

Welded Steel Tanks for Oil Storage

API STANDARD 650
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FOREWORD

07 This Standard is based on the accumulated knowledge and experience of Purchasers and Manufacturers of welded steel oil storage tanks of various sizes and capacities for internal pressures not more than 17.2 kPa (2¹/₂ pounds per square inch) gauge. This Standard is meant to be a purchase specification to facilitate the manufacture and procurement of storage tanks for the petroleum industry.

If the tanks are purchased in accordance with this Standard, the Purchaser is required to specify certain basic requirements. The Purchaser may want to modify, delete, or amplify sections of this Standard, but reference to this Standard shall not be made on the nameplates of or on the Manufacturer's certification for tanks that do not fulfill the minimum requirements of this Standard or that exceed its limitations. It is strongly recommended that any modifications, deletions, or amplifications be made by supplementing this Standard rather than by rewriting or incorporating sections of it into another complete standard.

The design rules given in this Standard are minimum requirements. More stringent design rules specified by the Purchaser or furnished by the Manufacturer are acceptable when mutually agreed upon by the Purchaser and the Manufacturer. This Standard is not to be interpreted as approving, recommending, or endorsing any specific design or as limiting the method of design or construction.

Shall: As used in a standard, "shall" denotes a minimum requirement in order to conform to the specification.

Should: As used in a standard, "should" denotes a recommendation or that which is advised but not required in order to conform to the specification.

07 • This Standard is not intended to cover storage tanks that are to be erected in areas subject to regulations more stringent than the specifications in this Standard. When this Standard is specified for such tanks, it should be followed insofar as it does not conflict with local requirements. The Purchaser is responsible for specifying any jurisdictional requirements applicable to the design and construction of the tank.

After revisions to this Standard have been issued, they may be applied to tanks that are to be completed after the date of issue. The tank nameplate shall state the date of the edition of the Standard and any revision to that edition to which the tank has been designed and constructed.

07 • Each edition, revision, or addenda to this API Standard may be used beginning with the date of issuance shown on the cover page for that edition, revision, or addenda. Each edition, revision, or addenda to this API Standard becomes effective six months after the date of issuance for equipment that is certified as being constructed, and tested per this Standard. During the six-month time between the date of issuance of the edition, revision, or addenda and the effective date, the Purchaser and the Manufacturer shall specify to which edition, revision, or addenda the equipment is to be constructed and tested.

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IMPORTANT INFORMATION CONCERNING USE OF ASBESTOS OR ALTERNATIVE MATERIALS

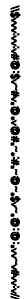
Asbestos is specified or referenced for certain components of the equipment described in some API standards. It has been of extreme usefulness in minimizing fire hazards associated with petroleum processing. It has also been a universal sealing material, compatible with most refining fluid services.

Certain serious adverse health effects are associated with asbestos, among them the serious and often fatal diseases of lung cancer, asbestosis, and mesothelioma (a cancer of the chest and abdominal linings). The degree of exposure to asbestos varies with the product and the work practices involved.

Consult the most recent edition of the Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, Occupational Safety and Health Standard for Asbestos, Tremolite, Anthophyllite, and Actinolite, 29 *Code of Federal Regulations* Section 1910.1001; the U.S. Environmental Protection Agency, National Emission Standard for Asbestos, 40 *Code of Federal Regulations* Sections 61.140 through 61.156; and the U.S. Environmental Protection Agency (EPA) rule on labeling requirements and phased banning of asbestos products (Sections 763.160-179).

There are currently in use and under development a number of substitute materials to replace asbestos in certain applications. Manufacturers and users are encouraged to develop and use effective substitute materials that can meet the specifications for, and operating requirements of, the equipment to which they would apply.

SAFETY AND HEALTH INFORMATION WITH RESPECT TO PARTICULAR PRODUCTS OR MATERIALS CAN BE OBTAINED FROM THE EMPLOYER, THE MANUFACTURER OR SUPPLIER OF THAT PRODUCT OR MATERIAL, OR THE MATERIAL SAFETY DATA SHEET.



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Welded Steel Tanks for Oil Storage

SECTION 1—SCOPE

1.1 GENERAL

1.1.1 This Standard establishes minimum requirements for material, design, fabrication, erection, and testing for vertical, cylindrical, aboveground, closed- and open-top, welded carbon or stainless steel storage tanks in various sizes and capacities for internal pressures approximating atmospheric pressure (internal pressures not exceeding the weight of the roof plates), but a higher internal pressure is permitted when additional requirements are met (see 1.1.12). This Standard applies only to tanks whose entire bottom is uniformly supported and to tanks in non-refrigerated service that have a maximum design temperature of 93°C (200°F) or less (see 1.1.19).

- **1.1.2** This Standard is designed to provide industry with tanks of adequate safety and reasonable economy for use in the storage of petroleum, petroleum products, and other liquid products. This Standard does not present or establish a fixed series of allowable tank sizes; instead, it is intended to permit the Purchaser to select whatever size tank may best meet his needs. This Standard is intended to help Purchasers and Manufacturers in ordering, fabricating, and erecting tanks; it is not intended to prohibit Purchasers and Manufacturers from purchasing or fabricating tanks that meet specifications other than those contained in this Standard.

Note: A bullet (•) at the beginning of a paragraph indicates that there is an expressed decision or action required of the Purchaser. The Purchaser's responsibility is not limited to these decisions or actions alone. When such decisions and actions are taken, they are to be specified in documents such as requisitions, change orders, data sheets, and drawings.

- **1.1.3** This Standard has requirements given in two alternate systems of units. The Manufacturer shall comply with either:
 1. all of the requirements given in this Standard in SI units, or
 2. all of the requirements given in this Standard in US Customary units.

The selection of which set of requirements (SI or US Customary) to apply shall be a matter of mutual agreement between the Manufacturer and Purchaser and indicated on the Data Sheet, Page 1.

1.1.4 All tanks and appurtenances shall comply with the Data Sheet and all attachments.

- **1.1.5** Field-erected tanks shall be furnished completely erected, tested, and ready for service connections, unless specified otherwise. Shop-fabricated tanks shall be furnished tested and ready for installation.
- **1.1.6** The appendices of this Standard provide a number of design options requiring decisions by the Purchaser, standard requirements, recommendations, and information that supplements the basic standard. Except for Appendix L, an appendix becomes a requirement only when the Purchaser specifies an option covered by that appendix or specifies the entire appendix. See Table 1-1 for the status of each appendix.

1.1.7 Appendix A provides alternative simplified design requirements for tanks where the stressed components, such as shell plates and reinforcing plates, are limited to a maximum nominal thickness of 12.5 mm ($1/2$ in.), including any corrosion allowance, and whose design metal temperature exceeds the minimums stated in the appendix.

1.1.8 Appendix B provides recommendations for the design and construction of foundations for flat-bottom oil storage tanks.

1.1.9 Appendix C provides minimum requirements for pontoon-type and double-deck-type external floating roofs.

1.1.10 Appendix D provides requirements for submission of technical inquiries regarding this Standard.

- **1.1.11** Appendix E provides minimum requirements for tanks subject to seismic loading. An alternative or supplemental design may be mutually agreed upon by the Manufacturer and the Purchaser.

1.1.12 Appendix F provides requirements for the design of tanks subject to a small internal pressure.

1.1.13 Appendix G provides requirements for aluminum dome roofs.

1.1.14 Appendix H provides minimum requirements that apply to an internal floating roof in a tank with a fixed roof at the top of the tank shell.

Table 1-1—Status of Appendices to API Std 650

Appendix	Title	Status
A	Optional design basis for small tanks	Purchaser's Option
B	Recommendations for design and construction of foundations for aboveground oil storage tanks	Recommendations
• C	External floating roofs	Requirements
D	Technical inquiries	Required Procedures
• E	Seismic design of storage tanks	Purchaser's Option
F	Design of tanks for small internal pressures	Requirements
• G	Structurally-supported aluminum dome roofs	Requirements
H	Internal floating roofs	Requirements
• I	Undertank leak detection and subgrade protection	Purchaser's Option
J	Shop-assembled storage tanks	Requirements
K	Sample application of the variable-design-point method to determine shell-plate thickness	Information
• L	API Std 650 storage tank data sheets	Requirements
M	Requirements for tanks operating at elevated temperatures	Requirements
N	Use of new materials that are not identified	Requirements
• O	Recommendation for under-bottom connections	Purchaser's Option
• P	Allowable external load on tank shell openings	Purchaser's Option
R	Load combinations	Requirements
S	Austenitic stainless steel storage tanks	Requirements
T	NDE requirements summary	Requirements
U	Ultrasonic examination in lieu of radiography	Purchaser's Option
• V	Design of storage tanks for external pressure	Purchaser's Option
• W	Commercial and Documentation Recommendations	Recommendations

- **1.1.15** Appendix I provides acceptable construction details that may be specified by the Purchaser for design and construction of tank and foundation systems that provide leak detection and subgrade protection in the event of tank bottom leakage, and provides for tanks supported by grillage.

1.1.16 Appendix J provides requirements covering the complete shop assembly of tanks that do not exceed 6 m (20 ft) in diameter.

1.1.17 Appendix K provides a sample application of the variable-design-point method to determine shell-plate thicknesses.

- 07 | • **1.1.18** Appendix L provides the Data Sheet and the Data Sheet instructions for listing required information to be used by the Purchaser and the Manufacturer. The use of the Data Sheet is mandatory, unless waived by the Purchaser.

1.1.19 Appendix M provides requirements for tanks with a maximum design temperature exceeding 93°C (200°F) but not exceeding 260°C (500°F).

1.1.20 Appendix N provides requirements for the use of new or unused plate and pipe materials that are not completely identified as complying with any listed specification for use in accordance with this Standard.

1.1.21 Appendix O provides recommendations for the design and construction of under-bottom connections for storage tanks.

- 07 | • **1.1.22** Appendix P provides requirements for design of shell openings that conform to Table 5-6 that are subject to external piping loads. An alternative or supplemental design may be agreed upon by the Purchaser or Manufacturer.

1.1.23 Appendix R provides a description of the load combinations used for the design equations appearing in this Standard.

1.1.24 Appendix S provides requirements for stainless steel tanks.

1.1.25 Appendix T summarizes the requirements for inspection by method of examination and the reference sections within the Standard. The acceptance standards, inspector qualifications, and procedure requirements are also provided. This appendix is not intended to be used alone to determine the inspection requirements within this Standard. The specific requirements listed within each applicable section shall be followed in all cases.

1.1.26 Appendix U provides requirements covering the substitution of ultrasonic examination in lieu of radiographic examination.

1.1.27 Appendix V provides additional requirements for tanks that are designed to operate under external pressure (vacuum) conditions.

- **1.1.28** Appendix W provides recommendations covering commercial and documentation issues. Alternative or supplemental requirements may be mutually agreed upon by the Manufacturer and the Purchaser.

1.2 LIMITATIONS

The rules of this Standard are not applicable beyond the following limits of piping connected internally or externally to the roof, shell, or bottom of tanks constructed according to this Standard:

- a. The face of the first flange in bolted flanged connections, unless covers or blinds are provided as permitted in this Standard.
- b. The first sealing surface for proprietary connections or fittings.
- c. The first threaded joint on the pipe in a threaded connection to the tank shell.
- d. The first circumferential joint in welding-end pipe connections if not welded to a flange.

1.3 RESPONSIBILITIES

1.3.1 The Manufacturer is responsible for complying with all provisions of this Standard. Inspection by the Purchaser's inspector does not negate the Manufacturer's obligation to provide quality control and inspection necessary to ensure such compliance. The Manufacturer shall also communicate specified requirements to relevant subcontractors or suppliers working at the request of the Manufacturer.

- **1.3.2** The Purchaser shall specify on the Data Sheet, Line 23, the applicable jurisdictional regulations and owner requirements that may affect the design and construction of the tank and those that are intended to limit the evaporation or release of liquid contents from the tank. Which regulations/requirements, if any, apply depend on many factors such as the business unit the tank is assigned to, the vapor pressure of the liquids stored in the tank, the components of the liquid stored in the tank, the geographic location of the tank, the date of construction of the tank, the capacity of the tank, and other considerations. These rules may affect questions such as 1) which tanks require floating roofs and the nature of their construction; 2) the types and details of seals used in the floating roof annular rim space and at openings in the roof, 3) details of tank vents, and 4) requirements regarding release prevention barriers.
- **1.3.3** The Purchaser shall provide any jurisdictional site permits that may be required to erect the tank(s), including permits for disposal of the hydro-test water. The Manufacturer shall provide all other permits that may be required to complete or transport the tank.

1.3.4 The Purchaser retains the right to provide personnel to observe all shop and job site work within the scope of the contracted work (including testing and inspection). Such individuals shall be afforded full and free access for these purposes, subject to safety and schedule constraints.

1.3.5 In this Standard, language indicating that the Purchaser accepts, agrees, reviews, or approves a Manufacturer's design, work process, manufacturing action, etc., shall not limit or relieve the Manufacturer's responsibility to conform to specified design codes, project specifications and drawings, and professional workmanship.

1.3.6 The Manufacturer shall advise the Purchaser of any identified conflicts between this Standard and any Purchaser-referenced document and request clarification.

1.3.7 In this Standard, language indicating that any particular issue is subject to agreement between the Purchaser and the Manufacturer shall be interpreted to require any such agreement to be documented in writing.

07 | ● **1.4 DOCUMENTATION REQUIREMENTS**

See Appendix W and the Data Sheet for the requirements covering the various documents to be developed for the tank.

SECTION 2—REFERENCES

The following standards, codes, specifications, and publications are cited in this Standard. The most recent edition shall be used unless otherwise specified.

API

- Std 620 *Design and Construction of Large, Welded, Low-Pressure Storage Tanks*
- RP 651 *Cathodic Protection of Aboveground Petroleum Storage Tanks*
- RP 652 *Lining of Aboveground Petroleum Storage Tank Bottoms*
- Std 2000 *Venting Atmospheric and Low-Pressure Storage Tanks: Non-refrigerated and Refrigerated*
- RP 2003 *Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents*
- Publ 2026 *Safe Access/Egress Involving Floating Roofs of Storage Tanks in Petroleum Service*
- RP 2350 *Overfill Protection for Storage Tanks in Petroleum Facilities*
- Spec 5L *Specification for Line Pipe*

Manual of Petroleum Measurements Standards (MPMS)

- Chapter 19 “Evaporative Loss Measurement”

AAI¹

- Aluminum Design Manual*
- Aluminum Standards and Data*
- Specifications for Aluminum Sheet Metal Work in Building Construction*

ACI²

- 318 *Building Code Requirements for Reinforced Concrete (ANSI/ACI 318)*
- 350 *Environmental Engineering Concrete Structures*

AISC³

- Manual of Steel Construction, Allowable Stress Design*

AISI⁴

- T-192 *Steel Plate Engineering Data Series—Useful Information—Design of Plate Structures, Volumes I & II*

ASCE⁵

- ASCE Std. 7 *Minimum Design Loads for Buildings and Other Structures*

ASME⁶

- B1.20.1 *Pipe Threads, General Purpose (Inch) (ANSI/ASME B1.20.1)*
- B16.1 *Cast Iron Pipe Flanges and Flanged Fittings (ANSI/ASME B16.1)*
- B16.5 *Pipe Flanges and Flanged Fittings (ANSI/ASME B16.5)*
- B16.21 *Nonmetallic Flat Gaskets for Pipe Flanges*
- B16.47 *Large Diameter Steel Flanges: NPS 26 Through NPS 60 (ANSI/ASME B16.47)*
- B96.1 *Welded Aluminum-Alloy Storage Tanks (ANSI/ASME B96.1)*

Boiler and Pressure Vessel Code, Section V, “Nondestructive Examination;” Section VIII, “Pressure Vessels,” Division 1; and Section IX, “Welding and Brazing Qualifications”

¹The Aluminum Association Inc., 1525 Wilson Boulevard, Suite 600, Arlington, Virginia 22209, www.aluminum.org.

²American Concrete Institute, P.O. Box 9094, Farmington Hills, Michigan 48333, www.aci-int.org.

³American Institute of Steel Construction, One East Wacker Drive, Suite 3100, Chicago, Illinois 60601-2001, www.aisc.org.

⁴American Iron and Steel Institute, 1540 Connecticut Avenue, N.W., Suite 705, Washington, D.C. 20036, www.steel.org.

⁵American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, Virginia 20191-4400, www.asce.org.

⁶ASME International, 3 Park Avenue, New York, New York 10016-5990, www.asme.org.

ASNT⁷

- CP-189 *Standard for Qualification and Certification of Nondestructive Testing Personnel*
 RP SNT-TC-1A *Personnel Qualification and Certification in Nondestructive Testing*

ASTM⁸

- A 6M/A 6 *General Requirements for Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use*
 A 20M/A 20 *General Requirements for Steel Plates for Pressure Vessels*
 A 27M/A 27 *Steel Castings, Carbon, for General Application*
 A 36M/A 36 *Structural Steel*
 A 53 *Pipe, Steel, Black and Hot-Dipped, Zinc-Coated Welded and Seamless*
 A 105M/A 105 *Forgings, Carbon Steel, for Piping Components*
 A 106 *Seamless Carbon Steel Pipe for High-Temperature Service*
 A 131M/A 131 *Structural Steel for Ships*
 A 181M/A 181 *Forgings, Carbon Steel, for General-Purpose Piping*
 A 182M/A 182 *Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service*
 A 193M/A 193 *Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service*
 A 194M/A 194 *Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service*
 A 213M/A 213 *Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes*
 A 216M/A 216 *Standard Specifications for Steel Castings for High-Temperature Service*
 A 234M/A 234 *Piping Fittings of Wrought Carbon Steel and Alloy Steel for Moderate and High-Temperature Service*
 A 240M/A 240 *Heat-Resisting Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels*
 A 276 *Stainless Steel Bars and Shapes*
 A 283M/A 283 *Low and Intermediate Tensile Strength Carbon Steel Plates*
 A 285M/A 285 *Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength*
 A 307 *Carbon Steel Bolts and Studs, 60,000 lbf/in.² Tensile Strength*
 A 312M/A 312 *Seamless and Welded Austenitic Stainless Steel Pipes*
 A 320M/A 320 *Alloy Steel Bolting Materials for Low-Temperature Service*
 A 333M/A 333 *Seamless and Welded Steel Pipe for Low-Temperature Service*
 A 334M/A 334 *Seamless and Welded Carbon and Alloy-Steel Tubes for Low-Temperature Service*
 A 350M/A 350 *Forgings, Carbon and Low-Alloy Steel, Requiring Notch Toughness Testing for Piping Components*
 A 351M/A 351 *Castings, Austenitic, Austenitic-Ferritic (Duplex), for Pressure-Containing Parts*
 A 358M/A 358 *Electric-Fusion-Welded Austenitic Chromium-Nickel Alloy Steel Pipe for High-Temperature Service*
 A 370 *Test Methods and Definitions for Mechanical Testing of Steel Products*
 A 380 *Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems*
 A 403M/A 403 *Wrought Austenitic Stainless Steel Piping Fittings*
 A 420M/A 420 *Piping Fittings of Wrought Carbon Steel and Alloy Steel for Low-Temperature Service*
 A 479M/A 479 *Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels*
 A 480M/A 480 *Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip*
 A 516M/A 516 *Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service*
 A 524 *Seamless Carbon Steel Pipe for Atmospheric and Lower Temperatures*
 A 537M/A 537 *Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel*
 A 573M/A 573 *Structural Carbon Steel Plates of Improved Toughness*
 A 633M/A 633 *Normalized High-Strength Low-Alloy Structural Steel*
 A 662M/A 662 *Pressure Vessel Plates, Carbon-Manganese, for Moderate and Lower Temperature Service*
 A 671 *Electric-Fusion-Welded Steel Pipe for Atmospheric and Lower Temperatures*
 A 678M/A 678 *Quenched and Tempered Carbon-Steel and High-Strength Low-Alloy Steel Plates for Structural Applications*

⁷American Society for Nondestructive Testing, 1711 Arlingate Lane, Columbus, Ohio 43228-0518, www.asnt.org.

⁸ASTM, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959, www.astm.org.

- A 737M/A 737 *Pressure Vessel Plates, High-Strength, Low-Alloy Steel*
- A 841M/A 841 *Standard Specification for Steel Plates for Pressure Vessels, Produced by the Thermo-Mechanical Control Process (TMCP)*
- A 924M/A 924 *General Requirements for Steel Sheet, Metallic-Coated by the Hot-Dip Process*
- A 992M/A 992 *Steel for Structural Shapes for Use in Building Framing*
- A 1011M/A 1011 *Standard Specification for Steel, Sheet and Strip, Hot-Rolled, Carbon, Structural, High-Strength Low-Alloy and High-Strength Low-Alloy with Improved Formability*
- C 509 *Cellular Electrometric Preformed Gasket and Sealing Material* | 07
- D 3453 *Flexible Cellular Materials—Urethane for Furniture and Automotive Cushioning, Bedding, and Similar Applications*
- E 84 *Test Method for Surface Burning Characteristics of Building Materials* | 07

AWS⁹

- A5.1 *Specification for Carbon Steel Covered Arc-Welding Electrodes (ANSI/AWS A5.1)*
- A5.5 *Specification for Low-Alloy Steel Covered Arc-Welding Electrodes (ANSI/AWS A5.5)*
- D1.2 *Structural Welding Code—Aluminum (ANSI/AWS D1.2)*

CSA¹⁰

- G40.21 *Structural Quality Steels, Supplement to National Building Code of Canada*

ISO¹¹

- 630 *Structural Steels*

NFPA¹²

- NFPA 11 *Standard for Low Expansion Foam*
- NFPA 30 *Flammable and Combustible Liquids Code*
- NFPA 780 *Standard for the Installation of Lightning Protection Systems*

Process Industry Practices¹³

- PIP STF05501 *Fixed Ladders and Cages Details*
- PIP STF05520 *Pipe Railing for Walking and Working Surface Details*
- PIP STF05521 *Details for Angle Railings for Walking and Working Surfaces*

U.S. EPA¹⁴

- 40 CFR Part 63 *National Emission Standards for Hazardous Air Pollutants for Source Categories (HON)*
- Subpart F *National Emission Standards for Organic Hazardous Air Pollutants from the Synthetic Organic Chemical Manufacturing Industry*
- Subpart G *National Emission Standards for Organic Hazardous Air Pollutants from the Synthetic Organic Chemical Manufacturing Industry for Process Vents, Storage Vessels, Transfer Operators, and Waste Water*
- Subpart H *National Emission Standards for Organic Hazardous Air Pollutants for Equipment Leaks*
- 40 CFR Part 68 *Chemical Accident Prevention Provisions*
- Subpart G *Risk Management Plan (RMP)*
- 40 CFR Part 264 *Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities (RCRA)*
- Subpart J *Tank Systems*

⁹American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126, www.aws.org.

¹⁰Canadian Standards Association, 178 Rexdale Boulevard, Rexdale, Ontario M9W 1R3, www.csa.ca.

