when horizontal joints between adjacent rings are butt-welded.

Interior stiffeners located in portions of the cylinder that are not in contact with stored product or external stiffeners shall be braced against lateral torsional buckling by additional braces installed between the outstanding stiffener flange and cylinder wall. These braces shall alternate sides of the stiffener and be spaced a maximum of $L_x r_y / r_x$ increments where the calculated spacing, L_{ul}, and r are expressed in consistent units (inches or millimeters). Lateral braces can be straps, angle shapes, or other material capable of providing lateral support and resisting lateral-torsional buckling. Lateral braces on internal stiffeners located in portions of the cylinder where stored product is present are not recommended.

6-6.5 Shell Design for External Pressure

6-6.5.1 General. This subsection describes the design of the shell to resist wind pressure combined with external pressure (vacuum) and applies to containers where the vacuum does not exceed 1.0 psi (6.9 kPa).

6-6.5.2 Shell Design For External Wind and Vacuum Pressure

6-6.5.2.1 Criteria. For an unstiffened container shell subjected to external pressure sufficient to cause buckling, buckling will occur elastically if the following criterion is satisfied. Note that this criterion will typically be satisfied except for very small, exceptionally thick containers. If this criterion is not satisfied, external pressure effects should be evaluated in accordance with the requirements of ASME BPVC, Section VIII, Division 1.

$$(d_c/t_u)^{0.75} \times \left[(H_1/d_c) \left(F_y/E_y \right)^{0.5} \right] \geq 0.19$$

where
d_c = nominal container diameter, ft
E_y = modulus of elasticity, psi
F_y = yield strength of material, psi
H_1 = maximum unstiffened shell height, ft
t_u = as ordered thickness of the thinnest shell course, unless otherwise specified by the purchaser, in.

6-6.5.2.2 Stability Factor, Ψ

Condition 1: Wind plus specified design vacuum, P_s
Ψ_1 = $(P_e + 15)/20$ for wind plus design vacuum when $P_e \leq 15$ psf (0.1042 psi). However, Ψ_1 shall not be less than 1.0.
= $(P_e/10)$ for wind plus design vacuum when 15 psf (0.1042 psi) < $P_e \leq 144$ psf (1.0 psi). However, Ψ_1 need not exceed 2.5.

Condition 2: Design vacuum only, P_e
Ψ_2 = 3.0

6-6.5.2.3 Allowable External Pressure. The total design external pressure for the shell shall not exceed the following:

$$P_s \leq 0.6E_y / \left[\Psi_1 (H_t/d_c)(d_c/t_u)^{2.5} \right]$$

$$P_e \leq 0.6E_y / \left[\Psi_2 (H_t/d_c)(d_c/t_u)^{2.5} \right]$$

where

P_e = external pressure (vacuum), psf

P_s = P_w + 0.4P_e

P_w = allowable stress design level wind velocity pressure without shape factor, psf

6-6.5.2.4 Minimum Nominal Shell Thickness. The equation in para. 6-6.5.2.3 can be rewritten to calculate the nominal thickness of the thinnest shell course required.

$$t_{smin} = 1.23(\Psi_1 H_t P_s)^{0.4} \times d_c{}^{0.6}/E_y^{0.4}$$
$$t_{smin} = 1.23(\Psi_2 H_t P_e)^{0.4} \times d_c{}^{0.6}/E_y^{0.4}$$

where t_{smin} = minimum required thickness of the thinnest shell course, in.

6-6.5.3 Height of the Transformed Shell. For containers with shell courses of varying thickness, the transformed shell height, H_t, for the container shell is determined in accordance with the following procedure. Calculate the transposed width, having the thinnest shell course thickness, as follows:

(a) The transformed height of the shell is calculated as the sum of the transformed widths of the individual shell courses as described in (b).

(b) The transformed width of each individual shell course is calculated by multiplying the actual shell course width by the ratio $(t_{amin}/t_{act})^{2.5}$.

The transformed shell height is determined from the following equation:

$$H_t = w_1(t_{amin}/t_{a1})^{2.5} + w_2(t_{amin}/t_{a2})^{2.5} + \ldots w_n(t_{amin}/t_{an})^{2.5}$$

where

H_t = transformed shell height, ft

$t_{a1}, t_{a2} \ldots t_{an}$ = nominal thickness of shell course 1, 2...n, where the subscript numbering is from the top to the bottom of the shell, in.

t_{amin} = nominal thickness of the thinnest shell course, in.

$w_1, w_2 \ldots w_n$ = width of shell courses 1, 2 through n, respectively, ft

The transformed shell height is an analytical model of the actual container. The transformed shell has a uniform thickness equal to the thinnest shell course and a height equal to the transformed height. This analytical model of the actual container will have essentially an equivalent resistance to buckling from external pressure as the actual container.

6-6.5.3.1 Minimum Unstiffened Shell Height. The equation in para. 6-6.5.2.4 can be rewritten to calculate the maximum height of an unstiffened shell based on the nominal thickness of the thinnest shell course, t_{amin}.

$$H_{max} = 0.6(t_{amin})^{2.5} \times E_y/d_c{}^{1.5} \times (P_s)\Psi_1$$
$$H_{max} = 0.6(t_{amin})^{2.5} \times E_y/d_c{}^{1.5} \times (P_e)\Psi_2$$

where H_{max} = maximum unstiffened shell height, ft.

6-6.5.4 Unstiffened Shells If the transformed shell height, H_t, is less than or equal to H_{max}, an intermediate girder is not required.

When no intermediate girders are used, H_{max} shall meet the following requirements. For containers without a hopper, H_{max} shall not exceed the transformed shell height between the top of the shell at the roof–shell connection and the bottom of the shell. For containers with a hopper, H_{max} shall not exceed the transformed shell height between the top of the shell at the roof–shell connection and the hopper-to-cylinder junction, and H_{max} shall not exceed the transformed shell height between the hopper-to-cylinder junction and the bottom of the shell.

6-6.5.5 Circumferentially Stiffened Shells

6-6.5.5.1 General. Container shells may be strengthened with circumferential girders to increase the resistance to buckling under external pressure loading. When circumferential girders are used, the design of the girders shall meet the following requirements.

6-6.5.5.2 Number and Spacing of Intermediate Girders. Calculate the number of intermediate stiffeners required, N_s, based on H_{max}, in accordance with the following equation. A zero or negative value of N_s means that no intermediate stiffeners are required. Round up the calculated value of N_s to the nearest integer for use in subsequent calculations.

$$N_s + 1 = H_t/H_{max}$$

Maximum stiffener spacing for each shell thickness shall be the following:

$$L_x = H_{max}(t_{ax}/t_{amin})^{2.5}$$

where

L_x = stiffener spacing for a given shell thickness, in.

t_{ax} = thickness of the shell in question, in.

6-6.5.5.2.1 The number of waves, N, into which a shell will theoretically buckle under uniform external pressure is determined in accordance with the following equation:

$$N^2 = \left(5.33 d_c{}^3 / t_{amin} H_t{}^2\right)^{0.5} \leq 100$$

For design purposes, the minimum value of N is 2, and the maximum value of N is 10. Use the same N^2 for intermediate and end stiffeners.

6-6.5.5.2.2 The distance between adjacent intermediate stiffeners on the actual shell for a shell of nonuniform thickness is determined in accordance with the following procedures:

(a) Calculate maximum spacing, L_s, on minimum shell thickness, t_{amin}, as follows:

$$L_s = H_t / (N_s + 1)$$

(b) Calculate maximum spacing, L_s, on other shell thicknesses as follows:

$$L_s = [H_t / (N_s + 1)](t_{ax} / t_{amin})^{2.5}$$

where t_{ax} is the individual shell thickness.

(c) Where the spacing between stiffeners includes different shell thicknesses, adjust the actual spacing using the transformed shell spacings adjusted accordingly.

6-6.5.5.2.3 The radial load imposed on the stiffener by the shell is determined in accordance with the following equation:

$$Q = (\text{maximum of } P_s \text{ or } P_e) L_s / 12, \text{ lb}$$

The stiffener should be located at $H_t/(N_s + 1)$ spacing, where N_s is the number of intermediate stiffeners on the transformed shell.

6-6.5.5.2.4 The actual moment of inertia of the intermediate stiffener region, I_{act}, shall be greater than or equal to the total required moment of inertia of this region, I_{reqd}, where

I_{act} = actual moment of inertia of the intermediate stiffener ring region, consisting of the combined moment of inertia of the intermediate stiffener and the shell within a contributing distance on each side of the intermediate stiffener. The contributing distance is determined in accordance with the following equation:

$$w_{shell} = 1.47 (d_c t_{shell})^{0.5} \text{ on each side of the stiffener}$$

where t_{shell} is the actual thickness of the shell plate on which the stiffener is located.

6-6.5.5.2.5 The required moment of inertia of the intermediate stiffener region, I_{reqd}, is determined in accordance with the following equation:

$$I_{reqd} = 648 Q d_c{}^3 / \left[E_y (N^2 - 1)\right]$$

6-6.5.5.2.6 In addition to the moment of inertia requirements stated above, the intermediate stiffener region shall satisfy the following area requirements:

(a) The total required cross-sectional area of the intermediate stiffener region, A_{reqd}, is determined in accordance with the following equation:

$$A_{reqd} = 6 Q d_c / f_c$$

where

f_c = smallest of the allowable compressive stresses of stiffener or shell materials
= $0.4 F_y$ for intermediate stiffeners

(b) The required cross-sectional area of the intermediate stiffener structural shape alone, A_{stiff}, is determined in accordance with the following equation:

$$A_{stiff} = A_{reqd} - 2.94\, t_{shell} \times (d_c t_{shell})^{0.5}$$

$$A_{stiff}(\text{actual}) \geq A_{stiff}(\text{required})$$

$$A_{stiff}(\text{actual}) \geq 0.5 A_{reqd}$$

6-7 OPENINGS IN CYLINDRICAL AND CONICAL SHELLS

Openings in containers shall be engineered and reinforced considering all vertical, horizontal, and shear forces.

6-8 ROOF DESIGN

6-8.1 General

6-8.1.1 Internal Column-Supported Roofs. Roofs supported on internal columns are outside the scope of this Standard.

6-8.1.2 External Pressure Design

(a) Roofs where the roof plate is supported by radial beams or a combination of radial and circumferential members shall meet the stability requirements of paras. 6-8.3 through 6-8.6 and shall be designed so that the sum of all static and dynamic stresses, including an external pressure, P_e, conforms to the ASD provisions of AISC 360 or an equivalent structural design code recognized by the jurisdiction where the container is located.

(b) Elliptical or flanged-and-dished roofs where the roof plate is not supported by any structural members shall follow the rules of the latest edition of ASME BPVC, Section VIII, Division 1 for external pressure design.

(c) Conical and spherical dome roofs discussed in this paragraph, where the roof plate is not supported by any structural members, may also be designed following the

rules of the latest edition of ASME BPVC, Section VIII, Division 1 for external pressure design. The thickness used may be the lesser value obtained from the two design methods. The 0.5-in. maximum roof plate thickness limitation does not apply to thicknesses calculated following the rules of ASME BPVC, Section VIII, Division 1.

6-8.1.3 Minimum Roof Sheet Thickness. Minimum roof sheet thickness for welded construction shall be 0.17 in. (4.5 mm), unless the nominal shell diameter is less than or equal to 14 ft, in which case the minimum roof plate thickness shall be 0.13 in. (3.5 mm), exclusive of corrosion allowance.

Minimum roof plate thickness for bolted construction is as follows:

(a) Roof sheets having a slope of 20 deg or greater shall have a minimum thickness of 0.07 in. (1.8 mm) when the container diameter does not exceed 35 ft (10.7 m) and a minimum thickness of 0.094 in. (2.4 mm) when the container diameter is greater than 35 ft (10.7 m).

(b) Roof sheets having a slope less than 20 deg, regardless of container diameter, shall have a minimum thickness of 0.094 in. (2.4 mm).

For ribbed panels on corrugated containers, reference subsection 6-13.

Minimum roof thickness provisions are not to be substituted for a rational engineering analysis of the roof for required loads.

6-8.2 Self-Supporting Cone Roofs

There are two types of self-supporting cone roofs: smooth and ribbed.

6-8.2.1 Limits on the Slope of a Self-Supporting Cone Roof. Self-supporting cone roofs shall have a cone angle, Θ, of the roof to the horizontal of no less than 9.5 deg and no greater than 45 deg.

6-8.2.2 Minimum Required Roof Thickness Against Buckling From External Pressure. The minimum calculated roof plate thickness is based on the membrane forces generated by uniform and symmetrical compressive loads, T, but shall not be less than the minimum roof thickness provisions of para. 6-8.1.3.

Based on a design margin of 2 against buckling, the minimum required roof plate thickness, t_h, is given by the following equation:

$$t_h = (2d_c/\sin\Theta)\left(T/E_y\right)^{0.5} + \text{CA}$$

where

CA = corrosion allowance, in.
d_c = nominal diameter of the container, ft
E_y = modulus of elasticity of the roof plate material, psi
T = total combined uniform external load, lb/ft^2
Θ = cone angle of the roof to the horizontal, deg

Maximum roof plate thickness is 0.5 in. (13 mm), exclusive of corrosion allowance.

6-8.2.3 Roof-to-Shell Cross Section. The required cross-sectional area, in square inches, of the top angle and participating cross-sectional areas of the shell and roof plates shall be determined using Figure 6-8.2.3-1 and shall equal or exceed the larger of the following:

(a) the requirements of para. 6-8.7

(b) the area, in square inches, determined from the following equation:

$$Td_c^{\,2}/(8F_a\tan\Theta)$$

where

d_c = nominal diameter of the container, ft
F_a = allowable tensile stress for the materials in the roof-to-shell joint, psi
= $0.6F_y$
F_y = the average yield strength of the roof-to-shell joint materials at maximum design temperature, psi
T = total combined uniform external load, lbf/ft^2
Θ = cone angle of the roof to the horizontal, deg

The area calculated from these expressions is based on the nominal material thickness less any corrosion allowance.

6-8.3 Self-Supporting Spherical and Umbrella Dome Roofs

6-8.3.1 Limits on Self-Supporting Spherical and Umbrella Dome Roofs. Self-supporting spherical and umbrella dome roofs shall conform to the following requirement:

$$20\text{ deg} \le \Theta \le 60\text{ deg}$$

where

Θ = dome roof angle to the horizontal at the junction with the container shell, deg

6-8.3.2 Required Thickness for Dome Roofs. Based on symmetrical roof loading and a factor of safety of 2 against buckling, the minimum required roof plate thickness is obtained from one of the following:

(a) For Spherical Domes

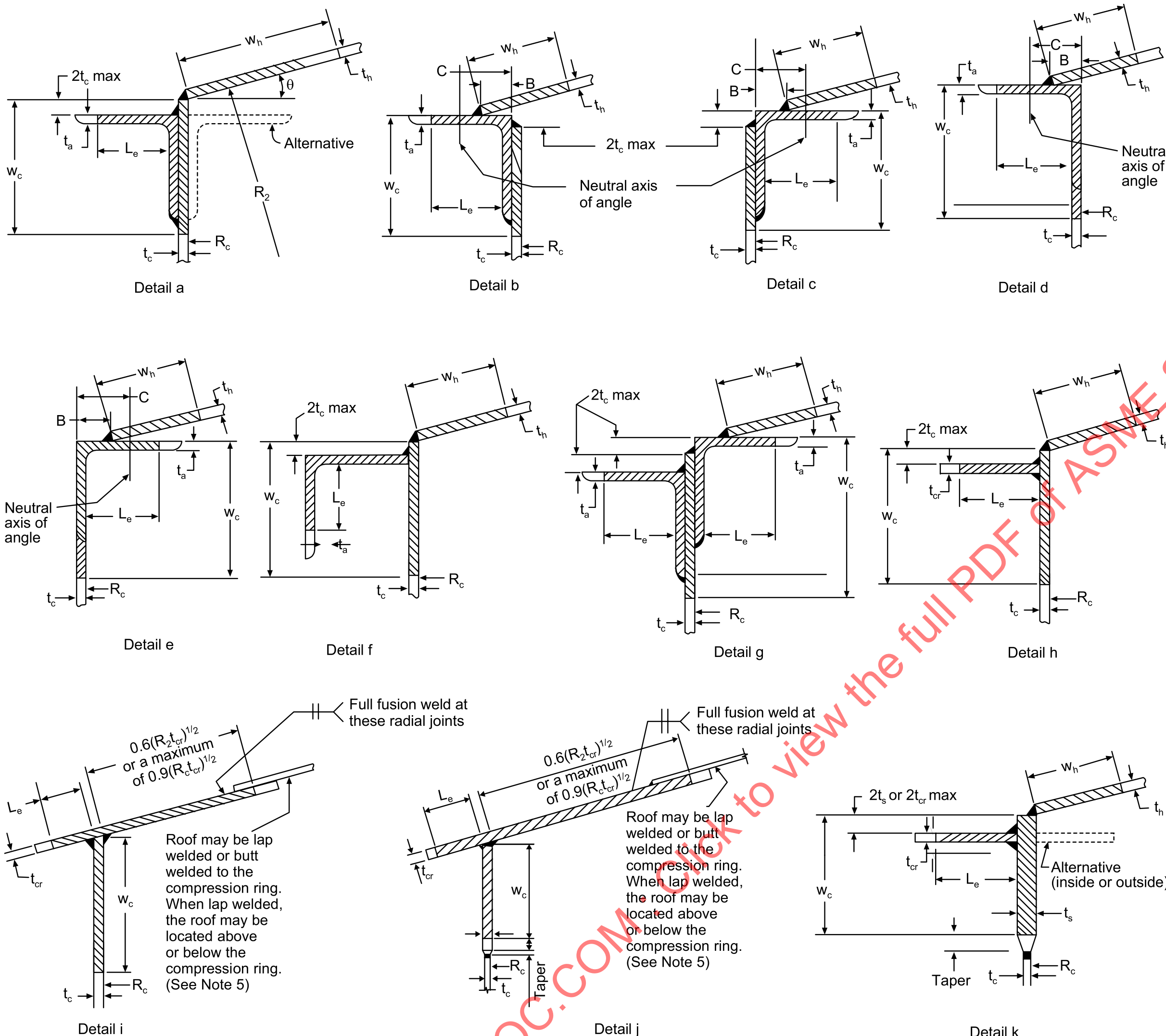
(1) For $R_2/t_h \ge 400$ to $\le 2{,}000$

$$T \le 21.6E_y\lambda_m(1 - 0.07R_2/400t_h)(t_h/R_2)^2$$

(2) For $R_2/t_h \ge 2{,}000$

$$T \le 14E_y\lambda_m(1 - 0.07R_2/400t_h)(t_h/R_2)^2$$

Figure 6-8.2.3-1
Permissible Roof-to-Shell Connection Details



t_a = thickness of angle leg
t_{cr} = thickness of bar
t_c = thickness of shell plate
t_h = thickness of roof plate
t_s = thickness of thickened plate in shell
t_f = t_a plus t_c (see note 4)
w_c = maximum width of participating shell = $0.6\,(R_c\,t)^{1/2}$, where $t = t_a$, t_c, t_s, or t_f as applicable.

w_h = maximum width of participating roof = $0.3(R_2\,t_h)^{1/2}$ or 300 mm (12 in.) whichever is less.
R_c = inside radius of tank shell
R_2 = length of the normal to the roof, measured from the vertical centerline of the tank = R_c / (sin θ)
θ = angle between roof and horizontal

NOTE 1 All dimensions and thicknesses are in millimeters (inches).

NOTE 2 Dimension B in details b, c, d, and e is 0 ≤ B ≤ C. C is the dimension to the neutral axis of the angle.

NOTE 3 The unstiffened length of the angle or bar, L_e, shall be limited to $250t/(F_y)^{1/2}$ mm $[3000t/(F_y)^{1/2}$ in.] where F_y is the minimum specified yield strength, MPa (lbf/in.²) and $t = t_a$ or t_b, as applicable.

NOTE 4 Where members are lap welded onto the shell (refer to details a, b, c, and g), t_f may be used in w_c formula only for the extent of the overlap.

NOTE 5 When the lap welded roof plate is located under the compression bar, the Purchaser should consider the use of caulking on top of the fillet weld to ensure the drainage of rainfall.

GENERAL NOTE: This figure is Figure F.2 from API Standard 650, Welded Tanks for Oil Storage (2020, 13th ed.). Reproduced courtesy of the American Petroleum Institute.

(b) For Umbrella Domes

(1) For $R_2/t_h \geq 400$ to < 2,000

$$T \leq 10.8E_y\lambda_m(1 - 0.07R_2/400t_h)(t_h/R_2)^2$$

(2) For $R_2/t_h \geq 2{,}000$

$$T \leq 7E_y\lambda_m(1 - 0.07R_2/400t_h)(t_h/R_2)^2$$

where

E_y = modulus of elasticity, psi
m = 1 − 0.175(Θ − 20 deg)/20 deg
R_2 = dome radius of roof, in.
T = total combined uniform external load, psf
t_c = thickness of the container shell, in.
t_h = required dome shell thickness to support the design load T, in.
λ = 1 for $t_c/t_h \geq 1$ (For $0 < t_c/t_h < 1$, λ is determined by interpolating linearly between 0.6 and 1.)

The maximum roof plate thickness is 0.5 in. (13 mm), exclusive of corrosion allowance.

6-8.3.3 Roof-to-Shell Cross Section. The required cross-sectional area of the top angle, in square inches, plus the participating cross-sectional areas of the shell and roof plates shall be determined using Figure 6-8.2.3-1 and shall equal or exceed the larger of the following:

(a) the requirements of para. 6-8.7

(b) the area, in square inches, determined from the following equation:

$$Td_c^{\,2}/(8F_a\tan\Theta)$$

where

d_c = nominal diameter of the container, ft
F_a = allowable tensile stress for the materials in the roof-to-shell joint, psi
= $0.6F_y$
F_y = the average yield strength of the roof-to-shell joint materials at maximum design temperature, psi
T = total combined uniform external load, lbf/ft^2
Θ = dome roof angle to the horizontal at the junction with the container shell, deg

The area calculated from this expression is based on the nominal material thickness less any corrosion allowance.

6-8.4 Rafter-Supported Cone Roofs

6-8.4.1 Minimum Slope for Conical Roofs. The slope of a rafter-supported cone roof shall be 1:16 or greater.

6-8.4.2 Types of Rafters. Rafters shall be rolled, fabricated sections, or trusses.

6-8.4.3 Effective Width of the Roof Plate. If the rafters are attached to the roof plate, an effective width of 16t on either side of the rafter may be considered as part of the rafter cross section, where t is the nominal roof plate thickness less any corrosion allowance. The attachment strength shall be sufficient to transfer shear between the roof plate and rafters to develop the required force in the plate.

6-8.4.4 Unattached Roof Plates. When a rafter is not attached to the roof plate, support of the rafter compression flange against lateral buckling due to design loads, T, is required only if the compression flange is not stabilized by roof plate friction.

6-8.4.5 Lateral Buckling of Rafters. Rafters shall be checked against lateral buckling due to forces resulting from loads resisted by the roof support system.

6-8.4.6 Maximum Rafter Spacing. For roofs with a slope of 20 deg or less, maximum spacing at the eave between rafters shall not exceed the larger of the requirements of (a) or (b).

(a) Rafters shall be spaced to satisfy the following:

$$L_{rc} = t_h\sqrt{\frac{1.5F_y}{T/144}} \leq 84\text{ in.}$$

where

F_y = minimum yield strength of roof plate material, psi
L_{rc} = maximum allowable spacing of rafters, measured circumferentially from center-to-center of rafters, in.
T = total combined uniform external load, lbf/ft^2
t_h = roof plate thickness less the corrosion allowance, in.

(b) The rafter spacing to limit local plate deformation shall be obtained from the following equations, including a design margin of 2:

(1) For $K_r \leq 1$

$$T \leq 9E_y(t_h/R_2)^2(K_r + 1/K_r)$$
$$\leq 71.7E_y(t_h/R_2)^2$$

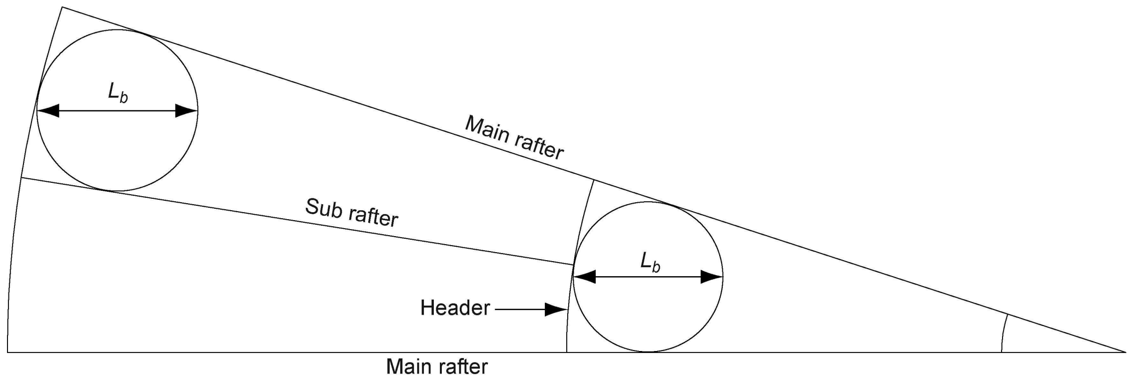
(2) For $K_r \geq 1$

$$T \leq 18E_y(t_h/R_2)^2$$

where T and t_h are as defined in (a) and

E_y = modulus of elasticity, psi
K_r = $L_b^{\,2}/(58.4R_2t_h)$
L_b = diameter of the buckle, in.
= diameter of the circle inscribed in the largest roof panel (see Figure 6-8.4.6-1)
R_2 = cone roof radius perpendicular to the cone surface at the point under consideration, in.

Figure 6-8.4.6-1
Maximum Spacing of Rafters in Spherical/Umbrella Dome Roofs



6-8.4.7 Circumferential Bracing of Rafters. The design engineer shall determine circumferential bracing requirements based on the structural system employed. Bracing systems may be added for lateral support during erection.

6-8.4.8 Roof-to-Shell Cross-Section Requirements. The required cross-sectional area, in square inches, of the top angle and participating cross-sectional areas of the shell and roof plates shall be determined using Figure 6-8.2.3-1 and shall equal or exceed the larger of the following:

(a) the requirements of para. 6-8.7

(b) the area, in square inches, determined from the following equation:

$$Td_c^{\,2}/(8F_a \tan\Theta)$$

where

d_c = nominal diameter of the container, ft
F_a = allowable tensile stress for the materials in the roof-to-shell joint, psi
= $0.6F_y$
F_y = the average yield strength of the roof-to-shell joint materials at maximum design temperature, psi
T = total combined uniform external load, lbf/ft^2
Θ = cone angle to the horizontal, deg

The area calculated from these expressions is based on the nominal material thickness less any corrosion allowance. This paragraph does not apply if the center ring is supported by beams or trusses.

6-8.5 Rafter-Supported Spherical and Umbrella Dome Roofs

6-8.5.1 Limitation of Geometry. Rafter-supported dome roofs shall conform to the following requirement:

$$20 \text{ deg} \leq \Theta \leq 60 \text{ deg}$$

where

Θ = dome roof angle to the horizontal at the junction with the container shell, deg

6-8.5.2 Acceptable Rafter Sections. Rafters may be rolled, fabricated sections, or trusses.

6-8.5.3 Effective Width of Roof Plate. If the rafters are attached to a roof plate that is 0.094 in. or thicker, an effective width of $16t$ of the roof plate on either side of the rafter may be considered as part of the rafter cross section, where t is the nominal roof plate thickness less any corrosion allowance. The attachment strength shall be sufficient to transfer shear between the roof plate and rafters to develop the required force in the plate portion of the composite cross section.

6-8.5.4 Support of Compression Flange. For rafters that are not attached to the roof plate, support of the compression flange against lateral buckling due to live and dead loads, T, is only required in the negative moment region where the compression flange is not stabilized by the roof plate friction force.

6-8.5.5 Design Model for Rafters. Rafters are to be designed as members of a three-hinged arch simply supported at the container shell and pinned at the center ring. An even number of rafters shall be used.

6-8.5.6 Lateral Buckling of Rafters. Rafters must be checked for lateral buckling due to axial forces resulting from loads caused by temperature probe cables, conveyors, or equipment supported by the center compression ring. It is possible for uplift to occur on portions of the roof due to wind or internal pressure that cause a loss of contact between the roof plate and rafter.

6-8.5.7 Maximum Spacing of Rafters. Spacing between rafters at the inner or outer ring may be the larger of the requirements in (a) or (b).