¹¹International Organization for Standardization. ISO publications can be obtained from the American National Standards Institute (ANSI) and national standards organizations such as the British Standards Institute (BSI), Japanese Industrial Standards (JIS), and Deutsches Institut fuer Normung (German Institute for Standardization [DIN]), www.iso.ch.

¹²National Fire Protection Agency, 1 Batterymarch Park, Quincy, Massachusetts 02169-7474, www.nfpa.org.

¹³Process Industry Practices, 3925 West Braker Lane (R4500), Austin, Texas 78759, www.pip.org.

¹⁴U.S. Environmental Protection Agency, Ariel Rios Building, 1200 Pennsylvania Avenue, Washington, D.C. 20460, www.epa.gov.

U.S. Federal Specifications¹⁵

- TT-S-00230C *Sealing Compound Electrometric Type, Single Component for Caulking, Sealing, and Glazing in Buildings and Other Structures*
- ZZ-R-765C *Rubber, Silicone (General Specification)*

U.S. OSHA¹⁶

- 29 CFR 1910 *Subpart D: Walking-Working Surfaces*
- 29 CFR 1910.119 *Process Safety Management of Highly Hazardous Chemicals*

Other Government Documents

- Hershfield, D. M. 1961. "Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years," *Technical Paper No. 40*, Weather Bureau, U.S. Department of Commerce, Washington, D.C., 115 pp.

WRC¹⁷

- Bulletin 297 *Local Stresses in Cylindrical Shells Due to External Loadings—Supplement to WRC Bulletin No. 107*

¹⁵Specifications Unit (WFSIS), 7th and D Streets, S.W., Washington, D.C. 20407.

¹⁶U.S. Department of Labor, Occupational Safety and Health Administration, 200 Constitution Avenue, N.W., Washington, D.C. 20210 www.osha.gov.

¹⁷The Welding Research Council, 3 Park Avenue, 27th Floor, New York, New York 10016-5902, www.forengineers.org.

SECTION 3—DEFINITIONS

- 3.1 centerline-stacked:** The mid-thickness centerlines of plates in all shell courses coincide.
- 3.2 coating:** A protective material applied to external and internal surfaces of a tank, or to inaccessible surfaces (the underside of the tank bottom) In this Standard, the term includes materials frequently described as painting and lining materials.
- 3.3 contract:** The commercial instrument, including all attachments, used to procure a tank.
- 3.4 design metal temperature:** The lowest temperature considered in the design, which, unless experience or special local conditions justify another assumption, shall be assumed to be 8°C (15°F) above the lowest one-day mean ambient temperature of the locality where the tank is to be installed. Isothermal lines of lowest one-day mean temperature are shown in Figure 4-2. The temperatures are not related to refrigerated-tank temperatures (see 1.1.1).
- 3.5 design thickness:** The thickness necessary to satisfy tension and compression strength requirements by this Standard or, in the absence of such expressions, by good and acceptable engineering practice for specified design conditions, without regard to construction limitations or corrosion allowances.
- 3.6 double-deck floating roof:** The entire roof is constructed of closed-top flotation compartments.
- 3.7 floating suction line:** Internal piping assembly that allows operator to withdraw product from the upper levels of the tank.
- 3.8 flush-stacked on the inside:** The inside surfaces of plates in all shell courses coincide.
- 3.9 inlet diffusers:** Internal fill line piping with impingement plate, baffles, slots, or lateral openings to reduce the velocity of the flow entering a tank.
- 3.10 inspector:** The person(s) designated by the Purchaser to perform inspections.
- 3.11 mandatory:** Required sections of the Standard become mandatory if the Standard has been adopted by a Legal Jurisdiction or if the Purchaser and the Manufacturer choose to make reference to this Standard on the nameplate or in the Manufacturer's certification.
- 3.12 Manufacturer:** The party having the primary responsibility to construct the tank (see 1.3 and 10.2).
- 3.13 maximum design temperature:** The highest temperature considered in the design, equal to or greater than the highest expected operating temperature during the service life of the tank.
- 3.14 Purchaser:** The owner or the owner's designated agent, such as an engineering contractor.
- 3.15 Purchaser's option:** A choice to be selected by the Purchaser and indicated on the Data Sheet. When the Purchaser specifies an option covered by an appendix, the appendix then becomes a requirement.
- 3.16 recommendation:** The criteria provide a good acceptable design and may be used at the option of the Purchaser and the Manufacturer.
- 3.17 requirement:** The criteria must be used unless the Purchaser and the Manufacturer agree upon a more stringent alternative design.
- 3.18 single-deck pontoon floating roof:** The outer periphery of the roof consists of closed-top pontoon compartments, with the inner section of the roof constructed of a single deck without flotation means.

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SECTION 4—MATERIALS

4.1 GENERAL

4.1.1 Miscellaneous

4.1.1.1 See the Data Sheet for material specifications.

4.1.1.2 Rimmed or capped steels are not permitted.

4.1.1.3 Use of cast iron for any pressure part or any part attached to the tank by welding is prohibited.

- 4.1.1.4 Because of hydrogen embrittlement and toxicity concerns, cadmium-plated components shall not be used without the expressed consent of the Purchaser.
- 4.1.2 Materials used in the construction of tanks shall conform to the specifications listed in this section, subject to the modifications and limitations indicated in this Standard. Material produced to specifications other than those listed in this section may be employed, provided that the material is certified to meet all of the requirements of an applicable material specification listed in this Standard and the material's use is approved by the Purchaser. The Manufacturer's proposal shall identify the material specifications to be used. When this Standard does not address material requirements for miscellaneous items and appurtenances, the Purchaser and/or the Manufacturer shall supply additional material requirements using a supplement to the Data Sheet.
- 4.1.3 When any new or unused plate and pipe material cannot be completely identified by records that are satisfactory to the Purchaser as material conforming to a specification listed in this Standard, the material or product may be used in the construction of tanks covered by this Standard only if the material passes the tests prescribed in Appendix N.

4.1.4 Where materials of construction are used that are certified to two or more material specifications, the material specification chosen for the design calculations shall also be used consistently in the application of all other provisions of this Standard. The Purchaser shall be notified of this choice and receive confirmation that the material fully complies with the chosen material specification in all respects.

4.1.5 When a tank is designed to the requirements of this Standard using plate material from Group-I through Group-III A steels, the tank Manufacturer responsible for any proposed material substitution to use Group-IV through Group-VI steels must:

- a. Maintain all of the original design criteria for the lower stress Group-I through Group III A steels.
- b. Obtain the prior written approval of the Purchaser.
- c. Ensure that all of the design, fabrication, erection and inspection requirements for the material being substituted will meet the lower stress Group-I through Group III A specifications for items including but not limited to:
 1. Material properties and production process methods.
 2. Allowable stress levels.
 3. Notch toughness.
 4. Welding procedures and consumables.
 5. Thermal stress relief.
 6. Temporary and permanent attachment details and procedures.
 7. Nondestructive examinations.
- d. Include the pertinent information in the documents provided to the Purchaser, including a certification statement that the substituted material fully complies with 4.1.3 in all respects, and provide all other records covered by the work processes applied to the material such as impact testing, weld procedures, nondestructive examinations, and heat treatments.

4.2 PLATES

4.2.1 General

4.2.1.1 Except as otherwise provided for in 4.1, plates shall conform to one of the specifications listed in 4.2.2 through 4.2.5, subject to the modifications and limitations in this Standard.

4.2.1.2 Plate for shells, roofs, and bottoms may be ordered on an edge-thickness basis or on a weight (kg/m^2 [lb/ft^2]) basis, as specified in 4.2.1.2.1 through 4.2.1.2.3.

4.2.1.2.1 The edge thickness ordered shall not be less than the computed design thickness or the minimum permitted thickness.

4.2.1.2.2 The weight ordered shall be great enough to provide an edge thickness not less than the computed design thickness or the minimum permitted thickness.

4.2.1.2.3 Whether an edge-thickness or a weight basis is used, an underrun not more than 0.25 mm (0.01 in.) from the computed design thickness or the minimum permitted thickness is acceptable.

- **4.2.1.3** All plates shall be manufactured by the open-hearth, electric-furnace, or basic oxygen process. Steels produced by the thermo-mechanical control process (TMCP) may be used, provided that the combination of chemical composition and integrated controls of the steel manufacturing is mutually acceptable to the Purchaser and the Manufacturer, and provided that the specified mechanical properties in the required plate thicknesses are achieved. Copper-bearing steel shall be used if specified by the Purchaser.

4.2.1.4 Shell plates are limited to a maximum thickness of 45 mm (1.75 in.) unless a lesser thickness is stated in this Standard or in the plate specification. Plates used as inserts or flanges may be thicker than 45 mm (1.75 in.). Plates thicker than 40 mm (1.5 in.) shall be normalized or quench tempered, killed, made to fine-grain practice, and impact tested.

4.2.2 ASTM Specifications

Plates that conform to the following ASTM specifications are acceptable as long as the plates are within the stated limitations:

- a. ASTM A 36M/A 36 for plates to a maximum thickness of 40 mm (1.5 in.). None of the specifications for the appurtenant materials listed in Table 1 of ASTM A 36M/A 36 are considered acceptable for tanks constructed under this Standard unless it is expressly stated in this Standard that the specifications are acceptable.
- b. ASTM A 131M/A 131, Grade A, for plates to a maximum thickness of 12.5 mm (0.5 in.); Grade B for plates to a maximum thickness of 25 mm (1 in.); Grade CS for plates to a maximum thickness of 40 mm (1.5 in.) (insert plates and flanges to a maximum thickness of 50 mm [2 in.]); and Grade EH36 for plates to a maximum thickness of 45 mm (1.75 in.) (insert plates and flanges to a maximum thickness of 50 mm [2 in.]).
- c. ASTM A 283M/A 283, Grade C, for plates to a maximum thickness of 25 mm (1 in.).
- d. ASTM A 285M/A 285, Grade C, for plates to a maximum thickness of 25 mm (1 in.).
- e. ASTM A 516M Grades 380, 415, 450, 485/A 516, Grades 55, 60, 65, and 70, for plates to a maximum thickness of 40 mm (1.5 in.) (insert plates and flanges to a maximum thickness of 100 mm [4 in.]).
- f. ASTM A 537M/A 537, Class 1 and Class 2, for plates to a maximum thickness of 45 mm (1.75 in.) (insert plates to a maximum thickness of 100 mm [4 in.]).
- g. ASTM A 573M Grades 400, 450, 485/A 573, Grades 58, 65, and 70, for plates to a maximum thickness of 40 mm (1.5 in.).
- h. ASTM A 633M/A 633, Grades C and D, for plates to a maximum thickness of 45 mm (1.75 in.) (insert plates to a maximum thickness of 100 mm [4.0 in.]).
- i. ASTM A 662M/A 662, Grades B and C, for plates to a maximum thickness of 40 mm (1.5 in.).
- j. ASTM A 678M/A 678, Grade A, for plates to a maximum thickness of 40 mm (1.5 in.) (insert plates to a maximum thickness of 65 mm [2.5 in.]) and Grade B for plates to a maximum thickness of 45 mm (1.75 in.) (insert plates to a maximum thickness of 65 mm [2.5 in.]). Boron additions are not permitted.
- k. ASTM A 737M/A 737, Grade B, for plates to a maximum thickness of 40 mm (1.5 in.).
- l. ASTM A 841M/A 841 Grade A, Class 1 and Grade B, Class 2 for plates to a maximum thickness of 40 mm (1.5 in.) (insert plates to a maximum thickness of 65 mm [2.5 in.]).

4.2.3 CSA Specifications

Plate furnished to CSA G40.21 in Grades 260W/(38W), 300W(44W), and 350W/(50W) is acceptable within the limitations stated below. (If impact tests are required, Grades 260W/[38W], 300W/[44W], and 350W/[50W] are designated as Grades 260WT/[38WT], 300WT/[44WT], and 350WT/[50WT], respectively.) Imperial unit equivalent grades of CSA Specification G40.21, shown in parenthesis, are also acceptable.

- The W grades may be semi-killed or fully killed.
- Fully killed steel made to fine-grain practice must be specified when required.
- Elements added for grain refining or strengthening shall be restricted in accordance with Table 4-1.
- Plates shall have tensile strengths that are not more than 140 MPa (20 ksi) above the minimum specified for the grade.
- Grades 260W/(38W) and 300W(44W) are acceptable for plate to a maximum thickness of 25 mm (1 in.) if semi-killed and to a maximum thickness of 40 mm (1.5 in.) if fully killed and made to fine-grain practice.
- Grade 350W(50W) is acceptable for plate to a maximum thickness of 45 mm (1.75 in.) (insert plates to a maximum thickness of 50 mm [2 in.]) if fully killed and made to fine-grain practice.

4.2.4 ISO Specifications

Plate furnished to ISO 630 in Grades E 275 and E 355 is acceptable within the following limitations:

- Grade E 275 in Qualities C and D for plate to a maximum thickness of 40 mm (1.5 in.) and with a maximum manganese content of 1.5% (heat).
- Grade E 355 in Qualities C and D for plate to a maximum thickness of 45 mm (1.75 in.) (insert plates to a maximum thickness of 50 mm [2 in.]).

• 4.2.5 National Standards

Plates produced and tested in accordance with the requirements of a recognized national standard and within the mechanical and chemical limitations of one of the grades listed in Table 4-2 are acceptable when approved by the Purchaser. The requirements of this group do not apply to the ASTM, CSA, and ISO specifications listed in 4.2.2, 4.2.3, and 4.2.4. For the purposes of this Standard, a *national standard* is a standard that has been sanctioned by the government of the country from which the standard originates.

Table 4-1—Maximum Permissible Alloy Content

Alloy	Heat Analysis (%)	Notes
Columbium	0.05	1, 2, 3
Vanadium	0.10	1, 2, 4
Columbium ($\leq 0.05\%$) plus Vanadium	0.10	1, 2, 3
Nitrogen	0.015	1, 2, 4
Copper	0.35	1, 2
Nickel	0.50	1, 2
Chromium	0.25	1, 2
Molybdenum	0.08	1, 2

- When the use of these alloys or combinations of them is not included in the material specification, their use shall be at the option of the plate producer, subject to the approval of the Purchaser. These elements shall be reported when requested by the Purchaser. When more restrictive limitations are included in the material specification, those shall govern.
- On product analysis, the material shall conform to these requirements, subject to the product analysis tolerances of the specification.
- When columbium is added either singly or in combination with vanadium, it shall be restricted to plates of 12.5 mm (0.50 in.) maximum thickness unless combined with 0.15% minimum silicon.
- When nitrogen ($\leq 0.015\%$) is added as a supplement to vanadium, it shall be reported, and the minimum ratio of vanadium to nitrogen shall be 4:1.

Table 4-2—Acceptable Grades of Plate Material Produced to National Standards (See 4.2.5)

Grade ^b	Mechanical Properties								Chemical Composition			
	Tensile Strength ^a				Minimum Yield Strength ^c		Maximum Thickness		Maximum Percent Carbon		Maximum Percent Phosphorus and Sulfur	
	Minimum ^c		Maximum									
	MPa	ksi	MPa	ksi	MPa	ksi	mm	in.	Heat	Product	Heat	Product
235 ^d	360	52	510	74	235	34	20	0.75	0.20	0.24	0.04	0.05
250	400	58	530	77	250	36	40	1.5	0.23	0.27	0.04	0.05
275	430	62	560	81	275	40	40	1.5	0.25	0.29	0.04	0.05

^aThe location and number of test specimens, elongation and bend tests, and acceptance criteria are to be in accordance with the appropriate national standard, ISO standard, or ASTM specification.

^bSemi-killed or fully killed quality; as rolled, controlled-rolled or TMCP (20 mm [0.75 in.] maximum when controlled-rolled steel or TMCP is used in place of normalized steel), or normalized.

• ^cYield strength ÷ tensile strength ≤ 0.75, based on the minimum specified yield and tensile strength unless actual test values are required by the Purchaser.

^dNonrimming only.

4.2.6 General Requirements for Delivery

4.2.6.1 The material furnished shall conform to the applicable requirements of the listed specifications but is not restricted with respect to the location of the place of manufacture.

4.2.6.2 This material is intended to be suitable for fusion welding. Welding technique is of fundamental importance, and welding procedures must provide welds whose strength and toughness are consistent with the plate material being joined. All welding performed to repair surface defects shall be done with low-hydrogen welding electrodes compatible in chemistry, strength, and quality with the plate material.

4.2.6.3 When specified by the plate purchaser, the steel shall be fully killed. When specified by the plate purchaser, fully killed steel shall be made to fine-grain practice.

4.2.6.4 For plate that is to be made to specifications that limit the maximum manganese content to less than 1.60%, the limit of the manganese content may be increased to 1.60% (heat) at the option of the plate producer to maintain the required strength level, provided that the maximum carbon content is reduced to 0.20% (heat) and the weldability of the plate is given consideration. The material shall be marked “Mod” following the specification listing. The material shall conform to the product analysis tolerances of Table B in ASTM A 6M/A 6.

4.2.6.5 The use or presence of columbium, vanadium, nitrogen, copper, nickel, chromium, or molybdenum shall not exceed the limitations of Table 4-1 for all Group VI materials (see Table 4-3) and ISO 630, Grade E 355.

4.2.7 Heat Treatment of Plates

4.2.7.1 When specified by the plate purchaser, fully killed plates shall be heat treated to produce grain refinement by either normalizing or heating uniformly for hot forming. If the required treatment is to be obtained in conjunction with hot forming, the temperature to which the plates are heated for hot forming shall be equivalent to and shall not significantly exceed the normalizing temperature. If the treatment of the plates is not specified to be done at the plate producer’s plant, testing shall be carried out in accordance with 4.2.7.2.

4.2.7.2 When a plate purchaser elects to perform the required normalizing or fabricates by hot forming (see 4.2.7.1), the plates shall be accepted on the basis of mill tests made on full-thickness specimens heat treated in accordance with the plate purchaser’s order. If the heat-treatment temperatures are not indicated on the contract, the specimens shall be heat treated under conditions considered appropriate for grain refinement and for meeting the test requirements. The plate producer shall inform the plate purchaser of the procedure followed in treating the specimens at the steel mill.

4.2.7.3 On the purchase order, the plate purchaser shall indicate to the plate producer whether the producer shall perform the heat treatment of the plates.

- **4.2.7.4** Subject to the Purchaser's approval, controlled-rolled or thermo-mechanical-control-process (TMCP) plates (plates produced by a mechanical-thermal rolling process designed to enhance notch toughness) may be used where normalized plates are required. Each plate-as-rolled shall receive Charpy V-notch impact energy testing in accordance with 4.2.8, 4.2.9, and 4.2.10. When controlled-rolled or TMCP steels are used, consideration should be given to the service conditions outlined in 5.3.3.

4.2.7.5 The tensile tests shall be performed on each plate as heat treated.

4.2.8 Impact Testing of Plates

- **4.2.8.1** When required by the Purchaser or by 4.2.7.4 and 4.2.9, a set of Charpy V-notch impact specimens shall be taken from plates after heat treatment (if the plates have been heat treated), and the specimens shall fulfill the stated energy requirements. Test coupons shall be obtained adjacent to a tension-test coupon. Each full-size impact specimen shall have its central axis as close to the plane of one-quarter plate thickness as the plate thickness will permit.

4.2.8.2 When it is necessary to prepare test specimens from separate coupons or when plates are furnished by the plate producer in a hot-rolled condition with subsequent heat treatment by the fabricator, the procedure shall conform to ASTM A 20.

4.2.8.3 An impact test shall be performed on three specimens taken from a single test coupon or test location. The average value of the specimens (with no more than one specimen value being less than the specified minimum value) shall comply with the specified minimum value. If more than one value is less than the specified minimum value, or if one value is less than two-thirds the specified minimum value, three additional specimens shall be tested, and each of these must have a value greater than or equal to the specified minimum value.

4.2.8.4 The test specimens shall be Charpy V-notch Type A specimens (see ASTM A 370), with the notch perpendicular to the surface of the plate being tested.

4.2.8.5 For a plate whose thickness is insufficient to permit preparation of full-size specimens (10 mm × 10 mm), tests shall be made on the largest subsize specimens that can be prepared from the plate. Subsize specimens shall have a width along the notch of at least 80% of the material thickness.

4.2.8.6 The impact energy values obtained from subsize specimens shall not be less than values that are proportional to the energy values required for full-size specimens of the same material.

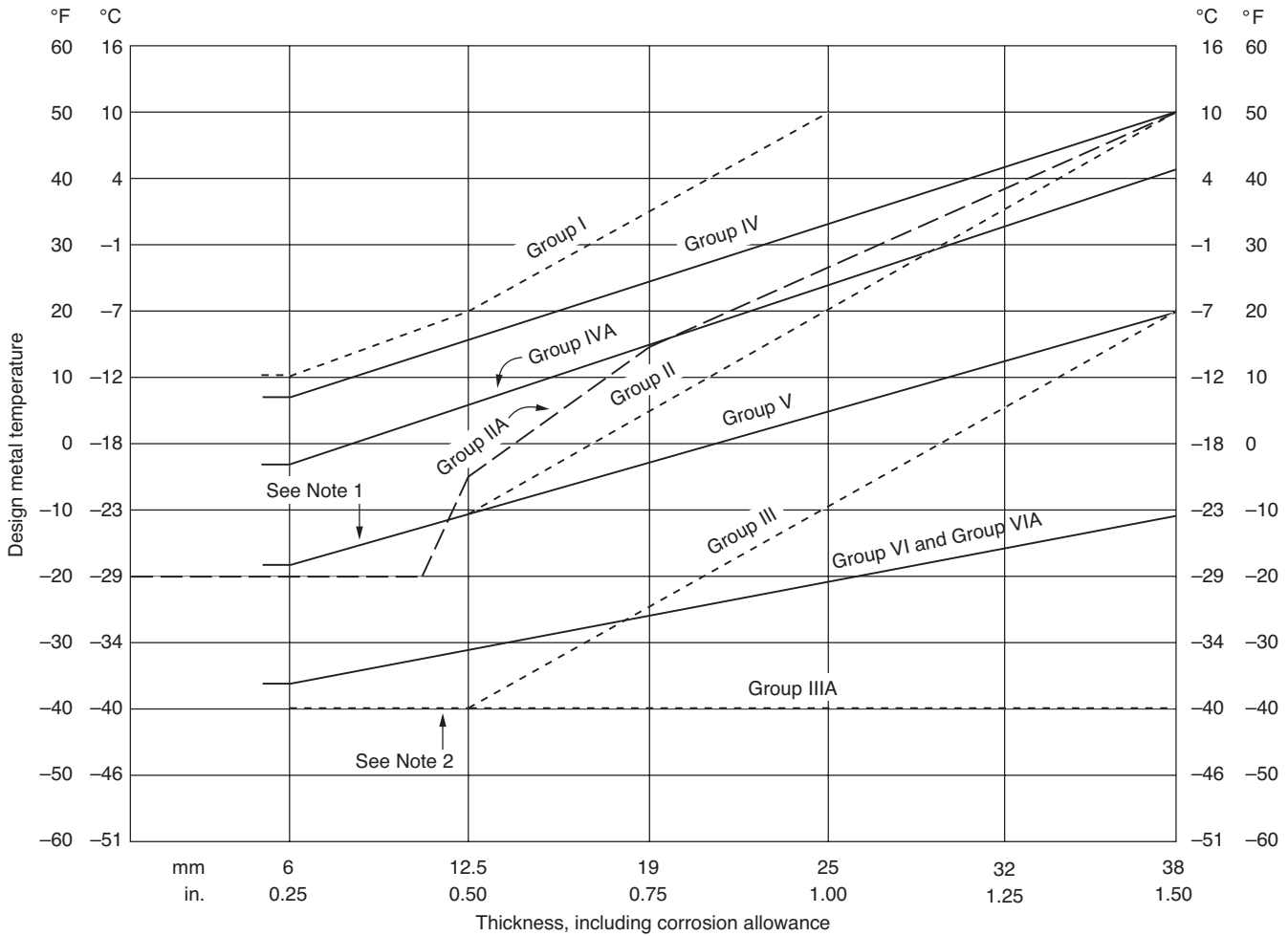
4.2.8.7 The testing apparatus, including the calibration of impact machines and the permissible variations in the temperature of specimens, shall conform to ASTM A 370 or an equivalent testing apparatus conforming to national standards or ISO standards.