(a) Rafters shall be spaced to satisfy

$$L_{rc} = t_h \sqrt{\frac{1.5F_y}{T/144}} \leq 84 \text{ in.}$$

where

F_y = minimum yield strength of roof plate material
L_{rc} = maximum allowable spacing of rafters, measured circumferentially from center-to-center of rafters, in.
T = total combined uniform external load, lbf/ft^2
t_h = roof/dome plate thickness in the corroded condition, in.

(b) The rafter spacing may be obtained from the following equations for local plate buckling between the rafters, including a safety factor of 2:

(1) For $K_r \geq 1$

$$T \geq 9E(t_h/R_2)^2(K_r + 1/K_r) \leq 71.7E_y(t_h/R_2)^2$$

(2) For $K_r \geq 1$

$$T \geq 18E_y(t_h/R_2)^2$$

where t_h and T are as defined in (a) and

E_y = modulus of elasticity, psi
K_r = $L_b{}^2/(58.4R_2t_h)$
L_b = diameter of the buckle, in.
= diameter of the circle inscribed in the largest roof plate panel (see Figure 6-8.4.6-1)
R_2 = roof/dome radius, in.

6-8.5.8 Rafter Buckling

(a) Industry experience has shown for normal, well-designed construction, the first three modes of rafter buckling shown in Figure 6-8.5.8-1 do not occur because they involve an outward movement of the rafter that is prevented by the roof plate, whether the plate is welded to the rafters or not. To prevent the snap-through buckling shown in Figure 6-8.5.8-1, illustration (d), the following ratio shall be satisfied:

$$h_r/r_x \geq 4.69$$

where

h_r = rise of the arch, in.
r_x = radius of gyration of the rafter in the axis normal to the buckling plane, in.

(b) To prevent roof buckling due to an asymmetrical live load, the roof shall be designed for a full uniform live load. Buckling due to asymmetrical loading will be prevented if the following equation is satisfied:

$$I_x = \beta nP(R_2/100)^2/29.4$$

where

I_x = rafter moment of inertia, in.^{4}
n = safety factor
= 1.3
P = largest axial force in rafter, kips
R_2 = dome radius, in.
β = 0.83 for roofs with attached plates
= 1.0 for unattached roof plates

6-8.5.8.1 Circumferential Bracing of Rafters. Circumferential bracing is not necessary, except when it is needed for lateral support in any negative moment regions or for support during erection.

6-8.5.8.2 Rafter Clips. Rafter clips for the outer row of rafters shall be attached to the container shell in a method adequate for required force transfer.

6-8.5.9 Roof-to-Shell Cross Section. The required cross-sectional area, in square inches, of the top angle and/or the participating cross-sectional areas of the shell and roof plates shall be determined using Figure 6-8.2.3-1. It shall equal or exceed the larger of the following:

(a) the requirements of para. 6-8.7

(b) the area, in square inches, determined from the following equation:

$$Td_c{}^2/(8F_a \tan\Theta)$$

where

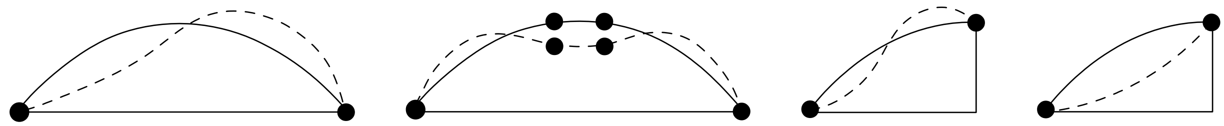
d_c = nominal diameter of the container, ft
F_a = allowable tensile stress for the materials in the roof-to-shell joint, psi
= $0.6F_y$
F_y = average yield strength of the roof-to-shell joint materials at maximum design temperature, psi
T = total combined uniform external load, lbf/ft^2
Θ = dome roof angle to the horizontal at the junction with the container shell, deg

The area calculated from this equation is based on the nominal material thickness less any corrosion allowance.

6-8.6 Internal Pressure Design

The roof thickness equations in paras. 6-8.6.1 through 6-8.6.4 apply to structurally supported and self-supported roofs. The roof thickness determined from the provisions

Figure 6-8.5.8-1
Dome Roof Rafter Buckling Modes



of paras. 6-8.6.1 through 6-8.6.3 shall not be less than the minimum roof thickness provisions of para. 6-8.1.3.

The anchorage for a ground-supported container without a hopper shall be checked for uplift if the internal pressure is greater than the combined weight of the shell, the roof, and any attached structural members.

6-8.6.1 Conical and Umbrella Roofs. The required roof plate thickness, t_h, for conical and umbrella roofs shall be calculated as follows:

$$t_h = R_{2c}(144p_i - D_{LR})/(12S_dE_{rf}) + CA$$

where

CA = corrosion allowance, in.
D_{LR} = dead load of roof plate plus any structure attached to roof plate, lbf/ft^2
E_{rf} = joint efficiency
p_i = internal design pressure, psi
R_{2c} = roof radius perpendicular to the roof surface at the location under consideration, ft
S_d = maximum allowable design tensile stress, psi

6-8.6.2 Spherical Roofs. The required roof plate thickness, t_h, for spherical roofs shall be calculated as follows:

$$t_h = R_{2c}(144p_i - D_{LR})/(24S_dE_{rf}) + CA$$

where terms are as defined in para. 6-8.6.1.

6-8.6.3 Elliptical and Flanged-and-Dished Roofs. The required thickness of these roofs shall be calculated in conformance with the rules of ASME BPVC, Section VIII, Division 1, para. UG-32.

6-8.6.4 Roof-to-Shell Cross Section. The required cross-sectional area, in square inches, of the top angle and/or the participating cross-sectional areas of the shell and roof plates shall be determined using Figure 6-8.2.3-1 and shall equal or exceed the larger of the following:

(a) the requirements of para. 6-8.7
(b) the area, in square inches, determined from the following equation:

$$d_c^2[27.7p_i - (0.245D_{LR}/d_c^2)]/0.962F_y\tan\Theta)$$

where

d_c = nominal diameter of the container, ft
D_{LR} = nominal weight of roof plate plus any structure attached to roof plate, lbf
F_y = average yield strength of the roof-to-shell joint materials at maximum design temperature, psi
p_i = internal pressure, psi
Θ = roof angle to the horizontal at the junction with the container shell, deg

The area calculated from this equation is based on the nominal material thickness less any corrosion allowance.

6-8.7 Compression or Tension Ring at the Roof–Cylindrical Shell Junction

6-8.7.1 General. This paragraph applies only to cone, spherical dome, and umbrella dome roofs with a radius greater than the container radius. The longitudinal forces in hemispherical, full elliptical, and flanged-and-dished heads at the junction with the cylindrical container are the same as in the cylindrical container, so there are no unbalanced forces.

When the roof attaching to a cylindrical container sidewall is a cone or partial sphere, the longitudinal membrane forces in the roof pull inward or push outward on the periphery of the container sidewalls. The inward pull, caused by axial tension stresses, results in circumferential compressive forces at the juncture. The outward push, caused by axial compressive stresses, results in circumferential tensile forces at the juncture. These unbalanced compressive or tensile forces are resisted by a limited zone at the juncture of the intersecting roof and container sidewall plates, supplemented if required by a horizontally disposed stiffener ring (see Figure 6-8.2.3-1).

6-8.7.2 External Pressure on the Roof. When the container is acted upon by external pressure, the circumferential force, Q, is positive, and the ring at the roof–cylinder junction is a tension ring. The final dimensions of the ring shall be the greater of the dimensions obtained in paras. 6-8.7.3 and 6-8.7.4 and those calculated in para. 6-6.6.

6-8.7.3 Compression or Tension Ring Dimensions. The variables used to calculate the required compression or tension ring are defined in (a) through (d). The equations in the following subparagraphs are not unit specific; however, consistent units shall be used with these equations.

(a) Width. The width of the roof and shell plate making up the compression or tension ring region is computed from the following equations:

$$w_h = 0.3\sqrt{R_{rs}(t_h - \text{CA})}$$
$$w_c = 0.6\sqrt{R_c(t_c - \text{CA})}$$

where

CA = corrosion allowance
R_c = shell radius at the roof-to-shell junction
R_{rs} = roof radius measured perpendicular to the roof surface at the roof-to-shell junction
t_c = thickness of the shell at the roof-to-shell junction
t_h = thickness of the roof plate at the roof-to-shell junction
w_c = participating width of the shell at the roof-to-shell junction
w_h = participating width of the roof plate at the roof-to-shell junction

(b) Force. The magnitude of the total circumferential force, Q, acting on any vertical cross section through the compression or tension ring region is computed from

$$Q = T_2 w_h + T_{2s} w_c - T_1 R_c \cos\Theta$$

where

T_1 = longitudinal force in the roof plate at the roof-to-shell junction
T_2 = hoop force in the roof plate at the roof-to-shell junction
T_{2s} = hoop force in the shell at the roof-to-shell junction
Θ = roof angle to the horizontal at the junction with the container shell, deg

(c) Area. The net cross-sectional area provided in the compression or tension ring region shall not be less than required by one of the following equations:

(1) If Q is negative

$$A_c = Q / 0.42 F_{yt}$$

(2) If Q is positive

$$A_c = Q / S_d E_{tr}$$

where

E_{tr} = joint efficiency for compression or tension ring region
F_{yt} = average yield strength of the roof-to-shell joint materials at maximum design temperature
S_d = maximum allowable design tensile stress

(d) Reinforcement. When the magnitude of the circumferential force, Q, is such that the required area, A_c, is not provided in the compression and tension ring region by the roof and shell plates, the compression or tension ring region shall be reinforced by one or both of the following:

(1) thickening the roof and sidewall plates as required to provide the necessary cross-sectional area and width for the thicker plates

(2) adding an angle section or rectangular bar at the juncture of the roof and side wall plates

6-8.7.4 Limiting Dimensions of Compression or Tension Ring Section. The horizontal width of the compression or tension ring angle or bar, where present, shall not be less than 0.015 times the horizontal radius, R_c, of the container's cylindrical shell at the juncture of the roof and side walls. When the cross-sectional area to be added by an angle or bar is not more than one-half of the required area, the width requirement for this member may be disregarded under the following conditions:

(a) The horizontal projection of the width, w_h, of the participating roof plate alone is equal to or greater than $0.015R_c$.

(b) If the angle or bar is located on the outside of the container, the sum of the projection of the width, w_h, and the horizontal width of the added angle or bar is equal to or greater than $0.015R_c$.

6-8.7.5 Butt Welding of Radial Joints. For welded containers, all radial joints in any angle or flat bar in the compression or tension ring shall be butt welded.

6-9 ANCHORAGE DESIGN

6-9.1 General

(a) When anchorage is required and the container is ground supported with the shell resting on concrete foundations or footings, the anchorage into the concrete may be designed using the provisions of ACI 318, Chapter 17. For containers supported on steel structures, the anchorage and supporting structure shall be designed per the latest edition of AISC 360.

(b) Containers with an elevated hopper shall be anchored with anchor rods.

(c) When anchor rods are required for ground-supported containers, a minimum of six rods shall be installed. The rods shall be equally spaced, except where interference with accessories does not permit uniform spacing. If two adjacent anchor rods must be moved more than 50% of their uniform spacing, a special analysis is required to recalculate the anchor rod loads. The maximum anchor rod spacing shall not exceed the following:

(1) 6 ft for ground-supported containers less than 40 ft in diameter

(2) 10 ft for ground-supported containers equal to or greater than 40 ft in diameter

(d) If more than the minimum six anchor rods are required [see (c)], the rods should be installed in multiples of four for ease of installation.

(e) The minimum anchor rod diameter shall be 0.625 in.

(f) Anchor rod material shall be selected in accordance with Section 5.

(g) Anchor rods may be attached to welded container shells through chair-type assemblies. An acceptable procedure for anchor chair design is given in AISI E-1, Volume II, Part VI. Other design procedures or anchor chair configurations may be used, provided they are based on a detailed structural analysis utilizing accepted methods and references.

(h) Anchor rods shall be tightened to a snug fit.

(i) The threaded ends of foundation anchor rods shall project above the foundation an amount to allow for tolerances in the foundation elevations as listed on the foundation documents and not be lower than flush with the top of the anchor rod nut.

(j) The foundation shall provide adequate counterbalancing weight to resist design uplift loads.

6-9.2 Self-Anchored Containers

6-9.2.1 Wind Load Resistance. For either ground-supported or elevated-hopper containers

$$Dc_w = W_r + W_s + W_h + W_{ep} + W_{eq}$$

where

Dc_w = total counteracting dead load in resistance to the wind-equivalent vertical load, lb
W_{ep} = weight of permanently mounted equipment, lb
W_{eq} = weight of equipment that is accounted for as inducing the total container wind load, lb
W_h = weight of the elevated hopper, lb
W_r = weight of the roof, lb
W_s = weight of the shell, lb

6-9.2.2 Earthquake Load Resistance

(a) Ground-supported containers' resistance to earthquake loads shall be determined for both the empty and product-filled (to capacity) conditions.

(1) For empty ground-supported containers

$$Dc_{ee} = W_r + W_s + W_{ep} + W_{eq}$$

where

Dc_{ee} = total counteracting dead load of the empty container in resistance to an earthquake-equivalent vertical load, lb
W_{ep} = weight of permanently mounted equipment, lb
W_{eq} = equipment dead load that was included in calculating the total container earthquake load, lb
W_r = weight of the roof, lb
W_s = weight of the shell, lb

(2) For ground-supported containers storing product

$$Dc_e = W_r + W_s + W_{ep} + W_{eq} + W_v$$

where

Dc_e = total counteracting dead load of the container and product in resistance to an earthquake-equivalent vertical load, lb
W_v = vertical load at the base of the container shell resulting from the friction force that the stored product exerts on the shell due to fill pressures, lb

See Section 5 and para. 6-4.1 for additional information on loads and load combinations.

(b) For elevated-hopper containers

$$Dc_e = W_r + W_s + W_h + W_{ep} + W_{eq} + W_l$$

where

Dc_e = total counteracting dead load to the empty container earthquake-equivalent vertical load, lb
W_h = weight of the elevated hopper, lb
W_l = weight of the product stored in the container, lb

6-9.3 Anchored Containers

6-9.3.1 Requirements for Anchorage. While listed in U.S. Customary units, the equations of para. 6-9.3 will work with use of consistent units of length and force.

(a) Anchorage against overturning shall be provided when the total equivalent vertical load (EVL) due to wind or earthquake exceeds the applicable resisting dead load, Dc_e, with all load combination factors included from referenced design code.

$$\text{EVL} = (4M_{oa}/d_c) + P_{\text{supp}}$$

where

d_c = nominal diameter of the container, ft
EVL = total equivalent vertical load due to overturning moment from wind or earthquake conditions, lb
M_{oa} = overturning moment due to wind or earthquake loads, ft-lb
P_{supp} = any additional vertical acceleration required by the applicable wind or earthquake design code, lb

(b) When the container is on a foundation other than concrete, anchorage shall be provided for the calculated shear force on the container.

(c) For containers bearing on concrete foundations, shear in anchorage shall be included in anchor and foundation design when the total shear force on the container from the appropriate load combination from the referenced building code, V_{st}, is greater than the sliding check.

If

$$V_{st} \geq (\tan 30 \text{ deg})Dc_i$$

then the anchorage system must be designed for the shear forces on the container.

where

Dc_i = the applicable total counteracting dead load (Dc_{ee},Dc_e) from para. 6-9.2.2, lb

V_{st} = total shear force on the container from wind or earthquake actions

6-9.3.2 Anchor Rod Design Forces

(a) When anchor rods are required, the design tension per anchor rod shall be determined as follows:

$$T_b = s_a(\text{EVL}a - Dc_{ai})$$

where

Dc_{ai} = applicable counteracting dead load per unit length of circumference, lb/ft

= $Dc_i/d_c\pi$

d_c = nominal diameter of the container, ft

Dc_i = as defined in para. 6-9.3.1

EVLa = equivalent vertical load per feet of circumference due to wind or earthquake overturning moment, at the anchor rod bolt circle

= $4M_{oa}/D_a{}^2\pi + P_{\text{suppcirc}}$, where

d_a = anchor rod diameter bolt circle, ft

M_{oa} = overturning moment due to wind or earthquake loads, ft-lb

P_{suppcirc} = any additional vertical acceleration required by the applicable wind or earthquake design code, per foot of circumference, lb/ft

s_a = anchor rod spacing around the container circumference, ft

T_b = tension per anchor rod, lb

(b) The design shear per anchor rod shall be determined as follows:

$$V_b = s_a(V_{ul} - VDc_{ai})$$

where

s_a = anchor rod spacing around the container circumference, ft

V_b = shear per anchor rod, lb

V_{ul} = equivalent shear per unit length of circumference due to wind or earthquake, lb/ft

= $V_t/d_c\pi$

d_c = nominal diameter of the container, ft

V_t = total shear, lb

VDc_{ai} = applicable counteracting dead load per unit length of circumference, lb/ft

= tan (30 deg)($Dc_i/d_c\pi$) for containers bearing on concrete foundations

= 0 for all other containers

NOTE: If there is shear in the anchor rod, the shell attachment shall be designed to allow for shear transfer between the shell and anchor rod.

(c) Anchor rods shall be designed using the provisions of ACI 318, Chapter 17, or AISC 360.

6-10 CONTAINERS WITH SUSPENDED CONICAL HOPPERS

6-10.1 General

The design procedure outlined in this subsection assumes that the product will flow freely during discharge and that it will not arch or remain suspended in the cone or the cylindrical portion of the shell. Erratic product flow during discharge imposes forces and loads outside the scope of this Standard that are not predictive by commonly accepted bulk material container load calculation methods.

If product is expected to flow erratically from a container with the defined geometry, cone surface finish, and discharge equipment, or there are other possible disruptions to product flow characteristics, flow testing shall be performed so that physical adjustments can be made to the container to ensure the free flow of product during discharge.

The equations of subsection 6-10 are valid with U.S. Customary or SI units, as long as consistent units are used.

6-10.2 Stresses in Suspended Conical Hoppers

The pressures from a contained solid on the walls of a conical hopper shall be taken from Section 5. The hopper is subject to both meridional (sloping) and circumferential (hoop) stresses, which shall be separately verified for bolted construction but may be verified together for welded construction.

The hopper wall pressures calculated from the equations in Section 5 are used in the stress equations.

(a) The resulting hoop force per unit width, $n_{\theta h}$, in the hopper wall is calculated as

$$n_{\theta h} = p_{ne}R_{n(x)}$$

(b) The resulting meridional force per unit width, $n_{\phi h}$, is calculated as

$$n_{\phi h} = q_v/\cos\theta$$

(c) The resulting combined force per unit width, n_{vm}, is calculated as

$$n_{vm} = \left(n_{\theta h}{}^2 + n_{\theta h} n_{\phi h} + n_{\phi h}{}^2\right)^{0.5}$$

where

pne = normal pressure on the hopper wall at level x above the apex [calculated from eq. (5-23)]
= $q_v = [P_v(x)D(x)^2\pi/4 + \gamma_u \text{Vol}(x) + w_e]/D(x)\pi$

$D(x)$ = diameter of hopper at level x above apex

$p_{v(x)}$ = vertical pressure at level x above the apex [calculated from eq. (5-25)]

Vol(x) = volume of the hopper at level x height above the apex

W_e = weight of equipment suspended from hopper

γ_u = upper characteristic value of the solid unit weight

$R_{n(x)}$ = radius normal to the hopper at level x above the apex
= $x \sec\theta \tan\theta$

θ = angle of inclination of hopper wall from vertical (hopper half angle)

See Figure 5-2.6.2-2.

6-10.3 Welded Conical Hoppers

The combined stress, S_{vm}, at every level should be found as

$$S_{vm} = n_{vm}/t$$

where n_{vm} is as defined in para. 6-10.2(c) and t is the plate thickness at the level being analyzed.

The combined stress, S_{vm}, at every level should be less than or equal to the maximum design allowable tensile stress.

$$S_{vm} \le ES_d/SF$$

where

E = joint efficiency factor (see Table 7-2.2.6-1). Alternatively, E = 0.85 for spot radiographed joints or 0.7 if spot radiography is omitted.

SF = safety margin
= 1.67

6-10.4 Bolted Conical Hoppers

The plates of a bolted conical hopper shall satisfy both the requirements of the welded hopper (see para. 6-10.3) and the requirements for forces to be transmitted through the bolted joints.

All meridional joints shall be dimensioned according to the requirements of para. 6-12.3 to properly transmit the circumferential force per unit width, $n_{\theta h}$.

All horizontal-bolted joints shall be dimensioned according to the requirements of para. 6-12.3 to properly transmit the meridional force per unit width, $n_{\phi h}$.

The joint efficiency factor, E, for bolted joints shall be used in these calculations (see subsection 6-12).

6-10.5 Reinforcement at the Cone–Cylinder Junction

6-10.5.1 General. In designing a compression ring, it is permissible to assume that the conical hopper supports the entire weight of the stored product within the container. Alternatively, the force in the compression ring may be found from the meridional tension, $n_{\phi h,\text{top}}$, at the top of the hopper. Note that this method results in a less conservative compression ring force value.

$$n_{\phi h,\text{top}} = \left\{p_{vft} + \left[\gamma_u \text{Vol}_{(x)} + W_e\right]/R^2\pi\right\}(h_h/2)\tan\theta/\cos\theta$$

where

h = height of the hopper from apex to the transition junction

p_{vft} = vertical pressure in the solid at the transition junction level [calculated from eq. (5-22)]

R = radius of the cylinder at the junction

Vol(x) = volume of the hopper at level x height above the apex

W_e = weight of equipment suspended from hopper

γ_u = upper characteristic value of the solid unit weight

θ = angle of inclination of hopper wall from vertical (hopper half angle; see Figure 6-10.5.1-1)

6-10.5.2 Circumferential Compressive Total Force. The circumferential total compressive force, N_c, at a cone–cylinder junction that is supported on a skirt or a ring girder may be determined as

$$N_c = n_{\varphi h} R \sin\theta$$

where

$n_{\phi h}$ = meridional tension at the top of the hopper (see para. 6-10.5.1)

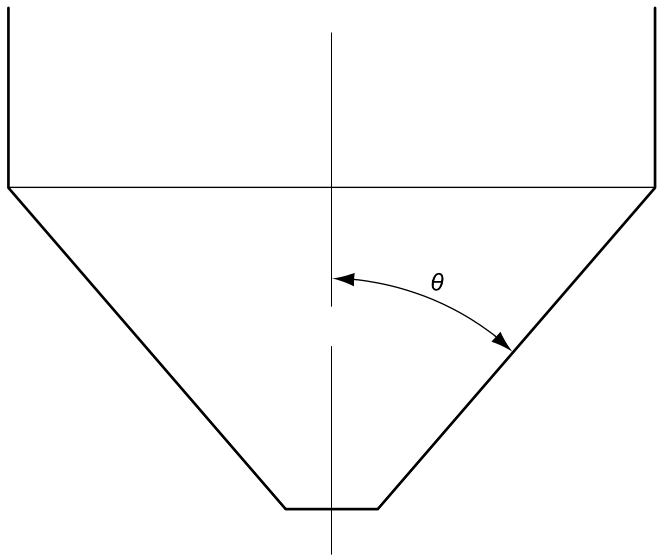
R = radius of the cylinder at the junction

θ = angle of inclination of hopper wall from vertical (hopper half angle)

6-10.5.3 Effective Area of a Compression Ring at the Cone–Cylinder Junction. The effective area of a compression ring, A_e, at the cone–cylinder junction shall be calculated as follows:

$$A_e = \Sigma A_i + A_r$$

Figure 6-10.5.1-1
Hopper Apex Half Angle



Legend:
θ = apex half angle

where

A_i = effective area of each element of the effective compression ring area (see Figure 6-10.5.3-1), which is the thickness of the element times the effective length of the element

A_r = cross-sectional area of an added rolled section [see Figure 6-10.5.3-2, illustrations (d), (f), and (g)]

Effective lengths are defined as follows:

$$l_e = 0.6(R_n t)^{0.5} \leq 16t$$

$$l_{eb} = 16t_b$$

where

l_e = effective length of the element from the attachment plate bolted or welded to the shell (Any vertical plate area that lies beyond l_e from the intersection of the centerlines should be discounted.)

l_{eb} = effective length of a horizontal stiffening element from the attachment to the shell wall

R_n = radius normal to the element

t = thickness of the element (t_c, t_s, and t_h are the thicknesses of the cylinder, skirt, and hopper, respectively.)

t_b = thickness of the bar

See Figures 6-10.5.3-1 and 6-10.5.3-2 for illustrations of l_e, l_{eb}, t, and t_b.

For elements that are comprised of slender sections beyond the limitations of l_e, the designer shall consider the occurrence of lateral bending across the member.

The centroid of any added rolled section or plate ring should be within $0.3(Rt)^{0.5}$ of the hopper to vertical element intersection (see Figure 6-10.5.3-3). Sections located beyond $0.3(Rt)^{0.5}$ may be used with additional design analysis.

Consistent units of measure shall be used.

6-10.5.4 Compressive Stress in the Effective Compression Ring at the Cone–Cylinder Junction. The circumferential compressive stress at the junction between the cone and cylinder can be evaluated as follows:

$$S_c = \frac{N_c}{A_e}$$

where

A_e = effective area of the compression ring, in.^{2}

N_c = circumferential total compressive force at a cone–cylinder junction that is supported on a skirt or a ring girder, lb

Consistent units of measure shall be used.