4.2.9 Toughness Requirements

4.2.9.1 The thickness and design metal temperature of all shell plates, shell reinforcing plates, shell insert plates, bottom plates welded to the shell, plates used for manhole and nozzle necks, plate-ring shell-nozzle flanges, blind flanges, and manhole cover plates shall be in accordance with Figure 4-1. Notch toughness evaluation of plate-ring flanges, blind flanges, and manhole cover plates shall be based on "governing thickness" as defined in 4.5.5.3. In addition, plates more than 40 mm (1.5 in.) thick shall be of killed steel made to fine-grain practice and heat treated by normalizing, normalizing and tempering, or quenching and tempering, and each plate as heat treated shall be impact tested according to 4.2.10.2. Each TMCP A 841 plate-as-rolled shall be impact tested. Impact test temperature and required energy shall be in accordance with 4.2.10.2 in lieu of the default temperature and energy given in A 841.

- **4.2.9.2** Plates less than or equal to 40 mm (1.5 in.) thick, except controlled-rolled plates (see 4.2.7.4), may be used at or above the design metal temperatures indicated in Figure 4-1 without being impact tested. To be used at design metal temperatures lower than the temperatures indicated in Figure 4-1, plates shall demonstrate adequate notch toughness in accordance with 4.2.10.3 unless 4.2.10.2 or 4.2.10.4 has been specified by the Purchaser. For heat-treated material, notch toughness shall be demonstrated on each plate as heat treated when 4.2.10.2 requirements are specified. Isothermal lines of lowest one-day mean temperature are shown in Figure 4-2.

4.2.9.3 Plate used to reinforce shell openings and insert plates shall be of the same material as the shell plate to which they are attached or shall be of any appropriate material listed in Table 4-3 and Figure 4-1. Except for nozzle and manway necks, the material shall be of equal or greater yield and tensile strength and shall be compatible with the adjacent shell material (see 4.2.9.1 and 5.7.2.3, Item d).



Notes:

1. The Group II and Group V lines coincide at thicknesses less than 12.5 mm ($1/2$ in.).
2. The Group III and Group IIIA lines coincide at thicknesses less than 12.5 mm ($1/2$ in.).
3. The materials in each group are listed in Table 4-3.
4. This figure is not applicable to controlled-rolled plates (see 4.2.7.4).
5. Use the Group IIA and Group VIA curves for pipe and flanges (see 4.5.5.2 and 4.5.5.3).

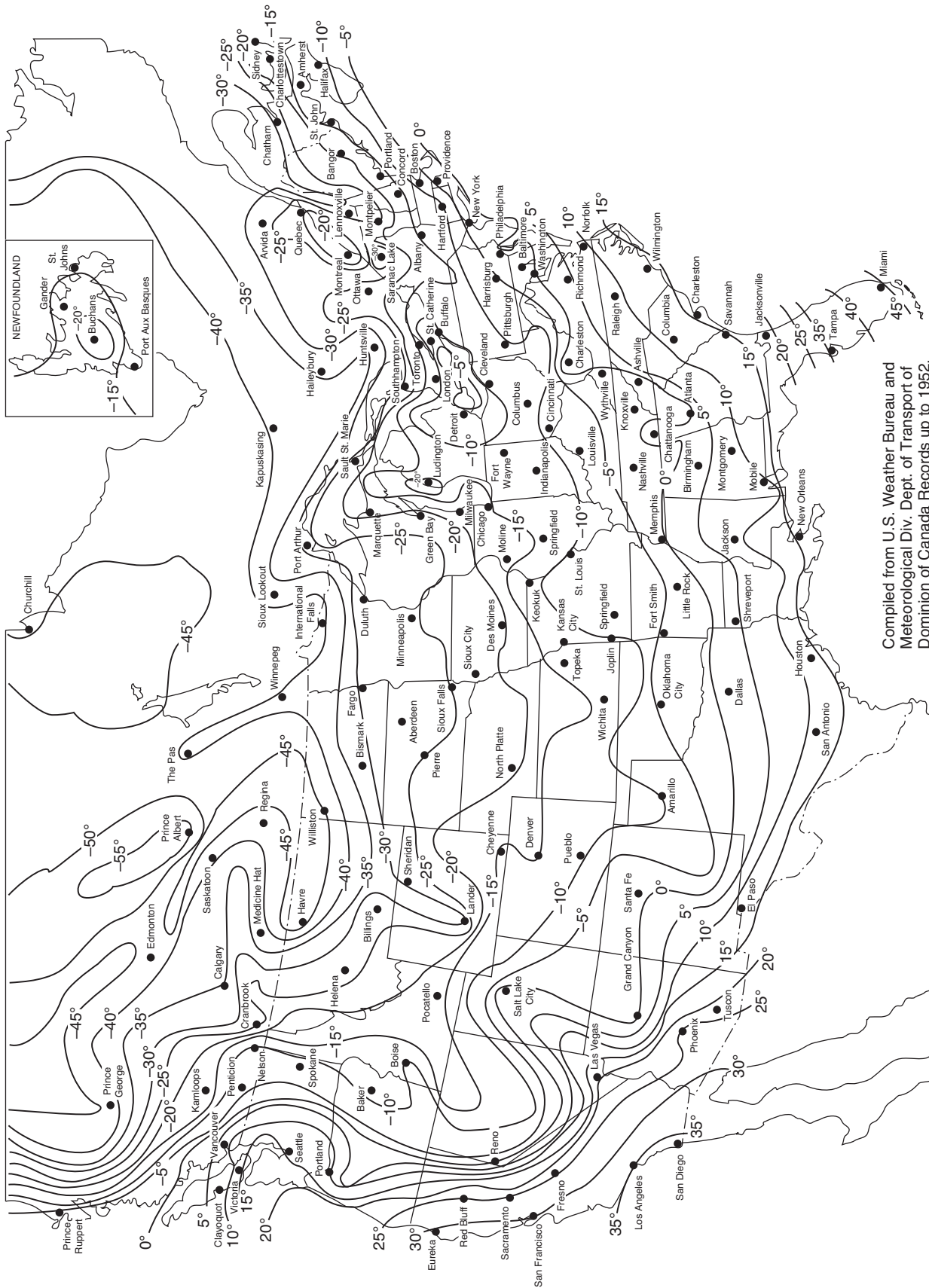
Figure 4-1—Minimum Permissible Design Metal Temperature for Materials Used in Tank Shells without Impact Testing

4.2.9.4 The requirements in 4.2.9.3 apply only to shell nozzles and manholes. Materials for roof nozzles and manholes do not require special toughness.

4.2.10 Toughness Procedure

4.2.10.1 When a material’s toughness must be determined, it shall be done by one of the procedures described in 4.2.10.2 through 4.2.10.4, as specified in 4.2.9.

4.2.10.2 Each plate as rolled or heat treated shall be impact tested in accordance with 4.2.8 at or below the design metal temperature to show Charpy V-notch longitudinal (or transverse) values that fulfill the minimum requirements of Table 4-4 (see 4.2.8 for the minimum values for one specimen and for subsize specimens). As used here, the term plate as rolled refers to the unit plate rolled from a slab or directly from an ingot in its relation to the location and number of specimens, not to the condition of the plate.



Compiled from U.S. Weather Bureau and Meteorological Div. Dept. of Transport of Dominion of Canada Records up to 1952.

Figure 4-2—Isothermal Lines of Lowest One-Day Mean Temperatures (°F)
°C = (°F - 32)/1.8

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Table 4-3a—Material Groups, SI Units (See Figure 4-1 and Note 1 Below)

Group I As Rolled, Semi-killed		Group II As Rolled, Killed or Semi-killed		Group III As Rolled, Killed Fine-Grain Practice		Group IIIA Normalized, Killed Fine-Grain Practice	
Material	Notes	Material	Notes	Material	Notes	Material	Notes
A 283M C	2	A 131M B	7	A 573M-400		A 131M CS	
A 285M C	2	A 36M	2, 6	A 516M-380		A 573M-400	10
A 131M A	2	G40.21-260W		A 516M-415		A 516M-380	10
A 36M	2, 3	Grade 250	5, 8	G40.21-260W	9	A 516M-415	10
Grade 235	3, 5			Grade 250	5, 9	G40.21-260W	9, 10
Grade 250	6					Grade 250	5, 9, 10
Group IV As Rolled, Killed Fine-Grain Practice		Group IVA As Rolled, Killed Fine-Grain Practice		Group V Normalized, Killed Fine-Grain Practice		Group VI Normalized or Quenched and Tempered, Killed Fine-Grain Practice Reduced Carbon	
Material	Notes	Material	Notes	Material	Notes	Material	Notes
A 573M-450		A 662M C		A 573M-485	10	A 131M EH 36	
A 573M-485		A 573M-485	11	A 516M-450	10	A 633M C	
A 516M-450		G40.21-300W	9, 11	A 516M-485	10	A 633M D	
A 516M-485		G40.21-350W	9, 11	G40.21-300W	9, 10	A 537M Class 1	
A 662M B				G40.21-350W	9, 10	A 537M Class 2	13
G40.21-300W	9					A 678M A	
G40.21-350W	9					A 678M B	13
E 275	4, 9					A 737M B	
E 355	9					A 841, Grade A, Class 1	12, 13, 14
Grade 275	5, 9					A 841, Grade B, Class 2	12, 13, 14

Notes:

- Most of the listed material specification numbers see ASTM specifications (including Grade or Class); there are, however, some exceptions: G40.21 (including Grade) is a CSA specification; Grades E 275 and E 355 (including Quality) are contained in ISO 630; and Grade 235, Grade 250, and Grade 275 are related to national standards (see 4.2.5).
- Must be semi-killed or killed.
- Thickness ≤ 20 mm.
- Maximum manganese content of 1.5%.
- Thickness 20 mm maximum when controlled-rolled steel is used in place of normalized steel.
- Manganese content shall be 0.80% – 1.2% by heat analysis for thicknesses greater than 20 mm, except that for each reduction of 0.01% below the specified carbon maximum, an increase of 0.06% manganese above the specified maximum will be permitted up to the maximum of 1.35%. Thicknesses ≤ 20 mm shall have a manganese content of 0.80% – 1.2% by heat analysis.
- Thickness ≤ 25 mm.
- Must be killed.
- Must be killed and made to fine-grain practice.
- Must be normalized.
- Must have chemistry (heat) modified to a maximum carbon content of 0.20% and a maximum manganese content of 1.60% (see 4.2.6.4).
- Produced by the thermo-mechanical control process (TMCP).
- See 5.7.4.6 for tests on simulated test coupons for material used in stress-relieved assemblies.
- See 4.2.9 for impact test requirements (each plate-as-rolled tested).

Table 4-3b—Material Groups, US Customary Units (See Figure 4-1 and Note 1 Below)

Group I As Rolled, Semi-killed		Group II As Rolled, Killed or Semi-killed		Group III As Rolled, Killed Fine-Grain Practice		Group IIIA Normalized, Killed Fine-Grain Practice	
Material	Notes	Material	Notes	Material	Notes	Material	Notes
A 283 C	2	A 131 B	7	A 573-58		A 131 CS	
A 285 C	2	A 36	2, 6	A 516-55		A 573-58	10
A 131 A	2	G40.21-38W		A 516-60		A 516-55	10
A 36	2, 3	Grade 250	5, 8	G40.21-38W	9	A 516-60	10
Grade 235	3, 5			Grade 250	5, 9	G40.21-38W	9, 10
Grade 250	6					Grade 250	5, 9, 10
Group IV As Rolled, Killed Fine-Grain Practice		Group IVA As Rolled, Killed Fine-Grain Practice		Group V Normalized, Killed Fine-Grain Practice		Group VI Normalized or Quenched and Tempered, Killed Fine-Grain Practice Reduced Carbon	
Material	Notes	Material	Notes	Material	Notes	Material	Notes
A 573-65		A 662 C		A 573-70	10	A 131 EH 36	
A 573-70		A 573-70	11	A 516-65	10	A 633 C	
A 516-65		G40.21-44W	9, 11	A 516-70	10	A 633 D	
A 516-70		G40.21-50W	9, 11	G40.21-44W	9, 10	A 537 Class 1	
A 662 B				G40.21-50W	9, 10	A 537 Class 2	13
G40.21-44W	9					A 678 A	
G40.21-50W	9					A 678 B	13
E 275	4, 9					A 737 B	
E 355	9					A 841, Grade A, Class 1	12, 13, 14
						A 841, Grade B, Class 2	12, 13, 14
Grade 275	5, 9						

Notes:

- Most of the listed material specification numbers see ASTM specifications (including Grade or Class); there are, however, some exceptions: G40.21 (including Grade) is a CSA specification; Grades E 275 and E 355 (including Quality) are contained in ISO 630; and Grade 235, Grade 250, and Grade 275 are related to national standards (see 4.2.5).
- Must be semi-killed or killed.
- Thickness ≤ 0.75 in.
- Maximum manganese content of 1.5%.
- Thickness 0.75 in. maximum when controlled-rolled steel is used in place of normalized steel.
- Manganese content shall be 0.80% – 1.2% by heat analysis for thicknesses greater than 0.75 in., except that for each reduction of 0.01% below the specified carbon maximum, an increase of 0.06% manganese above the specified maximum will be permitted up to the maximum of 1.35%. Thicknesses ≤ 0.75 in. shall have a manganese content of 0.80% – 1.2% by heat analysis.
- Thickness ≤ 1 in.
- Must be killed.
- Must be killed and made to fine-grain practice.
- Must be normalized.
- Must have chemistry (heat) modified to a maximum carbon content of 0.20% and a maximum manganese content of 1.60% (see 4.2.6.4).
- Produced by the thermo-mechanical control process (TMCP).
- See 5.7.4.6 for tests on simulated test coupons for material used in stress-relieved assemblies.
- See 4.2.9 for impact test requirements (each plate-as-rolled tested).

Table 4-4—Minimum Impact Test Requirements for Plates (See Note)

Plate Material ^a and Thickness (<i>t</i>) in mm (in.)	Thickness		Average Impact Value of Three Specimens ^b			
			Longitudinal		Transverse	
	mm	in.	J	ft-lbf	J	ft-lbf
Groups I, II, III, and IIIA <i>t</i> ≤ maximum thicknesses in 4.2.2 through 4.2.5			20	15	18	13
Groups IV, IVA, V, and VI (except quenched and tempered and TMCP)	<i>t</i> ≤ 40	<i>t</i> ≤ 1.5	41	30	27	20
	40 < <i>t</i> ≤ 45	1.5 < <i>t</i> ≤ 1.75	48	35	34	25
	45 < <i>t</i> ≤ 50	1.75 < <i>t</i> ≤ 2	54	40	41	30
	50 < <i>t</i> ≤ 100	2 < <i>t</i> ≤ 4	68	50	54	40
Group VI (quenched and tempered and TMCP)	<i>t</i> ≤ 40	<i>t</i> ≤ 1.5	48	35	34	25
	40 < <i>t</i> ≤ 45	1.5 < <i>t</i> ≤ 1.75	54	40	41	30
	45 < <i>t</i> ≤ 50	1.75 < <i>t</i> ≤ 2	61	45	48	35
	50 < <i>t</i> ≤ 100	2 < <i>t</i> ≤ 4	68	50	54	40

^aSee Table 4-3.

^bInterpolation is permitted to the nearest joule (ft-lbf).

Note: For plate ring flanges, the minimum impact test requirements for all thicknesses shall be those for *t* ≤ 40 mm (1.5 in.).

4.2.10.3 The thickest plate from each heat shall be impact tested in accordance with 4.2.8 and shall fulfill the impact requirements of 4.2.10.2 at the design metal temperature.

- **4.2.10.4** The Manufacturer shall submit to the Purchaser test data for plates of the material demonstrating that based on past production from the same mill, the material has provided the required toughness at the design metal temperature.

4.3 SHEETS

Sheets for fixed and floating roofs shall conform to ASTM A 1011M, Grade 33. They shall be made by the open-hearth or basic oxygen process. Copper-bearing steel shall be used if specified on the purchase order. Sheets may be ordered on either a weight or a thickness basis, at the option of the tank Manufacturer.

4.4 STRUCTURAL SHAPES

4.4.1 Structural steel shall conform to one of the following:

- ASTM A 36M/A 36.
 - ASTM A 131M/A 131.
 - ASTM A 992M/ A 992.
 - Structural Steels listed in AISC *Specification for Structural Steel Buildings, Allowable Stress Design*.
 - CSA G40.21, Grades 260W(38W), 300W(44W), 350W(50W), 260WT(38WT), 300WT(44WT), and 350WT(50WT). Imperial unit equivalent grades of CSA Specification G40.21, shown in parenthesis, are also acceptable.
 - ISO 630, Grade E 275, Qualities B, C, and D.
- g. Recognized national standards. Structural steel that is produced in accordance with a recognized national standard and that meets the requirements of Table 4-2 is acceptable when approved by the Purchaser.

- **4.4.2** All steel for structural shapes shall be made by the open-hearth, electric-furnace, or basic oxygen process. Copper-bearing steel is acceptable when approved by the Purchaser.

4.4.3 Not all of the structural steel shapes listed in AISC (4.4.1 [d]) and other national standards (4.4.1 [g]) are well suited for welding. Material selection for structural shapes requiring welded connections shall include confirmation of the material's weldability from the structural shape manufacturer, other reputable sources, or by weld testing. Structural steel shapes having poor weldability shall only be used for bolted connection designs

4.5 PIPING AND FORGINGS

4.5.1 Unless otherwise specified in this Standard, pipe and pipe couplings and forgings shall conform to the specifications listed in 4.5.1.1 and 4.5.1.2 or to national standards equivalent to the specifications listed.

4.5.1.1 The following specifications are acceptable for pipe and pipe couplings:

- a. API Spec 5L, Grades A, B, and X42.
- b. ASTM A 53, Grades A and B.
- c. ASTM A 106, Grades A and B.
- d. ASTM A 234M/A 234, Grade WPB.
- e. ASTM A 333M/A 333, Grades 1 and 6.
- f. ASTM A 334M/A 334, Grades 1 and 6.
- g. ASTM A 420M/A 420, Grade WPL6.
- h. ASTM A 524, Grades I and II.
- i. ASTM A 671 (see 4.5.3).

4.5.1.2 The following specifications are acceptable for forgings:

- a. ASTM A 105M/A 105.
- b. ASTM A 181M/A 181.
- c. ASTM A 350M/A 350, Grades LF1 and LF2.

4.5.2 Unless ASTM A 671 pipe is used (electric-fusion-welded pipe) (see 4.5.3), material for shell nozzles and shell manhole necks shall be seamless pipe, seamless forging, or plate material as specified in 4.2.9.1. When shell materials are Group IV, IVA, V, or VI, seamless pipe shall comply with ASTM A 106, Grade B; ASTM A 524; ASTM A 333M/A 333, Grade 6; or ASTM A 334M/A 334, Grade 6.

4.5.3 When ASTM A 671 pipe is used for shell nozzles and shell manhole necks, it shall comply with the following:

- a. Material selection shall be limited to Grades CA 55, CC 60, CC 65, CC 70, CD 70, CD 80, CE 55, and CE 60.
- b. The pipe shall be pressure tested in accordance with 8.3 of ASTM A 671.
- c. The plate specification for the pipe shall satisfy the requirements of 4.2.7, 4.2.8, and 4.2.9 that are applicable to that plate specification.
- d. Impact tests for qualifying the welding procedure for the pipe longitudinal welds shall be performed in accordance with 9.2.2.

4.5.4 Weldable-quality pipe that conforms to the physical properties specified in any of the standards listed in 4.5.1 may be used for structural purposes with the allowable stresses stated in 5.10.3.

4.5.5 Except as covered in 4.5.3, the toughness requirements of pipe and forgings to be used for shell nozzles and manholes shall be established as described in 4.5.5.1 through 4.5.5.4.

4.5.5.1 Piping materials made according to ASTM A 333M/A 333, A 334M/A 334, A 350M/A 350, and A 420, Grade WPL6 may be used at a design metal temperature no lower than the impact test temperature required by the ASTM specification for the applicable material grade without additional impact tests (see 4.5.5.4).

4.5.5.2 Other pipe and forging materials shall be classified under the material groups shown in Figure 4-1 as follows:

- a. Group IIA—API Spec 5L, Grades A, B, and X42; ASTM A 106, Grades A and B; ASTM A 53, Grades A and B; ASTM A 181M/A 181; ASTM A 105M/A 105; and A 234M/A234, Grade WPB.
- b. Group VIA—ASTM A 524, Grades I and II.

4.5.5.3 The materials in the groups listed in 4.5.5.2 may be used at nominal thicknesses, including corrosion allowance, at a design metal temperature no lower than those shown in Figure 4-1 without impact testing (see 4.5.5.4 and Figure 4-3). The governing thicknesses to be used in Figure 4-1 shall be as follows:

- a. For butt-welded joints, the nominal thickness of the thickest welded joint.
- b. For corner or lap welds, the thinner of the two parts joined.
- c. For nonwelded parts such as bolted blind flanges and manhole covers, $\frac{1}{4}$ of their nominal thickness.

4.5.5.4 When impact tests are required by 4.5.5.1 or 4.5.5.3, they shall be performed in accordance with the requirements, including the minimum energy requirements, of ASTM A 333M/A 333, Grade 6, for pipe or ASTM A 350M/A 350, Grade LF1, for forgings at a test temperature no higher than the design metal temperature. Except for the plate specified in 4.2.9.2, the materials specified in 4.5.1 and 4.5.2 for shell nozzles, shell manhole necks, and all forgings used on shell openings shall have a minimum Charpy V-notch impact strength of 18 J (13 ft-lbf) (full-size specimen) at a temperature no higher than the design metal temperature.

4.6 FLANGES

4.6.1 Hub, slip-on, welding, and welding-neck flanges shall conform to the material requirements of ASME B16.5 for forged carbon steel flanges. Plate material used for nozzle flanges shall have physical properties better than or equal to those required by ASME B16.5. Shell-nozzle flange material shall conform to 4.2.9.1.

- **4.6.2** For nominal pipe sizes greater than NPS 24, flanges that conform to ASME B16.47, Series B, may be used, subject to the Purchaser's approval. Particular attention should be given to ensuring that mating flanges of appurtenances are compatible.

4.7 BOLTING

- a. Unless otherwise specified on the Data Sheet, Table 2, flange bolting shall conform to ASTM A 193 B7 and the dimensions specified in ASME B18.2.1. Nuts shall conform to ASTM A 194 Grade 2H and the dimensions specified in ASME B18.2.2. Both shall be heavy hex pattern. All bolts and nuts shall be threaded in accordance with ASME B1.13M (SI), or with ASME B1.1(US) as follows:
 1. Bolts up to and including 1 in. diameter: UNC Class 2A fit
 2. Nuts for bolts up to and including 1 in. diameter: UNC Class 2B fit
 3. Bolts 1.125 in. diameter and larger: 8N Class 2A fit
 4. Nuts for bolts 1.125 in. diameter and larger: 8N Class 2B fit
- b. Unless otherwise specified on the Data Sheet, Table 2, all anchors shall be threaded, galvanized ASTM A 36 round bar with galvanized heavy hex nuts.
- c. All other bolting shall conform to ASTM A 307 or A 193M/A 193. A 325M/A 325 may be used for structural purposes only. The Purchaser should specify on the order what shape of bolt heads and nuts is desired and whether regular or heavy dimensions are desired.

4.8 WELDING ELECTRODES

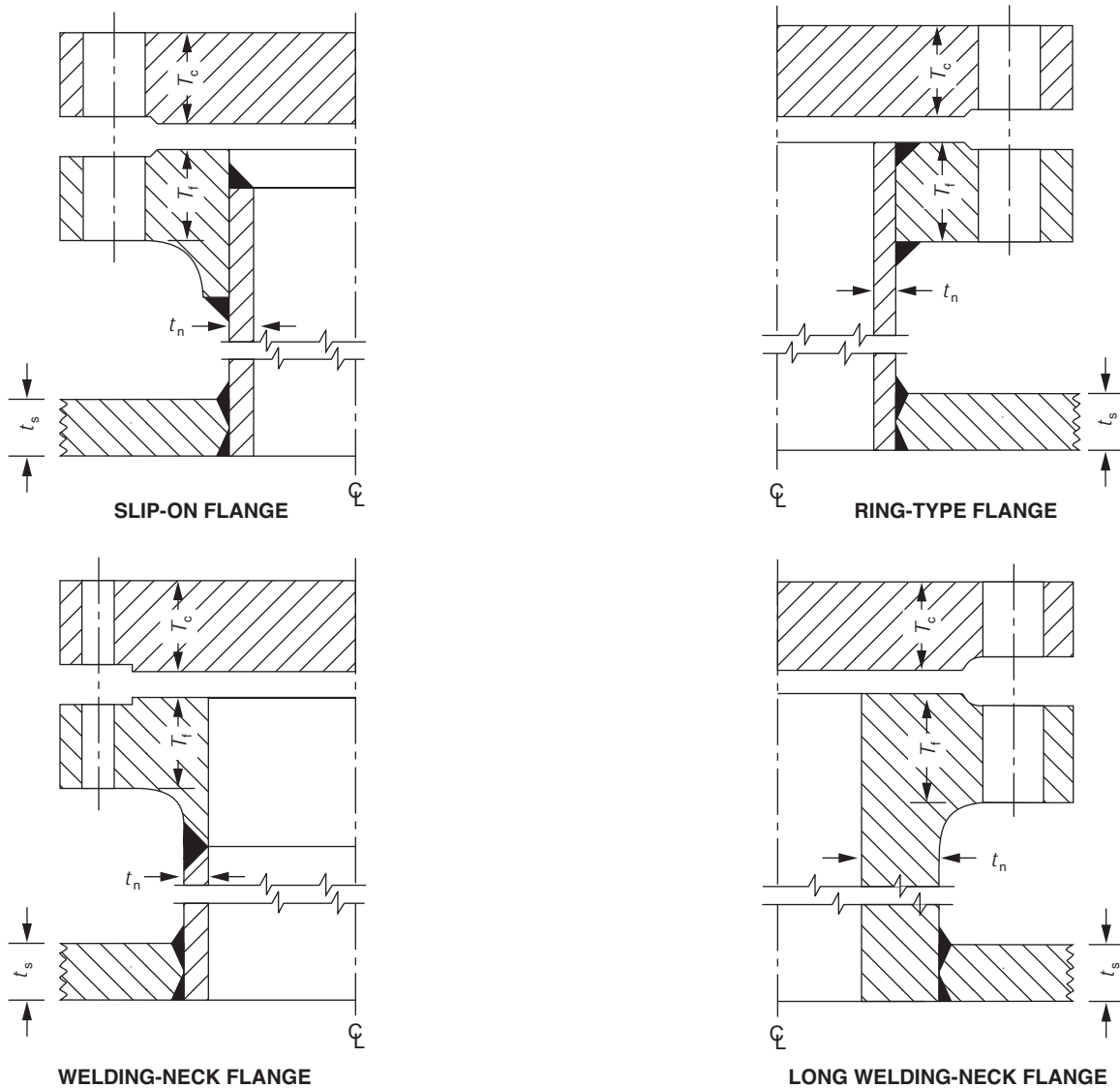
4.8.1 For the welding of materials with a minimum tensile strength less than 550 MPa (80 ksi), the manual arc-welding electrodes shall conform to the E60 and E70 classification series (suitable for the electric current characteristics, the position of welding, and other conditions of intended use) in AWS A5.1 and shall conform to 7.2.1.10 as applicable.

4.8.2 For the welding of materials with a minimum tensile strength of 550 MPa – 585 MPa (80 ksi – 85 ksi), the manual arc-welding electrodes shall conform to the E80XX-CX classification series in AWS A5.5.

4.9 GASKETS

4.9.1 General

- **4.9.1.1** Gasket materials shall be specified in Table 3 on the Data Sheet. Unless otherwise specified by the Purchaser, gasket materials shall not contain asbestos.



Notes:

1. Shell reinforcing plate is not included in these illustrations.
2. t_s = shell thickness; t_n = nozzle neck thickness; T_f = flange thickness; T_c = bolted cover thickness.
3. The governing thickness for each component shall be as follows:

Components	Governing Thickness (thinner of)
Nozzle neck at shell	t_n or t_s
Slip-on flange and nozzle neck	t_n or T_f
Ring-type flange and nozzle neck	t_n or T_f
Welding-neck flange and nozzle neck	t_n
Long welding-neck flange	t_n or t_s
Nonwelded bolted cover	$1/4 T_c$

Figure 4-3—Governing Thickness for Impact Test Determination of Shell Nozzle and Manhole Materials (See 4.5.5.3)

4.9.1.2 Sheet gaskets shall be continuous. Metal gaskets made continuous by welding are acceptable if the weld is ground flush and finished the same as the unwelded portion of the gasket. Rope or tape gaskets shall have overlapped ends.

4.9.1.3 Each gasket shall be made with an integral centering or positioning device.

- **4.9.1.4** No joint sealing compound, gasket adhesive, adhesive positioning tape, or lubricant shall be used on the sealing surfaces of gaskets, or flanges during joint make-up unless specifically allowed by the Purchaser. When these materials are approved by the Purchaser, consideration should be given to chemical compatibility with the gasket and flange materials.

- **4.9.1.5** Spare gaskets are not required unless specified in the Data Sheet, Line 23.

4.9.2 Service

- When service gaskets are designated to be furnished by the Manufacturer, the gaskets provided shall be as specified in the Data Sheet, Table 3.

4.9.3 Test

- **4.9.3.1** Test gaskets must have comparable dimensions and compressibility characteristics as service gaskets. Descriptions of gaskets for temporary use only as test gaskets shall be submitted for Purchaser's approval.

4.9.3.2 For joints that will not be disassembled after testing, the test gasket must be the specified service gasket.

4.9.3.3 Except for stainless steel bolting, flange bolts and nuts used for testing are acceptable for use in the completed tank.

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SECTION 5—DESIGN

5.1 JOINTS

5.1.1 Definitions

The definitions in 5.1.1.1 through 5.1.1.8 apply to tank joint designs (see 9.1 for definitions that apply to welders and welding procedures. Also see Section 2 for additional definitions).

5.1.1.1 butt-weld: A weld placed in a groove between two abutting members. Grooves may be square, V-shaped (single or double), or U-shaped (single or double), or they may be either single or double beveled.

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

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

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

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

5.1.1.6 single-welded butt joint with backing: A joint between two abutting parts lying in approximately the same plane that is welded from one side only with the use of a strip bar or another suitable backing material.

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

5.1.1.8 tack weld: A weld made to hold the parts of a weldment in proper alignment until the final welds are made.

5.1.2 Weld Size

5.1.2.1 The size of a groove weld shall be based on the joint penetration (that is, the depth of chamfering plus the root penetration when specified).

5.1.2.2 The size of an equal-leg fillet weld shall be based on the leg length of the largest isosceles right triangle that can be inscribed within the cross-section of the fillet weld. The size of an unequal-leg fillet weld shall be based on the leg lengths of the largest right triangle that can be inscribed within the cross-section of the fillet weld.

5.1.3 Restrictions on Joints

5.1.3.1 Restrictions on the type and size of welded joints are given in 5.1.3.2 through 5.1.3.8.

5.1.3.2 Tack welds shall not be considered as having any strength value in the finished structure.

5.1.3.3 The minimum size of fillet welds shall be as follows: On plates 5 mm ($3/16$ in.) thick, the weld shall be a full-fillet weld, and on plates more than 5 mm ($3/16$ in.) thick, the weld thickness shall not be less than one-third the thickness of the thinner plate at the joint and shall be at least 5 mm ($3/16$ in.).

5.1.3.4 Single-welded lap joints are permissible only on bottom plates and roof plates.

5.1.3.5 Lap-welded joints, as tack-welded, shall be lapped at least five times the nominal thickness of the thinner plate joined; however, with double-welded lap joints, the lap need not exceed 50 mm (2 in.), and with single-welded lap joints, the lap need not exceed 25 mm (1 in.).

5.1.3.6 Weld passes are restricted as follows:

- **5.1.3.6.1** For bottom plate welds and roof plate welds for all materials, and for shell-to-bottom welds for Groups I, II, III, and IIIA materials, the following weld size requirements apply:

a. For manual welding processes, fillet weld legs or groove weld depths greater than 6 mm ($1/4$ in.) shall be multipass, unless otherwise specified on the Data Sheet, Line 15.

b. For semi-automatic and automatic welding processes, with the exception for electro-gas welding in 7.2.3.4, fillet weld legs or groove weld depths greater than 10 mm ($3/8$ in.) shall be multipass, unless otherwise specified on the Data Sheet, Line 15.

5.1.3.6.2 For Groups IV, IVA, V, or VI shell-to-bottom welds for all welding processes, all welds shall be made using a minimum of two passes.

07 **5.1.3.7** All attachments to the exterior of the tank shall be completely seal welded. Intermittent welding is not permitted. The only exception to this requirement are wind girders as permitted in 5.1.5.8.

• **5.1.3.8** Except as permitted in 5.1.5.5 and 5.1.5.6, permanent weld joint backing strips are permitted only with the approval of the Purchaser.

5.1.4 Welding Symbols

Welding symbols used on drawings shall be the symbols of the American Welding Society.

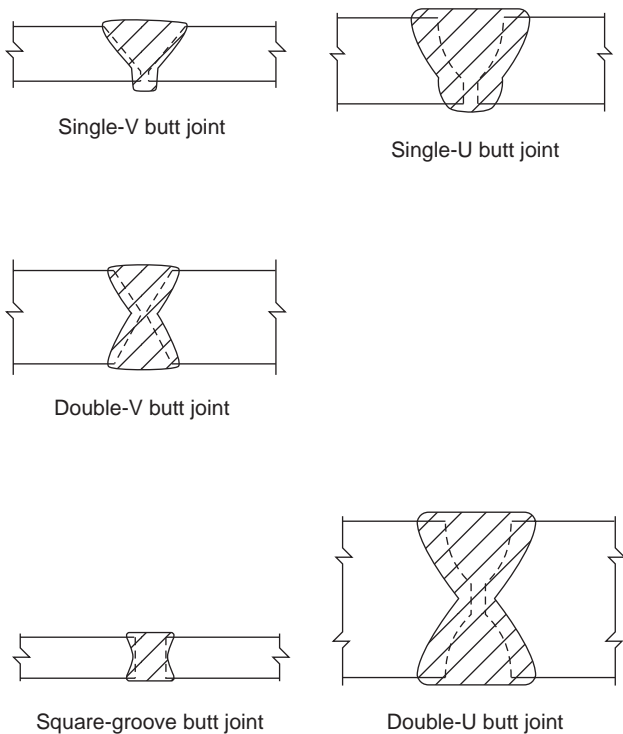
5.1.5 Typical Joints

5.1.5.1 General

- a. Typical tank joints are shown in Figures 5-1, 5-2, 5-3A, 5-3B, and 5-3C.
- 07 b. The top surfaces of bottom welds (butt-welded annular plates, butt-welded sketch plates, or Figure 5-3B joints) shall be ground flush where they will contact the bottoms of the shell, insert plates, or reinforcing plates.

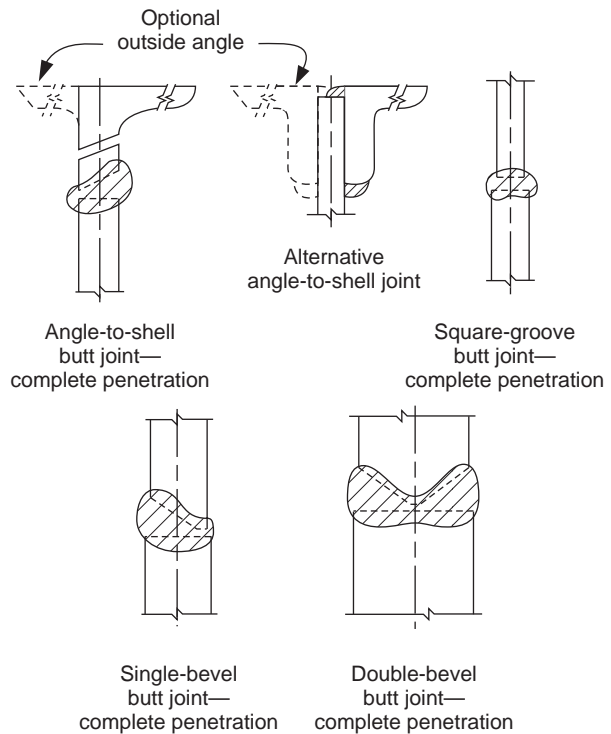
5.1.5.2 Vertical Shell Joints

- a. Vertical shell joints shall be butt joints with complete penetration and complete fusion attained by double welding or other means that will obtain the same quality of deposited weld metal on the inside and outside weld surfaces to meet the requirements of 7.2.1 and 7.2.3. The suitability of the plate preparation and welding procedure shall be determined in accordance with 9.2.
- 07 b. Vertical joints in adjacent shell courses shall not be aligned, but shall be offset from each other a minimum distance of $5t$, where t is the plate thickness of the thicker course at the point of offset.



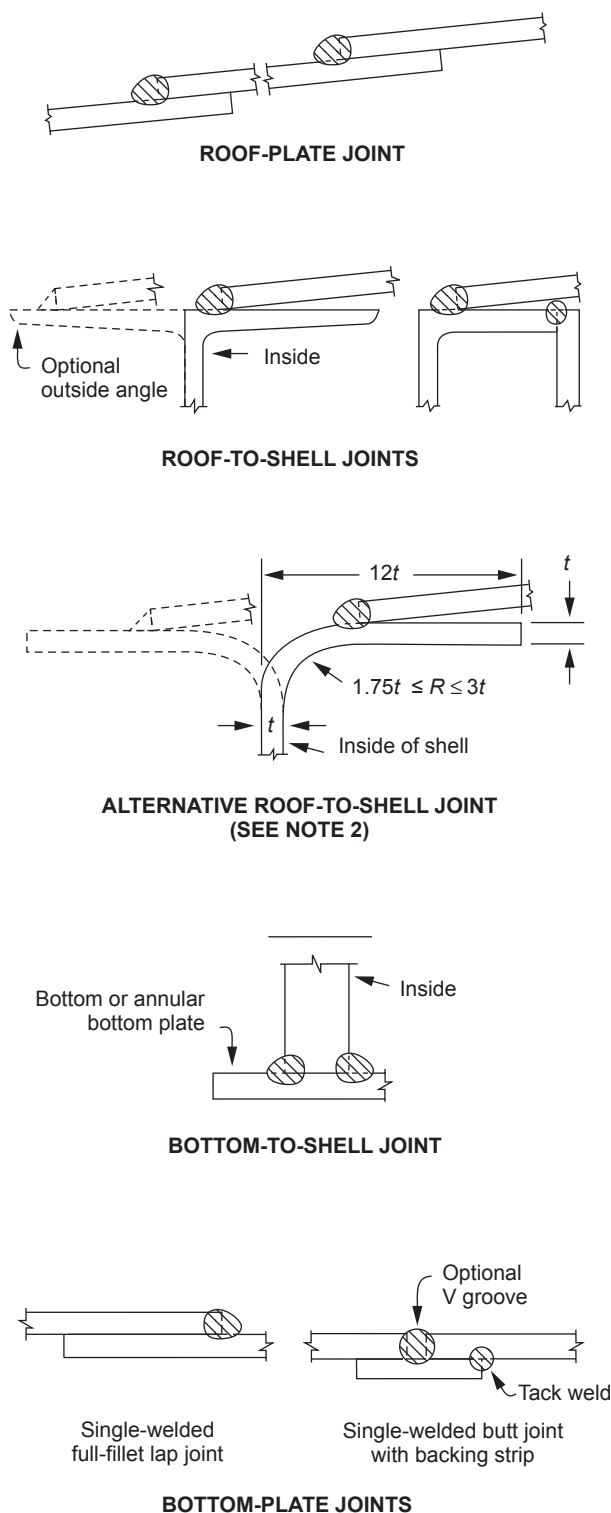
Note: See 5.1.5.2 for specific requirements for vertical shell joints.

Figure 5-1—Typical Vertical Shell Joints



Note: See 5.1.5.3 for specific requirements for horizontal shell joints.

Figure 5-2—Typical Horizontal Shell Joints



Notes:
 1. See 5.1.5.4 – 5.1.5.9 for specific requirements for roof and bottom joints.
 2. The alternative roof-to-shell joint is subject to the limitations of 5.1.5.9, Item f.

Figure 5-3A—Typical Roof and Bottom Joints

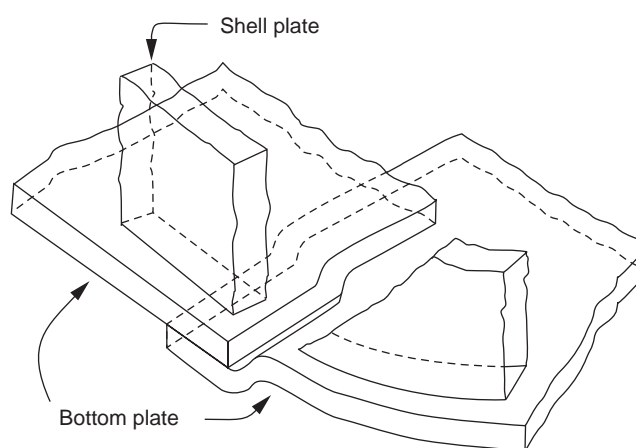


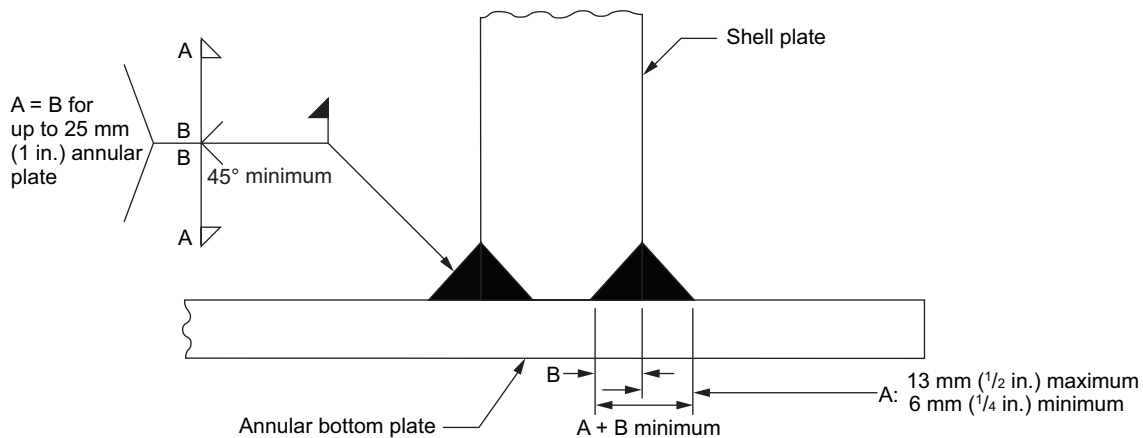
Figure 5-3B—Method for Preparing Lap-Welded Bottom Plates under Tank Shell (See 5.1.5.4)

5.1.5.3 Horizontal Shell Joints

- a. Horizontal shell joints shall have complete penetration and complete fusion; however, as an alternative, top angles may be attached to the shell by a double-welded lap joint. The suitability of the plate preparation and welding procedure shall be determined in accordance with 9.2.
- b. Unless otherwise specified, abutting shell plates at horizontal joints shall have a common vertical centerline.

5.1.5.4 Lap-Welded Bottom Joints

- Lap-welded bottom plates shall be reasonably rectangular. Additionally, plate may be either square cut or may have mill edges. Mill edges to be welded shall be relatively smooth and uniform, free of deleterious deposits, and have a shape such that a full fillet weld can be achieved. Unless otherwise specified by the Purchaser, lap welded plates on sloped bottoms shall be overlapped in a manner to reduce the tendency for liquid to puddle during draw-down. Three-plate laps in tank bottoms shall be at least 300 mm (12 in.) from each other, from the tank shell, from butt-welded annular-plate joints, and from joints between annular plates and the bottom. Lapping of two bottom plates onto the butt-welded annular plates does not constitute a three-plate lap weld. When annular plates are used or are required by 5.5.1, they shall be butt-welded and shall have a radial width that provides at least 600 mm (24 in.) between the inside of the shell and any lap-welded joint in the remainder of the bottom. Bottom plates need to be welded on the top side only, with a continuous full-fillet weld on all seams. Unless annular bottom plates are used, the bottom plates under the bottom shell ring shall have the outer ends of the joints fitted and lap-welded to form a smooth bearing surface for the shell plates, as shown in Figure 5-3B. Lap-welded bottom plates shall be seal-welded to each other on the exposed outer periphery of their lapped edges.