Figure 6-10.5.3-1
Effective Area of Compression Ring at Cone–Cylinder Junction

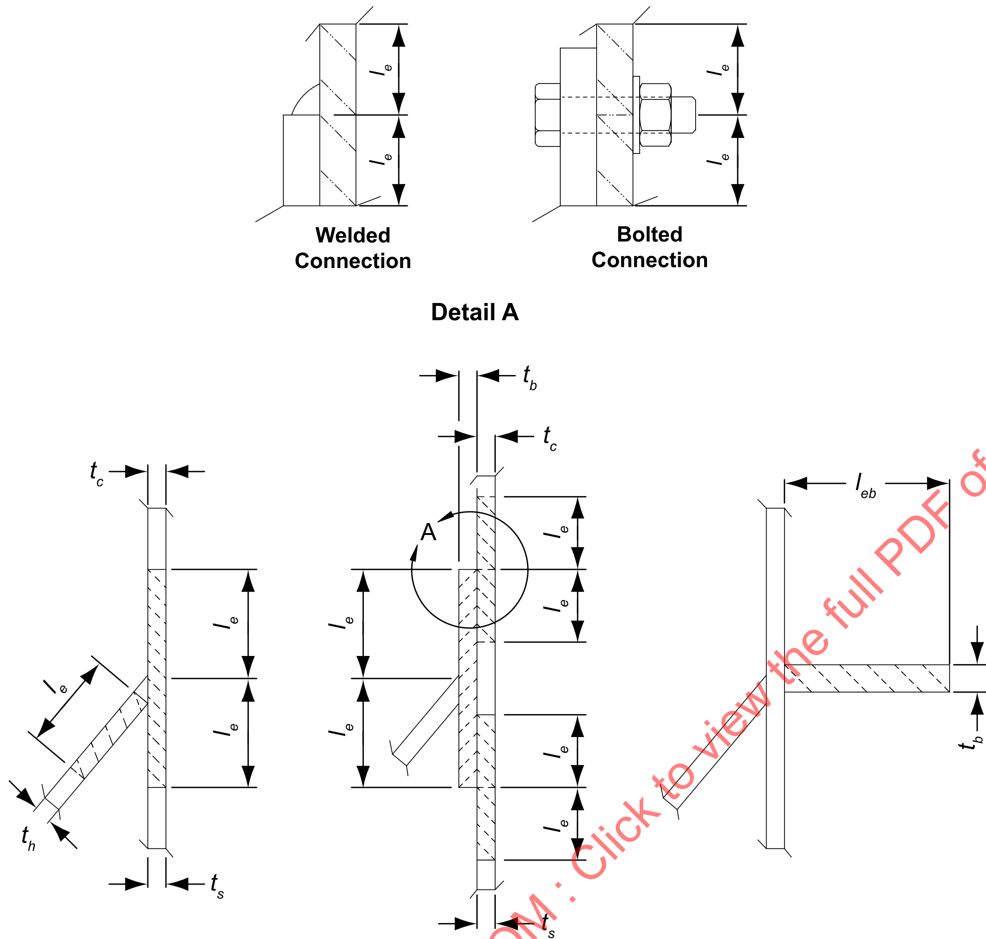


Figure 6-10.5.3-2
Typical Cone–Cylinder Compression Rings

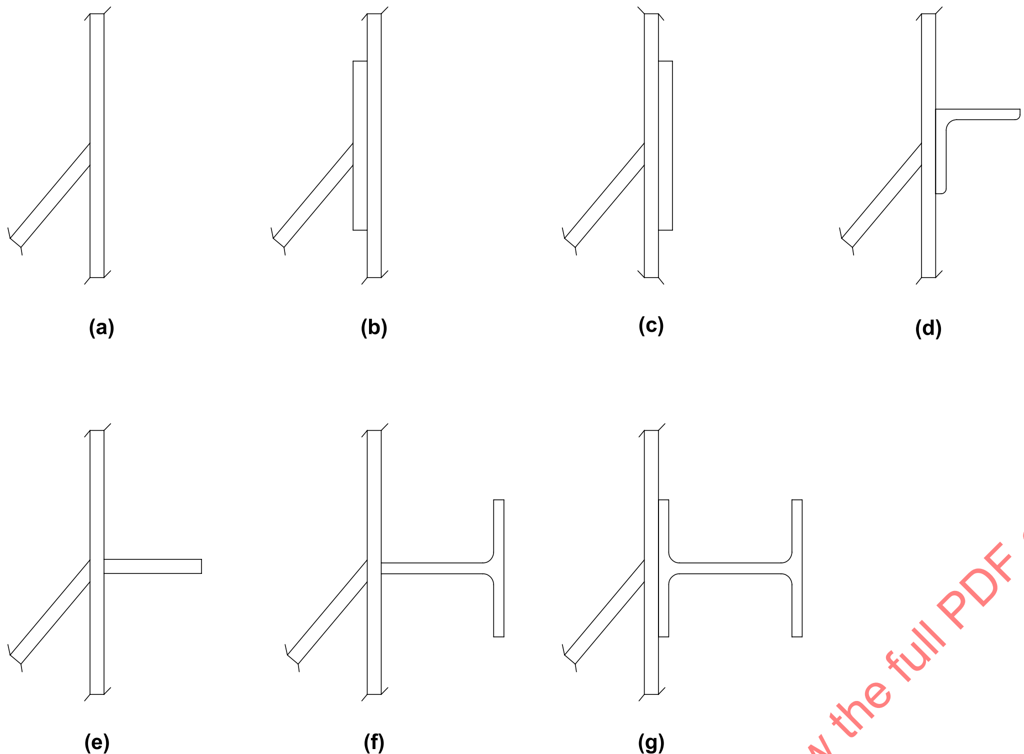


Figure 6-10.5.3-3
Placement Limit for Added Material Relative to Springline

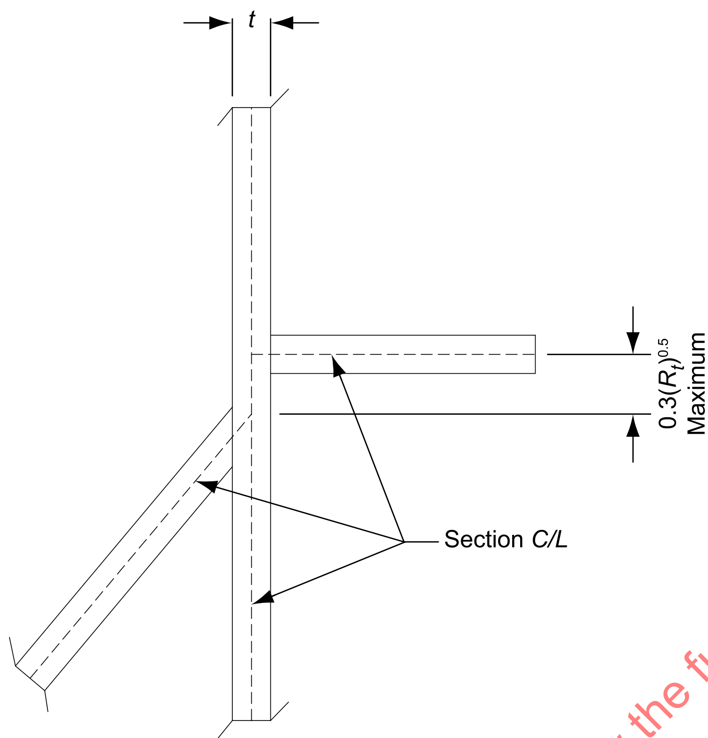
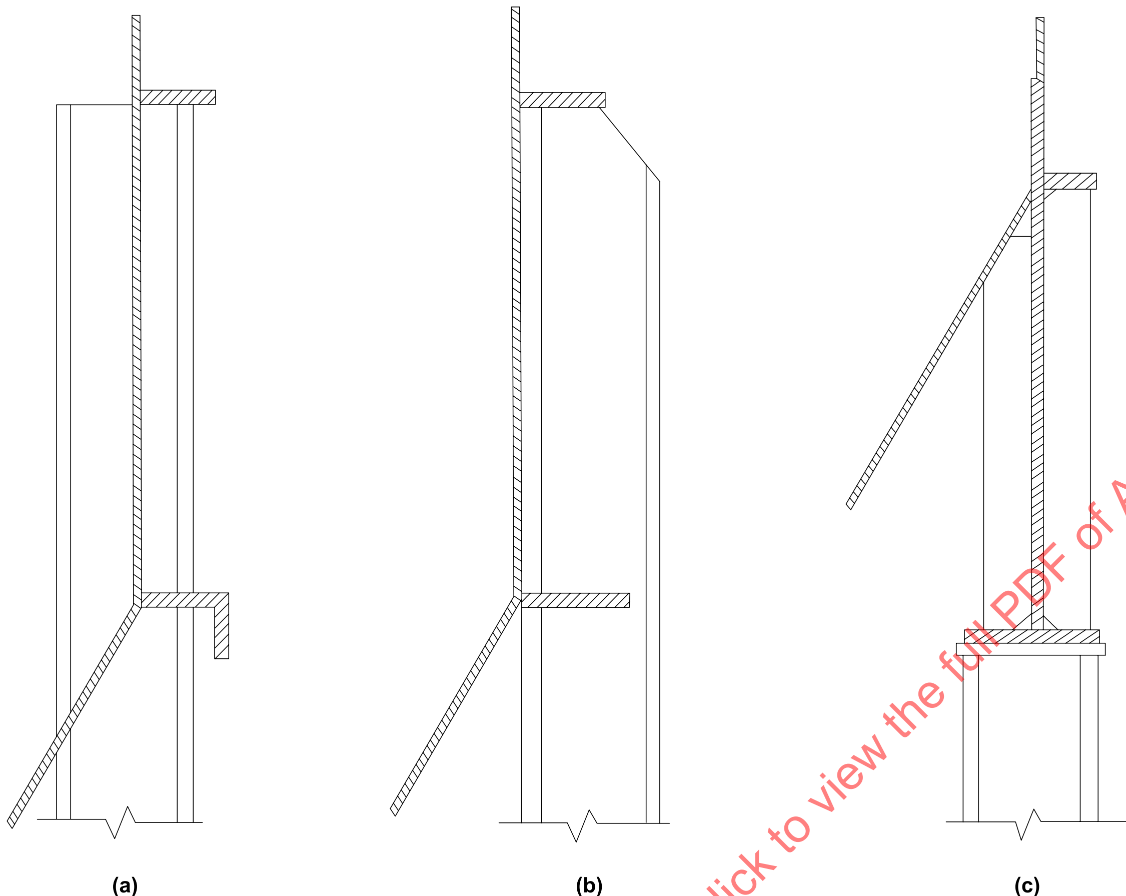


Figure 6-11.1-1
Typical Ring Girder/Column Attachment Details



The calculated stress, S_c, should be less than the design allowable stress.

$$S_c \leq S_d / SF_c$$

where

S_d = design stress, psi (MPa)
SF_c = safety margin
= 1.30

6-11 COLUMN-SUPPORTED ELEVATED CONTAINERS

6-11.1 General

(a) The container support consists of two main components: the columns or support brackets and the support-ring girder. For typical ring–girder or column attachment details, see Figure 6-11.1-1.

(b) The design outlined in this subsection is for columns that are continuously cross braced in all bays such that the centroidal axis of each member

(1) coincides with the line connecting the joint centers at each end of the member

(2) lies in a plane that also contains the lines of action of all the loads and reactions

(c) If noncircular columns are not continuously cross braced and act in bending, the designer shall consider that the horizontal force resisted by each column will be proportional to the effective column moment of inertia about a column axis perpendicular to the direction of horizontal loads, such as wind, earthquake, or other mechanical loads.

6-11.2 Direct Ring–Girder Moment, Torsional Moment, and Vertical Shear

6-11.2.1 For a circular horizontal ring girder, as shown in Figure 6-11.2.1-1 and meeting the following criteria:

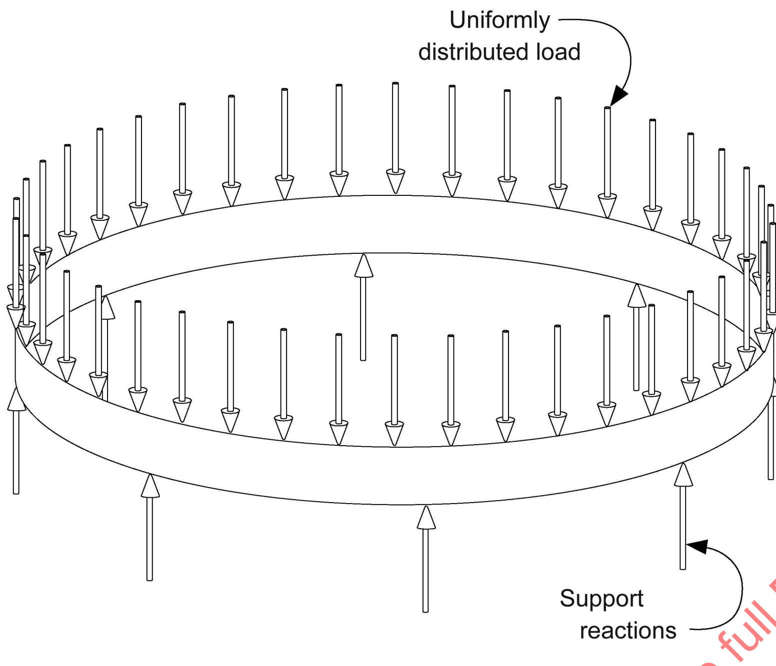
(a) having uniform cross section

(b) both the loads and supports act along a line passing through the centroid of the section

(c) supported by a number of equally spaced supports

(d) having an evenly distributed vertical load

Figure 6-11.2.1-1
Ring Girder on Equally Spaced Supports Under Uniform Vertical Load



6-11.2.2 The direct bending moment, M; the torsional bending moment, M_T, due to the eccentricity of the distributed load between two supports; and the vertical shear, V, at any point in a circular ring girder, are calculated as follows:

(a) direct bending moment, M

$$M = WR_{rg}[\sin\varphi/(2N_s) + \cos\varphi/(2N_s)\cot(180/N_s) - 1/(2\pi)]$$

NOTE: If the ring girder is made up of sections bolted to the columns, the bolted connection shall be able to transmit the end moment (ϕ = 0).

(b) torsional moment, M_T

$$M_T = WR_{rg}\{1/(2N_s)[-\sin\varphi\cot(180/N_s) - 2\sin^2(\varphi/2) + N_s\varphi/\pi]\}$$

The torsional moment is zero at the supports and midway between them. The maximum torsional moment occurs where the direct bending moment is zero.

The angular location β of the maximum torsional moment is obtained from

$$\sin(\beta) + \cos(\beta) \times \cot\left(\frac{180}{N_s}\right) = \frac{N_s}{\pi}$$

(c) vertical shear, V

$$V = W(1 - N_s\varphi/180)/(2N_s)$$

where

N_s = number of supports
R_{rg} = ring–girder centerline radius
W = total uniformly distributed vertical load on ring girder
ϕ = angle between support and point under consideration, deg (see Figure 6-11.2.2-1)

6-11.3 Thrust and Moment From Equally Spaced Radial Loads

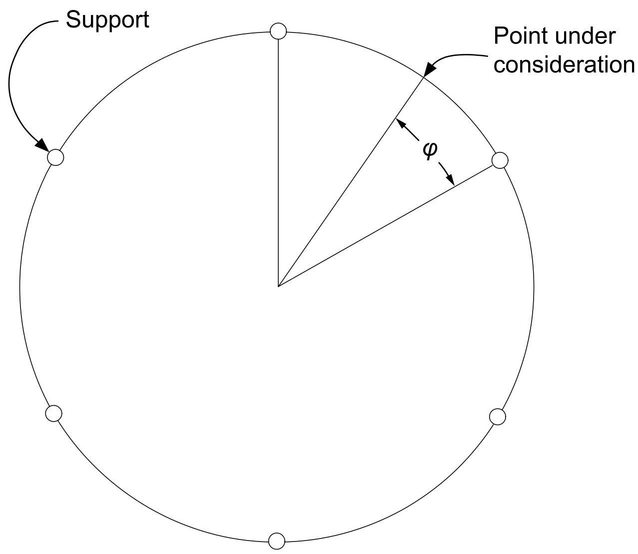
Eccentricity between the vertical centerline of the ring girder and the centerline of the support results in equal radial loads, P, at the point where the support columns attach to the ring girder. In this instance, P is defined as

$$P = We_c/N_sh$$

where

e_c = eccentricity between ring–girder vertical centerline and the centerline of the support
h = distance between the centerlines of the top and bottom ring–girder flanges
N_s = number of supports
W = total uniformly distributed vertical load on ring girder

Figure 6-11.2.2-1
Angle Between Support and Point Under Consideration



Values e_c and h must be consistent units of length.

Table 6-11.3-1 gives coefficients for thrust, T, and moment, M, at load and midway between loads for P.

6-11.4 Maximum Ring–Girder Loads From Horizontal Loads Resisted by Column Bracing

The horizontal force component, F_h, that is resisted by cross-bracing is a portion of the total external horizontal force, H_e, such as wind or an earthquake acting on the container.

$$F_h = 2H_e \sin\theta / N_s$$

where

H_e = total external horizontal force on the container, such as from wind or an earthquake

N_s = number of supports

Θ = angle, in horizontal projection, between a radius to the midpoint of the cross brace and the direction of the horizontal force (see Figure 6-11.4-1) (The sign of sin Θ is ignored.)

Maximum moments, thrusts, and shears in the ring girder do not occur at the same location or orientation to the direction of the external horizontal force. The maximum values of thrust, moment, and shear are given in Table 6-11.4-1. Assuming that the maximum values occur simultaneously at the same location will result in a safe ring–girder design.

6-11.5 Column-Supported Elevated Containers Without Ring Girders

(a) Column-to-shell connections shall be designed to

(1) distribute the axial load adequately into the shell

(2) ensure stresses from attaching welds, bolts, or both are below acceptable levels

(b) The shell must be designed to resist the resulting shear and bending stresses induced by

(1) wind or seismic loads

(2) eccentricities from nonsymmetrical axial loads

(c) It is recommended column-supported containers without ring girders be designed so that the column centroids are aligned with the centerline of the shell. Where column centroids cannot be aligned with the shell, the effects of eccentric loads shall be considered, as referenced in (b)(2).

6-12 SMOOTH-WALL BOLTED CONTAINERS

6-12.1 General

This subsection addresses additional requirements unique to smooth-wall bolted containers.

6-12.2 Materials

6-12.2.1 Permitted Materials. Permissible materials, including fastener materials, are listed in Section 5 of this Standard.

6-12.2.2 Screws. Except for roof panels, screws are not permitted for structural connections.

6-12.2.3 Bolts. The minimum permitted bolt diameter for structural connections shall be 0.3125 in.

6-12.3 Bolted Joint Design

6-12.3.1 General. These provisions shall apply to the design of vertical and horizontal joints of wall panels that make up the cylindrical shell of the container and any structural stiffening attachments to the panels.

(a) All connections shall be designed as bearing-type connections.

(b) For bolted joints, the designer shall ignore the effect of the gasket or sealant on joint thickness, provided the compressed thickness of the gasket or sealant does not exceed $\frac{1}{16}$ in.

(c) Longitudinal stiffeners, other than those used strictly for wind and seismic anchorage, shall not be attached to the shell at a vertical joint location.

(d) Where two connecting materials are of different yield or tensile strengths, the lower strength value shall be used.

(e) The joint load, F, may be distributed evenly over the bolts on a given joint-unit width strip.

(f) Vertical stiffening member-to-shell connections shall not share common bolt holes with vertical joints.

(g) The minimum permissible shell plate thickness for smooth-wall containers shall be 14 gage (0.074 in.).

(h) The bearing at the bolt hole and allowable bolt shear provisions of para. 6-12.3 are based on single shear joints.

6-12.3.2 Strength Requirements. Joints shall be designed using the provisions of paras. 6-12.3.4 through 6-12.3.7, and the lowest resulting value shall be used as the joint strength, T_{bjnt}.

6-12.3.3 Hoop Force. The hoop force in a unit strip or section under consideration, F, is found by

$$F = (p_{he} + 144p_i)Rs/12$$

where

F = force on section of width s, lb

p_{he} = normal product pressure at the level under consideration, psf

p_i = design supplemental pressure, psi

R = radius of cylindrical container at the level under consideration, ft

s = center-to-center spacing of the bolts perpendicular to the line of force, in.

Table 6-11.3-1
Coefficients for Thrusts and Moments From Equally Spaced, Equal Radial Loads, *P*

Number of Columns, N_s [Note (1)]	At Loads		Between Loads	
	Coefficients for Thrust, T/P	Coefficient for Moment, $M/R_{rg}P$	Coefficients for Thrust, T/P	Coefficient for Moment, $M/R_{rg}P$
2	0.000000 E−00	0.318310 E−00	−0.500000 E−00	−0.181690 E−00
3	−0.288675 E−00	0.188790 E−00	−0.577350 E−00	−0.998854 E−01
4	−0.500000 E−00	0.136620 E−00	−0.707107 E−00	−0.704870 E−01
5	−0.688191 E−00	0.107584 E−00	−0.850651 E−00	−0.548760 E−01
6	−0.866025 E−00	0.889042 E−01	−1.000000 E−00	−0.450703 E−01
7	−0.103826 E−01	0.758239 E−01	−0.115238 E−01	−0.382978 E−01
8	−0.120711 E−01	0.661327 E−01	−0.130656 E−01	−0.333234 E−01
9	−0.137374 E−01	0.586557 E−01	−0.146190 E−01	−0.295077 E−01
10	−0.153884 E−01	0.527076 E−01	−0.161803 E−01	−0.264845 E−01
11	−0.170284 E−01	0.478607 E−01	−0.177473 E−01	−0.240283 E−01
12	−0.186603 E−01	0.438339 E−01	−0.193185 E−01	−0.219923 E−01

GENERAL NOTE: Use the appropriate coefficient to determine thrust and moment. For example, for six columns, the thrust, T, at the load is $-0.866025P$ and the moment, M, is $0.0889042R_{rg}P$, where R_{rg} = ring–girder centerline radius.

NOTE:
(1) For values of N_s greater than 12, the thrust and moments may be approximated as follows:
(a) For thrust at and between the loads

$$T_t = N_s P/(2\pi)$$

Positive thrust indicates tension on the ring–girder cross-section area.
(b) For the moment at the loads

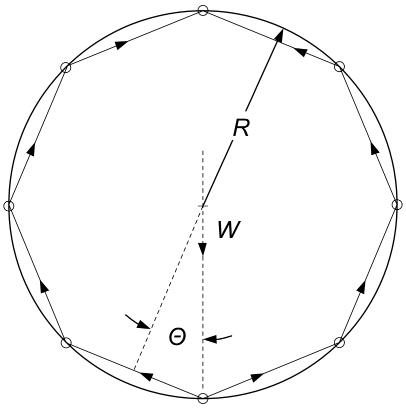
$$M = P\pi R_{rg}/(6N_s)$$

(c) For the moment between loads

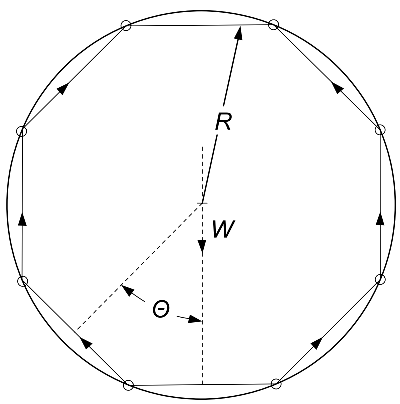
$$M = P\pi R_{rg}/(12N_s)$$

Positive moment at or between loads indicates compression on the outside fibers of the ring girder.

Figure 6-11.4-1
Horizontal Force Orientation



Case A



Case B

Reference para. 6-6.3.2.

The joint strength of a unit strip designed according to the provisions of paras. 6-12.3.4 through 6-12.3.7 shall exceed its design hoop force.

6-12.3.4 Bolt Spacing and Minimum Edge Distance Requirements

6-12.3.4.1 Bolt Spacing and Hole Size. The minimum distance between centers of bolt holes shall provide sufficient clearance for bolt heads, nuts, washers, and a wrench but shall not be less than 3 times the bolt diameter.

$$s \geq 3d_b$$

where

d_b = bolt diameter, in.

s = center-to-center spacing of the bolts perpendicular to the line of force, in.

The maximum bolt hole size, d_h, shall be

$$d_h \leq d_b + 0.0625 \text{ in.}$$

Table 6-11.4-1
Coefficients for Maximum Reactions in the Ring Girder From Horizontal Forces

Number of Columns	Coefficients for Thrust, T/H_e	Coefficient for Moment, M/H_eR_{rg}	Coefficient for Vertical Shear, V/H_e
3	−0.43397	0.23873	−0.5000
4	−0.37893	0.06831	−0.26517
5	−0.30728	0.03255	−0.17452
6	−0.30024	0.01637	−0.11779
7	−0.25104	0.00999	−0.07272
8	−0.22623	0.00616	−0.06567
10	−0.193	0.00300	−0.0422
12	−0.159	0.00162	−0.0294
16	−0.122	0.00068	−0.0164

GENERAL NOTE:

H_e = total external horizontal force on the container, such as from wind or an earthquake

M = moment

R_{rg} = ring–girder centerline radius

T_t = thrust

V = vertical shear

6-12.3.4.2 Minimum Edge Distance

(a) Along a line of transmitted force, the distance from the center of a standard hole to the edge of the connected part, e, shall not be less than the values calculated in (1) or (2) or the limitation of (b):

(1) When $F_u/F_y \geq 1.08$

$$e = 2P_b/F_ut$$

where

e = distance measured in the line of force from the center of a standard hole to the nearest edge of an adjacent hole or to the end of the connected part

F_u = ultimate tensile strength, psi

F_y = yield strength, psi

P_b = force transmitted by one fastener to the critical part, lb

t = shell thickness of one sheet or the total thickness of all laminated sheets for those that meet the criteria of para. 6-13.3.4

(2) When $F_u/F_y < 1.08$

$$e = 2.22P_b/F_ut$$

(b) The distance from the center of any standard hole to the end or other boundary of the connecting member shall not be less than $1.5d_b$.

In no case shall the distance between the edge of the hole and the end of the member be less than d_b.

6-12.3.5 Connection Strength Limit Due to Bearing at the Bolt Holes. Bearing stress, f_b, at the bolt holes shall be calculated by

$$f_b = P_b/(td_b)$$
$$f_b \leq S_{dp}$$

where d_b, P_b, and t are as defined in para. 6-12.3.4, and the allowable bearing stress, S_{dp}, is determined by (a), (b), or (c).

(a) $S_{db} = F_u$ for connections that meet the following minimum requirements:

(1) There are two or more bolts in the line of force.

(2) Minimum edge distance in the line of force is greater than or equal to $1.5d_b$.

(3) The center-to-center distance of the bolts complies with the provisions of para. 6-12.3.4.1.

(4) The thickness, t, of the connected material is greater than or equal to 0.028 in. but less than 0.1875 in.

(5) The diameter of the bolts, d_b, is greater than or equal to 0.3125 in.

(b) $S_{db} = 1.2F_u$ for connections that meet the requirements in (a)(1) through (a)(3) and the following:

(1) The thickness, t, of the connected material is greater than or equal to 0.1875 in.

(2) The diameter of the bolts, d_b, is greater than or equal to 0.375 in.

(c) $S_{db} = (eF_u)/(2d_b)$ for connections with one bolt in the line of force or a minimum edge distance less than $1.5d_b$. S_{db} shall be less than or equal to the smaller of $1.35F_y$ or F_u.

NOTE: See para. 6-12.3.4 for variable definitions not defined in this paragraph.

6-12.3.6 Allowable Tension on Net Section

6-12.3.6.1 Allowable Tension Stress Due to Rupture on Net Area The tensile stress, f_t, on the net section of a bolted connection shall not exceed the lesser of the values determined by one of the following equations:

(a) For joints where the thickness, t, of the connected material is greater than or equal to 0.028 in. but less than 0.13 in. and the bolt diameter, d_b, is greater than or equal to 0.3125 in.

$$f_t = 0.45F_u[1 - 0.9r + (3d_br)/s] \leq 0.6F_y$$

(b) For joints where multiple bolt lines are used and the thickness, t, of the connected material is greater than or equal to 0.13 in.

$$f_t = 0.5F_u[1 - 0.9r + (3d_br)/s] \leq 0.6F_y$$

where

d_b = bolt diameter, in.
F_u = ultimate tensile strength, psi
F_y = yield strength, psi
r = force transmitted by the bolt or bolts at the section considered divided by the tensile force in the member at that section (If r is less than 0.2, it may be taken as zero. Consistent units are to be used in computation of r.)
s = center-to-center spacing of the bolts perpendicular to the line of force, in.

6-12.3.6.2 Maximum Allowable Tension on Joint Due to Net Section. The maximum allowable tension, T_{ns}, on a unit width of the joint is calculated as follows:

$$T_{ns} = f_t(A_n)$$

where

A_n = minimum net cross-sectional area of a unit width of the joint, in.^{2} (The effective net section cross-sectional area shall not exceed 85% of the gross area.)
f_t = maximum allowable tensile stress on the net section of a bolted connection, psi

6-12.3.7 Allowable Bolt Shear and Tension

6-12.3.7.1 Bolt Shear Strength

(a) For bolts with diameters greater than or equal to 0.25 in. and less than 0.5 in., the nominal shear stress, F_{nv}, shall be taken from Table 6-12.3.7.1-1.

(b) For bolts with diameters greater than or equal to 0.5 in., F_{nv} shall be taken from Table 6-12.3.7.1-2.

(c) The shear strength for an individual bolt shall be determined from the equation

$$V_b = (A_bF_{nv})/2$$

where

A_b = bolt cross-sectional area, in.^{2}
= $\pi d_b^2/4$
d_b = bolt diameter, in.
F_{nv} = nominal bolt shear stress, psi

If the joint is designed with bolt threads outside of the shear plane, the designer shall consider all material thicknesses and fastener dimensions that will determine shear plane location. Doing so will allow the designer to verify that the threads will be outside of the shear plane and that adequate threading will be present to allow the bolt to be fully tightened. See Figure 6-12.3.7.1-1 for examples of joint configurations and calculated efficiencies.

Table 6-12.3.7.1-1
Nominal Tensile Strength and Shear Strength for Bolts ≥0.25 in. and <0.5 in. in Diameter

Description of Bolts	Nominal Tensile Strength, F_{nt}, psi (kPa)	Nominal Shear Strength, F_{nv}, psi (kPa)
ASTM A307, Grade A	40,000 (280 000)	24,000 (169 000)
SAE Grade 2		

Table 6-12.3.7.1-1
Nominal Tensile Strength and Shear Strength for Bolts ≥0.25 in. and 0.5 in. in Diameter (Cont'd)

Description of Bolts	Nominal Tensile Strength, F_{nt}, psi (kPa)	Nominal Shear Strength, F_{nv}, psi (kPa)
ASTM A449 SAE Grade 5	81,000 (560 000)	48,000 (334 000) [Note (1)] 68,000 (457 000) [Note (2)]
ASTM A354, Grade BD SAE Grade 8 or Grade 8.2 ISO 898-1 property class 10.9	101,000 (700 000)	61,000 (411 000) [Note (1)] 84,000 (579 000) [Note (2)]

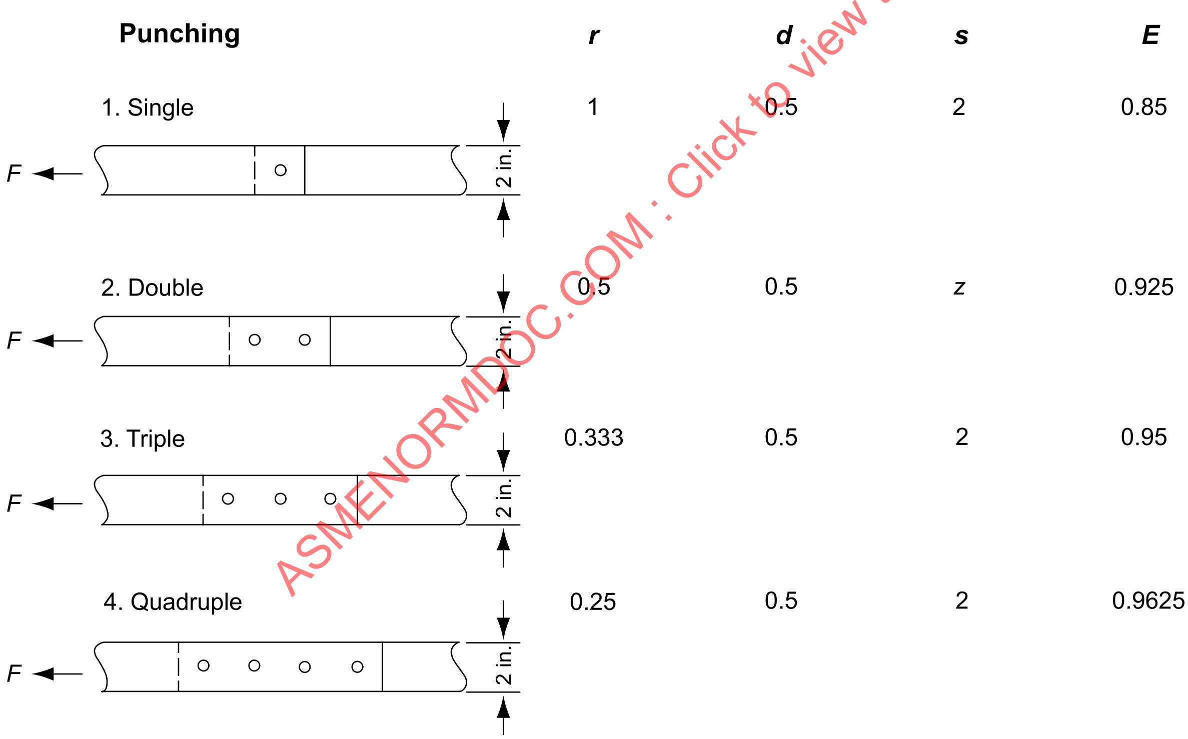
NOTES:
(1) This value applies if the threads are included in the shear planes.
(2) This value applies if the threads are excluded from the shear planes.

Table 6-12.3.7.1-2
Nominal Tensile and Shear Strength for Bolts ≥0.5 in. in Diameter

Description of Bolts	Nominal Tensile Strength, F_{nt}, psi (kPa)	Nominal Shear Strength, F_{nv}, psi (kPa)
ASTM A307, Grade A SAE Grade 2	45,000 (310 000)	27,000 (188 000)
ASTM A325 ASTM A449 SAE Grade 5	90,000 (620 000)	54,000 (372 000) [Note (1)] 68,000 (457 000) [Note (2)]
ASTM A354, Grade BD ASTM A490 SAE Grade 8 or Grade 8.2 ISO 898-1 property class 10.9	113,000 (780 000)	68,000 (457 000) [Note (1)] 84,000 (579 000) [Note (2)]

NOTES:
(1) This value applies if the threads are included in the shear planes.
(2) This value applies if the threads are excluded from the shear planes.

Figure 6-12.3.7.1-1
Examples of Joint Configurations and Calculated Efficiencies, *E*



GENERAL NOTE: To be calculated when using the provisions of para. 6-12.3.6.1, not considering the gross area limitations of the provision in (a).

6-12.3.7.2 Bolt Tensile Strength

(a) For bolts with diameters greater than or equal to 0.25 in. and less than 0.5 in., the nominal tensile strength, $F_{nt,}$ shall be taken from Table 6-12.3.7.1-1.

(b) For bolts with diameters greater than or equal to 0.5 in., F_{nt} shall be taken from Table 6-12.3.7.1-2.

(c) The allowable tensile strength for an individual bolt shall be determined from the following equation:

$$Q_b = A_b F_{nt}/2$$

where A_b and d_b are as defined in para. 6-12.3.7.1.

6-12.3.7.3 Joint Bolt Shear Strength. Bolt shear strength for a unit width of a joint, V_{bjnt}, shall be determined from the following equation:

$$V_{bjnt} = n_b V_b$$

where

n_b = number of bolts in a unit strip of a joint
V_b = allowable bolt shear strength, lb

6-12.3.7.4 Joint Bolt Tensile Strength. Bolt tensile strength for a unit width of a joint, T_{blt}, shall be determined from the following equation:

$$T_{blt} = n_b Q_b$$

where

n_b = number of bolts in a unit strip of a joint
Q_b = allowable bolt tensile strength, lb

6-12.3.8 Connection of Vertical Stiffening Members to Wall Panels. Connection of vertical stiffening members to the wall panels shall consider bearing stress and pullover of the sheet of the bolt head, nut, or washer, where applicable.

6-12.3.9 Sealing Container Joints. Container joints may be sealed with a synthetic rubber gasket or a sealant.

For flat-bottom, ground-supported containers, a base sealer or some other method shall be utilized to seal the base ring to the concrete foundation.

For column-supported containers, provisions shall be made to ensure sealing between the bottom tier of the shell to the hopper or support structure.

6-12.3.10 Sidewall Dimensional Specifications. The height and width of the sidewall sheets shall be determined by the container fabricator.

6-12.3.11 Bolted Joint Efficiency. Bolted joint efficiency and bolt spacing to resist hoop tension per para. 6-12.3.7.1 are shown in Figure 6-12.3.7.1-1. The figure is for illustration only and is not intended for design use. All bolted joint efficiency shall be determined per the provisions of para. 6-12.3.6 and the strength of the joint per all provisions of para. 6-12.3.

6-12.3.12 Bolting. Bolts shall be tightened according to the container manufacturer's written procedures.

Bolts used in shell joints are frequently special assembled fasteners for the purpose of sealing the joints.

Bolts with polymer-backed steel washers shall be tightened until the washer flattens. It is not uncommon to spin off part of the polymer backing of the washer to ensure a proper seal, as its purpose is to seal bolt threads.

Similarly, bolts may have polymer washers under flange head bolts that will be tightened until the washer flattens.

Plastic-encapsulated bolts shall be tightened until the raised ring on the bottom of the plastic cap has flattened.

6-12.4 Loads

Bolted containers shall be designed for the applicable loads given in subsection 6-4.

6-12.5 Steel Structural Members

Cold-formed structural members (except for vertical and horizontal joints) shall be designed in conformance with the ASD provisions of AISI S100.

Hot-rolled and built-up structural members (except for vertical and horizontal joints) shall be designed to the provisions of this Standard and, where applicable, the ASD provisions of AISC 360.

Vertical and horizontal joints are addressed in para. 6-12.3.

6-13 CORRUGATED-WALL BOLTED CONTAINER

6-13.1 General

This subsection addresses unique design considerations for corrugated-wall bolted containers.

6-13.2 General Limitations

The minimum permissible shell plate thickness for corrugated-wall containers is 20 gage (0.034 in.).

Corrugation pitch, *cp*, shall be between 2.5 in. to 5 in.

Corrugation depth, *cd*, shall be between 0.375 in. to 0.75 in.

Vertical joints in corrugated containers, except at access door locations, shall be offset from the tier above a minimum of 24 in. horizontally. The offset is measured as the shortest distance between the center of the vertical seam bolt-hole rows.

6-13.3 Design Considerations

6-13.3.1 Corrugated Sheet Joint Design. Corrugated sheet joint design shall conform to para. 6-12.3.

The distance, *s*, which is the center-to-center spacing of the bolts perpendicular to the line of force, may include the centerline length along the corrugation profile.

6-13.3.2 Corrugated Sheeting Compression Strength. Corrugated sheets have limited strength to resist forces perpendicular to the corrugations, such as the vertical compressive force, due to product friction acting on the container sidewall. Resistance to localized buckling or connection failure of the corrugated walls due to such forces shall be considered in the design of the container by the designer.

6-13.3.3 Limitations of Stiffener–Fastener Bearing Stress. The bolting attachment of the container wall sheets to the stiffeners shall be proportioned to ensure that the vertical compressive force due to stored material product friction acting on the container sidewall is transferred into the stiffeners. Wall sheeting thickness and bolt size and spacing shall be chosen to prevent local rupture at the bolts. The bearing stress of the bolt attachment of the longitudinal stiffener to the sidewall shall not exceed the lesser of 80% of the sidewall tensile or yield strength.

6-13.3.4 Laminated Sheets. Laminated sheets may be designed using their equivalent thickness only for tensile stress design. When in localized compression on a stiffened container, the allowable compressive load on each sheet shall be added together to obtain the allowable compressive load of the laminated sheet. All sheets shall be equal in thickness and equal to or greater than nominal 14 gage (0.074 in.). Lamination is limited to three sheets with a minimum of three rows of bolts in the vertical seam. All sheets used in lamination shall be ASTM A653 G90 hot-dip galvanized or other purchaser-approved corrosion-resistant coating. All laminated sheets shall have the same corrugation profile.

6-13.3.5 Vertical Stiffeners

(a) Vertical stiffeners shall be designed to resist applicable vertical loads, including the vertical load from the stored material, roof loads, overturning wind loads, and seismic loads (see para. 6-4.1).

(b) When bulk solid material is present, the unbraced length of the stiffener shall not be less than the spacing of the attachments between the stiffener and side wall panels and shall not be less than 8 in.

(c) The maximum attachment spacing shall be 8 in.

(d) Minimum permissible stiffener thickness shall be 0.055 in.

(e) Stiffeners shall extend from the base of the container to within 8 in. of the eave.

(f) In column-supported containers, each vertical stiffener shall be positioned directly above a support column.

(g) Vertical stiffeners shall be provided at a maximum uniform circumferential spacing of 60 in.

(h) Stiffener sections shall be fastened together adequately to resist applicable loads.

(i) End bearing connections shall be able to transfer all vertical forces, including any uplift. The connection shall ensure proper alignment of the stiffeners.

(j) Laminated stiffeners shall be tested and sufficiently analyzed by the container manufacturer to ensure performance is in accordance with the calculated load capacity.

(k) No component of laminated stiffener systems shall be thinner than 0.07 in.

6-13.3.6 Ring Girder in Column-Supported Containers

(a) Loads on the ring girder consist of the vertical and radial loads from the suspended bottom plus the vertical load imposed on the lowest cylindrical container sidewall sheet.

(b) All horizontal forces, such as wind or seismic shear, are transferred directly from the container sidewall to the ring girder.

6-13.3.7 Wind Girders. The container walls shall be designed to resist buckling failure due to external wind pressure.

Circumferentially stiffening ring girders may be used for wind force resistance. Wind girder loads shall be designed in accordance with the provisions of ASCE 7, unless another local design standard has been specified. Membrane theory may be used to compute the primary stresses for this loading condition. The possible stiffness of the stored bulk solids shall not be considered during container design.

Wind girders may be fabricated from spliced sections of structural members that attach directly to the vertical stiffeners.

The container manufacturer shall be responsible for designing the structural system to provide the required resistance to prevent buckling of the wall system under design loads.

6-13.3.8 Roof Requirements Related to Bolted Corrugated Containers

6-13.3.8.1 Minimum Required Roof Thickness for Bolted Corrugated Containers. Roof–sheet thickness specified in this paragraph is the minimum only. Engineering analysis of the roof system for the required loads shall be performed.

(a) Bolted corrugated containers with a nominal diameter greater than or equal to 21 ft shall have a roof slope of 30 deg or greater, and roof sheets shall have formed ribs for strength if the minimum uncoated thickness of the sheets is less than 0.094 in. (2.4 mm). Roof sheets composed of panels with formed ribs for strength shall have a minimum uncoated thickness of 0.0245 in. (0.62 mm).

(b) Bolted corrugated containers with a nominal diameter of less than 21 ft and a roof slope of 30 deg or greater shall have roof sheets with a minimum uncoated thickness of 0.0215 in. (0.55 mm).

(c) Bolted corrugated containers with a nominal diameter of less than 21 ft and a roof slope of less than 30 deg shall have roof sheets with a minimum uncoated thickness of 0.094 in. (2.4 mm).

(d) Bolted corrugated containers with a nominal diameter greater than 48 ft shall have a rafter or truss support system if the minimum uncoated thickness of the roof sheets is less than 0.094 in. (2.4 mm).

6-13.3.8.2 Eave Members for Roofs of Corrugated Containers. Bolted corrugated containers with rafter or truss roof support systems that connect to the container wall shall have eave members with the capacity to carry tensile loads resulting from the horizontal reaction of the rafters. The eave tensile members shall be designed to resist the entire tensile load.

Section 7
Fabrication

7-1 GENERAL FABRICATION AND ERECTION

The rules of this Section cover fabrication of welded or bolted containers for bulk solids that are fabricated using materials covered in Section 5.

7-1.1 Workmanship

7-1.1.1 Surfaces and edges to be joined shall be smooth, uniform, and free from slag, tears, cracks, or other discontinuities.

7-1.1.2 Special precautions may be required for fabrication and erection of stainless steel containers. Depending on the service, iron residue from contact with carbon steel equipment and tools may be detrimental to the stainless steel. When iron-contamination precautions are specified by the owner for the inside surface or all surfaces of the container, the owner shall initiate or approve procedures that will limit contact with carbon steel.

Procedures shall include methods to prevent iron contamination of the stainless steel, such as

(a) use of only stainless steel wire brushes

(b) use of grinding wheels reserved for work on stainless steel only

(c) use of fit-up material other than carbon steel

(d) proper cleaning of lifting, rolling, and cutting equipment

(e) pickling and passivation of stainless steel

7-1.2 Shaping and Forming of Shells, Bottom Transition Cones, Roofs, and Heads

7-1.2.1 All plates shall be formed (except as described in para. 7-1.2.2) to the required shape by any process that will not unduly impair the physical properties of the material.

7-1.2.1.1 Carbon and low-alloy steel plates shall not be cold formed by blows. Carbon and low-alloy steel plates may be formed by blows at a forging temperature, provided the blows do not deform the plate and it is subsequently postweld heat treated.

7-1.2.1.2 Carbon and low-alloy steel plates fabricated by cold forming shall be heat treated when the resulting extreme fiber elongation is more than 5% from the as-rolled condition and any of the following apply:

(a) The material requires impact testing.

(b) The thickness of the material exceeds $^5\!/_8$ in. (16 mm) before forming.

(c) The reduction in thickness due to cold forming is more than 10%.

(d) The container will contain either solid or gaseous lethal substances.

(e) The temperature of the material during forming ranges from 250°F to 900°F (120°C to 480°C).

The extreme fiber elongation shall be determined by the following formulas:

For double curvature (e.g., heads)

$$\%\ \text{extreme fiber elongation} = \frac{75t}{R_f}\left(1 - R_f/R_o\right)$$

For single curvature (e.g., cylinders)

$$\%\ \text{extreme fiber elongation} = \frac{50t}{R_f}\left(1 - R_f/R_o\right)$$

where

R_f = final centerline radius, ft

R_o = original centerline radius (equal to infinity for flat plate), ft

t = plate thickness, in.

7-1.2.1.3 Stainless steel fabricated by cold forming shall have fiber elongation no more than 10% per the percentage of fiber elongation equations in para. 7-1.2.1.2, unless forming is followed by a solution heat treatment at 1,900°F (1 040°C) for 20 min/in. (20 min/25 mm) or 10 min, whichever is greater.

7-1.2.1.4 If plates are to be rolled, the adjoining edges or longitudinal joints of cylindrical containers shall first be shaped to the proper curvature by preliminary rolling or forming to avoid having objectionable flat spots along the completed joints.

7-1.2.2 Elastic Forming. Cylindrical shell plates may be elastically erected to suit the curvature of the structure and the erection procedure (see Table 7-1.2.2-1). When thickness exceeds that shown for a given diameter, the plate must be mechanically formed by rolling or pressing operations, unless otherwise approved by the owner.

Table 7-1.2.2-1
Elastic Forming Limits

Nominal Plate Thickness, in. (mm)	Nominal Diameter, ft (m)
<3/8 (<10)	≥40 (≥12)
≥3/8 to <1/2 (≥10 to <13)	≥60 (≥18)
≥1/2 to <5/8 (≥13 to <16)	≥120 (≥36)
≥5/8 (≥16)	[Note (1)]

NOTE: (1) All plates shall be formed.

7-1.2.3 Edge Shaping of Rolled Plates. When plates are to be rolled, forming shall extend completely to the end of the plate. The adjoining edge of longitudinal joints of cylindrical shells may require shaping to the proper curvature by preliminary rolling or forming to avoid flat spots along the completed joints.

7-1.3 Dimensional Tolerances for Assembled Structures

7-1.3.1 General. The purpose of the tolerances given in paras. 7-1.3.2 through 7-1.3.4 is to provide for structural integrity, acceptable appearance, and proper material fill and removal. These tolerances may be waived by agreement between the owner and manufacturer. The owner may accept fabrication methods that are out of compliance with paras. 7-1.3.2 through 7-1.3.4 if the container passes a structural stress analysis using as-built measurements.

7-1.3.2 Plumbness. The maximum out-of-plumbness of the top of the structure relative to the bottom of the shell or support base shall not exceed 1/200 of the total structure height. The out-of-plumbness in one shell course shall not exceed the permissible variations for flatness and waviness as specified in SA 6M/A 6, SA 20M/A 20, or SA 480M/A 480, as applicable. The 1/200 criterion shall also apply to support columns.

7-1.3.3 Roundness. The cylindrical portion of the structure shell shall have a tolerance on the radius per Table 7-1.3.3-1 when measured at a location 1 ft (0.3 m) above the bottom or base plate to cylindrical shell intersection, or at the cylindrical shell to bottom transition cone intersection.

7-1.3.4 Local Deviations. Local deviations from the theoretical shape (e.g., weld discontinuities and flat spots) shall be limited as follows:

(a) Deviations (peaking) at vertical joints shall not exceed the limits of Table 7-1.3.3-1. Peaking at vertical weld joints shall be determined using a horizontal sweep board 36 in. (900 mm) long. The sweep board shall be made to the nominal radius of the shell.

(b) Deviations (banding) at horizontal joints shall not exceed the limits of Table 7-1.3.3-1. Banding at horizontal joints shall be determined using a straight edge vertical sweep board 36 in. (900 mm) long.

(c) Flat spots measured in the vertical plane shall not exceed the appropriate plate flatness and waviness requirements given in para. 7-1.3.2.

7-1.3.5 Tolerances for Bolted Body Flanges. Container body flanges shall have a maximum positive radial tilt (see Figure 7-1.3.5-1) of 0.003 in. (0.076 mm) measured at the outer edge of the gasket seating surface. Negative radial tilt is not permitted. Flange waviness shall be limited to 0.006 in. (0.152 mm) on the total indicator reading measured over the entire surface of a circular arc halfway across the gasket face or along the mean gasket diameter. Note the figure shows a raised-face, slip-on flange, but these tolerances apply to other types, such as flat-faced, weld neck, and ring flanges. The surface finish for gasket seating surfaces shall be 125 Ra to 250 Ra (3.2 μm to 6.4 μm).

7-1.3.6 Measurements. Dimensional tolerance measurements shall be taken prior to final integrity testing.

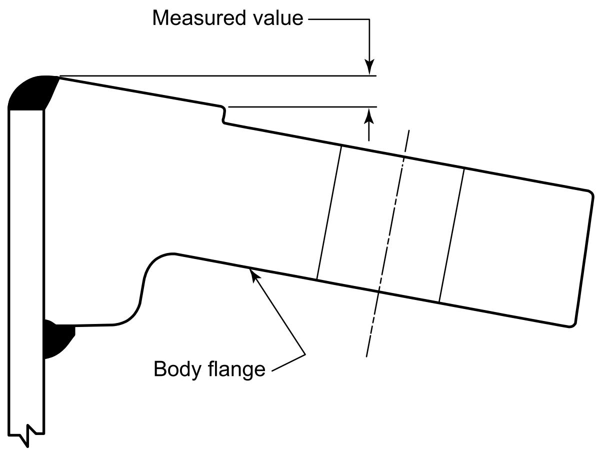
7-1.4 Marking

All material that is cut to size before shipment or assembled into shipping assemblies shall be marked as shown on the manufacturer's drawings. It is acceptable to mark a container or bundle of small parts. Chloride-free markers are required for stainless steel materials.

Table 7-1.3.3-1
Roundness Tolerance

Cylindrical Diameter, ft (m)	Radius Tolerance, in. (mm)	Deviations at Vertical Joints, in. (mm)	Deviations at Horizontal Joints, in. (mm)
<16 (<5)	±1/4 (6)	±1/4 (6)	±1/4 (6)
≥16 to <40 (≥5 to <12)	±1/2 (13)	±1/2 (13)	±1/2 (13)
≥40 to <150 (≥12 to <45)	±3/4 (19)	±1/2 (13)	±1/2 (13)
≥150 to <250 (≥45 to <75)	±1 (25)	±1/2 (13)	±1/2 (13)
≥250 (75)	±1 1/4 (32)	±1/2 (13)	±1/2 (13)

Figure 7-1.3.5-1
Radial Tilt



GENERAL NOTE: Positive tilt shown. Negative tilt not shown.

7-1.5 Shipping

7-1.5.1 General Shipping. Plates and container materials shall be loaded in a manner that ensures delivery without damage. Bolts, nuts, nipples, and other small parts shall be boxed or put in kegs or bags for shipment to prevent loss or damage. Shop assemblies, including completely assembled structures, shall be stiffened or braced to prevent damage and maintain the required tolerances during shipment.

7-1.5.2 Stainless Steel. Packaging stainless steel for shipping may require special consideration to protect the material from contamination that could affect its corrosion resistance and to prevent normal shipping damage. If the intended service requires special precautions, packaging and shipping instructions should be supplied by the owner.

7-1.6 Inspection

See Section 8 for inspection requirements during fabrication and field erection.

7-1.7 Foundation Preparation

7-1.7.1 Foundations should be supplied to the tolerances specified in Nonmandatory Appendix A; this is the responsibility of the foundation contractor. Firm bearing of the foundation is required under shells, skirts, and column-type supports due to the nature of the loads experienced from product drag, seismic activity, wind, roof live loads, and dead loads. Except as described in paras. 7-1.7.2 and 7-1.7.3, containers constructed on foundations supplied within tolerances of Nonmandatory Appendix A may have baseplates or bottoms placed directly on the foundation using a layer of protective cushioning material, such as sand, fiberboard, or grout between the metal bottom and concrete foundation.

7-1.7.2 Each column of a column-supported container shall be adequately anchored. The column baseplates shall be shimmed to the correct elevation. Grouting or shimming procedures specified by the container manufacturer or designer must be completed prior to load testing.

7-1.7.3 Containers with shell or skirt baseplates bearing directly on the foundation that also require anchor rods shall be shimmed a minimum of 1 in. (25 mm) and then grouted prior to load testing.

7-1.7.4 Foundations that fail to meet Nonmandatory Appendix A tolerances shall be resurfaced by removal of foundation material, proper surface preparation, and the addition of cement-based leveling material. Alternatively, by agreement between the owner and container manufacturer, the baseplates can be shimmed and grouted as noted in para. 7-1.7.2 with a maximum grout thickness of 2 in. (50 mm).

7-1.7.5 Grout shall be a nonshrink type of adequate strength. It shall extend under skirt, shell, or column load points a minimum of 3 in. (75 mm) in each direction or to the edge of the baseplate. Grout shall be tapered on the outside of baseplates at a 45-deg angle from the vertical down to the foundation surface.

7-1.7.6 For vertical stiffened containers, the base plates of the vertical stiffening members may be supported directly on the foundation and be shimmed or grouted as necessary around the container perimeter for levelness where prescribed or permitted by the container manufacturer.

7-2 FABRICATION AND ERECTION OF WELDED CONTAINERS

7-2.1 General Fabrication

The requirements in this subsection apply specifically to the fabrication and erection of containers for bulk solids that are fabricated by welding.

7-2.1.1 General Fitting and Alignment

7-2.1.1.1 Plates that are being welded shall be fitted, aligned, and retained in position during the welding operation.

7-2.1.1.2 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 or butt weld procedure qualified in accordance with ASME BPVC, Section IX.

Table 7-2.1.4.1-1
Joint Alignment Tolerances for Butt Weld Joints

Section Thickness, in. (mm)	Joint Alignment Tolerance, in. (mm)	
	Longitudinal Butt Weld Joints	Circumferential and Other Butt Weld Joints
≤$\frac{1}{2}$ (≤13)	$\frac{1}{4}t$	$\frac{1}{4}t$
>$\frac{1}{2}$ to ≤$\frac{3}{4}$ (>13 to ≤18)	$\frac{1}{8}$ (3)	$\frac{1}{4}t$
>$\frac{3}{4}$ to ≤1$\frac{1}{2}$ (>18 to ≤36)	$\frac{1}{8}$ (3)	$\frac{3}{16}$ (5)
>1$\frac{1}{2}$ to ≤2 (>36 to ≤50)	$\frac{1}{8}$ (3)	$\frac{1}{8}t$
>2 (>50)	Lesser of $\frac{1}{16}t$ or $\frac{3}{16}$ (5)	Lesser of $\frac{1}{8}t$ or $\frac{3}{8}$ (9)

Tack welds to be left in place as well as all production welds shall be made by welders qualified in accordance with ASME BPVC, Section IX and shall be examined visually for defects. If found to be defective, the weld shall be removed.

7-2.1.1.3 The edges of butt joints shall be held during welding to meet the tolerances described in para. 7-2.1.4. When fitted joints have deviations exceeding the permitted tolerances, they shall be reformed until the errors are within the specified limits. Where fillet lap welds are used, the lapped plates shall fit closely and be kept in contact during welding.

7-2.1.2 Finish of Nozzle Edges. Exposed cut inside edges of nozzles and manways shall be chamfered or rounded to eliminate sharp edges.

7-2.1.3 Cleaning of Surfaces to Be Welded

7-2.1.3.1 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.

7-2.1.3.2 The requirements in para. 7-2.1.3.1 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.

7-2.1.4 Alignment Tolerances

7-2.1.4.1 Edges of sections to be butt welded shall be aligned such that the maximum offset is not greater than the applicable amount for the type of welded joint under consideration as listed in Table 7-2.1.4.1-1. The section thickness, t, is the nominal thickness of the thinner section at the joint.

7-2.1.4.2 Any offset within the allowable tolerances provided in Table 7-2.1.4.1-1 shall be flared at a three-to-one taper over the width of the finished weld. Weld metal may be added beyond what would otherwise be the edge of the weld if it is necessary to achieve the taper. Any additional welds shall be made using the butt weld procedure used to make the connecting weld.

7-2.1.5 Miscellaneous Welding Requirements

7-2.1.5.1 The reverse side of double-welded joints shall be prepared by chipping, grinding, or melting out to secure sound metal at the base of weld metal first deposited, before applying weld metal from the reverse side.

7-2.1.5.2 The above requirements are not intended to apply to any process of welding by which proper fusion and penetrations are otherwise obtained and by which the base of the weld remains free from defects.

7-2.1.5.3 If welding is stopped for any reason, 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.

7-2.1.5.4 Where single-welded joints are used, 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.

7-2.1.5.5 No welding of any kind shall be performed when the surfaces of the parts to be welded are wet from rain, snow, or ice; when rain or snow is falling on such surfaces; or during periods of high winds, unless the welder and work are properly shielded. Welding shall not be performed when the temperature of the base metal is less than 0°F to 32°F (−20°C to 0°C) or the thickness of the base metal is in excess of 1$\frac{1}{4}$ in. (32 mm). The base metal within 3 in. (75 mm) of the place where welding is to be started shall be heated to a temperature warm to the hand. Carbon steel plate greater than 1$\frac{1}{2}$ in. (38 mm) shall be preheated to a minimum of 200°F (90°C).

7-2.1.6 Surface Weld Metal Buildup. Construction in which deposits of weld metal are applied to the surface of base metal for the purpose of restoring the thickness of the base metal for strength consideration or modifying the configuration of weld joints in order to meet the tapered transition requirements of para. 7-2.1.4.2 shall be performed in accordance with the following:

Table 7-2.1.8.4-1
Weld Reinforcement

Material Nominal Thickness, in. (mm)	Maximum Reinforcement, in. (mm)	
	Circumferential Shell, Flange, or Flat-Head Attachment Butt Welds	Longitudinal and Other Butt Welds
<$^3/_{32}$ (<2.5)	$^3/_{32}$ (2.5)	$^1/_{32}$ (1)
$^3/_{32}$ to ≤$^3/_{16}$ (2.5 to ≤5)	$^1/_8$ (3)	$^1/_{16}$ (1.5)
>$^3/_{16}$ to ≤$^1/_2$ (>5 to ≤13)	$^5/_{32}$ (4)	$^3/_{32}$ (2.5)
>$^1/_2$ to ≤1 (>13 to ≤25)	$^3/_{16}$ (5)	$^3/_{32}$ (2.5)
>1 to ≤2 (>25 to ≤50)	$^1/_4$ (6)	$^1/_8$ (3)
>2 (>50)	$^1/_4$ (6)	$^5/_{32}$ (4)

(a) Prior to production welding, a butt-welding procedure shall be qualified in accordance with ASME BPVC, Section IX for the thickness of the weld metal deposited.