Notes:

1. A = Fillet weld size limited to 13 mm ($1/2$ in.) maximum.
2. A + B = Thinner of shell or annular bottom plate thickness.
3. Groove weld B may exceed fillet size A only when annular plate is thicker than 25 mm (1 in.).

Figure 5-3C—Detail of Double Fillet-Groove Weld for Annular Bottom Plates with a Nominal Thickness Greater Than 13 mm ($1/2$ in.) (See 5.1.5.7, Item b)

5.1.5.5 Butt-Welded Bottom Joints

Butt-welded bottom plates shall have their parallel edges prepared for butt welding with either square or V grooves. Butt-welds shall be made using an appropriate weld joint configuration that yields a complete penetration weld. Typical permissible bottom butt-welds without a backing strip are the same as those shown in Figure 5-1. The use of a backing strip at least 3 mm ($1/8$ in.) thick tack welded to the underside of the plate is permitted. Butt-welds using a backing strip are shown in Figure 5-3A. If square grooves are employed, the root openings shall not be less than 6 mm ($1/4$ in.). A metal spacer shall be used to maintain the root opening between the adjoining plate edges unless the Manufacturer submits another method of butt-welding the bottom for the Purchaser's approval. Three-plate joints in the tank bottom shall be at least 300 mm (12 in.) from each other and from the tank shell.

5.1.5.6 Bottom Annular-Plate Joints

Bottom annular-plate radial joints shall be butt-welded in accordance with 5.1.5.5 and shall have complete penetration and complete fusion. The backing strip, if used, shall be compatible for welding the annular plates together.

5.1.5.7 Shell-to-Bottom Fillet Welds

a. For bottom and annular plates with a nominal thickness 12.5 mm ($1/2$ in.), and less, the attachment between the bottom edge of the lowest course shell plate and the bottom plate shall be a continuous fillet weld laid on each side of the shell plate. The size of each weld shall not be more than 12.5 mm ($1/2$ in.) and shall not be less than the nominal thickness of the thinner of the two plates joined (that is, the shell plate or the bottom plate immediately under the shell) or less than the following values:

Nominal Thickness of Shell Plate		Minimum Size of Fillet Weld	
(mm)	(in.)	(mm)	(in.)
5	0.1875	5	$3/16$
> 5 to 20	> 0.1875 to 0.75	6	$1/4$
> 20 to 32	> 0.75 to 1.25	8	$5/16$
> 32 to 45	> 1.25 to 1.75	10	$3/8$

b. For annular plates with a nominal thickness greater than 12.5 mm ($1/2$ in.), the attachment welds shall be sized so that either the legs of the fillet welds or the groove depth plus the leg of the fillet for a combined weld is of a size equal to the annular-plate thickness (see Figure 5-3C), but shall not exceed the shell plate thickness.

- c. Shell-to-bottom fillet weld around low-type reinforcing pads shown in Figure 5-8 Details a and b or around shell insert plates that extend beyond the outside surface of the adjacent tank shell shall be sized as required by paragraphs a or b above.
- d. The bottom or annular plates shall be sufficient to provide a minimum 13 mm ($1/2$ in.) from the toe of the fillet weld referenced in 5.1.5.7c to the outside edge of the bottom or annular plates.

5.1.5.8 Wind Girder Joints

- a. Full-penetration butt-welds shall be used for joining ring sections.
- b. Continuous welds shall be used for all horizontal top-side joints and for all vertical joints. Horizontal bottom-side joints shall be seal-welded unless specified otherwise by the Purchaser.

5.1.5.9 Roof and Top-Angle Joints

- a. Roof plates shall, as a minimum, be welded on the top side with a continuous full-fillet weld on all seams. Butt-welds are also permitted.
- b. For frangible roofs, roof plates shall be attached to the top angle of a tank with a continuous fillet weld on the top side only, as specified in 5.10.2.6. For non-frangible roofs, alternate details are permitted.
- c. The top-angle sections, tension rings, and compression rings shall be joined by butt-welds having complete penetration and fusion. Joint efficiency factors need not be applied when conforming to the requirements of 5.10.5 and 5.10.6.
- d. At the option of the Manufacturer, for self-supporting roofs of the cone, dome, or umbrella type, the edges of the roof plates may be flanged horizontally to rest flat against the top angle to improve welding conditions.
- e. Except as specified for open-top tanks in 5.9, for tanks with frangible joints per 5.10.2.6, for self-supporting roofs in 5.10.5 and 5.10.6, and for tanks with the flanged roof-to-shell detail described in Item f below, tank shells shall be supplied with top angles of not less than the following sizes:

Tank Diameter (D)	Minimum Top Angle Size (in.)	Minimum Top Angle Size ^a (mm)
$D \leq 11$ m, ($D \leq 35$ ft)	$2 \times 2 \times 3/16$	$51 \times 51 \times 4.8$
$11 \text{ m} < D \leq 18$ m, ($35 \text{ ft} < D \leq 60$ ft)	$2 \times 2 \times 1/4$	$51 \times 51 \times 6.4$
$D > 18$ m, ($D > 60$ ft)	$3 \times 3 \times 3/8$	$76 \times 76 \times 9.5$

^aApproximate equivalent sizes may be used to accommodate local availability of materials.

For fixed roof tanks equipped with full shell height insulation or jacketing, the horizontal leg of the top shell stiffener shall project outward. For insulation system compatibility, the Purchaser shall specify if the horizontal leg is to be larger than specified above.

- f. For tanks with a diameter less than or equal to 9 m (30 ft) and a supported cone roof (see 5.10.4), the top edge of the shell may be flanged in lieu of installing a top angle. The bend radius and the width of the flanged edge shall conform to the details of Figure 5-3A. This construction may be used for any tank with a self-supporting roof (see 5.10.5 and 5.10.6) if the total cross-sectional area of the junction fulfills the stated area requirements for the construction of the top angle. No additional member, such as an angle or a bar, shall be added to the flanged roof-to-shell detail.

5.2 DESIGN CONSIDERATIONS

5.2.1 Loads

Loads are defined as follows:

- a. **Dead Load (D_L):** The weight of the tank or tank component, including any corrosion allowance unless otherwise noted.
- b. **Design External Pressure (P_e):** Shall not be less than 0.25 kPa (1 in. of water). This Standard does not contain provisions for external pressures greater than 0.25 kPa (1 in. of water). Design requirements for vacuum exceeding this value and design requirements to resist flotation and external fluid pressure shall be a matter of agreement between the Purchaser and the Manufacturer (see Appendix V).
- c. **Design Internal Pressure (P_i):** Shall not exceed 18 kPa (2.5 lbf/in.²).
- d. **Hydrostatic Test (H_t):** The load due to filling the tank with water to the design liquid level.
- e. **Minimum Roof Live Load (L_r):** 1.0 kPa (20 lb/ft²) on the horizontal projected area of the roof.

- f. **Seismic (E):** Seismic loads determined in accordance with E.1 through E.6 (see Data Sheet, Line 8).
- g. **Snow (S):** The ground snow load shall be determined from ASCE 7, Figure 7-1 or Table 7-1 unless the ground snow load that equals or exceeds the value based on a 2% annual probability of being exceeded (50-year mean recurrence interval) is specified by the Purchaser. The design snow load shall be 0.84 times the ground snow load. Alternately, the design snow load shall be determined from the ground snow load in accordance with ASCE 7. The design snow load shall be reported to the Purchaser.
- h. **Stored Liquid (F):** The load due to filling the tank to the design liquid level (see 5.6.3.2) with liquid with the design specific gravity specified by the Purchaser.
 - i. **Test Pressure (P_t):** As required by F.4.4 or F.7.6.
- j. **Wind (W):** The design wind speed (V) shall be 190 km/hr (120 mph), the 3-sec gust design wind speed determined from ASCE 7, Figure 6-1, or the 3-sec gust design wind speed specified by the Purchaser (this specified wind speed shall be for a 3-sec gust based on a 2% annual probability of being exceeded [50-year mean recurrence interval]). The design wind pressure shall be $0.86 \text{ kPa } (V/190)^2$, $([18 \text{ lbf/ft}^2][V/120]^2)$ on vertical projected areas of cylindrical surfaces and $1.44 \text{ kPa } (V/190)^2$, $([30 \text{ lbf/ft}^2][V/120]^2)$ uplift (see item 2 below) on horizontal projected areas of conical or doubly curved surfaces, where V is the 3-sec gust wind speed. The 3-sec gust wind speed used shall be reported to the Purchaser.
 - 1. These design wind pressures are in accordance with ASCE 7 for wind exposure Category C. As an alternative, pressures may be determined in accordance with ASCE 7 (exposure category and importance factor provided by Purchaser) or a national standard for the specific conditions for the tank being designed.
 - 2. The design uplift pressure on the roof (wind plus internal pressure) need not exceed 1.6 times the design pressure P determined in F.4.1.
 - 3. Windward and leeward horizontal wind loads on the roof are conservatively equal and opposite and therefore they are not included in the above pressures.
 - 4. Fastest mile wind speed times 1.2 is approximately equal to 3-sec gust wind speed.

• 5.2.2 Design Factors

The Purchaser shall state the design metal temperature (based on ambient temperatures), the maximum design temperature, the design specific gravity, the corrosion allowance (if any), and the seismic factors.

5.2.3 External Loads

- a. The Purchaser shall state the magnitude and direction of external loads or restraint, if any, for which the shell or shell connections must be designed. The design for such loadings shall be a matter of agreement between the Purchaser and the Manufacturer.
- b. Unless otherwise specified, seismic design shall be in accordance with Appendix E.
- 07 • c. Design for localized wind induced forces on roof components shall be a matter of agreement between the Purchaser and the Manufacturer.
- d. Localized loads resulting from items such as ladders, stairs, platforms, etc., shall be considered.

• 5.2.4 Protective Measures

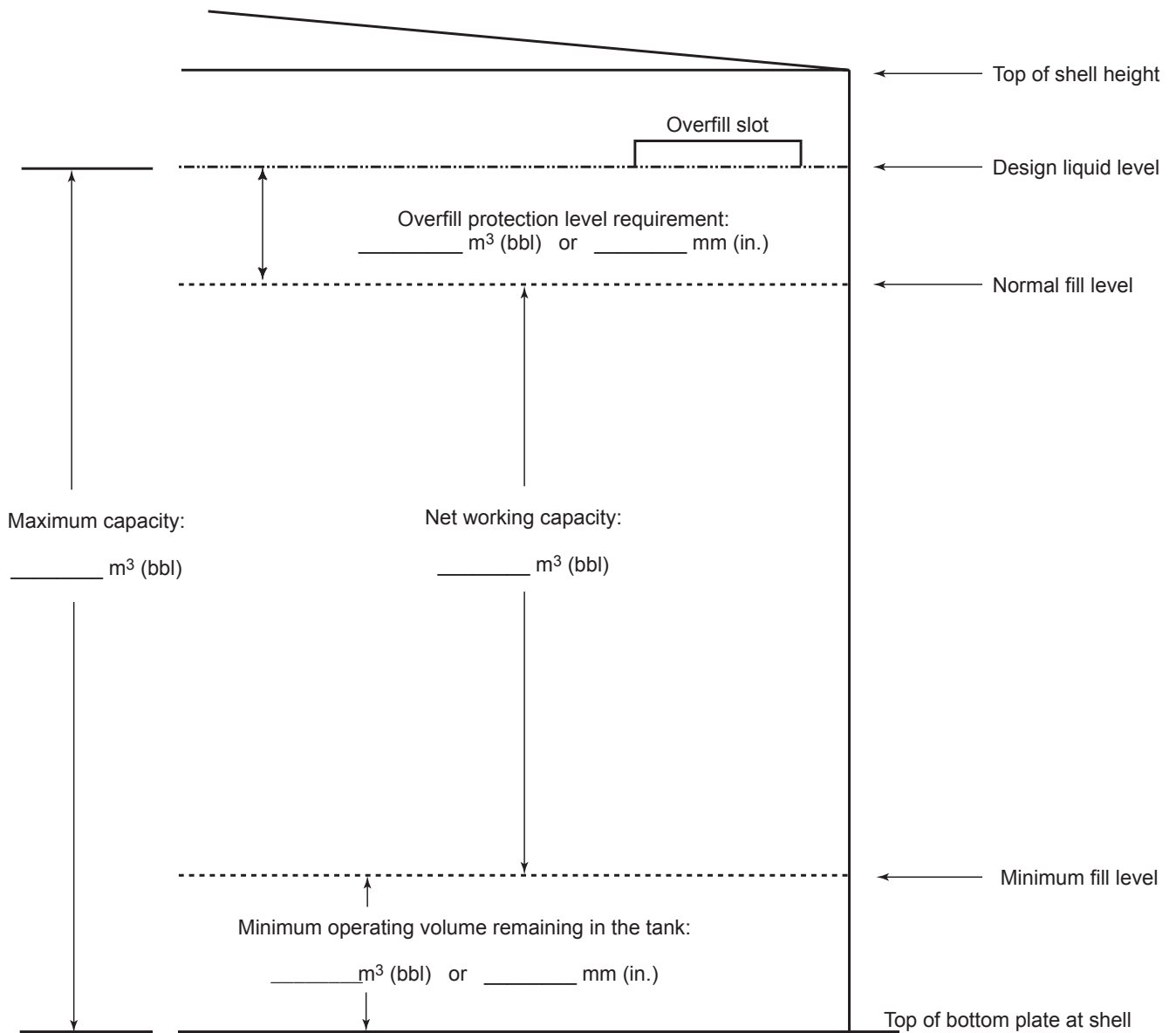
The Purchaser shall consider foundations, corrosion allowance, hardness testing, and any other protective measures deemed necessary. For example, for insulated tanks, means to prevent infiltration of water into the insulation shall be specified, especially around penetrations of the insulation and at the roof-to-shell junction.

5.2.5 External Pressure

See Appendix V for the provisions for the design of tanks subject to partial internal vacuum exceeding 0.25 kPa (1 in. of water). Tanks that meet the requirements of this Standard may be subjected to a partial vacuum of 0.25 kPa (1 in. of water), without the need to provide any additional supporting calculations.

5.2.6 Tank Capacity

- 5.2.6.1** The Purchaser shall specify the maximum capacity and the overfill protection level (or volume) requirement (see API RP 2350).
- 5.2.6.2** Maximum capacity is the volume of product in a tank when the tank is filled to its design liquid level as defined in 5.6.3.2 (see Figure 5-4).
- 5.2.6.3** The net working capacity is the volume of available product under normal operating conditions. The net working capacity is equal to the maximum capacity (see 5.2.6.2) less the minimum operating volume remaining in the tank, less the overfill protection level (or volume) requirement (see Figure 5-4).



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Figure 5-4—Storage Tank Volumes and Levels

5.3 SPECIAL CONSIDERATIONS

5.3.1 Foundation

07 • **5.3.1.1** The selection of the tank site and the design and construction of the foundation shall be given careful consideration, as outlined in Appendix B, to ensure adequate tank support. The adequacy of the foundation is the responsibility of the Purchaser. Foundation loading data shall be provided by the Manufacturer on the Data Sheet, Line 13.

• **5.3.1.2** Sliding friction resistance shall be verified for tanks subject to lateral wind loads or seismic loads (see 5.11.4 and E.7.6).

5.3.2 Corrosion Allowances

07 • **5.3.2.1** The Purchaser, after giving consideration to the total effect of the liquid stored, the vapor above the liquid, and the atmospheric environment, shall specify in the Data Sheet, Tables 1 and 2, any corrosion allowances to be provided for all components, including each shell course, for the bottom, for the roof, for nozzles and manholes, and for structural members.

• **5.3.2.2** Excluding nozzle necks, corrosion allowances for nozzles, flush-type cleanouts, manholes, and self-supporting roofs shall be added to the design thickness, if calculated, or to the minimum specified thickness.

07 • **5.3.2.3** For nozzle necks, any specified nozzle neck corrosion allowance shall, by agreement between the Purchaser and the Manufacturer, be added to either the nominal neck thickness shown in Table 5-6 (or Table 5-7) or to the minimum calculated thickness required for pressure head and mechanical strength. In no case shall the neck thickness provided be less than the nominal thickness shown in the table.

• **5.3.2.4** Corrosion allowance for anchor bolts shall be added to the nominal diameter.

• **5.3.2.5** Corrosion allowance for anchor straps and brackets shall be added to the required strap and bracket thickness.

• **5.3.2.6** For internal structural members, the corrosion allowance shall be applied to the total thickness unless otherwise specified.

5.3.3 Service Conditions

07 • The Purchaser shall specify any applicable special metallurgical requirements pertaining to the selection of materials and the fabrication processes as required by any anticipated service conditions. When the service conditions might include the presence of hydrogen sulfide or other conditions that could promote hydrogen-induced cracking, notably near the bottom of the shell at the shell-to-bottom connections, care should be taken to ensure that the materials of the tank and details of construction are adequate to resist hydrogen-induced cracking. The Purchaser should consider limits on the sulfur content of the base and weld metals as well as appropriate quality control procedures in plate and tank fabrication. The hardness of the welds, including the heat-affected zones, in contact with these conditions should be considered. The weld metal and adjacent heat-affected zone often contain a zone of hardness well in excess of Rockwell C 22 and can be expected to be more susceptible to cracking than unwelded metal is. Any hardness criteria should be a matter of agreement between the Purchaser and the Manufacturer and should be based on an evaluation of the expected hydrogen sulfide concentration in the product, the possibility of moisture being present on the inside metal surface, and the strength and hardness characteristics of the base metal and weld metal. See the Data Sheet, Line 5.

5.3.4 Weld Hardness

a. Weld metal and Heat Affected Zone (HAZ) hardnesses shall comply with the H₂S Supplemental Specification listed on the Data Sheet, Line 5, when specified by the Purchaser.

b. When specified by the Purchaser, the hardness of the weld metal for shell materials in Group IV, IVA, V, or VI shall be evaluated by one or both of the following methods:

07 1. The welding-procedure qualification tests for all welding shall include hardness tests of the weld metal and heat-affected zone of the test plate. The methods of testing and the acceptance standards shall be agreed upon by the Purchaser and the Manufacturer.

2. All welds deposited by an automatic process shall be hardness tested on the product-side surface. Unless otherwise specified, one test shall be conducted for each vertical weld, and one test shall be conducted for each 30 m (100 ft) of circumferential weld. The methods of testing and the acceptance standards shall be agreed upon by the Purchaser and the Manufacturer.

5.4 BOTTOM PLATES

- **5.4.1** All bottom plates shall have a minimum nominal thickness of 6 mm ($1/4$ in.) (49.8 kg/m² (10.2 lbf/ft²) (see 4.2.1.2)], exclusive of any corrosion allowance specified by the Purchaser for the bottom plates. Unless otherwise agreed to by the Purchaser, all rectangular and sketch plates (bottom plates on which the shell rests that have one end rectangular) shall have a minimum nominal width of 1800 mm (72 in.).
- **5.4.2** Bottom plates of sufficient size shall be ordered so that, when trimmed, at least a 50 mm (2 in.) width will project outside the shell or meet requirements given in 5.1.5.7 d whichever is greater.
- **5.4.3** Bottom plates shall be welded in accordance with 5.1.5.4 or 5.1.5.5.
- **5.4.4** Unless otherwise specified on the Data Sheet, Line 12, tank bottoms requiring sloping shall have a minimum slope of 1:120 upwards toward center of the tank.
- **5.4.5** If specified on the Data Sheet, Line 12, a foundation drip ring shall be provided to prevent ingress of water between the tank bottom and foundation. Unless the Purchaser specifies otherwise, the ring shall meet the following requirements (see Figure 5-5):
 1. Material shall be carbon steel, 3 mm ($1/8$ -in.) minimum thickness.
 2. All radial joints between sections of the drip rings, as well as between the drip ring and the annular plate or bottom, shall be continuously seal-welded.
 3. The drip ring shall extend at least 75 mm (3 in.) beyond the outer periphery of the foundation ringwall and then turn down (up to 90°) at its outer diameter.
 4. The top and bottom of the drip ring, and the top of the tank bottom edge protection beyond the shell, and a portion of the tank shell shall be coated if specified by the Purchaser.

5.5 ANNULAR BOTTOM PLATES

5.5.1 When the bottom shell course is designed using the allowable stress for materials in Group IV, IVA, V, or VI, butt-welded annular bottom plates shall be used (see 5.1.5.6). When the bottom shell course is of a material in Group IV, IVA, V, or VI and the maximum product stress (see 5.6.2.1) for the first shell course is less than or equal to 160 MPa (23,200 lbf/in.²) or the maximum hydrostatic test stress (see 5.6.2.2) for the first shell course is less than or equal to 172 MPa (24,900 lbf/in.²), lap-welded bottom plates (see 5.1.5.4) may be used in lieu of butt-welded annular bottom plates.

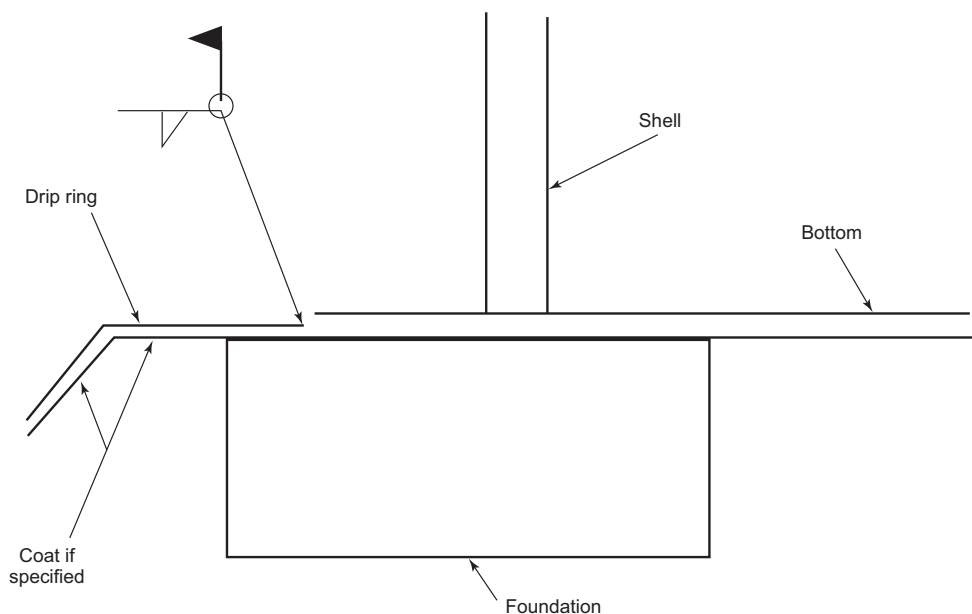


Figure 5-5—Drip Ring (Suggested Detail)

5.5.2 Annular bottom plates shall have a radial width that provides at least 600 mm (24 in.) between the inside of the shell and any lap-welded joint in the remainder of the bottom. Annular bottom plate projection outside the shell shall meet the requirements of 5.4.2. A greater radial width of annular plate is required when calculated as follows:

In SI units:

$$\frac{215t_b}{(HG)^{0.5}}$$

where

- t_b = thickness of the annular plate (see 5.5.3), in mm,
- H = maximum design liquid level (see 5.6.3.2), in m,
- G = design specific gravity of the liquid to be stored.