(b) All weld metal buildup for the purposes of restoring material thickness must be examined over the full surface of the deposit by either magnetic particle examination (MT) per ASME BPVC, Section VIII, Division 1, Mandatory Appendix 6 or by liquid penetrant examination (PT) per Section VIII, Division 1, Mandatory Appendix 8. Weld metal buildup shall be included in any full or spot radiographic examination required for welded joints.

7-2.1.7 Fillet Welds

7-2.1.7.1 Fillet welds may be employed as strength welds for pressure parts within the limitations in this Standard. Care shall be taken in the layout of joints in which fillet welds are to be used to ensure complete fusion at the root of the fillet.

7-2.1.7.2 The reduction of the base metal thickness due to the welding process at the edges of the fillet weld shall meet the same requirements as for butt welds (see para. 7-2.1.8.2).

7-2.1.8 Butt Welds

7-2.1.8.1 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 NDEs. If there is a question regarding the surface condition of the weld when interpreting a radiographic film, the film shall be compared to the actual weld surface to determine acceptability.

7-2.1.8.2 A reduction in thickness due to the welding process is acceptable, provided the following conditions are met:

(a) The reduction in thickness shall not reduce the material of the adjoining surface below the minimum required thickness at any point.

(b) The reduction in thickness shall not exceed $^1/_{32}$ in. (1 mm) or 10% of the nominal thickness of the adjoining surface, whichever is less.

7-2.1.8.3 When a single-welded butt joint is made by using a backing strip that is left in place, the reinforcement requirement applies only to the side opposite the backing strip.

7-2.1.8.4 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 material, 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 dimensions shown in Table 7-2.1.8.4-1.

7-2.2 Details of Welding

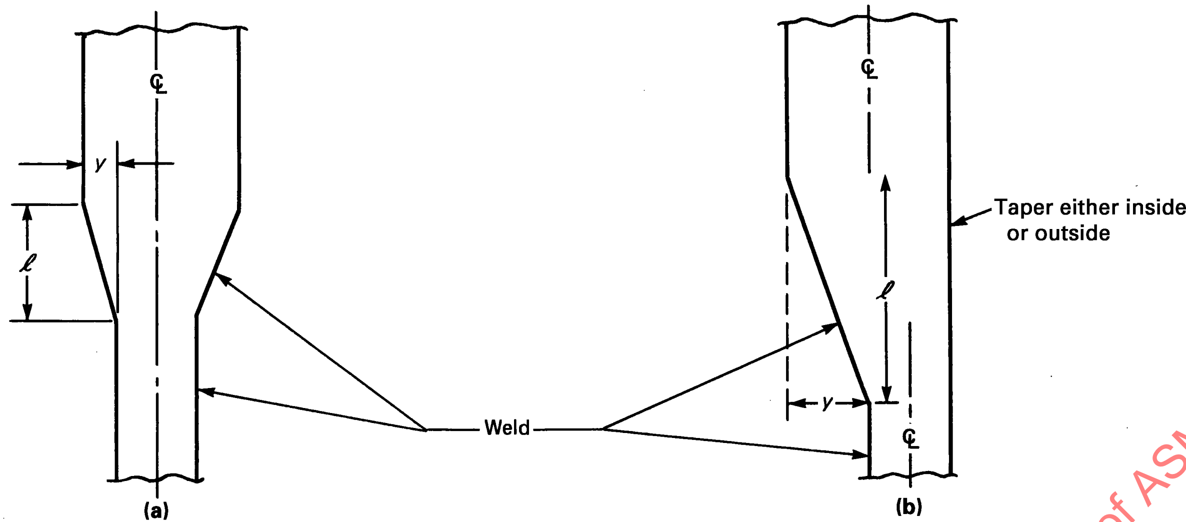
7-2.2.1 General. The requirement in paras. 7-2.2.1 through 7-2.2.7 apply specifically to the design of structures for bulk solids and structure parts that are fabricated by welding.

7-2.2.1.1 Permissible Types. The types of welded joints permitted in arc and gas welding processes are listed in Table 7-2.2.6-1, together with the limiting plate thickness for each type.

7-2.2.1.2 Welding Grooves. The dimensions and shape of the edges to be joined shall permit complete fusion and joint penetration. Qualification of the welding procedure, as required in para. 7-2.4.3, is acceptable proof that the welding groove is satisfactory.

7-2.2.1.3 Tapered Transitions. A tapered transition having a length not less than 3 times the offset between the adjacent surfaces of abutting sections, as shown in Figure 7-2.2.1.3-1, 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 $^1/_8$ in. (3 mm), whichever is less. The transition may be formed by any process that will provide a uniform taper.

Figure 7-2.2.1.3-1
Butt Welding 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 $3y$.

7-2.2.1.4 Longitudinal Intersections. Except when the longitudinal joints are radiographed 4 in. (100 mm) on each side of a circumferential welded intersection, structures made up of two or more courses shall have the centers of the welded longitudinal joints of adjacent courses staggered by a distance of at least 5 times the thickness of the thicker plate.

7-2.2.1.5 Lap Joints. For lapped joints, the surface overlap shall be not less than 4 times the thickness of the thinner plate except as noted for roofs in para. 7-2.2.2. The overlap need not be greater than 1 in. (25 mm).

Table 7-2.2.1.6-1
Minimum Fillet Weld Size

Maximum Plate Thickness, in. (mm)	Minimum Fillet Weld Size, in. (mm)
≤$^1/_2$ (≤13)	$^3/_{16}$ (5) [Note (1)]
>$^1/_2$ (>13)	$^1/_4$ (6) [Note (2)]

NOTES:
(1) The minimum weld size may be reduced to the thickness of the material being welded or $^3/_{16}$ in. (5 mm), whichever is less.
(2) The minimum weld size may be reduced to $^3/_{16}$ in. (5 mm) if one or both of the following apply:
   (a) The joint is preheated to 200°F (93°C).
   (b) Magnetic particle or liquid penetrant examination is performed after welding.

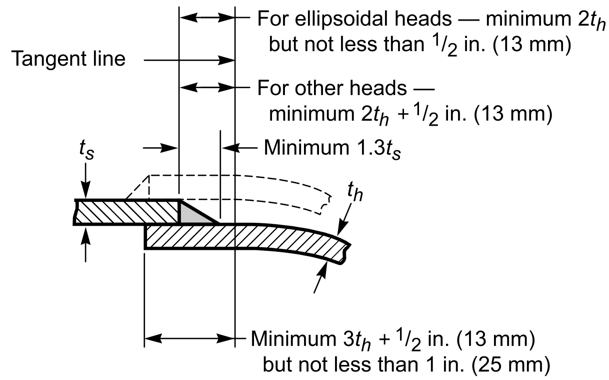
7-2.2.1.6 Minimum Weld Sizes. Minimum fillet weld size for structural welds in the shell and heads is $^3/_{16}$ in. (5 mm) or the thickness of the material being welded, whichever is less. When fillet welds are used, the minimum fillet weld size shall be per Table 7-2.2.1.6-1.

7-2.2.2 Roofs. Paragraphs 7-2.2.2.1 and 7-2.2.2.2 apply to weld joints that are used to attach roofs to the upper shell. Roofs shall be self-supporting cones, umbrellas, or domes with or without stiffening or shall be formed heads with a head skirt (straight flange).

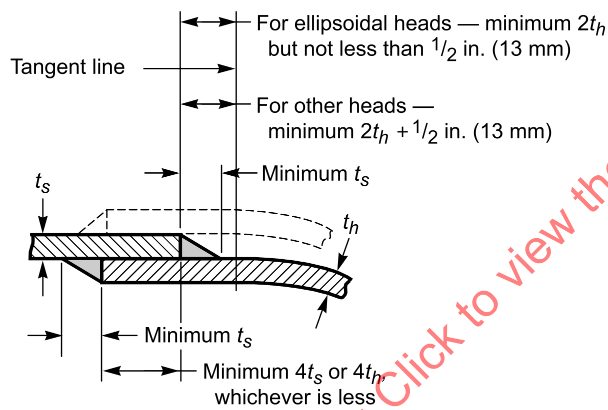
7-2.2.2.1 Roof-to-Shell Joints. Roofs that are formed heads with skirts shall be attached to the upper shell using continuous butt or lap welds as shown in Figure 7-2.2.2.1-1, illustration (a), (b), or (c). Roofs without knuckles may be attached to the top edge of the shell or welded directly to the top of an inside or outside compression ring using a single-sided fillet weld. Roofs may also be welded to the shell directly with a compression ring for reinforcement [see Figure 6-8.2.3-1, illustrations (a) through (k)]. Frangible-style roofs (roofs which are designed to fail during an overpressure event) shall be welded to the compression ring with a maximum $^3/_{16}$ in. (5 mm) continuous weld on the outside only per Figure 6-8.2.3-1, illustration (b), (c), or (f).

7-2.2.2.2 Roof Plate Joints. Joints within shallow-cone, umbrella, or domed-head roof plates without knuckles may be butt or lap-type joints, as shown in

Figure 7-2.2.2.1-1
Head- or Cone-to-Shell Attachment Types

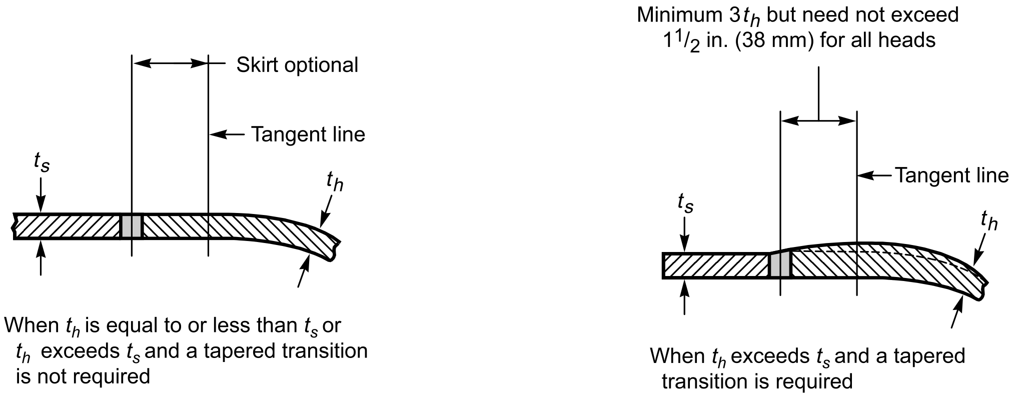


(a) Single Full-Fillet Lap Joint

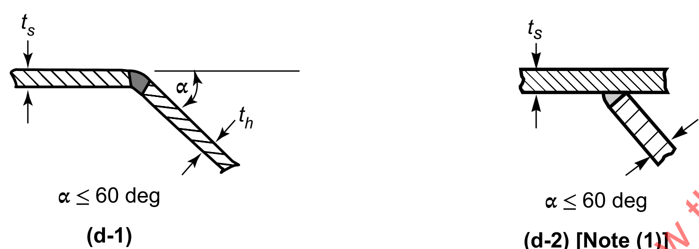


(b) Double Full-Fillet Lap Weld

Figure 7-2.2.2.1-1
Head- or Cone-to-Shell Attachment Types (Cont'd)



(c) Butt Joints at Shell to Head With Knuckle



Permissible Cone-to-Shell Corner Butt Joints

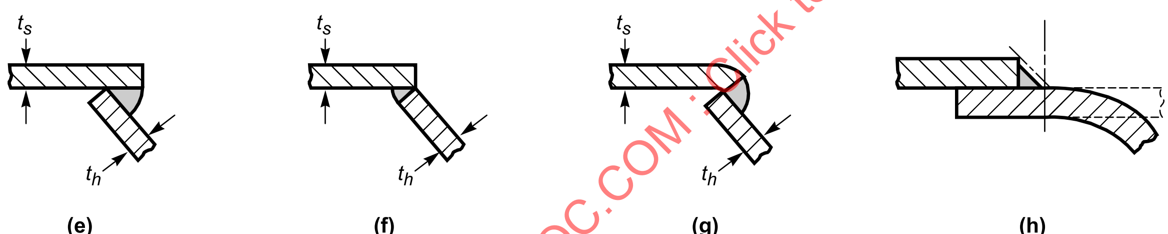
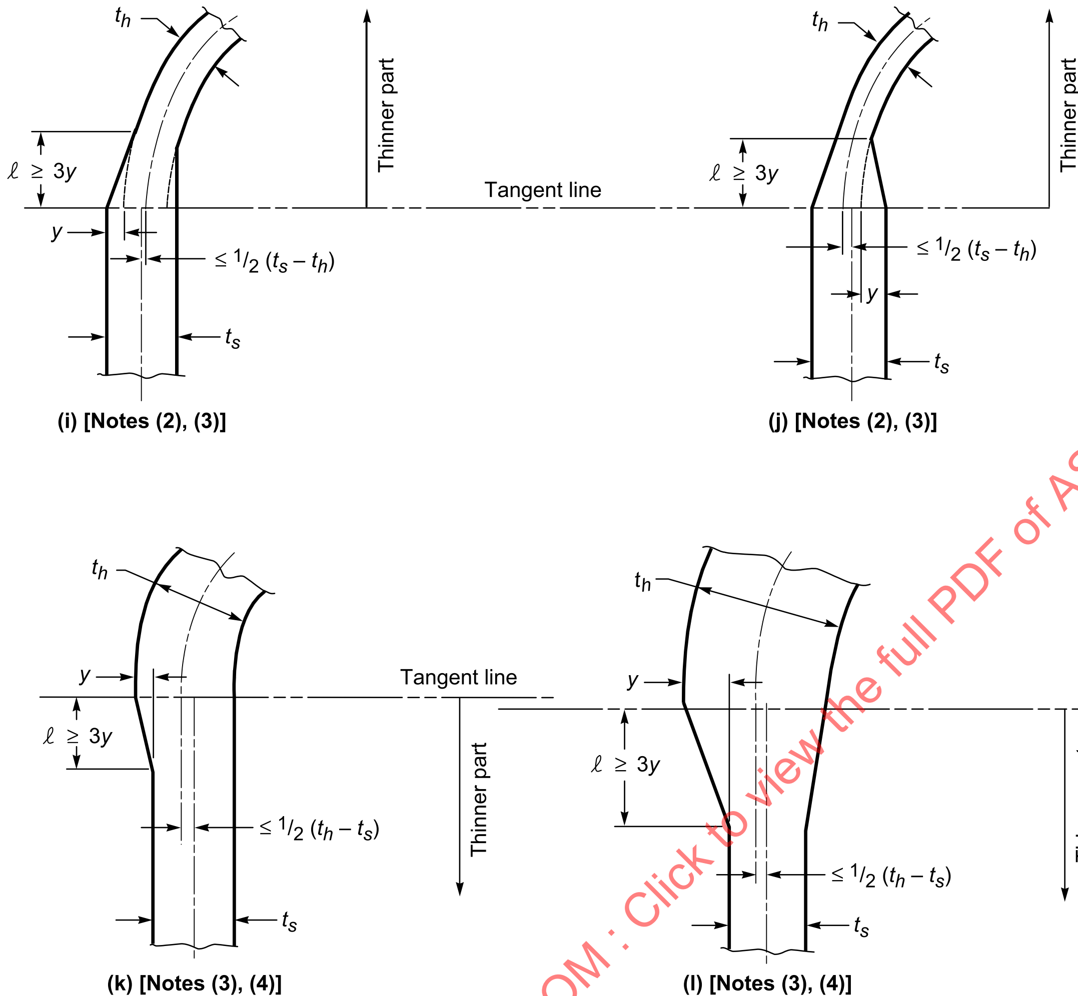


Figure 7-2.2.2.1-1
Head- or Cone-to-Shell Attachment Types (Cont'd)



NOTES:

(1) If t_s exceeds $^1/_2$ in. (13 mm), the shell must be UT examined for a distance of $4t_s$ above and below the shell-to-cone intersection in (d-2).

(2) In all cases, the projected length of taper, ℓ, shall be not less than $3y$.

(3) 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.

(4) 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 $1^1/_2$ in. (38 mm) 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.

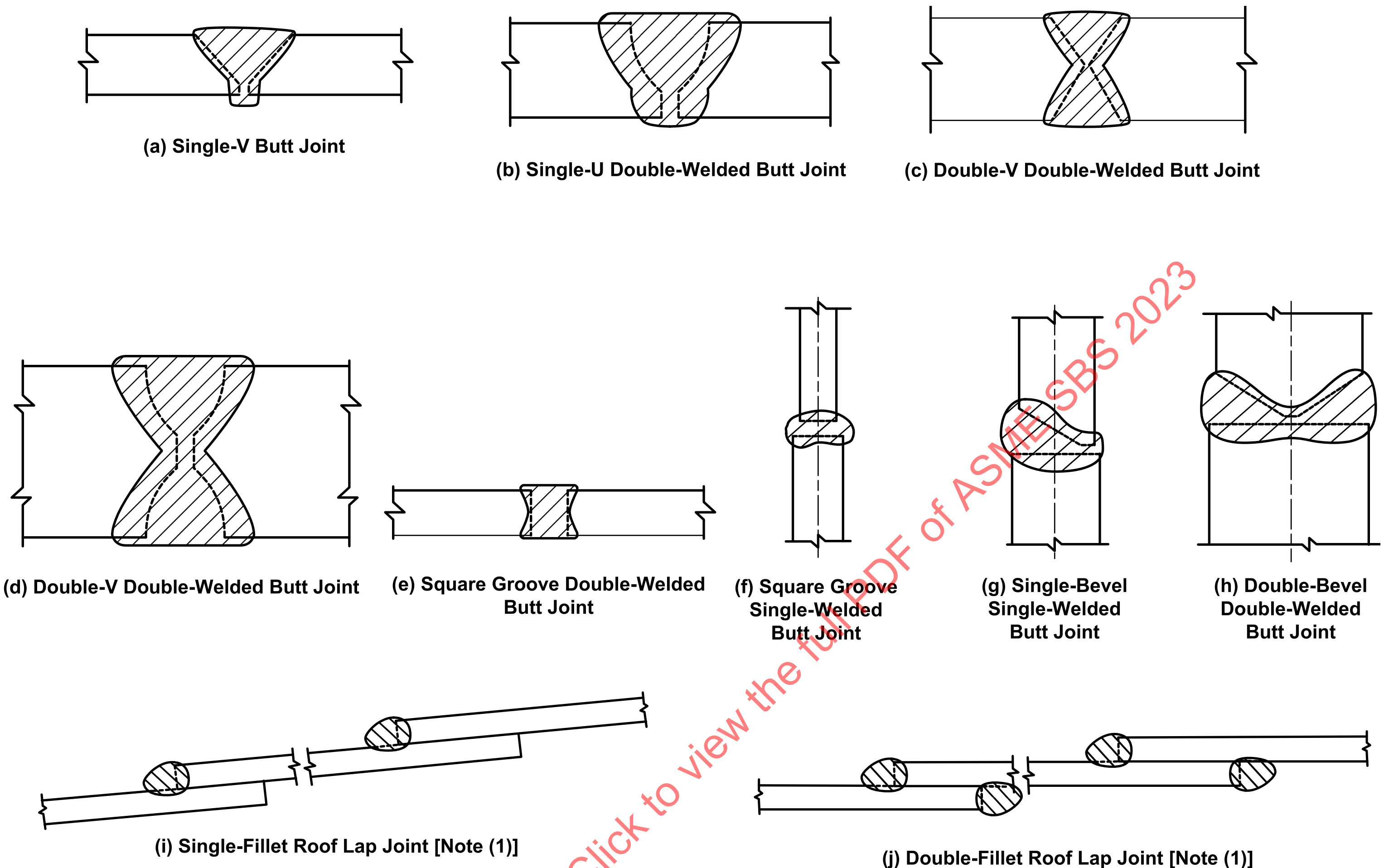
Figure 7-2.2.2.2-1, illustration (i) or (j). Lap welds shall be limited to roofs on bulk solid structures having internal pressures less than or equal to 2.5 psig (17.24 kPa). All longitudinal or circumferential joints within formed heads that have skirts serving as roofs shall be butt type only, as shown in Figure 7-2.2.2.2-1, illustrations (a) through (h). All butt welds shall be continuous and full penetration with full fusion. All fillet welds shall be the same size as the thickness of the thinner plate being joined.

7-2.2.3 Shell-to-Head Attachment Details

(a) Ellipsoidal, tori-spherical, tori-conical, and other types of formed heads shall be attached to the shell as illustrated in Figure 7-2.2.2.1-1, illustration (a), (b), or (c). Limitations relative to the use of these attachments shall be as given in the illustrations and related notes and in Table 7-2.2.6-1. Illustrations (e) through (h) in Figure 7-2.2.2.1-1 are examples of attachment methods that are not permissible.

(b) Formed heads, concave to the pressure of solids loading, shall have a skirt length not less than that shown in the applicable illustration of Figure 7-2.2.2.1-1.

Figure 7-2.2.2.2-1
Weld Joints in Shells, Heads, and Roofs



GENERAL NOTES:
(a) The illustrations are from API Standard 650, Welded Tanks for Oil Storage (2020, 13th ed.), Figures 5.1, 5.2, and 5.3a. Reproduced courtesy of the American Petroleum Institute.
(b) All butt joints are to be full penetration with full fusion.
(c) All joints in shells, formed heads, cones, and bottoms shall be butt type.

NOTE: (1) Illustrations (i) and (j) lap welds are limited to cone and umbrella roofs not exceeding 2.5 psig (17.24 kPa) internal pressure.

(c) A tapered transition having a length at least 3 times the offset between the adjacent surfaces of abutting sections, as shown in Figure 7-2.2.2.1-1, illustrations (i) and (j), 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 $\frac{1}{8}$ in. (3 mm), whichever is less.

(1) When a taper is required on any formed head that is thicker than the shell and intended for butt-welded attachment [see Figure 6-8.2.3-1, illustrations (k) and (l)], the skirt shall be long enough so that the taper does not extend beyond the tangent line.

(2) When the transition is formed by removing material from the thicker section, the minimum thickness of that section after the material is removed shall not be less than that required by the imposed loadings on that section.

(3) When the transition is formed by adding additional weld metal beyond what would otherwise be the edge of the weld, the additional weld metal buildup shall be subject to the requirements of para. 7-2.2.6.

7-2.2.4 Bottom Transition Cones. The requirements in paras. 7-2.2.4.1 and 7-2.2.4.2 apply to the weld joints attaching the bottom transition cone to the structure shell and the joints within the bottom transition cone.

7-2.2.4.1 Cone-to-Shell Attachment. Only full-penetration continuous butt or bevel welds may be used to join either bottom transition cones with or without a skirt to the lower shell course [see Figure 7-2.2.2.1-1, illustrations (c), (d-1), and (d-2)]. In the case of a cone without a skirt that is welded directly to the shell, the butt weld may be at the cone-to-shell junction with the weld orientation being the same as the angle of the cone. Such a joint is a Category B or Category D joint per para. 7-2.2.5.2. Such configurations usually require external reinforcement in the shell-to-cone region. For tori-conical heads with a skirt, the attachment shall be a straight butt weld. In all cases, welds shall be made such that the inside surface of the cone is flush with the inside surface of the shell at the weld joint. In addition, the inside edge of all cone-to-shell joints shall provide a smooth transition into both internal surfaces.

7-2.2.4.2 Cone Joints. All longitudinal or circumferential joints within the lower transition cone shall be continuous full-penetration butt joints as shown in Figure 7-2.2.2.2-1, illustrations (a) through (h). Only circumferential joints may be double full-fillet lap joints as shown in Figure 7-2.2.2.1-1, illustration (b). Circumferential lap joints shall be shingled in the direction of product flow. The inside surface of all butt welds shall be ground flush and smooth when specified by the purchaser.

7-2.2.5 Welded Joint Categories

7-2.2.5.1 The term "category" used herein defines the location of a joint in a structure for bulk solids but not the type of joint. The categories established by this paragraph are used in this Standard to specify special requirements regarding joint types and the degree of inspection for certain welded pressure joints. Since these special requirements, which are based on service, material, and thickness, do not apply to every welded joint, only joints to which special requirements apply are included in the categories. The special requirements will apply to joints of a given category only when specified. The joints are designated by category as described in Table 7-2.2.5.1-1. Figure 7-2.2.5.1-1 illustrates typical joint locations included in each category.

7-2.2.5.2 When Category B butt-welded joints are required elsewhere in this Standard, an angle joint connecting a transition in diameter to a cylinder shall be considered as meeting this requirement, provided the angle α (see Figure 7-2.2.5.1-1) does not exceed 30 deg. All requirements pertaining to the butt-welded joint shall apply to the angle joint.

7-2.2.6 Joint Efficiencies. Table 7-2.2.6-1 gives the joint efficiencies, E, for joints completed by an arc- or gas-welding process. A joint efficiency depends only on the type of joint and degree of examination of the joint. The user or the user's designated agent shall establish the type of joint and degree of examination when this Standard does not mandate specific requirements. Requirements for determining the applicability of the efficiencies are found in the design formulas of Section 6.

(a) A value of E less than or equal to the value in column (a) of Table 7-2.2.6-1 shall be used in the design calculations for fully radiographed butt joints, except when the Category A butt welds in any head are not fully radiographed. In that case, a value of E that is less than or equal to that in column (b) shall be used.

(b) A value of E less than or equal to the value in column (b) of Table 7-2.2.6-1 shall be used in the design calculations for spot radiographed butt-welded joints.

(c) A value of E less than or equal to the value in column (c) shall be used in the design calculations for welded joints that are neither fully nor spot radiographed.

7-2.2.7 Weld Spacing Requirements. The requirements in paras. 7-2.2.7.1 through 7-2.2.7.4 apply to all main container welds, including welded details in bolted structures.

7-2.2.7.1 Distance From Reinforcing or Insert Plates

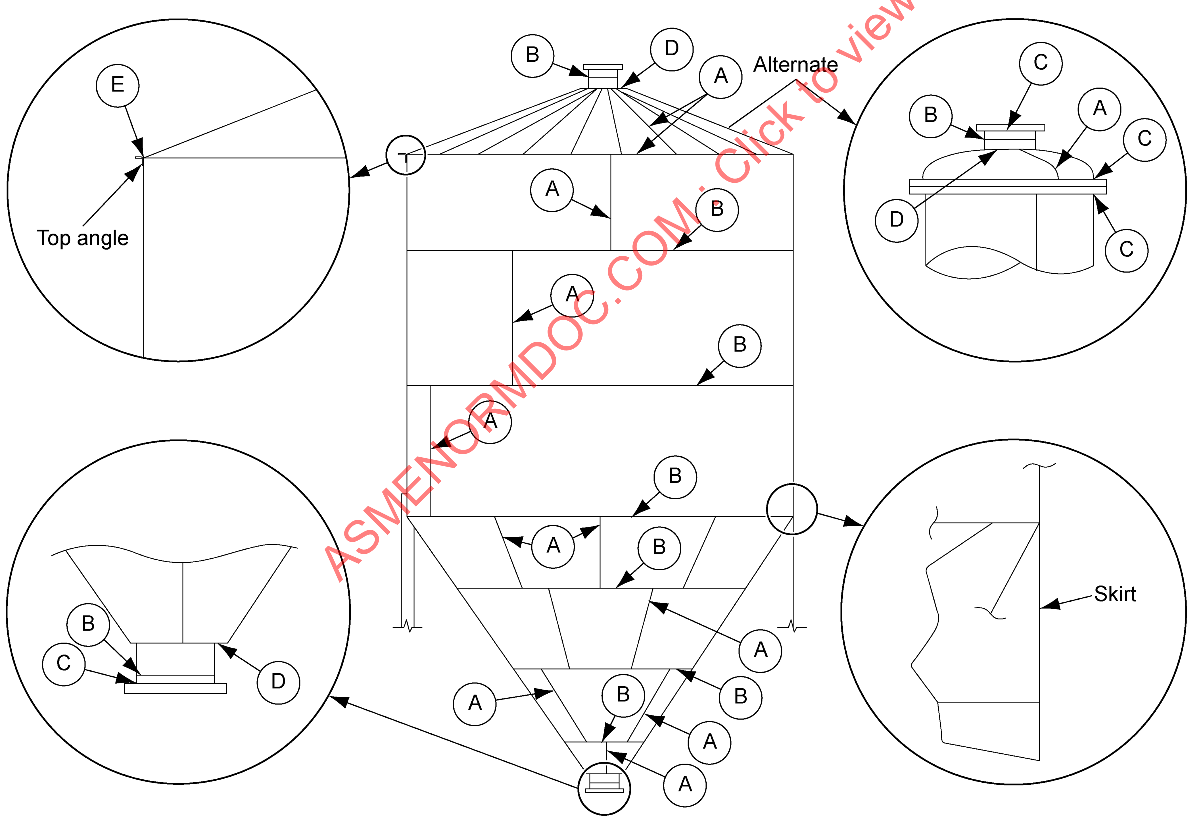
(a) For non-stress-relieved welds over $\frac{1}{2}$ in. (13 mm) thick, the outer edge of the fillet weld or insert butt weld shall be spaced at least the greater of 8 times the weld size or 10 in. (250 mm) from all butt-welded joints or other reinforcing plate fillet welds (see Figure 7-2.2.7.1-1).

Table 7-2.2.5.1-1
Weld Joint Categories

Category	Joints Included
A	Longitudinal welded joints within the main shell, transitions in diameter, or nozzles
	Any welded joint within a formed or flat head
	Circumferential heads to main shells, transitions in diameters, nozzles, or communicating chambers
B	Circumferential welded joints within the main-shell communicating chambers, nozzles, or transitions in diameter, including joints between the transition and a cylinder at either the large or small end
	Circumferential welded joints connecting formed heads (other than hemispherical) to main shells, transitions in diameter, nozzles, or communicating chambers
C	Welded joints connecting flanges, Van Stone laps, or flat heads to main shell, formed heads, transitions in diameter, nozzles, or communicating chambers
D	Welded joints connecting communicating chambers or nozzles to main shells, transitions in diameter [Note (1)], or heads
	Joints connecting nozzles to communicating chambers
E	Fillet-welded joints connecting flat, conical, dome, or umbrella roofs without a knuckle to main shells
	Compression rings and fillet-welded joints connecting flat bottoms without a knuckle to the main shell

NOTE: (1) For nozzles at the small end of a diameter transition, see Category B.

Figure 7-2.2.5.1-1
Weld Joint Categories



GENERAL NOTE: See Table 7-2.2.5.1-1 for definitions of weld joint categories.

Table 7-2.2.6-1
Maximum Allowable Joint Efficiencies for Arc- and Gas-Welded Joints

Type No.	Joint Description	Limitations	Joint Category	Degree of Radiographic Examination		
				(a) Full	(b) Spot	(c) None
1	Butt joints attained by double-welding or other means; see para. 7-2.1.8 (excludes welds that use metal backing strips that remain in place)	None	A, B, C, D	1	0.85	0.7
2	Single-welded butt joint with backing strip other than those included under (1)	None	A, B, C, D	0.9	0.8	0.65
3	Single-welded butt joint without use of backing strip	Circumferential butt joints only, not over $5/8$ in. (16 mm) thick and ≤24 in. (610 mm) outside diameter	A, B, C	NA	NA	0.6
4	Double full-fillet lap joint	Longitudinal joints ≤$3/8$ in. (9 mm) thick	B, C	NA	NA	0.55
		Circumferential joints ≤$5/8$ in. (16 mm) thick		NA	NA	0.55
5	Single full-fillet lap joints with or without plug welds	For the attachment of heads having pressure on either side, to shells ≤24 in. (610 mm) inside diameter and ≤$1/4$ in. (6 mm) required thickness, where fillet weld is on the outside of head flange only	A, B	NA	NA	0.45
6	Single or double fillet welds	For the attachment of dome, umbrella, conical, or flat roofs without knuckles to shells with or without compression rings and flat bottoms	E	NA	NA	0.45
7	Groove and fillet full-penetration corner joint	For the attachment of conical hoppers to the bottom of shells	B	NA	NA	0.35

(b) Where postweld heat treatment has been performed prior to welding of the adjacent butt-shell or transition-cone weld, or for welds on shells or transition cones less than $1/2$ in. (13 mm) thick, the outer edge of the fillet weld or insert butt weld shall be spaced at least the greater of 8 times the weld size or 6 in. (150 mm) from all butt-welded joints or other reinforcing plate fillet welds (see Figure 7-2.2.7.1-1).

7-2.2.7.2 Reinforcing or Structural Pad Plates. Every effort should be made to avoid covering a butt weld with a reinforcing or structural pad plate. If it is unavoidable, the butt weld must be ground flush under the reinforcing or pad plate and, if specified by the owner, shall be vacuum-box tested, including a length of 2 in. (50 mm) beyond the limits of the reinforcing or pad plate. A magnetic particle examination shall be performed on both surfaces of the butt weld. A length of at least 6 in. (150 mm) shall be examined, including a length of 2 in. (50 mm) beyond the reinforcing or pad plate. Magnetic particle examination shall meet the requirements of ASME BPVC, Section VIII, Division 1, Mandatory Appendix 6.

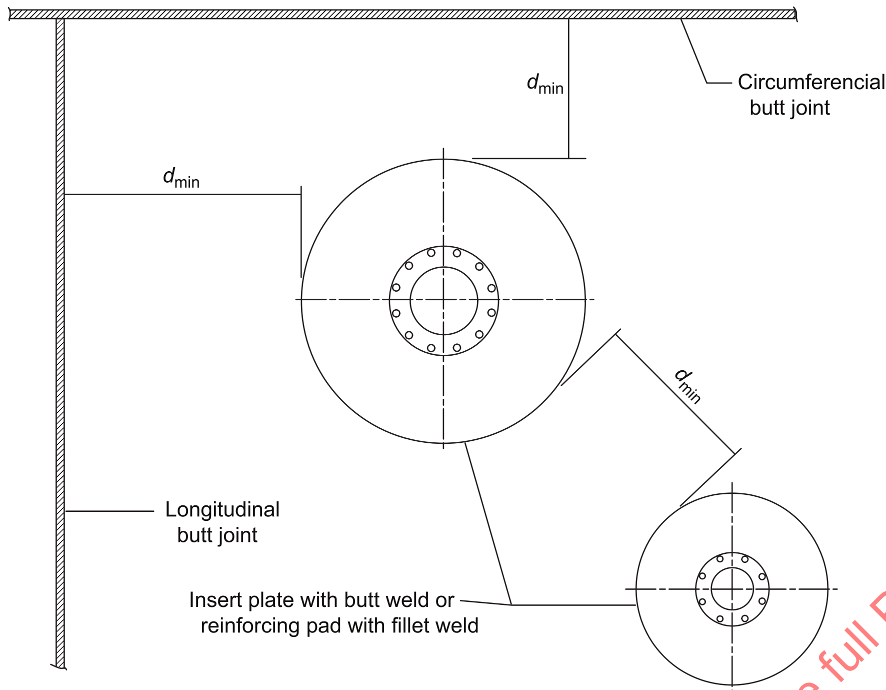
NOTE: Liquid penetrant examination is used in lieu of magnetic particle examination for stainless steel. LT shall meet the requirements of ASME BPVC, Section VIII, Division 1, Mandatory Appendix 8.

(a) For Reinforcing Plate. After the reinforcing-plate fillet weld has cooled, magnetic particle examination shall be performed on the total length of fillet weld and on the butt weld for a length of 2 in. (50 mm) beyond the intersection.

(b) For Structural Pad Plates (Excluding Those Used for Lightly Loaded Attachments per Para. 7-2.2.7.3). After the pad-plate fillet weld has cooled, a magnetic particle examination shall be performed on the fillet weld for 6 in. (150 mm) on each side of the intersection and on the butt weld for a length of 2 in. (50 mm) beyond the pad plate weld.

7-2.2.7.3 Structural Pad Plate for Lightly Loaded Attachments. Structural pad plates may be used for lightly loaded attachments, such as ladders and stairways, with essentially no moment loads. For containers having

Figure 7-2.2.7.1-1
Weld-Spacing Requirements



GENERAL NOTES:
(a) For nonstress-relieved welds or where the insert plate or reinforcing pad fillet weld is greater than ½ in. (13 mm), d_{min} is greater of 10 in. (250 mm) or 8 times the weld size.
(b) For stress-relieved welds or where the insert plate or reinforcing pad fillet weld is less than or equal to ½ in. (13 mm), d_{min} is greater of 6 in. (150 mm) or 8 times the weld size.

shell thicknesses 1 in. (25 mm) or less made from Table 4-2-1 materials (A36-Mod) with design metal temperatures of 10°F (−12 °C) or higher requiring shell support pad plates ⅜ in. (9.5 mm) maximum thickness, structural pad plates may be lapped across the shell weld seams, provided all of the following apply:

(a) The pad plate is attached with ¼ in. (6 mm) maximum fillet welds.

(b) All butt welds are ground flush prior to fitting the pad plate to the shell.

(c) The fillet welds attaching the pad plate to the shell shall intersect with the shell butt welds at an angle no less than 30 deg and preferably approaching 90 deg.

(d) The pad plate shall either overlap the butt seam by a minimum of 1 in. (25 mm) or miss the butt seam by 1 in. (25 mm) (i.e., no fillet welds on top of butt welds or heat-affected zone, except where the fillet weld crosses the butt weld at 90 deg).

(e) All fillet welds shall be given a close visual exam. Undercutting shall be eliminated where the fillet welds cross the butt welds and for 2 in. (50 mm) on either side of the shell butt welds.

7-2.2.7.4 Insert Plates. Insert plates that will intersect shell or head butt welds that are not postweld heat treated should intersect those welds as close to 90 deg as possible but at an angle not less than 30 deg in any case.

The insert butt weld and 2 in. (50 mm) of the shell butt weld shall be examined via magnetic particle examination after the weld cools to approximately ambient temperature.

7-2.3 Attachments

7-2.3.1 Welded Connections. Nozzles, other connections, and their reinforcements may be attached to structures for bulk solids by arc or gas welding. Reinforcing plates and saddles of nozzles attached to the outside of a container shall include at least one telltale hole (maximum size: NPS ¼ tap) that may be tapped for a preliminary compressed air and bubble solution test to check tightness of welds that seal off the inside of the structure. These telltale holes may be left open or plugged when the structure is in service. If the holes are plugged, the plugging material shall not be capable of sustaining pressure between the reinforcing plate and pressure boundary for structures that are operated above 2.5 psig (17.23 kPa) internal pressure.

7-2.3.2 Minimum Requirements for Attachment Welds at Openings

7-2.3.2.1 Terms. The terms "nozzles," "connections," "reinforcements," "necks," "tubes," "fittings," "pads," and other similar terms used in this paragraph define essentially the same type construction and form a Category D weld joint between the nozzle (or other term) and the shell, head, etc., as defined in Table 7-2.2.5.1-1.

7-2.3.2.2 Location and Size of Attachments. 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 reinforcement plate requirements of para. 7-2.3.1.

7-2.3.2.3 Corners. The illustrations in Figure 7-2.3.2.3-1 that show rounded corners or radii on exterior or interior corners without a value for the radius shall be correspondingly chamfered to $^1\!/_{16}$ in. (1.5 mm) minimum, rounded to a $^1\!/_8$ in. (3 mm) minimum radius, or machined or ground to a $3t$ minimum radius, where t is the thickness of the member. The inside and outside corners of openings shown in Figure 7-2.3.2.3-1, illustrations (x), (y), (z), (aa), and (bb), do not have specific radius or chamfer requirements.

7-2.3.2.4 Symbols. The symbols used in this paragraph and in Figures 7-2.3.2.3-1 and 7-2.3.2.4-1 are defined as follows:

Radius = $^1\!/_8$ in. (3 mm) minimum

r_1 = minimum inside corner radius, the lesser of $^1\!/_4 t$ or $^3\!/_4$ in. (19 mm)

t = nominal thickness of structure shell or head, in. (mm)

t_1 or t_2 = not less than the smaller of $^1\!/_4$ in. (6 mm) or $0.7t_{\min}$

t_c = not less than the smaller of $^1\!/_4$ in. (6 mm) or $0.7t_{\min}$ (Inside corner welds may be further limited by a lesser length of projection of the nozzle wall beyond the inside face of the structure wall.)

t_e = thickness of reinforcing plate, in. (mm)

$t_{\min}$ = the smaller of $^3\!/_4$ in. (19 mm) or the thickness of the thinner of the parts joined by a fillet, single-bevel, or single-J weld, in. (mm)

t_n = nominal thickness of nozzle wall, in. (mm)

t_w = dimension of attachment welds (fillet, single-bevel, or single-J), measured as shown in Figure 7-2.3.2.3-1, in. (mm)

7-2.3.2.5 Necks Attached by a Full Penetration Weld. Necks abutting a structure wall shall be attached by a full-penetration groove weld [see Figure 7-2.3.2.3-1, illustrations (a) and (b)]. Necks inserted through the structure wall may be attached by a full-penetration groove weld [see Figure 7-2.3.2.3-1, illustrations (c) through (e)]. When complete joint penetration cannot be verified by visual inspection or other means permitted by this Standard, backing strips or an equivalent shall be used with full-penetration welds deposited from one side.

If additional reinforcement is required, it shall be provided as integral reinforcement described in (a) or by the addition of separate reinforcement elements (plates) attached by welding as described in (b).

(a) 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. See Figure 7-2.3.2.3-1, illustrations (a) through (e), (f-1) through (f-4), (g), (x-1), (y-1), and (z-1) for examples of nozzles with integral reinforcement where the correction factor used in design calculations may be taken as 1.00.

(b) Separate reinforcement elements (plates) may be added to the outside, inside, or both surfaces of the shell wall. When this is done, the nozzle and reinforcement is no longer considered a nozzle with integral reinforcement where the correction factor used in design calculations may be taken as 1.00. Figure 7-2.3.2.3-1, illustrations (a-1), (a-2), and (a-3), depict various applications of reinforcement elements. Any of these applications of reinforcement elements may be used with neck types shown in Figure 7-2.3.2.3-1, illustrations (b) through (e), or any other integral reinforcement types listed in (a). 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 nozzle neck periphery or inner edge of the plate if no nozzle neck is adjacent to the plate. The welds at the outer and inner edges of a reinforcement plate that does not abut a nozzle neck shall be fillet welds with a minimum throat dimension of $^1\!/_2 t_{\min}$ [see Figure 7-2.3.2.3-1, illustration (h)]. The welds attaching a reinforcement plate to a nozzle neck abutting a structure wall shall be a full-penetration weld plus a fillet weld with a minimum throat dimension, t_w, not less than $0.7t_{\min}$.

Figure 7-2.3.2.3-1
Acceptable Types of Welded Nozzles and Other Connections to Heads, Shells, etc.

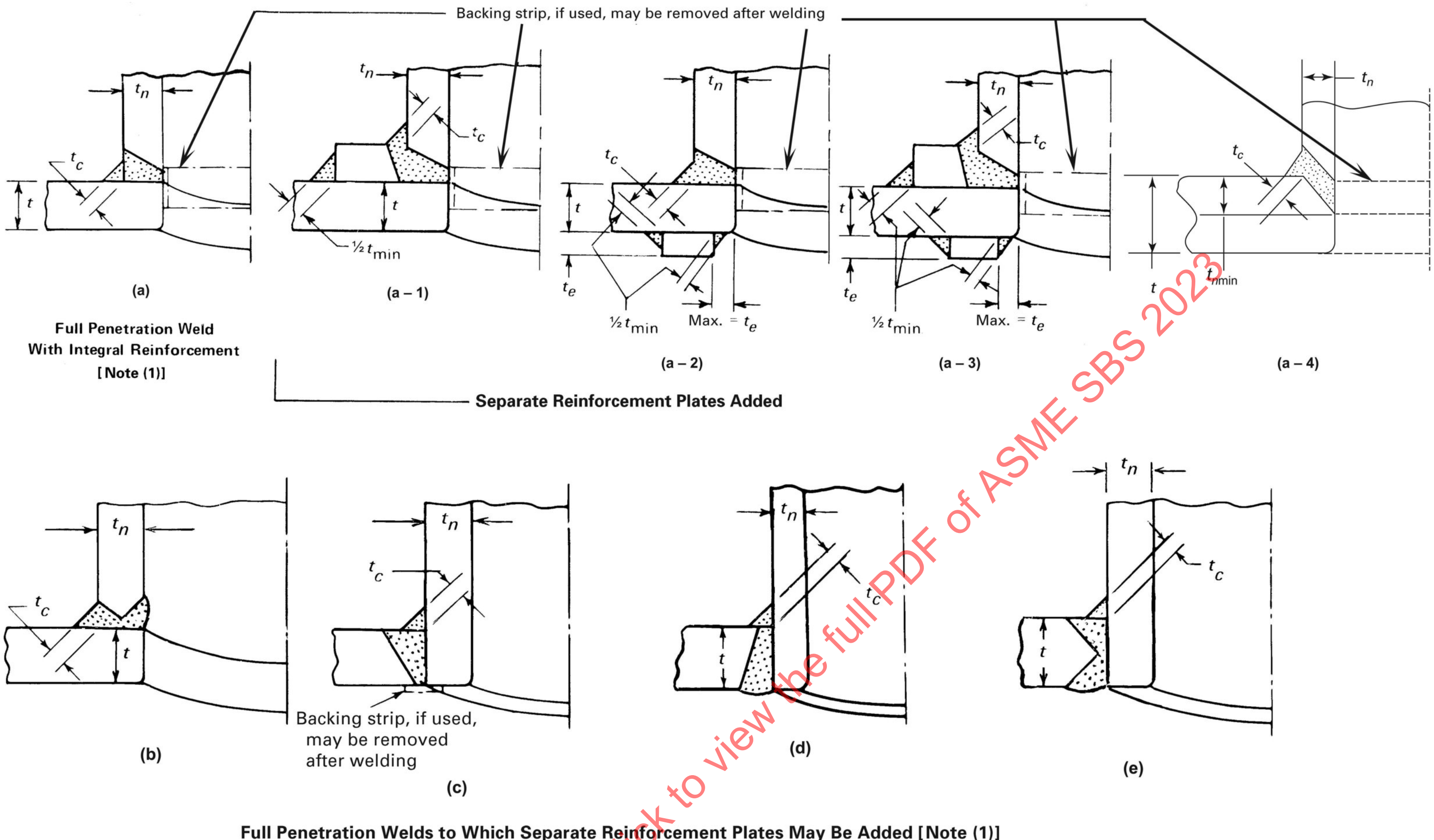
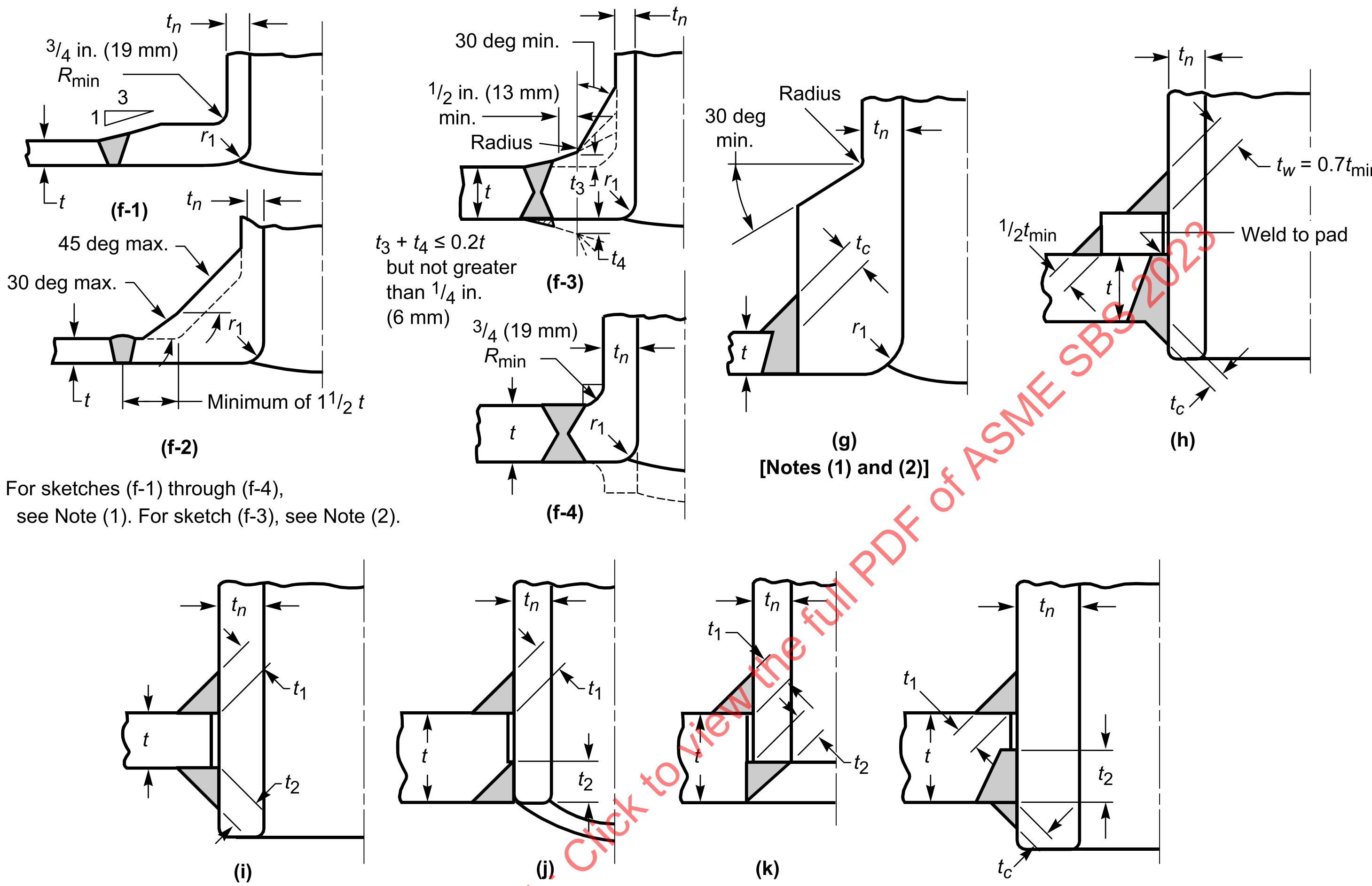


Figure 7-2.3.2.3-1
Acceptable Types of Welded Nozzles and Other Connections to Heads, Shells, etc. (Cont'd)



For sketches (f-1) through (f-4), see Note (1). For sketch (f-3), see Note (2).

$t_1 + t_2 \ge 1\frac{1}{4}t_{min}$

t_1 and t_2 each shall not be less than the smaller of 1/4 in. (6 mm) or $0.7t_{min}$

Figure 7-2.3.2.3-1
Acceptable Types of Welded Nozzles and Other Connections to Heads, Shells, etc. (Cont'd)

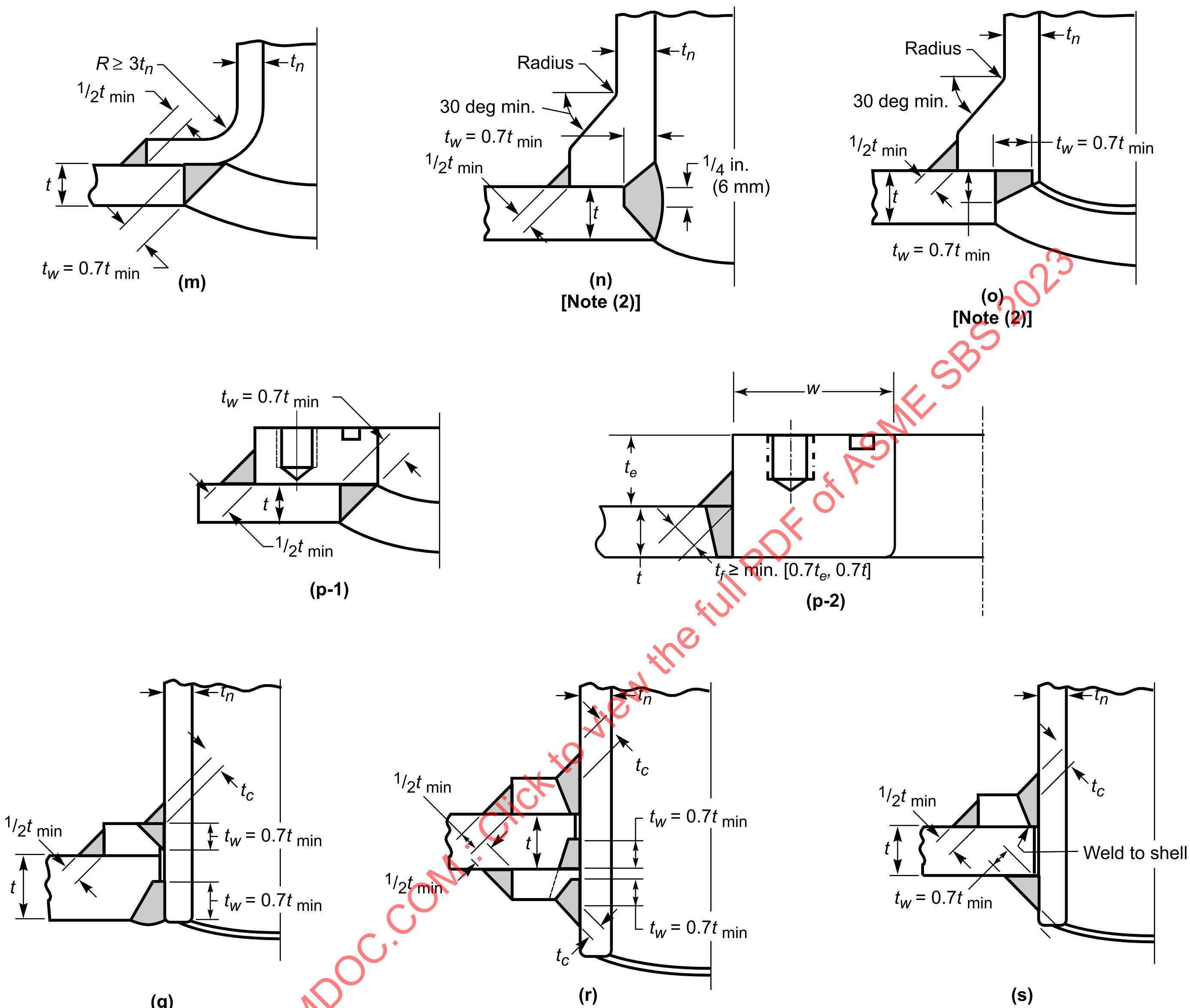


Figure 7-2.3.2.3-1
Acceptable Types of Welded Nozzles and Other Connections to Heads, Shells, etc. (Cont'd)