In US Customary units:

$$\frac{390t_b}{(HG)^{0.5}}$$

where

- t_b = thickness of the annular plate (see 5.5.3), (in.),
- H = maximum design liquid level (see 5.6.3.2), (ft),
- G = design specific gravity of the liquid to be stored.

5.5.3 The thickness of the annular bottom plates shall not be less than the greater thickness determined using Table 5-1 for product design (plus any specified corrosion allowance) or for hydrostatic test design. Table 5-1 is applicable for effective product height of $H \times G \leq 23$ m (75 ft). Beyond this height an elastic analysis must be made to determine the annular plate thickness.

Table 5-1—Annular Bottom-Plate Thicknesses (t_{br})

SI Units				
Plate Thickness ^a of First Shell Course (mm)	Stress ^b in First Shell Course (MPa)			
	≤ 190	≤ 210	≤ 220	≤ 250
$t \leq 19$	6	6	7	9
$19 < t \leq 25$	6	7	10	11
$25 < t \leq 32$	6	9	12	14
$32 < t \leq 38$	8	11	14	17
$38 < t \leq 45$	9	13	16	19
US Customary				
Plate Thickness ^a of First Shell Course (in.)	Stress ^b in First Shell Course (lbf/in ²)			
	≤ 27,000	≤ 30,000	≤ 32,000	≤ 36,000
$t \leq 0.75$	1/4	1/4	9/32	11/32
$0.75 < t \leq 1.00$	1/4	9/32	3/8	7/16
$1.00 < t \leq 1.25$	1/4	11/32	15/32	9/16
$1.25 < t \leq 1.50$	5/16	7/16	9/16	11/16
$1.50 < t \leq 1.75$	11/32	1/2	5/8	3/4

^aPlate thickness refers to shell plate thickness exclusive of corrosion allowance for product design and thickness as constructed for hydrostatic test design.

^bThe stress to be used is the maximum stress in the first shell course (greater of product or hydrostatic test stress). The stress may be determined using the required thickness divided by the thickness from “a” then multiplied by the applicable allowable stress:

Product Stress = (t_d /as-constructed t exclusive of CA) (S_d)

Hydrostatic Test Stress = (t_t /as-constructed t) (S_t)

Note: The thicknesses specified in the table, as well as the width specified in 5.5.2, are based on the foundation providing uniform support under the full width of the annular plate. Unless the foundation is properly compacted, particularly at the inside of a concrete ringwall, settlement will produce additional stresses in the annular plate.

5.5.4 The ring of annular plates shall have a circular outside circumference, but may have a regular polygonal shape inside the tank shell, with the number of sides equal to the number of annular plates. These pieces shall be welded in accordance with 5.1.5.6 and 5.1.5.7, Item b.

5.5.5 In lieu of annular plates, the entire bottom may be butt-welded provided that the requirements for annular plate thickness, welding, materials, and inspection are met for the annular distance specified in 5.5.2.

5.6 SHELL DESIGN

5.6.1 General

5.6.1.1 The required shell thickness shall be the greater of the design shell thickness, including any corrosion allowance, or the hydrostatic test shell thickness, but the shell thickness shall not be less than the following:

Nominal Tank Diameter		Nominal Plate Thickness	
(m)	(ft)	(mm)	(in.)
< 15	< 50	5	$\frac{3}{16}$
15 to < 36	50 to < 120	6	$\frac{1}{4}$
36 to 60	120 to 200	8	$\frac{5}{16}$
> 60	> 200	10	$\frac{3}{8}$

Notes:

- 1. Unless otherwise specified by the Purchaser, the nominal tank diameter shall be the centerline diameter of the bottom shell-course plates.
- 2. Nominal plate thickness refers to the tank shell as constructed. The thicknesses specified are based on erection requirements.
- 3. When specified by the Purchaser, plate with a minimum nominal thickness of 6 mm may be substituted for $\frac{1}{4}$ -in. plate.
- 4. For diameters less than 15 m (50 ft) but greater than 3.2 m (10.5 ft), the minimum thickness of the lowest shell course only is increased to 6 mm ($\frac{1}{4}$ in.).

- 5.6.1.2** Unless otherwise agreed to by the Purchaser, the shell plates shall have a minimum nominal width of 1800 mm (72 in.). Plates that are to be butt-welded shall be properly squared.

5.6.1.3 The calculated stress for each shell course shall not be greater than the stress permitted for the particular material used for the course. No shell course shall be thinner than the course above it.

5.6.1.4 The tank shell shall be checked for stability against buckling from the design wind speed in accordance with 5.9.7. If required for stability, intermediate girders, increased shell-plate thicknesses, or both shall be used.

5.6.1.5 Isolated radial loads on the tank shell, such as those caused by heavy loads on platforms and elevated walkways between tanks, shall be distributed by rolled structural sections, plate ribs, or built-up members.

5.6.2 Allowable Stress

5.6.2.1 The maximum allowable product design stress, S_d , shall be as shown in Table 5-2. The net plate thicknesses—the actual thicknesses less any corrosion allowance—shall be used in the calculation. The design stress basis, S_d , shall be either two-thirds the yield strength or two-fifths the tensile strength, whichever is less.

5.6.2.2 The maximum allowable hydrostatic test stress, S_t , shall be as shown in Table 5-2. The gross plate thicknesses, including any corrosion allowance, shall be used in the calculation. The hydrostatic test basis shall be either three-fourths the yield strength or three-sevenths the tensile strength, whichever is less.

5.6.2.3 Appendix A permits an alternative shell design with a fixed allowable stress of 145 MPa (21,000 lbf/in.²) and a joint efficiency factor of 0.85 or 0.70. This design may only be used for tanks with shell thicknesses less than or equal to 12.5 mm ($\frac{1}{2}$ in.).

5.6.2.4 Structural design stresses shall conform to the allowable working stresses given in 5.10.3.

5.6.3 Calculation of Thickness by the 1-Foot Method

5.6.3.1 The 1-foot method calculates the thicknesses required at design points 0.3 m (1 ft) above the bottom of each shell course. Appendix A permits only this design method. This method shall not be used for tanks larger than 60 m (200 ft) in diameter.

Table 5-2—Permissible Plate Materials and Allowable Stresses

Plate Specification	Grade	Minimum Yield Strength MPa (psi)	Minimum Tensile Strength MPa (psi)	Product Design Stress S_d MPa (psi)	Hydrostatic Test Stress S_t MPa (psi)
ASTM Specifications					
A 283M (A 283)	C (C)	205 (30,000)	380 (55,000)	137 (20,000)	154 (22,500)
A 285M (A 285)	C (C)	205 (30,000)	380 (55,000)	137 (20,000)	154 (22,500)
A 131M (A 131)	A, B, CS (A, B, CS)	235 (34,000)	400 (58,000)	157 (22,700)	171 (24,900)
A 36M (A 36)	—	250 (36,000)	400 (58,000)	160 (23,200)	171 (24,900)
A 131M (A 131)	EH 36 (EH 36)	360 (51,000)	490 ^a (71,000 ^a)	196 (28,400)	210 (30,400)
A 573M (A 573)	400 (58)	220 (32,000)	400 (58,000)	147 (21,300)	165 (24,000)
A 573M (A 573)	450 (65)	240 (35,000)	450 (65,000)	160 (23,300)	180 (26,300)
A 573M (A 573)	485 (70)	290 (42,000)	485 ^a (70,000 ^a)	193 (28,000)	208 (30,000)
A 516M (A 516)	380 (55)	205 (30,000)	380 (55,000)	137 (20,000)	154 (22,500)
A 516M (A 516)	415 (60)	220 (32,000)	415 (60,000)	147 (21,300)	165 (24,000)
A 516M (A 516)	450 (65)	240 (35,000)	450 (65,000)	160 (23,300)	180 (26,300)
A 516M (A 516)	485 (70)	260 (38,000)	485 (70,000)	173 (25,300)	195 (28,500)
A 662M (A 662)	B (B)	275 (40,000)	450 (65,000)	180 (26,000)	193 (27,900)
A 662M (A 662)	C (C)	295 (43,000)	485 ^a (70,000 ^a)	194 (28,000)	208 (30,000)
A 537M (A 537)	1 (1)	345 (50,000)	485 ^a (70,000 ^a)	194 (28,000)	208 (30,000)
A 537M (A 537)	2 (2)	415 (60,000)	550 ^a (80,000 ^a)	220 (32,000)	236 (34,300)
A 633M (A 633)	C, D (C, D)	345 (50,000)	485 ^a (70,000 ^a)	194 (28,000)	208 (30,000)
A 678M (A 678)	A (A)	345 (50,000)	485 ^a (70,000 ^a)	194 (28,000)	208 (30,000)
A 678M (A 678)	B (B)	415 (60,000)	550 ^a (80,000 ^a)	220 (32,000)	236 (34,300)
A 737M (A 737)	B (B)	345 (50,000)	485 ^a (70,000 ^a)	194 (28,000)	208 (30,000)
A 841M (A 841)	Class 1 (Class 1)	345 (50,000)	485 ^a (70,000 ^a)	194 (28,000)	208 (30,000)
A 841M (A 841)	Class 2 (Class 2)	415 (60,000)	550 ^a (80,000 ^a)	220 (32,000)	236 (34,300)
CSA Specifications					
G40.21	260W (38W)	260 (38,000)	410 (60,000)	164 (24,000)	176 (25,700)
G40.21	300W (44W)	300 (44,000)	450 (65,000)	180 (26,000)	193 (27,900)
G40.21	350WT (50WT)	350 (50,000)	480 ^a (75,000 ^a)	192 (28,000)	206 (30,000)
G40.21	350W (50W)	350 (50,000)	450 (65,000)	180 (26,000)	193 (27,900)
National Standards					
	235	235 (34,000)	365 (52,600)	137 (20,000)	154 (22,500)
	250	250 (36,000)	400 (58,300)	157 (22,700)	171 (25,000)
	275	275 (40,000)	430 (62,600)	167 (24,000)	184 (26,800)
ISO 630					
E 275	C, D	265 (38,400)	410 (59,500)	164 (23,800)	175 (25,500)
E 355	C, D	345 (50,000)	490 ^a (71,000 ^a)	196 (28,400)	210 (30,400)

- ^aBy agreement between the Purchaser and the Manufacturer, the tensile strength of these materials may be increased to 515 MPa (75,000 psi) minimum and 620 MPa (90,000 psi) maximum (and to 585 MPa [85,000 psi] minimum and 690 MPa [100,000 psi] maximum for ASTM A 537M, Class 2, and A 678M, Grade B). When this is done, the allowable stresses shall be determined as stated in 5.6.2.1 and 5.6.2.2.

- **5.6.3.2** The required minimum thickness of shell plates shall be the greater of the values computed by the following formulas:

In SI units:

$$t_d = \frac{4.9D(H-0.3)G}{S_d} + CA$$

$$t_t = \frac{4.9D(H-0.3)}{S_t}$$

where

t_d = design shell thickness, in mm,

t_t = hydrostatic test shell thickness, in mm,

D = nominal tank diameter, in m (see 5.6.1.1, Note 1),

- H = design liquid level, in m,

= height from the bottom of the course under consideration to the top of the shell including the top angle, if any; to the bottom of any overflow that limits the tank filling height; or to any other level specified by the Purchaser, restricted by an internal floating roof, or controlled to allow for seismic wave action,

- G = design specific gravity of the liquid to be stored, as specified by the Purchaser,

- CA = corrosion allowance, in mm, as specified by the Purchaser (see 5.3.2),

S_d = allowable stress for the design condition, in MPa (see 5.6.2.1),

S_t = allowable stress for the hydrostatic test condition, in MPa (see 5.6.2.2).

In US Customary units:

$$t_d = \frac{2.6D(H-1)G}{S_d} + CA$$

$$t_t = \frac{2.6D(H-1)}{S_t}$$

where

t_d = design shell thickness (in.),

t_t = hydrostatic test shell thickness (in.),

D = nominal tank diameter, in ft (see 5.6.1.1, Note 1),

- H = design liquid level, (ft),

= height from the bottom of the course under consideration to the top of the shell including the top angle, if any; to the bottom of any overflow that limits the tank filling height; or to any other level specified by the Purchaser, restricted by an internal floating roof, or controlled to allow for seismic wave action,

- G = design specific gravity of the liquid to be stored, as specified by the Purchaser,

- CA = corrosion allowance, (in.), as specified by the Purchaser (see 5.3.2),

S_d = allowable stress for the design condition, (lbf/in.²) (see 5.6.2.1),

S_t = allowable stress for the hydrostatic test condition, (lbf/in.²) (see 5.6.2.2).

5.6.4 Calculation of Thickness by the Variable-Design-Point Method

Note: This procedure normally provides a reduction in shell-course thicknesses and total material weight, but more important is its potential to permit construction of larger diameter tanks within the maximum plate thickness limitation. For background information, see L.P. Zick and R.V. McGrath, "Design of Large Diameter Cylindrical Shells."¹⁸

- **5.6.4.1** Design by the variable-design-point method gives shell thicknesses at design points that result in the calculated stresses being relatively close to the actual circumferential shell stresses. This method may only be used when the Purchaser has not specified that the 1-foot method be used and when the following is true:

In SI units:

$$\frac{L}{H} \leq \frac{1000}{6}$$

where

$$L = (500 Dt)^{0.5}, \text{ in mm,}$$

$$D = \text{tank diameter, in m,}$$

$$t = \text{bottom-course shell thickness, excluding any corrosion allowance, in mm,}$$

$$H = \text{maximum design liquid level (see 5.6.3.2), in m.}$$

In US Customary units:

$$\frac{L}{H} \leq 2$$

where

$$L = (6 Dt)^{0.5}, \text{ (in.),}$$

$$D = \text{tank diameter, (ft),}$$

$$t = \text{bottom-course shell thickness, excluding any corrosion allowance (in.),}$$

$$H = \text{maximum design liquid level (see 5.6.3.2), (ft).}$$

5.6.4.2 The minimum plate thicknesses for both the design condition and the hydrostatic test condition shall be determined as outlined. Complete, independent calculations shall be made for all of the courses for the design condition, exclusive of any corrosion allowance, and for the hydrostatic test condition. The required shell thickness for each course shall be the greater of the design shell thickness plus any corrosion allowance or the hydrostatic test shell thickness, but the total shell thickness shall not be less than the shell thickness required by 5.6.1.1, 5.6.1.3, and 5.6.1.4. When a greater thickness is used for a shell course, the greater thickness may be used for subsequent calculations of the thicknesses of the shell courses above the course that has the greater thickness, provided the greater thickness is shown as the required design thickness on the Manufacturer's drawing (see W.3).

5.6.4.3 To calculate the bottom-course thicknesses, preliminary values t_{pd} and t_{pt} for the design and hydrostatic test conditions shall first be calculated from the formulas in 5.6.3.2.

5.6.4.4 The bottom-course thicknesses t_{1d} and t_{1t} for the design and hydrostatic test conditions shall be calculated using the following formulas:

In SI units:

$$t_{1d} = \left(1.06 - \frac{0.0696D}{H} \sqrt{\frac{HG}{S_d}}\right) \left(\frac{4.9HDG}{S_d}\right) + CA$$

¹⁸L.P. Zick and R.V. McGrath, "Design of Large Diameter Cylindrical Shells," *Proceedings*—Division of Refining, American Petroleum Institute, New York, 1968, Volume 48, pp. 1114 – 1140.

In US Customary units:

$$t_{1d} = \left(1.06 - \frac{0.463D}{H} \sqrt{\frac{HG}{S_d}} \right) \left(\frac{2.6HDG}{S_d} \right) + CA$$

Note: For the design condition, t_{1d} need not be greater than t_{pd} .

In SI units:

$$t_{1t} = \left(1.06 - \frac{0.0696D}{H} \sqrt{\frac{H}{S_t}} \right) \left(\frac{4.9HD}{S_t} \right)$$

In US Customary units:

$$t_{1t} = \left(1.06 - \frac{0.463D}{H} \sqrt{\frac{H}{S_t}} \right) \left(\frac{2.6HD}{S_t} \right)$$

Note: For the hydrostatic test condition, t_{1t} need not be greater than t_{pt} .

5.6.4.5 To calculate the second-course thicknesses for both the design condition and the hydrostatic test condition, the value of the following ratio shall be calculated for the bottom course:

$$\frac{h_1}{(rt_1)^{0.5}}$$

where

h_1 = height of the bottom shell course, in mm (in.),

r = nominal tank radius, in mm (in.),

t_1 = calculated thickness of the bottom shell course, less any thickness added for corrosion allowance, in mm (in.), used to calculate t_2 (design). The calculated hydrostatic thickness of the bottom shell course shall be used to calculate t_2 (hydrostatic test).

If the value of the ratio is less than or equal to 1.375:

$$t_2 = t_1$$

If the value of the ratio is greater than or equal to 2.625:

$$t_2 = t_{2a}$$

If the value of the ratio is greater than 1.375 but less than 2.625,:

$$t_2 = t_{2a} + (t_1 - t_{2a}) \left[2.1 - \frac{h_1}{1.25(rt_1)^{0.5}} \right]$$

where

t_2 = minimum design thickness of the second shell course excluding any corrosion allowance, in mm (in.),

t_{2a} = thickness of the second shell course, in mm (in.), as calculated for an upper shell course as described in 5.6.4.6 to 5.6.4.8, exclusive of any corrosion allowance. d_n calculating second shell course thickness (t_2) for design case and hydrostatic test case, applicable values of t_{2a} and t_1 shall be used.

The preceding formula for t_2 is based on the same allowable stress being used for the design of the bottom and second courses. For tanks where the value of the ratio is greater than or equal to 2.625, the allowable stress for the second course may be lower than the allowable stress for the bottom course when the methods described in 5.6.4.6 through 5.6.4.8 are used.

5.6.4.6 To calculate the upper-course thicknesses for both the design condition and the hydrostatic test condition, a preliminary value t_u for the upper-course thickness shall be calculated using the formulas in 5.6.3.2 excluding any corrosion allowance, and then the distance x of the variable design point from the bottom of the course shall be calculated using the lowest value obtained from the following:

In SI units:

$$x_1 = 0.61 (rt_u)^{0.5} + 320 CH$$

$$x_2 = 1000 CH$$

$$x_3 = 1.22 (rt_u)^{0.5}$$

where

t_u = thickness of the upper course at the girth joint, exclusive of any corrosion allowance, in mm,

$$C = [K^{0.5} (K - 1)] / (1 + K^{1.5}),$$

$$K = t_L / t_u,$$

t_L = thickness of the lower course at the girth joint, exclusive of any corrosion allowance, in mm,

- H = design liquid level (see 5.6.3.2), in m.

In US Customary units:

$$x_1 = 0.61 (rt_u)^{0.5} + 3.84 CH$$

$$x_2 = 12 CH$$

$$x_3 = 1.22 (rt_u)^{0.5}$$

where

t_u = thickness of the upper course at the girth joint, exclusive of any corrosion allowance, (in.),

$$C = [K^{0.5} (K - 1)] / (1 + K^{1.5}),$$

$$K = t_L / t_u,$$

t_L = thickness of the lower course at the girth joint, exclusive of any corrosion allowance, (in.),

- H = design liquid level (see 5.6.3.2), (ft).

5.6.4.7 The minimum thickness t_x for the upper shell courses shall be calculated for both the design condition (t_{dx}) and the hydrostatic test condition (t_{tx}) using the minimum value of x obtained from 5.6.4.6:

In SI units:

$$t_{dx} = \frac{4.9D \left(H - \frac{x}{1000} \right) G}{S_d} + CA$$

$$t_{tx} = \frac{4.9D \left(H - \frac{x}{1000} \right)}{S_t}$$

In US Customary units:

$$t_{dx} = \frac{2.6D\left(H - \frac{x}{12}\right)G}{S_d} + CA$$

$$t_{tx} = \frac{2.6D\left(H - \frac{x}{12}\right)}{S_t}$$

5.6.4.8 The steps described in 5.6.4.6 and 5.6.4.7 shall be repeated using the calculated value of t_x as t_u until there is little difference between the calculated values of t_x in succession (repeating the steps twice is normally sufficient). Repeating the steps provides a more exact location of the design point for the course under consideration and, consequently, a more accurate shell thickness.

5.6.4.9 The step-by-step calculations in Appendix K illustrate an application of the variable-design-point method to a tank with a diameter of 85 m (280 ft) and a height of 19.2 m (64 ft) to determine shell-plate thicknesses for the first three courses for the hydrostatic test condition only.

5.6.5 Calculation of Thickness by Elastic Analysis

For tanks where L/H is greater than $1000/6$ (2 in US Customary units), the selection of shell thicknesses shall be based on an elastic analysis that shows the calculated circumferential shell stresses to be below the allowable stresses given in Table 5-2. The boundary conditions for the analysis shall assume a fully plastic moment caused by yielding of the plate beneath the shell and zero radial growth.

5.7 SHELL OPENINGS

5.7.1 General

5.7.1.1 The following requirements for shell openings are intended to restrict the use of appurtenances to those providing for attachment to the shell by welding. See Figure 5-6.

5.7.1.2 The shell opening designs described in this Standard are required, except for alternative designs allowed in 5.7.1.8. | 07

5.7.1.3 Flush-type cleanout fittings and flush-type shell connections shall conform to the designs specified in 5.7.7 and 5.7.8.

- **5.7.1.4** When a size intermediate to the sizes listed in Tables 5-3 through 5-14 is specified by the Purchaser, the construction details and reinforcements shall conform to the next larger opening listed in the tables. The size of the opening or tank connection shall not be larger than the maximum size given in the appropriate table.