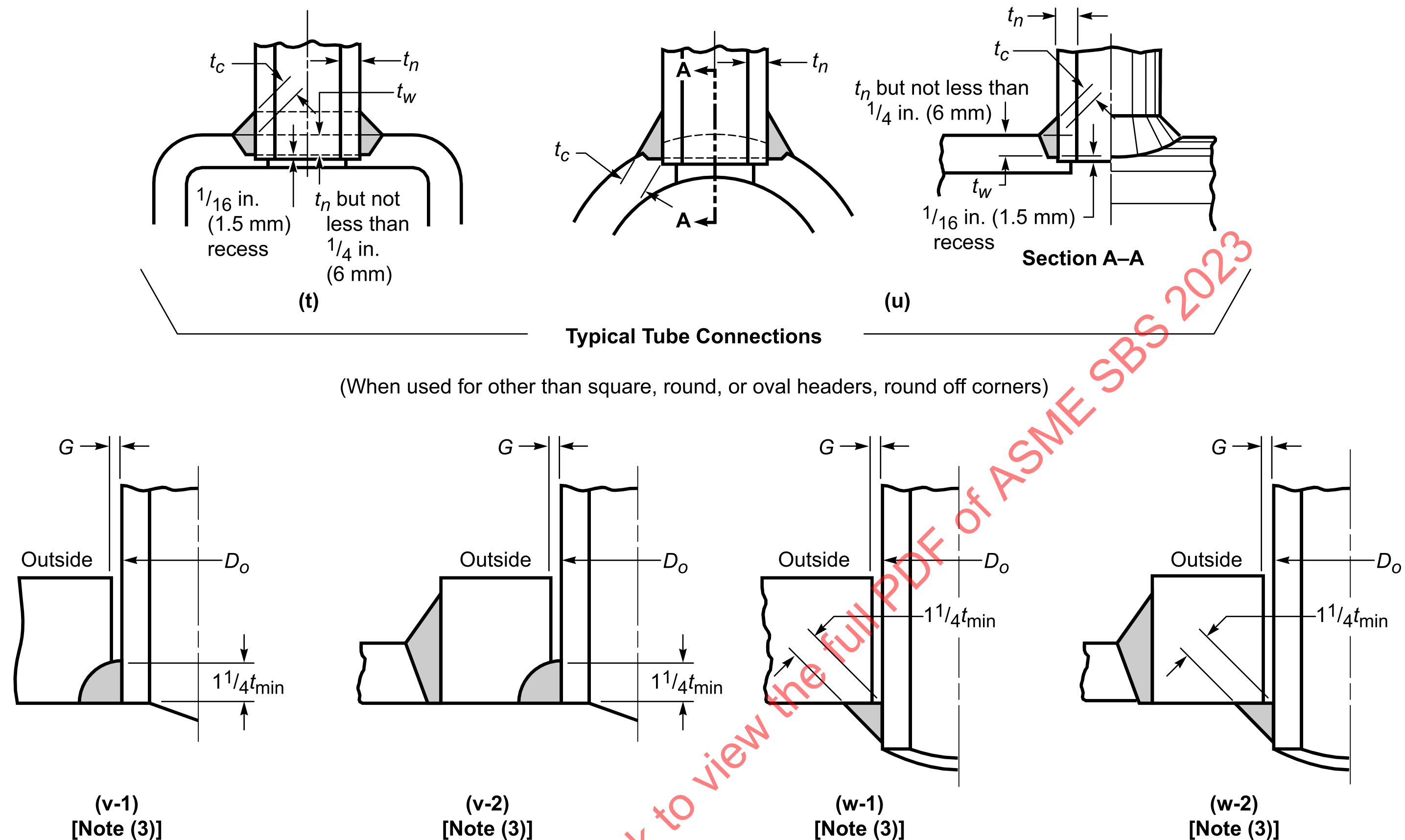
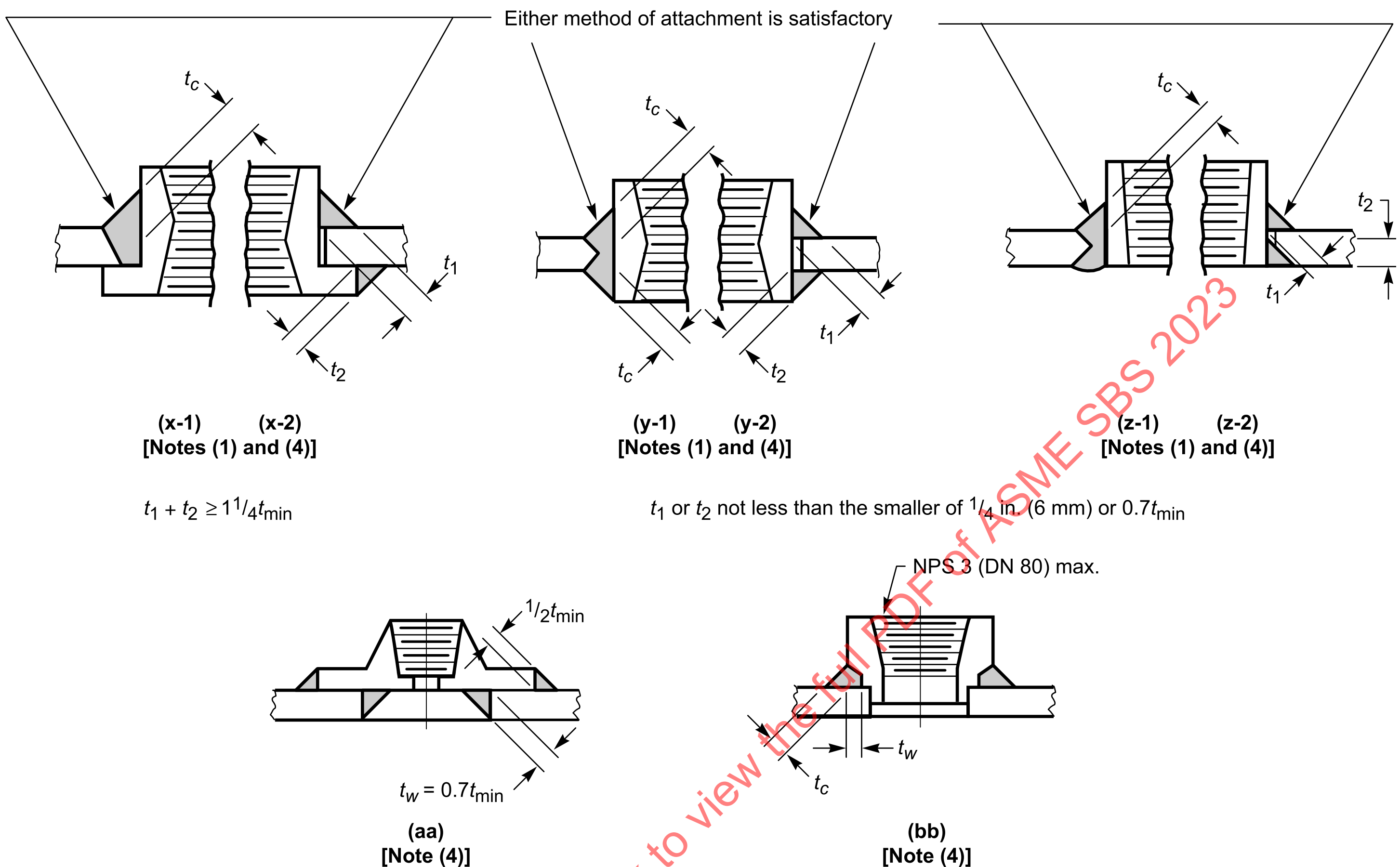


Figure 7-2.3.2.3-1
Acceptable Types of Welded Nozzles and Other Connections to Heads, Shells, etc. (Cont'd)



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 $^1/_8$ in. (3 mm) minimum blend radius.

(3) For sketches (v-1) through (w-2):

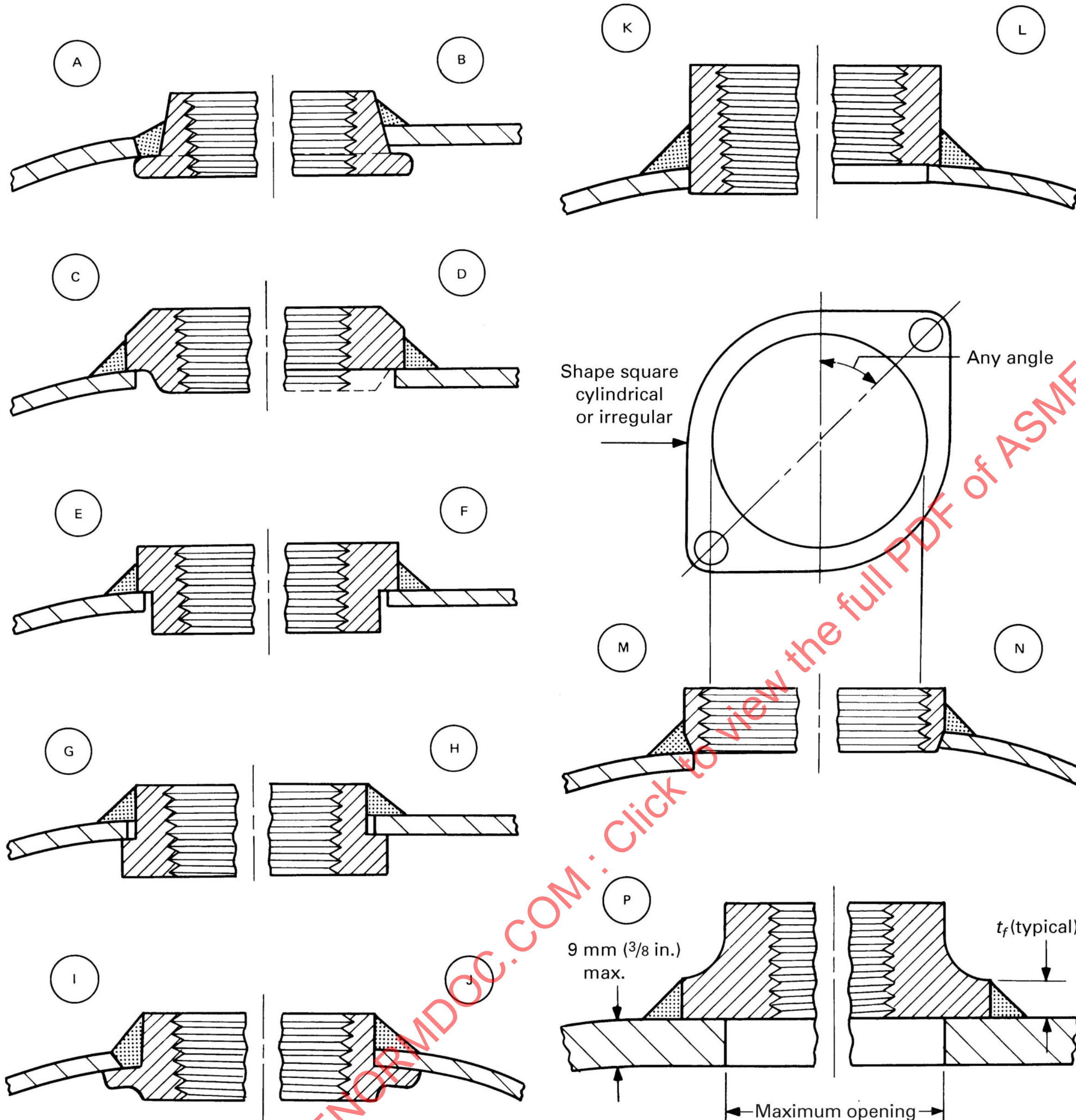
(a) For applications where there are no external loads, $G = {}^1/_8$ in. (3 mm) max.

(b) With external loads:

$G = 0.005$ for $D_o \leq 1$ in. (25 mm); $G = 0.10$ for 1 in. (25 mm) $< D_o \leq 4$ in. (100 mm); $G = 0.015$ for 4 in. (100 mm) $< D_o \leq 6^5/_8$ in. (170 mm).

(4) For NPS 3 (DN 80) and smaller, see exemptions in paras. 7-2.3.2.8(b) and 7-2.3.2.8(c).

Figure 7-2.3.2.4-1
Some Acceptable Types of Small Fittings



GENERAL NOTE: See para. 7-2.3.2.8(c) for limitations.

7-2.3.2.6 Neck Attached by Fillet or Partial Penetration Welds

(a) Necks inserted into or through the structure wall may be attached by fillet or partial penetration welds, one on each face of the structure wall. The welds may be any desired combination of fillet, single-bevel, and single-J welds. The t_1 or t_2 dimension for each weld shall not be less than the smaller of $^1\!/_4$ in. (6 mm) or $0.7t_{min}$, and their sum shall be not less than $1^1\!/_4 t_{min}$ [see Figure 7-2.3.2.3-1, illustrations (i) through (l)].

If additional reinforcement is required, it may be provided in the form of extended or thickened necks, thickened shell plates, forgings, separate reinforcement plates, or a combination thereof attached by welding. Weld requirements shall be the same as given in para. 7-2.3.2.5(b), except as follows. The welds attaching the neck to the structure wall or to the reinforcement plate shall consist of one of the following:

(1) a single-bevel or single-J weld in the shell plate or in each reinforcement plate; the dimension t_w of each weld shall be not less than $0.7t_{min}$ [see Figure 7-2.3.2.3-1, illustrations (q) and (r)]

(2) a full-penetration groove weld in each reinforcement plate and a fillet, single-bevel, or single-J weld with t_w not less than $0.7t_{min}$ in the shell plate [see Figure 7-2.3.2.3-1, illustration (s)]

(b) Nozzle necks, flared necks, and studding outlet-type flanges may be attached by fillet or partial penetration welds between the outside diameter of the attachment and the outside surface of the shell and at the inside of the shell opening. The throat dimension of the outer attachment weld shall not be less than $^1\!/_2 t_{min}$. The dimension t_w of the weld at the inside of the shell cutout shall not be less than $0.7t_{min}$ [see Figure 7-2.3.2.3-1, illustrations (m) through (p)].

7-2.3.2.7 Necks and Tubes Attached From One Side Only. Necks and tubes may be attached from the outside surface only of the structure. Such attachments are limited to top heads and roofs not exceeding 1 psig (6.89 kPa) internal pressure [see Figure 7-2.3.2.3-1, illustrations (t) and (u)].

7-2.3.2.8 Fittings: Internally Threaded, Externally Threaded, Socket Welded, or Butt Welded. The attachment of fittings shall meet the following requirements:

(a) Except as described in (b) through (f), fittings shall be attached by a full-penetration groove weld or two fillet or partial penetration welds, one on each face of the structure wall. The minimum weld dimensions shall be as shown in Figure 7-2.3.2.3-1, illustrations (x) through (aa).

(b) Fittings not exceeding NPS 3 shown in Figure 7-2.3.2.3-1, illustrations (x) through (bb), may be attached by welds that are exempt from size requirements, with the following limitations:

(1) Paragraph 7-2.3.1.1 requirements shall be satisfied for all applicable loadings.

(2) For partial penetration or fillet welds, t_1 or t_2 shall not be less than the smaller of $^3\!/_{32}$ in. (2.5 mm) or $0.7t_{min}$.

(c) Fittings and bolting pads not exceeding NPS 3 may be attached to containers by a fillet weld deposited from the outside only, with the following limitations (see Figure 7-2.3.2.4-1):

(1) The maximum structure wall thickness shall be $^3\!/_8$ in. (9 mm).

(2) The maximum size of the opening in the structure shall not exceed the outside diameter of the attached pipe plus $^3\!/_4$ in. (19 mm) but shall not be greater than one-half of the container inside diameter.

(3) The attachment weld throat shall be the greater of the following:

(-a) the minimum nozzle neck thickness required for the same nominal size connections

(-b) the value necessary to satisfy the requirements of para. 7-2.1.8 for all applicable loadings

The typical fitting dimension, t_f, as shown in Figure 7-2.3.2.4-1, illustration (P), shall be sufficient to accommodate a weld leg that will provide a weld throat dimension. If the opening exceeds the requirements of (c)(2) or (d) in any direction, or is greater than one-half the structure's inside diameter, the affected part of the container shall be reinforced and the nozzle or other connection attached using a suitable detail in Figure 7-2.3.2.3-1, when welded.

(d) Fittings not exceeding NPS 3 may be attached by a fillet groove weld from the outside only as shown in Figure 7-2.3.2.3-1, illustration (bb). The groove weld width, t_w, shall not be less than the thickness of Schedule 160 pipe (ANSI/ASME B36.10).

(e) Flange-type fittings not exceeding NPS 2 (see Figure 7-2.3.2.4-1 for some acceptable types) may be attached without additional reinforcement other than that in the fitting and its attachment to the container wall. The construction satisfies the requirements of this Standard without further calculation, provided the following conditions are met:

(1) Maximum structure wall thickness shall not exceed $^3\!/_8$ in. (9 mm).

(2) Minimum fillet leg, t_f, is $^3\!/_{32}$ in. (2.5 mm).

(3) The finished opening, defined as the hole in the structure wall, shall not exceed the outside diameter of the nominal pipe size plus $^3\!/_4$ in. (19 mm).

(f) Fittings conforming to Figure 7-2.3.2.4-1, illustration (k), that do not exceed NPS 3 may be attached by a single fillet weld on the outside of the structure only, provided the criteria of (c) are met.

7-2.4 Welding Process

7-2.4.1 General. Each manufacturer shall be responsible for the quality of the welding done for its weld quality. The manufacturer shall test not only the welding procedure to determine its suitability for producing the required welds but also the welders and welding operators to determine their ability to apply the procedure properly. No production welding shall be undertaken until the welding procedures have been qualified. Only welders and welding operators who are qualified in accordance with ASME BPVC, Section IX shall be used for production.

7-2.4.2 Requirements and Limitations

(a) The welding processes that may be used in the construction of structures for bulk solids under this Standard are restricted to the following arc welding processes: atomic hydrogen, electro-gas, gas-metal arc, gas-tungsten arc, plasma arc, shielded-metal arc, stud, flux core, and submerged arc.

(b) Other than pressure inherent to the welding processes, no mechanical pressure or blows shall be applied to the finished weld other than in the rolling of shell and hopper sections.

(c) Definitions are given in ASME BPVC, Section IX, which include variations of these processes.

(d) Arc stud welding and resistance stud welding may be used only for non-pressure-bearing attachments with either a load or nonload function. For attachments composed of ferrous materials, the heat treatment requirements of para. 7-2.6.1 and the requirements of paras. 7-2.6.2 and 7-2.6.3 shall be met before the start of production welding. Studs shall be limited to 1 in. (25 mm) maximum diameter for round studs and an equivalent cross-sectional area for studs of other shapes.

(e) The electro-slag welding process may be used for butt welds only in ferritic steels and austenitic stainless steels, provided that any welds over $1\frac{1}{2}$ in. (38 mm) thick are fully radiographed.

(f) The electro-gas welding process may be used for butt welds only in ferritic steels and austenitic stainless steels, provided that any welds over $1\frac{1}{2}$ in. (38 mm) thick are fully radiographed. When a single pass is greater than $1\frac{1}{2}$ in. (38 mm) in ferritic materials, the joint shall be given a grain-refining (austenitizing) heat treatment.

7-2.4.3 Qualification of Welding Procedures. Each procedure used in the welding of structural and nonstructural parts for the construction of bulk solids containers shall be qualified in accordance with ASME BPVC, Section IX.

7-2.4.4 Tests of Welders and Welding Operators. All welders and welding operators who weld structural and nonstructural parts used in the construction of bulk solids containers shall be qualified in accordance with ASME BPVC, Section IX.

7-2.5 Repair of Weld Defects

7-2.5.1 All defects found in welds shall be brought to the attention of the owner's inspector, and the inspector's approval shall be obtained before the defects are repaired. All completed repairs shall be subject to the approval of the owner's inspector. Acceptance criteria are specified in Section 8. Defects in welds shall be repaired by chipping or machining out the defects from one or both sides of the joint and rewelding. The amount of material removed from the defective joint shall be the minimum necessary to correct the defect.

7-2.5.2 Pinhole leaks or porosity in a roof or flat-bottom joint, where design is not controlled by pressure, may be repaired by applying an additional weld bead over the defective area. Other defects or cracks in roof or bottom joints shall be repaired per para. 7-2.5.3. Mechanical caulking is not permitted.

7-2.5.3 All defects, cracks, or leaks in shell or transition-cone joints shall be repaired in accordance with paras. 7-2.5.1, 7-2.5.4, and 7-2.5.5.

7-2.5.4 If defects are discovered during owner-required water testing, repairs shall be made when the water level is at least 1 ft (0.3 m) below any point in need of repair.

7.2.5.5 If defects are discovered during initial bulk solid filling, the repair process shall satisfy the following requirements:

(a) Welding shall not be done on any structure where the repaired material is in contact with bulk solids or the vapor space, unless all connecting lines have been completely blinded.

(b) Repairs shall not be attempted on a structure that is filled with bulk solids until the structure has been emptied, cleaned, and freed of gas or it has been determined that an explosive environment is not present.

(c) The manufacturer shall not attempt repairs on a structure that has contained bulk solids unless the owner has approved the manner of repair in writing and the repairs are made in the presence of the owner's inspector.

7-2.6 Postweld Heat Treatment

7-2.6.1 General Requirements. The general requirements for PWHT in accordance with this Standard are given in paras. 7-2.6.1.1 through 7-2.6.1.7. Procedures are given in para. 7-2.6.2 and the heat treatment of test specimens in para. 7-2.6.3. These requirements apply to all Category A, B, C, and D welds joining structural parts.

Table 7-2.6.1.1-1
PWHT Requirements for Carbon Steels

Material	Minimum Normal Holding Temperature, °F (°C)	Minimum Holding Time at Normal Temperature for Nominal Thickness	
		Up to 2 in. (50 mm)	Over 2 in. (50 mm) to 3 in. (75 mm)
P-No. 1 Gr. Nos. 1, 2, 3	1,100 (593)	1 hr/in. (1 hr/25 mm), 15 min	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)

GENERAL NOTES:

(a) When it is impractical to postweld heat treat at the temperatures specified in this table, it is permissible to carry out PWHT at lower temperatures for longer periods of time in accordance with Table 7-2.6.1.1-2, and the requirements of para. 7-2.6.3 shall be met in this reduction in PWHT. Additionally, where the manufacturer can provide evidence that the minimum temperature has been achieved throughout the material thickness, the additional 15 min/in. (25 mm) holding time is not required.

(b) For P-No. 1 material, PWHT is mandatory, except as noted by (c), under the following conditions:

(1) for welded joints over 1½ in. (38 mm) nominal thickness

(2) for welded joints over 1¼ in. (32 mm) nominal thickness through 1½ in. (38 mm) nominal thickness, unless preheat is applied at a minimum temperature of 200°F (93°C) during welding

(c) PWHT is not mandatory for P-No. 1 material under the following conditions:

(1) for groove welds not over ½ in. (13 mm) in size and fillet welds with a throat not over ½ in. (13 mm) that attach nozzle connections having a finished inside diameter not greater than 2 in. (50 mm), provided the connections do not form ligaments that require an increase in shell or heat thickness, and preheat to a minimum temperature of 200°F (93°C) is applied

(2) for groove welds not over ½ in. (13 mm) in size or fillet welds with a throat thickness of ½ in. (13 mm) or less used to attach nonstructural parts to structural parts, provided preheat to a minimum temperature of 200°F (93°C) is applied when the thickness of the structural part exceeds 1¼ in. (32 mm)

(3) for corrosion-resistant weld metal overlay cladding or for welds attaching corrosion-resistant applied lining, provided preheat to a minimum temperature of 200°F (93°C) is maintained during application of the first layer when the thickness of the structural part exceeds 1¼ in. (32 mm)

(4) for studs welded to pressure parts, provided preheat to a minimum temperature of 200°F (93°C) is applied when the thickness of the structural part exceeds 1¼ in. (32 mm)

(5) for components in compression

7-2.6.1.1 Except as otherwise specifically provided in the notes in Tables 7-2.6.1.1-1 and 7-2.6.1.1-2, all welds in structures or structure parts shall undergo PWHT at a temperature not less than specified in the tables when the nominal thickness, including corrosion allowance, exceeds the limits in those tables. The exemptions provided in Tables 7-2.6.1.1-1 and 7-2.6.1.1-2 are not permitted when PWHT is a service requirement or when welding ferritic materials greater than ⅛ in. (3 mm) thick with an electron beam welding process. For P-No. 1 materials only, the heating and cooling rate restrictions of para. 7-2.6.1.2 do not apply when the PWHT is in the austenitizing range. The materials in Table 7-2.6.1.1-1 are listed in accordance with the P-Number material groupings established in ASME BPVC, Section IX, Table QW/QB-422, and per ASME BPVC, Section II, Part D.

Table 7-2.6.1.1-2
Alternative PWHT Requirements for Carbon Steels

Decrease in Temperature Below Minimum Specified Temperature, °F (°C)	Minimum Holding Time at Decreased Temperature, hr [Note (1)]
50 (10)	2
100 (38)	4
150 (66) [Note (2)]	10
200 (93) [Note (2)]	20

NOTES:

(1) Minimum holding time for 1 in. (25 mm) thickness or less. Add 15 min per inch (25 mm) of thickness for thicknesses greater than 1 in. (25 mm).

(2) These lower PWHT temperatures are permitted for P-No. 1 Group Nos. 1 and 2 materials only.

7-2.6.1.2 The term "nominal thickness" used in Table 7-2.6.1.1-1 is the thickness of the welded joint as it is defined below. For structures or parts of structures being postweld heat treated in a furnace charge, it is the greatest weld thickness in any structure or structure part that has not previously been postweld heat treated.

(a) When the welded joint connects parts of the same thickness using a full-penetration butt weld, the nominal thickness is the total depth of the weld exclusive of any permitted weld reinforcement.

(b) For groove welds, the nominal thickness is the depth of the groove.

(c) For fillet welds, the nominal thickness is the throat dimension. If a fillet weld is used in conjunction with a groove weld, the nominal thickness is the depth of the groove or the throat dimension, whichever is greater.

(d) For stud welds, the nominal thickness is the diameter of the stud.

(e) When a welded joint connects parts of unequal thicknesses, the nominal thickness shall be the following:

(1) the thinner of two adjacent butt-welded parts, including head-to-shell connections

(2) the thickness of the shell in connection to flat heads, covers, flanges, or similar construction

(3) the thickness of the weld across the nozzle neck, shell, head, reinforcing pad, or attachment fillet weld, whichever is greater (see Figures 7-2.3.2.3-1 and 7-2.3.2.4-1)

(4) the thickness of the nozzle neck at the joint in nozzle neck to flange connections

(5) the thickness of the weld at the point of attachment where a nonstructural part is welded to a structural part

(f) The thickness of the head, shell, nozzle neck, or other parts shall be the wall thickness of the part at the welded joint under consideration. For plate material, the manufacturer may choose to use the thickness shown on the material test report (MTR) or material certificate of compliance for forming in lieu of measuring the wall thickness at the welded joint.

(g) For repairs, the nominal thickness is the depth of the repair weld.

7-2.6.1.3 Except where prohibited in Table 7-2.6.1.1-1, holding temperatures and/or holding times greater than the minimum values given in Table 7-2.6.1.1-1 may be used. Intermediate PWHTs need not conform to the requirements of Table 7-2.6.1.1-1. The holding time at the temperature specified in Table 7-2.6.1.1-1 may be the accumulation of time from multiple PWHT cycles.

7-2.6.1.4 When structure parts of two different P-Number groups are joined by welding, the PWHT shall be that specified in either Table 7-2.6.1.1-1 or Table 7-2.6.1.1-2 (with applicable notes) for the material requiring the higher postweld temperature. When nonstructural parts are welded to structural parts, the PWHT temperature of the structural part shall be used.

7-2.6.1.5 PWHT shall be carried out by one of the procedures given in para. 7-2.6.2 in accordance with the following requirements:

(a) The temperature of the furnace shall not exceed 800°F (427°C) at the time the structure or part is placed in it.

(b) Above 800°F (427°C), the rate of heating shall be not more than 400°F/hr (204°C/h) divided by the maximum metal thickness of the shell or head plate in inches (millimeters), but in no case shall it be more than 400°F/hr (204°C/h). During the heating period, the temperature within any 15-ft (4 572-mm) length of the portion of the structure being heated shall not vary more than 250°F (121°C).

(c) The structure or structure part shall be held at or above the temperature specified in Table 7-2.6.1.1-1 or Table 7-2.6.1.1-2 for the period of time specified in the tables. During the holding period, there shall not be a temperature difference greater than 150°F (66°C) throughout the portion of the structure being heated, except where the range is further limited in Table 7-2.6.1.1-1.

(d) During the heating and holding periods, the furnace atmosphere shall be controlled to avoid excessive oxidation of the structure's surface. The furnace shall be designed to prevent direct impingement of the flame on the structural wall.

(e) If the PWHT temperature exceeds 800°F (427°C), the container shall be cooled in the closed furnace or cooling chamber at a rate not greater than 500°F/hr (260°C/h) divided by the maximum metal thickness of the shell or head plate in inches (millimeters), but in no case shall the rate be more than 500°F/hr (260°C/h). Below 800°F (427°C), the container may be cooled in still air.

7-2.6.1.6 Except as permitted in para. 7-2.6.1.7, structures or parts of structures that have been postweld heat treated in accordance with the requirements of this paragraph shall be postweld heat treated again if weld repairs have been made.

7-2.6.1.7 Weld repairs to P-No. 1 Group Nos. 1, 2, and 3 and to the weld metals used to join these materials may be made after the final PWHT but prior to the final hydrostatic or pneumatic test, with additional PWHT, provided that the PWHT is not required as a service requirement. Exemptions are listed in Table 7-2.6.1.1-1. The welded repairs shall meet the requirements of (a) through (f). 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, provided that the surface is not exposed to the contents of the container.

(a) The manufacturer shall give prior notification of the repair to the user or the user's designated agent and shall not proceed with the repair until the plan has been accepted. Such repairs shall be recorded on the manufacturer's data report.

(b) The total repair depth shall not exceed $1\frac{1}{2}$ in. (38 mm) for P-No. 1 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.

(c) After removal of the defect, the groove shall be examined using either the magnetic particle or liquid penetrant examination method in accordance with ASME BPVC, Section VIII, Division 1, Mandatory Appendix 6 or Mandatory Appendix 8, respectively.

(d) In addition to the requirements of ASME BPVC, Section IX, for the qualification of welding procedure specifications for groove welds, the following requirements shall apply:

(1) The weld metal shall be deposited by the manual shielded-metal arc process using low hydrogen electrodes. The electrodes shall be properly conditioned in accordance with ASME BPVC, Section II, Part C,

SFA-5.5/SFA-5.5M, Annex A, A6.11. The maximum bead width shall be 4 times the electrode core diameter.

(2) For P-No. 1 Group Nos. 1, 2, and 3 materials, the repair area shall be preheated and maintained at a minimum temperature of 200°F (93°C) during welding.

(e) After the finished repair weld has reached ambient temperature, it shall be inspected using the same NDE that was used in (c). If the examination is by the magnetic particle method, only the alternating-current yoke type is acceptable. In addition, welded repairs deeper than $^3/_8$ in. (9.5 mm) in materials and welds that are required to be radiographed shall be examined per the requirements of Section 8.

(f) The structure shall be hydrostatically tested after the welded repair.

7-2.6.2 Procedures for Heat Treatment

7-2.6.2.1 PWHT shall be performed in accordance with the requirements given in para. 7-2.6.1 using one of the following procedures. In these procedures, the soak band is defined as the volume of metal required to meet or exceed the minimum PWHT temperatures listed in Table 7-2.6.1.1-1. At minimum, the soak band shall contain the weld, its heat-affected zone, and a portion of base metal adjacent to the weld being heat treated. The minimum width of the soak band is the widest width of the weld plus 1*t* or 2 in. (50 mm), whichever is less, on each side or end of the weld. The portion outside the soak band shall be protected so that the temperature gradient is not harmful. The term *t* is the nominal thickness as defined in para. 7-2.6.1.2.

Acceptable PWHT procedures are as follows:

(a) heating the structure as a whole in an enclosed furnace. This is the preferred procedure and should be used whenever practicable.

(b) heating the structure in more than one heat in a furnace, provided the overlap of the heated sections of the structure is at least 5 ft (1 524 mm). The cross section where the structure projects from the furnace shall not intersect a nozzle or other structural discontinuity.

(c) heating shell sections and/or portions of structures to postweld heat-treat longitudinal joints or complicated welded details prior to erecting the completed structure. When the structure is required to be postweld heat treated and it is not practicable to treat the completed structure as a whole or in two or more heats as provided in (b), any circumferential joints not previously postweld heat treated may undergo local PWHT by any appropriate means that will ensure the required uniformity. For such local heating, the soak band shall extend around the full circumference. This procedure may also be used to postweld heat treat portions of new structures after repairs.

(d) heating the structure internally by any appropriate means and with adequate temperature-recording devices to maintain a uniform temperature distribution in the structure wall. Before this operation, the structure 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 PWHT.

(e) heating a circumferential band containing nozzles or other welded attachments in such a manner that the entire band shall be brought up uniformly to the required temperature and held for the specified time. Except as modified in this paragraph, the soak bank shall extend around the entire structure and 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 band around the nozzle or attachment weld is heated to the required temperature and held for the required time. As an alternative, 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. This procedure may also be used to postweld heat treat portions of containers after repairs.

(f) heating the circumferential joints of pipe or tubing by any appropriate means using a soak band that extends around the entire circumference. The proximity to the shell increases thermal restraint. Therefore, the designer should provide adequate length to permit heat treatment without creating harmful gradients at the nozzle attachment or heat a full circumferential band around the shell, including the nozzle.

(g) 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 such that the area is brought up uniformly to the required temperature and held for the specified time. The soak band shall include the nozzle or welded attachment. The soak band shall also include a circle that extends beyond the edges of the attachment weld in all directions by a minimum of *t* or 2 in. (50 mm), whichever is less.

Local area heating of other configurations not addressed in (a) though (g) is permitted, provided that other measures (based on documented experience or engineering evaluation) are taken to consider the effect of thermal gradients, significant structural discontinuities (such as nozzles, attachments, and head-to-shell junctures), and any mechanical loads that may be present during PWHT.

7-2.6.2.2 The minimum temperature for PWHT (see Table 7-2.6.1.1-1) shall be the minimum temperature of the plate material of the shell or head of any structure in one furnace charge. Where more than one structure or structure part is postweld heat treated in one furnace charge, thermocouples shall be placed on the structures at the bottom, center, and top of the charge, or in other zones of possible temperature variation, so that the indicated temperature shall be the true temperature for all structures or parts in those zones.

7-2.6.2.3 When structural parts of two different P-number groups are joined by welding, the PWHT shall be specified according to para. 7-2.6.1 for the material requiring the higher PWHT temperature.

7-2.6.2.4 PWHT, when required, shall be done before the hydrostatic test and after any welded repairs except as permitted by para. 7-2.6.2.1(f). A preliminary hydrostatic test to reveal leaks prior to PWHT is permissible.

7-2.6.3 Heat Treatment of Test Specimens. The following provisions shall apply in addition to, or as exceptions to, the general rules for heat treatment given elsewhere in this Standard:

(a) Heat treatment as defined in this Standard shall include all thermal treatments of the material during fabrication that exceed 900°F (480°C), except as exempted in (b) through (h).

(b) The material used in a container shall be represented by test specimens heated above the lower transformation temperature and PWHT criteria, 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 structure 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 does not include local heating such as thermal cutting, preheating, welding, or heating below the lower transformation temperature for bending or sizing of tubing and pipe.

(d) Standard items such as pipe flanges and fittings shall be exempt from the requirements of (b). These may be subject to PWHT with the structure or structure part without equivalent levels of test specimen heat treatment. 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 ASME BPVC, Section IX, Table QW/QB-422, and all carbon and low alloy steels used in the annealed condition as permitted by the material specifications are exempt from the requirements of (b) when the heat treatment during fabrication is limited to PWHT below the lower transformation temperature of the steel.

(f) Materials listed in ASME BPVC, Section IX, Table QW/QB-422, as P-No. 1 Group No. 3 that are certified in accordance with (b) from test specimens subject to the PWHT requirements of Table 7-2.6.1.1-1 need not be recertified if subjected to the alternate PWHT conditions permitted by Table 7-2.6.1.1-2.

(g) The simulation of cooling rates is not required for test specimens from nonimpact tested materials 3 in. and under in thickness subjected to heat treatments below the lower transformation temperature.

(h) Any heat treatment at higher temperatures prior to material austenitizing heat treatment need not include test specimens.

7-2.7 Clad Construction

The base materials used in the construction of clad structures and of structures with corrosion linings shall comply with the requirements of Section 3 of this Standard and ASME BPVC, Section II.

7-2.7.1 Clad Material. Materials used for integral clad construction, weld metal overlay clad construction, and loose-type liner clad construction shall meet the requirements of ASME BPVC, Section II, but shall be used only for corrosion and/or erosion protection of the base structural wall. The thickness of the cladding shall not be considered part of the design thickness of the structural wall. In the case of loose-type liners, the liner must be capable of withstanding all external loads by itself since it is not attached integrally to the structural wall. Integrally clad materials subject to external loading that use the structural base material to resist these loadings must meet the following requirements:

(a) Clad material shall conform to the following specifications:

(1) SA-263
(2) SA-264
(3) SA-265

In addition, the base material shall show a minimum shear strength of 20,000 psi (138 MPa) when tested in the manner described in the clad plate specification. One shear test shall be made on each clad plate as rolled, and the results shall be reported on the certified MTR. When the composite thickness of the clad material is $^3/_4$ in. (19 mm) or less, and/or when the cladding metal thickness is nominally 0.075 in. (1.9 mm) or less, the bond strength test, as described in ASME SA-263, ASME SA-264, or ASME SA-265, may be used in lieu of the bond shear strength test to fulfill the criteria for acceptable minimum shear strength. The bend test specimen shall be $1^1/_2$ in. (38 mm) thick and shall be bent at room temperature to an angle of 180 deg to the bend diameter provided in the material specifications applicable to the backing metal. The results of the bond strength test shall be reported on the certified MTR.

(b) A shear or bond strength test is not required for weld-metal overlay cladding.

(c) When any part of the cladding thickness is specified as an allowance for corrosion or erosion, such added thickness shall be removed before mill tension tests are completed. When corrosion and/or erosion of the cladding is not expected, no part of the cladding need be removed before testing, even though excess thickness seems to have been provided or is available as a corrosion and/or erosion allowance.

7-2.7.2 Lining. Material used for applied corrosion- and/or erosion-resistant lining may be of any metallic material of weldable quality that the user deems suitable for the intended purpose.

7-2.7.3 Joints in Integral or Weld Metal Overlay Cladding and Applied Linings

7-2.7.3.1 The types of joints and welding procedure used shall be such as to minimize the formation of brittle weld composition by mixed metals corrosion and/or erosion-resistant alloys/base material.

7-2.7.3.2 When a shell, head, or other structural part is welded to form a corner joint, the weld shall be made between the base materials, either by removing the clad material prior to welding the joint or by using weld procedures that will ensure the base materials are fused. The corrosion and/or erosion resistance of the joint may be provided by using corrosion- and/or erosion-resistant and compatible weld filler material or may be restored by any other appropriate means.

7-2.7.4 Weld Metal Composition. Welds that are exposed to the corrosive and/or erosive action of the contents of the structure should have a resistance to corrosion and/or erosion that is similar to the corrosion and/or erosion resistance of the integral or weld-metal overlay cladding or lining. Filler metal of very similar composition to the material being joined is recommended. Weld metal of different compositions may be used, provided it has better mechanical properties in the opinion of the manufacturer, and the user is satisfied with its resistance to corrosion and/or erosion for the intended service. The columbium content of columbium-stabilized austenitic stainless steel weld metal shall not exceed 1.00%, except when a higher columbium content is permitted in the material being welded.

7-2.7.5 Inserted Strips in Clad Material. The thickness of inserted strips used to restore cladding at joints shall be equal to that of the nominal minimum thickness of the cladding specified for the material backed, if necessary, with corrosion- and/or erosion-resistant weld metal deposited in the groove to bring the insert flush with the surface of the adjacent cladding.

7-2.7.6 Postweld Heat Treatment

7-2.7.6.1 Structures or parts of structures for bulk solids constructed of base material with corrosion- and/or erosion-resistant integral or weld metal overlay cladding or applied corrosion- and/or erosion-resistant lining material shall be postweld heat treated when PWHT is required for the base material. The total thickness of the base material shall determine whether PWHT is required. When the base material requires PWHT, it shall be performed after the application of weld metal overlay cladding or applied lining, unless exempted by Table 7-2.6.1.1-1, General Note (c).

7-2.7.6.2 Structures or parts of structures for bulk solids constructed of chromium stainless steel integral or weld metal overlay cladding and those lined with chromium stainless steel shall be postweld heat treated regardless of thickness. Structures that are integrally clad or lined with Type 405 or Type 410S and welded with an austenitic electrode or non-air-hardening nickel–chromium–iron electrode need not be postweld heat treated unless required by para. 7-2.7.6.1.

7-2.7.7 Welding Procedures. Welding procedures for weld overlay, composite (clad) metals, and the attachment of applied linings shall be prepared and qualified in accordance with the requirements of ASME BPVC, Section IX.

7-2.7.8 Alloy Welds in Base Metal. Groove joints in base material and parts may be made with corrosion- and/or erosion-resistant alloy-steel filler metal or between corrosion and/or erosion-resistant alloy steel and carbon or low alloy steel, provided the welding procedure and welders or welding operators have been qualified in accordance with the requirements of ASME BPVC, Section IX, for the combination of materials used. Example applications of this rule are base metal welded with alloy-steel electrodes and alloy nozzles welded to steel shells.

7-2.7.9 Fillet Welds. Fillet welds between corrosion- and/or erosion-resistant metal deposited in contact with two materials of dissimilar compositions may be used for shell joints (see para. 7-2.2.6), connection attachments (see paras. 7-2.3.1 and 7-2.3.2), and any other uses permitted by this Standard. The qualification of the welding procedures and welders or welding operators to be used on fillet welds for a given combination of materials and alloy weld metals shall be made in accordance with the requirements of ASME BPVC, Section IX.

7-3 ERECTION OF BOLTED CONTAINERS

7-3.1 General

The container shall be erected according to procedures provided by the manufacturer. The erector shall acquire and review all construction drawings and assembly procedures prior to beginning the erection. The manufacturer shall provide erection procedures that are specific to the product. Procedures and specific requirements provided by the manufacturer shall include

(a) safety issues, including use of decals
(b) site storage of components (where applicable)
(c) roof and hopper erection, as applicable
(d) material identification
(e) thickness schedule of the container and all components
(f) shell erection, including sidewall sheets, stiffeners, stiffening rings, etc., as applicable
(g) fitting and splicing of components
(h) bolting and hardware requirements
(i) gasketing, caulking, and sealing requirements
(j) erection and installation of access door or hatch
(k) accessory erection, orientation, and sequencing details
(l) coating repair (where applicable)

The erector shall be skilled in normal container erection. The erector shall have the knowledge and skill to perform the construction procedures for the type of container being erected.

7-3.2 Assembly

Bolt holes shall be round, unless otherwise specified in drawings or procedures, and properly sized for the specified fastener. Bolt holes shall be smooth and free from burrs and shall not be torn or excessively elongated. Enlargement of factory bolt holes by drilling or similar means for alignment purposes is not allowed unless otherwise specified in the manufacturer's supplied procedures and details.

Shell stiffening components shall be assembled as specified by the manufacturer. Modifications of stiffening components shall not be done without approval of the manufacturer. Manufacturer erection procedures, including a bolt-tightening sequence of complete courses or subsections of the container, shall be followed.

7-3.3 Preparation of Surfaces to Be Bolted

Cleaning and any special preparation of the surfaces specified by the manufacturer for structural or sealing requirements of the joints must be followed by the erector.

7-3.4 Bolting

All bolts, nuts, and washers shall be located and installed in accordance with the erection procedures. Erection procedures shall include information on size and grade of bolt to be used and locations of such usage.

Only hardware supplied with the container shall be used.

7-3.5 Bolt Tightening Requirements

The manufacturer shall specify tightening and any sequencing requirements for all fasteners that are installed in container structural connections.

7-3.6 Gasketing and Sealants

Gasketing and/or sealants shall be supplied with the container and installed in all joints in compliance with the erection procedures. Care shall be exercised in properly locating and installing all gaskets and/or sealants.

Sealing and/or grouting of the container to the foundation shall be completed prior to service. Materials for sealing to the foundation are outside the scope of this Standard.

7-3.7 Dimensional Tolerance

Reference para. 7-1.3 and Nonmandatory Appendix A for dimensional tolerances.

7-3.8 Access Hatches, Openings, and Penetrations

Access hatches or doors shall be placed in the location specified by the manufacturer. Penetrations and openings (bottom, shell, or roof) shall be made in accordance with details and procedures supplied by the manufacturer.

Section 8
Examination and Testing

8-1 GENERAL

(a) Requirements in this Section pertain to the shop or field examination and testing of welded and bolted containers for bulk solids.

(b) The scope of this Section includes the specific examination or test requirements that may apply to the shop fabrication or field erection of welded or bolted containers for bulk solids.

(c) The purchaser shall be allowed to perform or to have performed radiographic, magnetic particle, liquid penetrant, visual, or other suitable examinations at any location selected by the purchaser. Purchaser-specified inspection witness points shall be established before fabrication begins.

(d) Any work found to be not in conformance with this Standard, contract drawings, or the inspection requirements detailed herein shall be reworked or replaced. This includes modifications not authorized by the manufacturer or engineer of record or damage that occurs during fabrication, handling, or shipment of completed containers or parts of containers.

8-2 SHOP INSPECTION

(a) Mill test reports of cylindrical shell, conical bottom and roof plates, unmarked nozzle tubes, and fabricated flanges and fittings shall be sufficient to establish the quality of the furnished material. Certified mill test reports shall be made available to the purchaser upon request for all such material. Consideration should be given to the use of positive material identification (PMI) in containers constructed of stainless steel and other alloy materials. The method and sample size shall be determined by the purchaser.

(b) Mill and shop inspection shall not release the manufacturer from responsibility for replacing or repairing any defective material or workmanship.

(c) Material or workmanship that does not meet the applicable requirements of this Standard or the contract drawings may be rejected by the purchaser or the purchaser's inspector. The manufacturer shall be notified of this rejection in writing and shall be required to furnish new material or to make any necessary replacement or suitable repairs on a mutually agreeable schedule.

8-3 DIMENSIONAL TOLERANCES

8-3.1 General

The purpose of the tolerances given in paras. 7-1.3.2 through 7-1.3.4 is to produce a container of acceptable appearance and appropriate construction to provide for proper load distribution during the planned material fill and removal operations. These tolerances may be altered or waived by agreement between the purchaser and manufacturer after consultation with a qualified engineer familiar with design of containers for solids storage. Containers that are completely field-erected should meet dimensional tolerances given in paras. 7-3.2 through 7-3.4 as well as alignment tolerances given in para. 7-2.1.4 for welded containers, unless otherwise agreed between erector and purchaser. See subsection 8-12 for tolerances applicable to bolted shop-built containers.

8-3.2 Plumbness

The maximum out-of-plumbness of the container relative to the bottom of the shell shall meet the tolerance requirements of para. 7-1.3.2.

8-3.3 Roundness

The cylindrical portion of the container shall meet the tolerance requirements of para. 7-1.3.3.

8-3.4 Local Deviations

Local deviations from the theoretical shape (e.g., weld discontinuities and flat spots) shall meet the tolerance limits of para. 7-1.3.4.

8-3.5 Measurements

Dimensional tolerance measurements shall be taken prior to testing for field-erected containers. Measurements shall be taken prior to shipment for shop-built containers.

8-4 RADIOGRAPHY

8-4.1 General

For requirements detailed in paras. 8-4.2 through 8-4.7, plates shall be considered to be of the same thickness when the difference in their specified or supplied thickness does not exceed $^1\!/_8$ in. (3 mm).

8-4.2 Application

Radiographic inspection is required only for shell-plate butt welds and conical bottom-plate butt welds. By agreement between purchaser and manufacturer, radiography requirements may be waived subject to appropriate adjustment of the design joint efficiency for shell or conical-bottom butt welds (see Table 7-2.2.6-1).

8-4.3 Required Radiography

Radiographs shall be taken as specified in paras. 8-4.3.1 through 8-4.3.7.

8-4.3.1 The following requirements apply to shell or conical bottom butt-welded joints:

(a) For butt-welded joints in which the thinner plate is less than or equal to $^3\!/_8$ in. (10 mm) thick, one spot radiograph shall be taken in the first 10 ft (3 m) of a completed joint of each type and thickness welded by each welder or weld operator. Subsequently, regardless of the number of welders or weld operators, one additional spot radiograph shall be taken in each additional 100 ft (30 m), plus any remaining fraction of joint of the same type and thickness. At least 25% of the selected spot radiographs shall be taken at intersections of perpendicular joints, with a minimum of two such intersections per container being radiographed.

(b) For butt-welded joints in which the thinner plate is greater than $^3\!/_8$ in. (10 mm) but less than or equal to 1 in. (25 mm) in thickness, spot radiographs shall be taken in accordance with (a). In addition, all junctions of vertical to horizontal joints in the first (lowest) cylindrical shell course shall be radiographed. For the first (lowest) cylindrical course, each vertical joint shall have two spot radiographs taken, one as close to the shell-to-bottom transition as possible, the other to be taken at any random length of the joint.

(c) Butt-welded joints in plates greater than 1 in. (25 mm) shall be fully radiographed. All junctions in vertical and horizontal joints of this thickness range shall be radiographed.

8-4.3.2 One spot radiograph shall be taken in the first 10 ft (3 m) of the completed shell butt-welded joint of the same type and thickness of joint (based on the thickness of the thinner plate) without regard to the number of welders or weld operators. Subsequently, one radiograph shall be taken in each additional 200 ft (60 m) and any remaining partial length of shell butt joint of the same type and thickness. These radiographs are in addition to those specified in para. 8-4.3.1(c).

8-4.3.3 When two or more containers are erected in the same location by the same erector for the same purchaser, either concurrently or in sequence, the number of spot radiographs to be taken may be based on the aggregate length of the welds of the same type and thickness in each group of containers rather than the weld length in each individual container.

8-4.3.4 The same welder or weld operator may not necessarily weld both sides of the same butt joint. If two or more welders or weld operators work on the same or opposite sides of a joint, it is permissible to inspect the finished joint with one spot radiograph. If the radiograph is rejected, further radiography shall be performed as required by ASME BPVC, Section VIII, Division 1, UW-51(b) or UW-52(d).

8-4.3.5 Spot radiographs shall be taken from the work of each welder or weld operator in direct proportion to the length of joints each has welded, as identified on the plate joints by stenciled initials or on a weld map of the container as assembled. Where no such weld operator data are available, the extent of radiography required shall be determined by mutual agreement between the purchaser's inspector and the erector.

8-4.3.6 Radiography shall begin after sufficient completed weld footage is in place by any one welder or weld operator. The location for radiographs to be taken shall be determined by the purchaser's inspector.

8-4.3.7 Each radiograph shall clearly show a minimum of 6 in. (150 mm) of weld length. The film shall be centered on the weld and shall be of sufficient width to permit adequate space for the location of identification marks and an image quality indicator (IQI).

8-4.4 Technique

8-4.4.1 Except as otherwise noted in para. 8-4.3, the radiographic examination method to be used shall be in accordance with ASME BPVC, Section V, Article 2.

8-4.4.2 Personnel who perform and evaluate radiographic examinations shall be qualified by the manufacturer as meeting the certification requirements outlined in Level II or Level III of ASNT SNT-TC-1A . Level I personnel may be used if they are given written acceptance and rejection procedures prepared by Level II or Level III personnel. These written procedures shall contain the applicable requirements of ASME BPVC, Section V, Article 2B. In addition, all Level I personnel shall be under the direct supervision of Level II or Level III personnel.

8-4.4.3 The requirements of ASME BPVC, Section V, Article 2, T-285 are to be used as a guide only. Final acceptance of radiographs shall be based on the ability to adequately see the prescribed IQI.

8-4.4.4 The finished surface of the weld reinforcement at the location of the radiograph shall be either flush with the plate or have a reasonably uniform crown not to exceed the values given in Table 7-2.1.8.4-1.

8-4.4.5 Before any completed welds are repaired due to rejectable radiographic defects, the radiographs shall be submitted to the inspector with information requested by the inspector regarding the radiographic technique used.

8-4.5 Acceptance Criteria

Welds examined by radiography shall be judged as acceptable or unacceptable by the standards of ASME BPVC, Section VIII, Division 1, UW-51(b) or UW-52(d).

8-4.6 Limits of Defective Welding

When a section of weld is shown by a radiograph to be unacceptable under the provisions of para. 8-4.5 or the limits of the deficient welding are not defined by the radiograph, two spots adjacent to the section shall be examined by radiography. However, if the original radiograph shows at least 3 in. (75 mm) of acceptable weld between the defect and any one edge of the film, an additional radiograph need not be taken of the weld on that side of the defect. If the weld at either of the adjacent sections fails to comply with the requirements of para. 8-4.5, additional spots shall be examined until the limits of unacceptable welding are determined. Alternatively, the manufacturer or erector may replace all of the welding performed by the welder or weld operator on that joint.

8-4.7 Radiographic Examination Records

(a) The manufacturer shall prepare an as-built radiograph map showing the location of all radiographs taken along with the film identification marks.

(b) After the container is completed, the films shall be retained as agreed between the purchaser and manufacturer.

8-5 ULTRASONIC EXAMINATION OF WELDED JOINTS

(a) Ultrasonic (shear-wave) examination of welded joints may be substituted for radiography by agreement with the purchaser and, if so substituted, shall be performed in accordance with ASME BPVC, Section VIII, Division 1, Mandatory Appendix 12. The written examination procedure shall be available to the inspector and shall be proven by actual demonstration to the satisfaction of the Inspector to be capable of detecting and locating imperfections described in this Standard.

(b) Ultrasonic examination shall be performed in accordance with a written procedure that is certified by the manufacturer to be in compliance with the applicable requirements of ASME BPVC, Section V.

(c) Examiners who perform ultrasonic examinations under this subsection shall be qualified and certified by the manufacturer as meeting the requirements of certification as outlined in Level II or Level III of ASNT SNT-TC-1A. Level I personnel may be used if they are given written acceptance and rejection criteria prepared by Level II or Level III personnel. In addition, all Level I personnel shall be under the direct supervision of Level II or Level III personnel.

8-6 MAGNETIC PARTICLE EXAMINATION

(a) Magnetic particle examination, where required, shall be performed in accordance with a written procedure that is certified by the manufacturer to be in compliance with the applicable requirements of ASME BPVC, Section V.

(b) The manufacturer shall determine that each magnetic particle examiner meets the following requirements:

(1) The examiner has the visual acuity (with correction, if necessary) to read a Jaeger Type 2 standard chart at a distance of at least 12 in. (300 mm) and to differentiate contrast between the colors used. Examiners shall be checked annually to ensure that they meet these requirements.

(2) The examiner is competent in the method of magnetic particle examination to be used, including making the examination and evaluating the results.

(c) Welds examined by magnetic particle methods shall be judged as acceptable or unacceptable based on the acceptance standards in subsection 6-4 of ASME BPVC, Section VIII, Division 1, Mandatory Appendix 6. Weld defects identified as unacceptable by magnetic particle examination shall be removed by grinding or air arc-gouging methods. The removed weld shall be replaced, and the area of repair shall be retested.

8-7 LIQUID PENETRANT EXAMINATION

(a) Liquid penetrant examination, where required or used in lieu of magnetic particle examination, shall be performed in accordance with a written procedure that is certified by the manufacturer to be in compliance with the applicable requirements of ASME BPVC, Section V.

(b) The manufacturer shall determine and certify that each liquid penetrant examiner meets the following requirements:

(1) The examiner has the visual acuity (with correction, if necessary) to read a Jaeger Type 2 standard chart at a distance of at least 12 in. (300 mm) and to differentiate contrast between the colors used. Examiners shall be checked annually to ensure that they meet these requirements.

(2) The examiner is competent in the method of liquid penetrant examination for which he or she is certified, including making the examination and evaluating the results.

(c) Welds examined by liquid penetrant methods shall be judged as acceptable or unacceptable based on the acceptance standards in subsection 8-4 of ASME BPVC, Section VIII, Division 1, Mandatory Appendix 8. Weld defects identified as unacceptable by magnetic particle examination shall be removed by grinding or air arc-gouging methods. The removed weld shall be replaced, and the area of repair shall be retested.

8-8 VISUAL EXAMINATION

(a) Visual inspection of welds shall meet the following criteria:

(1) There are no crater cracks, other surface cracks, or arc strikes in or adjacent to the welded joint.

(2) The undercut does not exceed the limits of $^1/_{64}$ in. (0.4 mm) for vertical or conical butt joints in the base metal or $^1/_{32}$ in. (0.8 mm) for horizontal butt joints. For welds that attach nozzles, manways, and permanent attachments, permissible undercut shall not exceed $^1/_{64}$ in. (0.4 mm).

(3) The frequency of surface porosity in the weld does not exceed one cluster (one or more pores) in any 4 in. (100 mm) of length, and the diameter of each cluster does not exceed $^3/_{32}$ in. (2.5 mm).

(b) Any weld that fails to meet the criteria given in (a) shall be repaired as follows:

(1) Any defects shall be removed by mechanical means (i.e., grinding flush) or by thermal gouging processes followed by grinding. Arc strikes discovered in or adjacent to welded joints shall be repaired by grinding or rewelding as required. Arc strikes repaired by welding shall be ground flush with the base metal (see ASME BPVC, Section VIII, Division 1, UW-38 and UG-40).

(2) Rewelding is required if the resulting thickness after removal of the defect is less than the minimum required for the design or test conditions. All defects in areas thicker than the minimum shall be blend ground to at least a 4:1 taper.

(3) The repair weld shall be visually examined for defects.

(c) Examiners performing visual inspection shall have the visual acuity (with correction, if necessary) to read a Jaeger Type 2 standard chart at a distance of at least 12 in. (300 mm) and to differentiate contrast between the colors used. Examiners shall be tested on an annual basis to verify that they meet these minimum requirements.

8-9 COATING INSPECTION

8-9.1 General

Inspection of container coatings is recommended to verify that project specification requirements are met. Inspection shall be performed immediately following completion of surface preparation to establish that metal profile requirements meet the coating manufacturer's recommendations, during application to verify work processes and application results, and upon completion of all coating to establish the quality and compliance of the completed coating system.

8-9.2 Personnel Qualification

Personnel performing coating inspection on containers built to the requirements of this Standard shall be certified per National Association of Corrosion Engineers (NACE) qualification standards or shall have demonstrated knowledge and capability to perform coating inspection.

8-9.3 Inspection Procedures

The inspection procedures outlined in NACE RP 288 shall be followed where they are applicable to the work being performed. These procedures include checking surface cleanliness, metal profile, temperature and humidity (or records of such readings taken during application), film thickness of the applied coating, hardness of the applied coating, and continuity of the applied coating (i.e., integrity of the coating system).

8-9.3.1 Surface Cleanliness and Profile. Proper surface preparation to establish the specified or recommended metal profile prior to coating application is critical to a successful coating system. The field inspector shall apply acceptable standards, such as SSPC-VIS 1 and NACE TM 175, to evaluate the prepared metal surface. SSPC-VIS 1 provides photographs or steel comparator panels to help classify and assess the degree of surface cleanliness. The degree of metal profile achieved during surface preparation can be established using the methods outlined in NACE RP 287 using comparators that can be obtained through SSPC or through coating-supply vendors. Any metal cleanliness or profile that does not meet specified requirements will be cause for rejection by the coating inspector until the area is reworked to meet acceptable standards.

8-9.3.2 Temperature and Humidity (Dew Point). Temperature and humidity (dew point) readings shall be taken during application of coatings. These readings shall be within the limits set forth by the coating manufacturer, or the application process will be halted until acceptable readings are achieved.