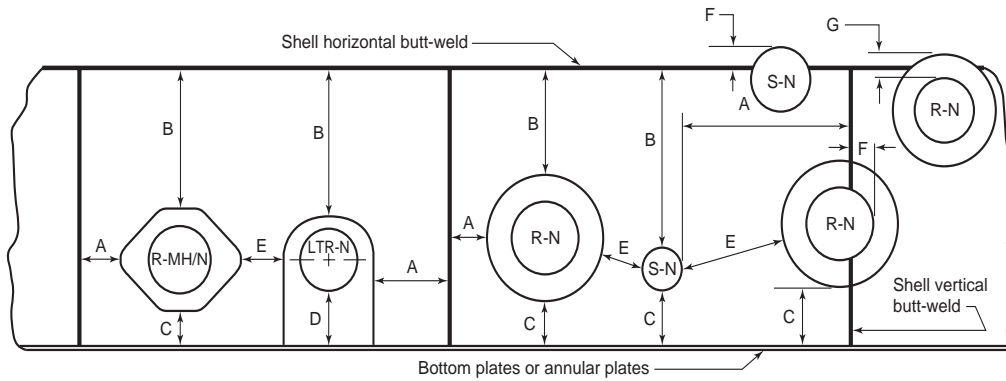
5.7.1.5 Openings near the bottom of a tank shell will tend to rotate with vertical bending of the shell under hydrostatic loading. Shell openings in this area that have attached piping or other external loads shall be reinforced not only for the static condition but also for any loads imposed on the shell connections by the restraint of the attached piping to the shell rotation. The external loads shall be minimized, or the shell connections shall be relocated outside the rotation area. Appendix P provides a method for evaluating openings that conform to Table 5-6.

5.7.1.6 Sheared or oxygen-cut surfaces on manhole necks, nozzle necks, reinforcing plates, and shell-plate openings shall be made uniform and smooth, with the corners rounded except where the surfaces are fully covered by attachment welds.

5.7.1.7 The periphery of the insert plates shall have a 1:4 tapered transition to the thickness of the adjacent shell plates.

- **5.7.1.8** With the approval of the Purchaser, the shape and dimensions of the shell reinforcing plates, illustrated in Figures 5-7A, 5-7B, and 5-8 and dimensioned in the related tables, may be altered as long as the thickness, length, and width dimensions of the proposed shapes meet the area, welding, and spacing requirements outlined in 5.7.2 and 5.7.3. Reinforcement and welding of shell openings that comply with API Std 620 are acceptable alternatives. This statement of permissible alternatives of shell opening reinforcement does not apply to flush-type cleanout fittings and flush-type shell connections. | 07

5.7.1.9 The flange facing shall be suitable for the gasket and bolting employed. Gaskets shall be selected to meet the service environment so that the required seating load is compatible with the flange rating and facing, the strength of the flange, and its bolting (see 4.9).



Note:

- R-MH/N = Reinforced Opening (manhole or nozzle with diamond shape reinforcing plate, see Figures 5-7A and 5-8).
- LTR-N = Low-Type Reinforced Opening (manhole or nozzle with tombstone shape reinforcing plate, see Figure 5-8, Detail a and b).
- R-N = Reinforced Opening (manhole or nozzle with circular reinforcing plate or thickened insert plate, see Figure 5-8).
- S-N = Non-Reinforced Opening (manhole or nozzle inserted into the shell per the alternate neck detail of Figure 5-7B).

Variables		Reference	Minimum Dimension Between Weld Toes or Weld Centerline (1)(3)						
Shell <i>t</i>	Condition	Paragraph Number	A (2)	B (2)	C (2)	D (4)	E (2)	F (5)	G (5)
$t \leq 12.5 \text{ mm}$ ($t \leq 1/2 \text{ in.}$)	As welded or PWHT	5.7.3.2	150 mm (6 in.)	75 mm (3 in.) or $2^{1/2}t$	75 mm (3 in.) or $2^{1/2}t$ 75 mm (3 in.) for S-N	Table 5-6	75 mm (3 in.) or $2^{1/2}t$	$8t$ or $1/2 r$	$8t$
		5.7.3.3							
		5.7.3.3							
		5.7.3.3 • 5.7.3.4 • 5.7.3.4							
$t > 12.5 \text{ mm}$ ($t > 1/2 \text{ in.}$)	As Welded	5.7.3.1.a	$8W$ or 250 mm (10 in.)	$8W$ or 250 mm (10 in.)	$8W$ or 250 mm (10 in.) 75 mm (3 in.) for S-N	Table 5-6	$8W$ or 150 mm (6 in.)	$8t$ or $1/2 r$	$8t$
		5.7.3.1.b							
		5.7.3.3							
		5.7.3.3 • 5.7.3.4 • 5.7.3.4							
$t > 12.5 \text{ mm}$ ($t > 1/2 \text{ in.}$)	PWHT	5.7.3.2	150 mm (6 in.)	75 mm (3 in.) or $2^{1/2}t$	75 mm (3 in.) or $2^{1/2}t$ 75 mm (3 in.) for S-N	Table 5-6	75 mm (3 in.) or $2^{1/2}t$	$8t$ or $1/2 r$	$8t$
		5.7.3.3							
		5.7.3.3							
		5.7.3.3 • 5.7.3.4 • 5.7.3.4							

Notes:

1. If two requirements are given, the minimum spacing is the greater value, except for dimension "F." See Note 5.
2. t = shell thickness. $8W$ = 8 times the largest weld size for reinforcing plate or insert plate periphery weld (fillet or butt-weld) from the toe of the periphery weld to the centerline of the shell butt-weld.
3. For tanks designed to Appendix A, see A.5.2. Spacing = $2^{1/2}t$ toe-to-toe of adjacent welds.
4. D = spacing distance established by minimum elevation for low-type reinforced openings from Table 5-6, column 9.
5. Purchaser option to allow shell openings to be located in horizontal or vertical shell butt-welds. See Figure 5-9.
 t = shell thickness, r = radius of opening. Minimum spacing for dimension F is the lesser of $8t$ or $1/2 r$.

Figure 5-6—Minimum Weld Requirements for Openings in Shells According to 5.7.3

Table 5-3—Thickness of Shell Manhole Cover Plate and Bolting Flange

Column 1 Max. Design Liquid Level m (ft) H	Column 2 Equivalent Pressure ^a kPa (lb/ft ²)	Column 3-6 Minimum Thickness of Cover Plate ^b (<i>t_c</i>)				Column 7-10 Minimum Thickness of Bolting Flange After Finishing ^b (<i>t_f</i>)			
		500 mm (20 in.) Manhole	600 mm (24 in.) Manhole	750 mm (30 in.) Manhole	900 mm (36 in.) Manhole	500 mm (20 in.) Manhole	600 mm (24 in.) Manhole	750 mm (30 in.) Manhole	900 mm (36 in.) Manhole
5.2 (17.1)	51 (7.4)	8 (5/16)	10 (3/8)	11 (7/16)	13 (1/2)	6 (1/4)	6 (1/4)	8 (5/16)	10 (3/8)
6.7 (21.9)	66 (9.5)	10 (3/8)	11 (7/16)	13 (1/2)	14 (9/16)	6 (1/4)	8 (5/16)	10 (3/8)	11 (7/16)
8.0 (26.1)	78 (11.3)	10 (3/8)	11 (7/16)	14 (9/16)	16 (5/8)	6 (1/4)	8 (5/16)	11 (7/16)	13 (1/2)
9.9 (32.6)	97 (14.1)	11 (7/16)	13 (1/2)	16 (5/8)	18 (11/16)	8 (5/16)	10 (3/8)	13 (1/2)	14 (9/16)
11.1 (36.5)	109 (15.8)	13 (1/2)	14 (9/16)	16 (5/8)	19 (3/4)	10 (3/8)	11 (7/16)	13 (1/2)	16 (5/8)
13.4 (43.9)	131 (19)	13 (1/2)	14 (9/16)	18 (11/16)	21 (13/16)	10 (3/8)	11 (7/16)	14 (9/16)	18 (11/16)
16.1 (52.9)	158 (22.9)	14 (9/16)	16 (5/8)	19 (3/4)	22 (7/8)	11 (7/16)	13 (1/2)	16 (5/8)	19 (3/4)
18.6 (61.0)	182 (26.4)	16 (5/8)	18 (11/16)	21 (13/16)	24 (15/16)	13 (1/2)	14 (9/16)	18 (11/16)	21 (13/16)
22.9 (75.1)	224 (32.5)	18 (11/16)	19 (3/4)	24 (15/16)	25 (1)	13 (1/2)	14 (9/16)	18 (11/16)	24 (15/16)

^aEquivalent pressure is based on water loading.

^bFor addition of corrosion allowance, see 5.7.5.2.

^cCover Plate and Flange thickness given can be used on Manholes dimensioned to ID or OD.

Note: See Figure 5-7A.

Table 5-4—Dimensions for Shell Manhole Neck Thickness

Thickness of Shell and Manhole Reinforcing Plate ^a <i>t</i> and <i>T</i>	Minimum Neck Thickness ^{b,c} <i>t_n</i> mm (in.)			
	For Manhole Diameter 500 mm (20 in.)	For Manhole Diameter 600 mm (24 in.)	For Manhole Diameter 750 mm (30 in.)	For Manhole Diameter 900 mm (36 in.)
5 (3/16)	5 (3/16)	5 (3/16)	5 (3/16)	5 (3/16)
6 (1/4)	6 (1/4)	6 (1/4)	6 (1/4)	6 (1/4)
8 (5/16)	6 (1/4)	6 (1/4)	8 (5/16)	8 (5/16)
10 (3/8)	6 (1/4)	6 (1/4)	8 (5/16)	10 (3/8)
11 (7/16)	6 (1/4)	6 (1/4)	8 (5/16)	10 (3/8)
12.5 (1/2)	6 (1/4)	6 (1/4)	8 (5/16)	10 (3/8)
14 (9/16)	6 (1/4)	6 (1/4)	8 (5/16)	10 (3/8)
16 (5/8)	6 (1/4)	6 (1/4)	8 (5/16)	10 (3/8)
18 (11/16)	6 (1/4)	6 (1/4)	8 (5/16)	10 (3/8)
19 (3/4)	6 (1/4)	6 (1/4)	8 (5/16)	10 (3/8)
21 (13/16)	8 (5/16)	6 (1/4)	8 (5/16)	10 (3/8)
22 (7/8)	10 (3/8)	8 (5/16)	8 (5/16)	10 (3/8)
24 (15/16)	11 (7/16)	11 (7/16)	11 (7/16)	11 (7/16)
25 (1)	11 (7/16)	11 (7/16)	11 (7/16)	11 (7/16)
27 (11/16)	11 (7/16)	11 (7/16)	11 (7/16)	11 (7/16)
28 (11/8)	13 (1/2)	13 (1/2)	13 (1/2)	13 (1/2)
30 (13/16)	14 (9/16)	14 (9/16)	14 (9/16)	14 (9/16)
32 (11/4)	16 (5/8)	14 (9/16)	14 (9/16)	14 (9/16)
33 (15/16)	16 (5/8)	16 (5/8)	16 (5/8)	16 (5/8)
34 (13/8)	17 (11/16)	16 (5/8)	16 (5/8)	16 (5/8)
36 (17/16)	17 (11/16)	17 (11/16)	17 (11/16)	17 (11/16)
40 (11/2)	19 (3/4)	19 (3/4)	19 (3/4)	19 (3/4)

^aIf a shell plate thicker than required is used for the product and hydrostatic loading (see 5.6), the excess shell-plate thickness, within a vertical distance both above and below the centerline of the hole in the tank shell plate equal to the vertical dimension of the hole in the tank shell plate, may be considered as reinforcement, and the thickness *T* of the manhole reinforcing plate may be decreased accordingly. In such cases, the reinforcement and the attachment welding shall conform to the design limits for reinforcement of shell openings specified in 5.7.2.

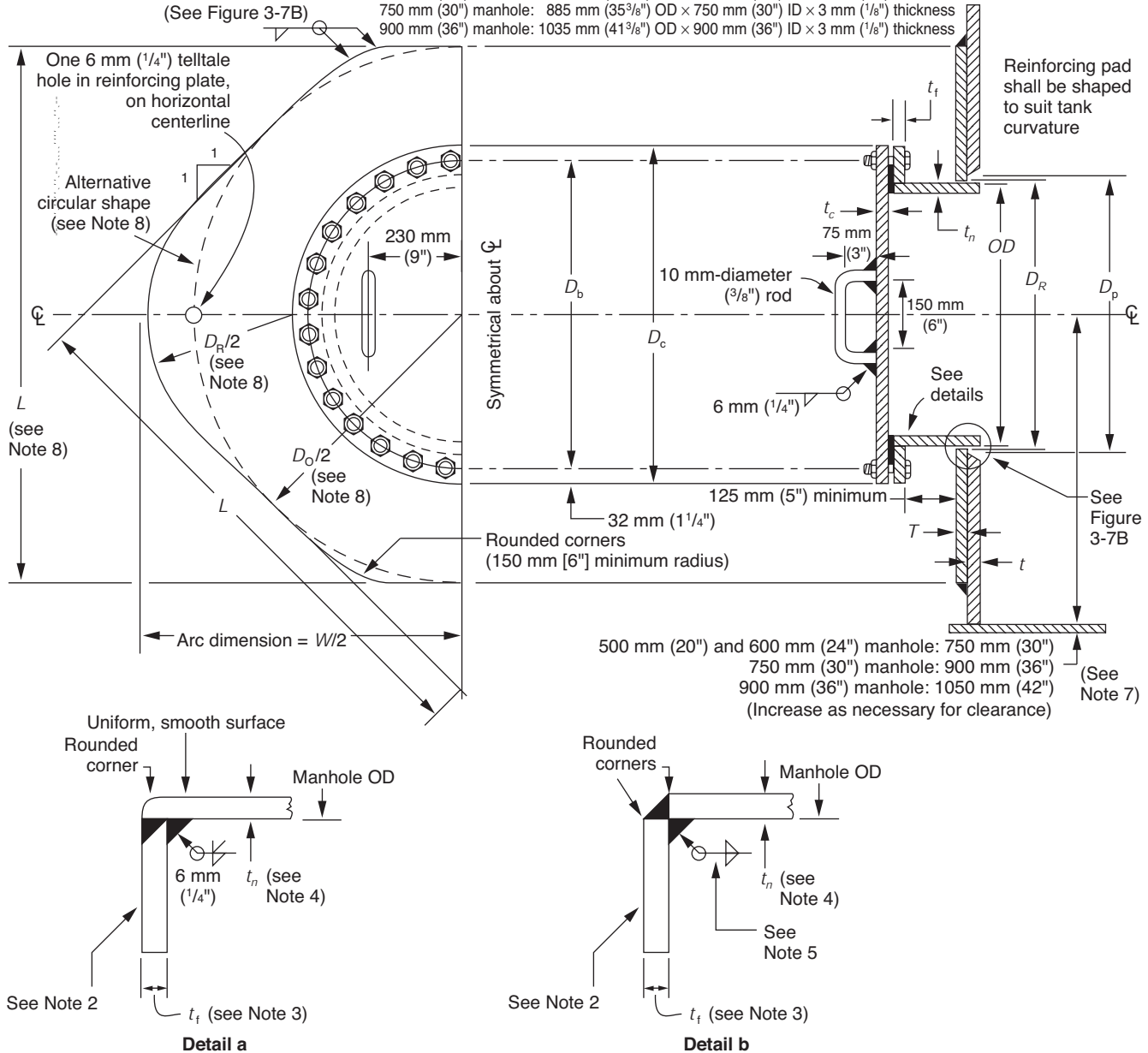
^bReinforcement shall be added if the neck thickness is less than that shown in the column. The minimum neck thickness shall be the thickness of the shell plate or the allowable finished thickness of the bolting flange (see Table 5-3), whichever is thinner, but in no case shall the neck in a built-up manhole be thinner than the thicknesses given. If the neck thickness on a built-up manhole is greater than the required minimum, the manhole reinforcing plate may be decreased accordingly within the limits specified in 5.7.2.

^cFor addition of corrosion allowance, see 5.7.5.2.

500 mm (20") and 600 mm (24") shell manholes: twenty-eight 20 mm-diameter (3/4") bolts in 24 mm (7/8") holes
 750 mm (30") and 900 mm (36") shell manholes: forty-two 20 mm-diameter (3/4") bolts in 24 mm (7/8") holes
 (Bolt holes shall straddle the flange vertical centerline.)

Gasket (see Note 1):

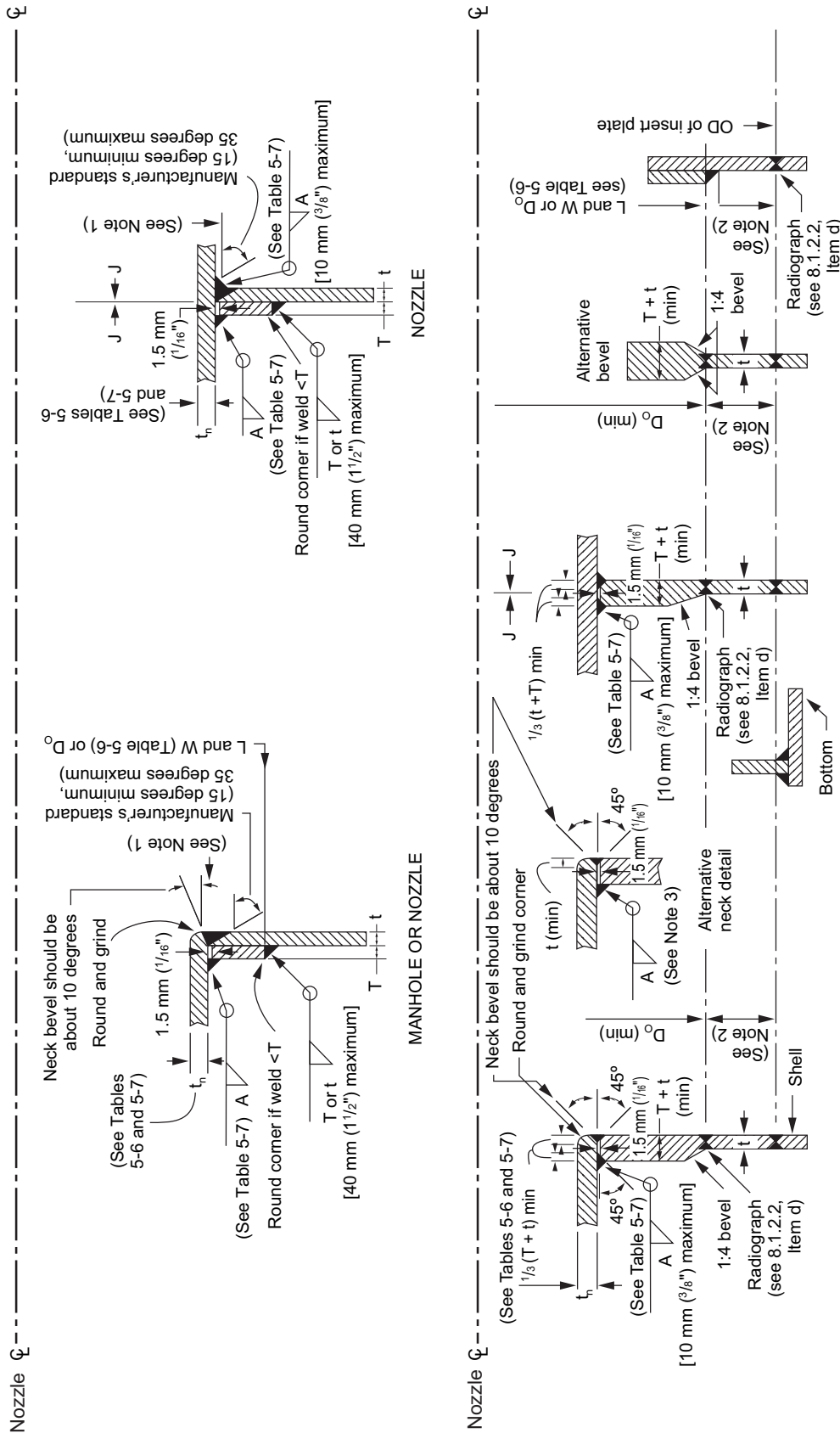
500 mm (20") manhole: 635 mm (25 3/8") OD x 500 mm (20") ID x 3 mm (1/8") thickness
 600 mm (24") manhole: 735 mm (29 3/8") OD x 600 mm (24") ID x 3 mm (1/8") thickness
 750 mm (30") manhole: 885 mm (35 3/8") OD x 750 mm (30") ID x 3 mm (1/8") thickness
 900 mm (36") manhole: 1035 mm (41 3/8") OD x 900 mm (36") ID x 3 mm (1/8") thickness



Notes:

- 1. Gasket material shall be specified by the Purchaser. See 5.7.5.4.
- 2. The gasketed face shall be machine-finished to provide a minimum gasket-bearing width of 20 mm (3/4 in.).
- 3. See Table 5-3.
- 4. See Table 5-4.
- 5. The size of the weld shall equal the thickness of the thinner member joined.
- 6. The shell nozzles shown in Figure 5-8 may be substituted for manholes.
- 7. The minimum centerline elevations allowed by Table 5-6 and Figure 5-6 may be used when approved by the Purchaser.
- 8. For dimensions for OD, D_r, D_o, L, and W, see Table 5-6, Columns 2, 4, 5, and 6. For Dimension D_p see Table 5-7 Column 3.
- 9. At the option of the Manufacturer, the manhole ID may be set to the OD dimension listed in Table 5-6, column 2. Reinforcement area and weld spacing must meet 5.7.2 and 5.7.3 requirements respectively.

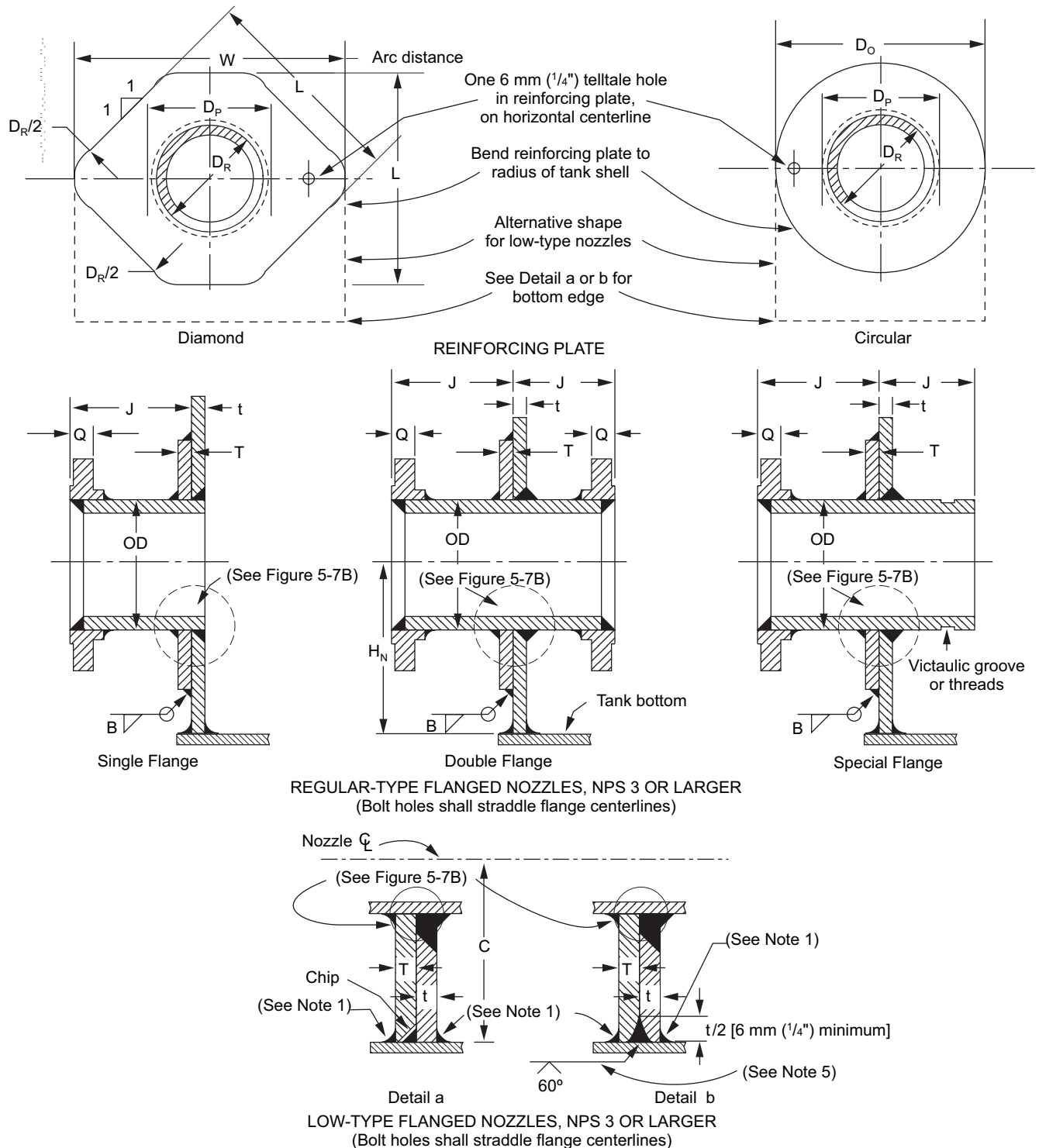
Figure 5-7A—Shell Manhole



INSERT-TYPE REINFORCEMENT FOR MANHOLES AND NOZZLES

- Notes:
1. See Table 5-7, Column 3, for the shell cutout, which shall not be less than the outside diameter of the neck plus 13 mm (1/2) in.
 2. See 5.7.3 for minimum spacing of welds at opening connections.
 3. The weld size shall be either A (from Table 5-7, based on t) or t_r (minimum \bullet t_r (minimum \bullet t_r , whichever is greater. Details of welding bevels may vary from those shown if agreed to by the Purchaser.
 4. Other permissible insert details are shown in Figure 3-8 of API Std 620. The reinforcement area shall conform to 5.7.2.
 5. Dimensions and weld sizes that are not shown are the same as those given in Figure 5-7A and Tables 5-4 – 5-8.
 6. Details of welding bevels may vary from those shown if agreed to by the Purchaser.

Figure 5-7B—Details of Shell Manholes and Nozzles

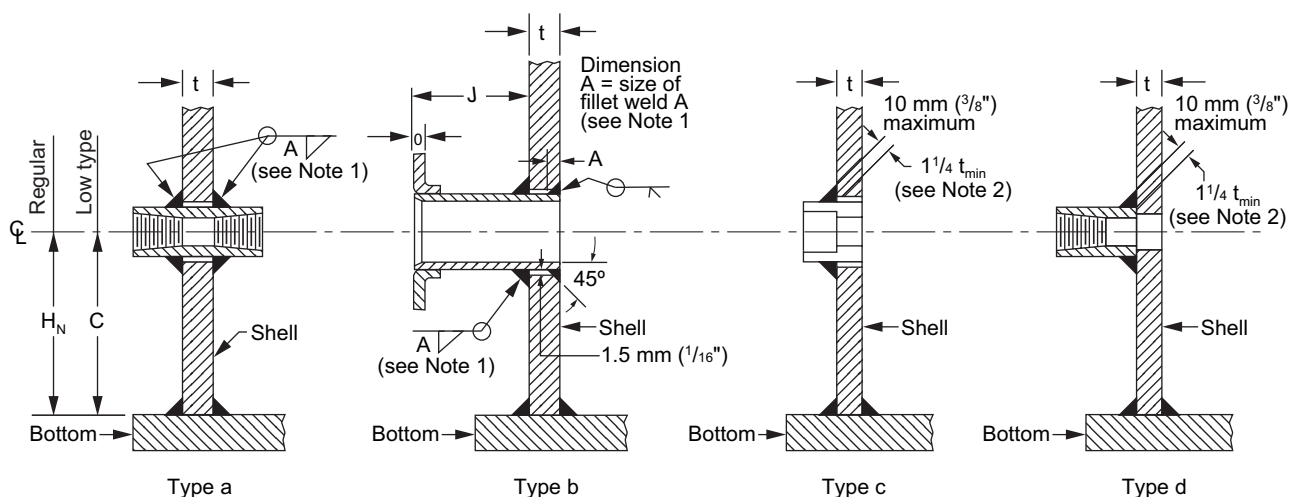


Notes:

- 1. See 5.1.5.7 for information on the size of welds.
- 2. See 5.8.9 for information on the couplings used in shell nozzles.
- 3. Nozzles NPS 3 or larger require reinforcement.

- 4. Details of welding bevels may vary from those shown if agreed to by the Purchaser.
- 5. Shop weld not attached to bottom plate.
- 6. See 5.7.6.2 for information on supplying nozzles flush or with an internal projection.

Figure 5-8—Shell Nozzles (See Tables 5-6, 5-7, and 5-8)



COUPLINGS AND FLANGED FITTINGS, NPS 3/4 THROUGH NPS 2 (SEE NOTE 3)

Notes: (continued)

- 7. See Table 5-7, Column 6.
- 8. t_{min} shall be 19 mm (3/4 in.) or the thickness of either part joined by the fillet weld, whichever is less.
- 9. The construction details apply to unreinforced threaded, non-threaded, and flanged nozzles.

Figure 5-8—Shell Nozzles (continued)

Table 5-5—Dimensions for Bolt Circle Diameter D_b and Cover Plate Diameter D_c for Shell Manholes

Column 1 Manhole Diameter OD mm (in.)	Column 2 Bolt Circle Diameter D_b mm (in.)	Column 3 Cover Plate Diameter D_c mm (in.)
500 (20)	656 (26 1/4)	720 (28 3/4)
600 (24)	756 (30 1/4)	820 (32 3/4)
750 (30)	906 (36 1/4)	970 (38 3/4)
900 (36)	1056 (42 1/4)	1120 (44 3/4)

Note: See Figure 5-7A.

5.7.2 Reinforcement and Welding

5.7.2.1 Openings in tank shells larger than required to accommodate a NPS 2 flanged or threaded nozzle shall be reinforced. The minimum cross-sectional area of the required reinforcement shall not be less than the product of the vertical diameter of the hole cut in the shell and the nominal plate thickness, but when calculations are made for the maximum required thickness considering all design and hydrostatic test load conditions, the required thickness may be used in lieu of the nominal plate thickness. The cross-sectional area of the reinforcement shall be measured vertically, coincident with the diameter of the opening.

- **5.7.2.2** The only shell openings that may utilize welds having less than full penetration through the shell are those that do not require reinforcement and those that utilize a thickened insert plate as shown in Figures 5-7B and 5-8. However, any openings listed in Table 3 of the Data Sheet that are marked “yes” under “Full Penetration on Openings” shall utilize welds that fully penetrate the shell and the reinforcement, if used.

5.7.2.3 Except for flush-type openings and connections, all effective reinforcements shall be made within a distance above and below the centerline of the shell opening equal to the vertical dimension of the hole in the tank shell plate. Reinforcement may be provided by any one or any combination of the following:

- a. The attachment flange of the fitting.
- b. The reinforcing plate. Reinforcing plates for manholes, nozzles, and other attachments shall be of the same nominal composition (i.e., same ASME P-number and Group Number) as the tank part to which they are attached, unless approved otherwise by the Purchaser.

Table 5-6—Dimensions for Shell Nozzles (mm [in.])

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7 ^c	Column 8 ^c	Column 9 ^c
NPS (Size of Nozzle)	Outside Diameter of Pipe OD	Nominal Thickness of Flanged Nozzle Pipe Wall ^a <i>t_n</i>	Diameter of Hole in Reinforcing Plate <i>D_R</i>	Length of Side of Reinforcing Plate ^b or Diameter <i>L = D_o</i>	Width of Reinforcing Plate <i>W</i>	Minimum Distance from Shell-to-Flange Face <i>J</i>	Minimum Distance from Bottom of Tank to Center of Nozzle Regular Type ^d <i>H_N</i>	Low Type <i>C</i>
Flanged Fittings								
48	1219.2 (48)	e	1222 (48 ^{1/8})	2455 (96 ^{3/4})	2970 (117)	400 (16)	1325 (52)	1230 (48 ^{3/8})
46	1168.4 (46)	e	1172 (46 ^{1/8})	2355 (92 ^{3/4})	2845 (112)	400 (16)	1275 (50)	1180 (46 ^{3/8})
44	1117.6 (44)	e	1121 (44 ^{1/8})	2255 (88 ^{3/4})	2725 (107 ^{1/4})	375 (15)	1225 (48)	1125 (44 ^{3/8})
42	1066.8 (42)	e	1070 (42 ^{1/8})	2155 (84 ^{3/4})	2605 (102 ^{1/2})	375 (15)	1175 (46)	1075 (42 ^{3/8})
40	1016 (40)	e	1019 (40 ^{1/8})	2050 (80 ^{3/4})	2485 (97 ^{3/4})	375 (15)	1125 (44)	1025 (40 ^{3/8})
38	965.2 (38)	e	968 (38 ^{1/8})	1950 (76 ^{3/4})	2355 (92 ^{3/4})	350 (14)	1075 (42)	975 (38 ^{3/8})
36	914.4 (36)	e	918 (36 ^{1/8})	1850 (72 ^{3/4})	2235 (88)	350 (14)	1025 (40)	925 (36 ^{3/8})
34	863.6 (34)	e	867 (34 ^{1/8})	1745 (68 ^{3/4})	2115 (83 ^{1/4})	325 (13)	975 (38)	875 (34 ^{3/8})
32	812.8 (32)	e	816 (32 ^{1/8})	1645 (64 ^{3/4})	1995 (78 ^{1/2})	325 (13)	925 (36)	820 (32 ^{3/8})
30	762.0 (30)	e	765 (30 ^{1/8})	1545 (60 ^{3/4})	1865 (73 ^{1/2})	300 (12)	875 (34)	770 (30 ^{3/8})
28	711.2 (28)	e	714 (28 ^{1/8})	1440 (56 ^{3/4})	1745 (68 ^{3/4})	300 (12)	825 (32)	720 (28 ^{3/8})
26	660.4 (26)	e	664 (26 ^{1/8})	1340 (52 ^{3/4})	1625 (64)	300 (12)	750 (30)	670 (26 ^{3/8})
24	609.6 (24)	12.7 (0.50)	613 (24 ^{1/8})	1255 (49 ^{1/2})	1525 (60)	300 (12)	700 (28)	630 (24 ^{3/4})
22	558.8 (22)	12.7 (0.50)	562 (22 ^{1/8})	1155 (45 ^{1/2})	1405 (55 ^{1/4})	275 (11)	650 (26)	580 (22 ^{3/4})
20	508.0 (20)	12.7 (0.50)	511 (20 ^{1/8})	1055 (41 ^{1/2})	1285 (50 ^{1/2})	275 (11)	600 (24)	525 (20 ^{3/4})
18	457.2 (18)	12.7 (0.50)	460 (18 ^{1/8})	950 (37 ^{1/2})	1160 (45 ^{3/4})	250 (10)	550 (22)	475 (18 ^{3/4})
16	406.4 (16)	12.7 (0.50)	410 (16 ^{1/8})	850 (33 ^{1/2})	1035 (40 ^{3/4})	250 (10)	500 (20)	425 (16 ^{3/4})
14	355.6 (14)	12.7 (0.50)	359 (14 ^{1/8})	750 (29 ^{1/2})	915 (36)	250 (10)	450 (18)	375 (14 ^{3/4})
12	323.8 (12 ^{3/4})	12.7 (0.50)	327 (12 ^{7/8})	685 (27)	840 (33)	225 (9)	425 (17)	345 (13 ^{1/2})
10	273.0 (10 ^{3/4})	12.7 (0.50)	276 (10 ^{7/8})	585 (23)	720 (28 ^{1/4})	225 (9)	375 (15)	290 (11 ^{1/2})
8	219.1 (8 ^{5/8})	12.7 (0.50)	222 (8 ^{3/4})	485 (19)	590 (23 ^{1/4})	200 (8)	325 (13)	240 (9 ^{1/2})
6	168.3 (6 ^{5/8})	10.97 (0.432)	171 (6 ^{3/4})	400 (15 ^{3/4})	495 (19 ^{1/2})	200 (8)	275 (11)	200 (7 ^{7/8})
4	114.3 (4 ^{1/2})	8.56 (0.337)	117 (4 ^{5/8})	305 (12)	385 (15 ^{1/4})	175 (7)	225 (9)	150 (6)
3	88.9 (3 ^{1/2})	7.62 (0.300)	92 (3 ^{5/8})	265 (10 ^{1/2})	345 (13 ^{1/2})	175 (7)	200 (8)	135 (5 ^{1/4})
2 ^f	60.3 (2 ^{3/8})	5.54 (0.218)	63 (2 ^{1/2})	—	—	150 (6)	175 (7)	h
1 ^{1/2} ^f	48.3 (1.90)	5.08 (0.200)	51 (2)	—	—	150 (6)	150 (6)	h
1 ^f	33.4 (1.315)	6.35 (0.250)	—	—	—	150 (6)	150 (6)	h
3/4 ^f	26.7 (1.05)	5.54 (0.218)	—	—	—	150 (6)	150 (6)	h
Threaded and Socket-Welded Couplings								
3 ^g	108.0 (4.250)	Coupling	111.1 (4 ^{3/8})	285 (11 ^{1/4})	360 (14 ^{1/4})	—	225 (9)	145 (5 ^{5/8})
2 ^f	76.2 (3.000)	Coupling	79.4 (3 ^{1/8})	—	—	—	175 (7)	h
1 ^{1/2} ^f	63.5 (2.500)	Coupling	66.7 (2 ^{5/8})	—	—	—	150 (6)	h
1 ^f	44.5 (1.750)	Coupling	47.6 (1 ^{7/8})	—	—	—	125 (5)	h
3/4 ^f	35.0 (1.375)	Coupling	38.1 (1 ^{1/2})	—	—	—	100 (4)	h

^aFor extra-strong pipe, see ASTM A 53 or A 106 for other wall thicknesses; however, piping material must conform to 4.5.

^bThe width of the shell plate shall be sufficient to contain the reinforcing plate and to provide clearance from the girth joint of the shell course.

• ^cUnless otherwise specified by the Purchaser, the nozzle shall be located at the minimum distance but shall also meet the weld spacing requirements of 5.7.3.

^dThe *H_N* dimensions given in this table are for Appendix A tank designs only; see 5.7.3 to determine minimum *H_N* for basic tank designs.

^eSee Table 5-7, Column 2.

^fFlanged nozzles and couplings in pipe sizes NPS 2 or smaller do not require reinforcing plates. *D_R* will be the diameter of the hole in the shell plate, and Weld *A* will be as specified in Table 5-7, Column 6. Reinforcing plates may be used if the construction details comply with reinforced nozzle details.

^gA coupling in an NPS 3 requires reinforcement.

^hSee 5.7.3.

Note: See Figure 5-8.

Table 5-7—Dimensions for Shell Nozzles: Pipe, Plate, and Welding Schedules (mm [in.])

Column 1 Thickness of Shell and Reinforcing Plate ^a <i>t</i> and <i>T</i>	Column 2 Minimum Pipe Wall Thickness of Flanged Nozzles ^b <i>t_n</i>	Column 3 Maximum Diameter of Hole in Shell Plate (<i>D_p</i>) Equals Outside Diameter of Pipe Plus	Column 4 Size of Fillet Weld <i>B</i>	Column 5 Size of Fillet Weld <i>A</i>		Column 6 NPS ³ / ₄ to 2 Nozzles
				Nozzles Larger Than NPS 2		
5 (³ / ₁₆)	12.5 (¹ / ₂)	16 (⁵ / ₈)	5 (³ / ₁₆)	6 (¹ / ₄)		6 (¹ / ₄)
6 (¹ / ₄)	12.5 (¹ / ₂)	16 (⁵ / ₈)	6 (¹ / ₄)	6 (¹ / ₄)		6 (¹ / ₄)
8 (⁵ / ₁₆)	12.5 (¹ / ₂)	16 (⁵ / ₈)	8 (⁵ / ₁₆)	6 (¹ / ₄)		6 (¹ / ₄)
10 (³ / ₈)	12.5 (¹ / ₂)	16 (⁵ / ₈)	10 (³ / ₈)	6 (¹ / ₄)		6 (¹ / ₄)
11 (⁷ / ₁₆)	12.5 (¹ / ₂)	16 (⁵ / ₈)	11 (⁷ / ₁₆)	6 (¹ / ₄)		6 (¹ / ₄)
12.5 (¹ / ₂)	12.5 (¹ / ₂)	16 (⁵ / ₈)	13 (¹ / ₂)	6 (¹ / ₄)		8 (⁵ / ₁₆)
14 (⁹ / ₁₆)	12.5 (¹ / ₂)	20 (³ / ₄)	14 (⁹ / ₁₆)	6 (¹ / ₄)		8 (⁵ / ₁₆)
16 (⁵ / ₈)	12.5 (¹ / ₂)	20 (³ / ₄)	16 (⁵ / ₈)	8 (⁵ / ₁₆)		8 (⁵ / ₁₆)
17 (¹¹ / ₁₆)	12.5 (¹ / ₂)	20 (³ / ₄)	18 (¹¹ / ₁₆)	8 (⁵ / ₁₆)		8 (⁵ / ₁₆)
20 (³ / ₄)	12.5 (¹ / ₂)	20 (³ / ₄)	20 (³ / ₄)	8 (⁵ / ₁₆)		8 (⁵ / ₁₆)
21 (¹³ / ₁₆)	12.5 (¹ / ₂)	20 (³ / ₄)	21 (¹³ / ₁₆)	10 (³ / ₈)		8 (⁵ / ₁₆)
22 (⁷ / ₈)	12.5 (¹ / ₂)	20 (³ / ₄)	22 (⁷ / ₈)	10 (³ / ₈)		8 (⁵ / ₁₆)
24 (¹⁵ / ₁₆)	12.5 (¹ / ₂)	20 (³ / ₄)	24 (¹⁵ / ₁₆)	10 (³ / ₈)		8 (⁵ / ₁₆)
25 (1)	12.5 (¹ / ₂)	20 (³ / ₄)	25 (1)	11 (⁷ / ₁₆)		8 (⁵ / ₁₆)
27 (¹ / ₁₆)	14 (⁹ / ₁₆)	20 (³ / ₄)	27 (¹ / ₁₆)	11 (⁷ / ₁₆)		8 (⁵ / ₁₆)
28 (¹ / ₈)	14 (⁹ / ₁₆)	20 (³ / ₄)	28 (¹ / ₈)	11 (⁷ / ₁₆)		8 (⁵ / ₁₆)
30 (¹ / ₁₆)	16 (⁵ / ₈)	20 (³ / ₄)	30 (¹ / ₁₆)	13 (¹ / ₂)		8 (⁵ / ₁₆)
32 (¹ / ₄)	16 (⁵ / ₈)	20 (³ / ₄)	32 (¹ / ₄)	13 (¹ / ₂)		8 (⁵ / ₁₆)
33 (¹ / ₁₆)	17 (¹¹ / ₁₆)	20 (³ / ₄)	33 (¹ / ₁₆)	13 (¹ / ₂)		8 (⁵ / ₁₆)
35 (¹ / ₈)	17 (¹¹ / ₁₆)	20 (³ / ₄)	35 (¹ / ₈)	14 (⁹ / ₁₆)		8 (⁵ / ₁₆)
36 (¹ / ₁₆)	20 (³ / ₄)	20 (³ / ₄)	36 (¹ / ₁₆)	14 (⁹ / ₁₆)		8 (⁵ / ₁₆)
38 (¹ / ₂)	20 (³ / ₄)	20 (³ / ₄)	38 (¹ / ₂)	14 (⁹ / ₁₆)		8 (⁵ / ₁₆)
40 (⁹ / ₁₆)	21 (¹³ / ₁₆)	20 (³ / ₄)	38 (⁹ / ₁₆)	14 (⁹ / ₁₆)		8 (⁵ / ₁₆)
41 (⁵ / ₈)	21 (¹³ / ₁₆)	20 (³ / ₄)	38 (¹ / ₂)	16 (⁵ / ₈)		8 (⁵ / ₁₆)
43 (¹¹ / ₁₆)	22 (⁷ / ₈)	20 (³ / ₄)	38 (¹ / ₂)	16 (⁵ / ₈)		8 (⁵ / ₁₆)
45 (³ / ₄)	22 (⁷ / ₈)	20 (³ / ₄)	38 (¹ / ₂)	16 (⁵ / ₈)		8 (⁵ / ₁₆)

^aIf a shell plate thicker than required is used for the product and hydrostatic loading (see 5.6), the excess shell-plate thickness, within a vertical distance both above and below the centerline of the hole in the tank shell plate equal to the vertical dimension of the hole in the tank shell plate, may be considered as reinforcement, and the thickness *T* of the nozzle reinforcing plate may be decreased accordingly. In such cases, the reinforcement and the attachment welding shall conform to the design limits for reinforcement of shell openings specified in 5.7.2.

^bThis column applies to NPS 48, 46, 44, 42, 40, 38, 36, 34, 32, 30, 28, and 26 flanged nozzles. See 4.5 for piping materials.

^cNote: See Figure 5-8.

Table 5-8—Dimensions for Shell Nozzle Flanges (mm [in.])

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10		Column 11		Column 12	
									Diameter of Bore		Minimum Diameter of Hub at Point of Weld			
									Slip-On Type: Outside Diameter of Pipe Plus B	Welding Neck Type ^a B ₁	Slip-On Type ^b E	Welding- Neck Type ^c E ₁		
NPS (Size of Nozzle)	Minimum Thickness of Flange ^d Q	Outside Diameter of Flange A	Diameter of Raised Face D	Diameter of Bolt Circle C	Number of Holes	Diameter of Holes	Diameter of Bolts							
48	70 (2 ³ / ₄)	1510 (59 ¹ / ₂)	1360 (53 ¹ / ₂)	1420 (56)	44	42 (1 ⁵ / ₈)	38 (1 ¹ / ₂)	6.8 (0.25)	a	b	c			
46	68 (2 ¹¹ / ₁₆)	1460 (57 ¹ / ₂)	1295 (51)	1365 (53 ³ / ₄)	40	42 (1 ⁵ / ₈)	38 (1 ¹ / ₂)	6.6 (0.25)	a	b	c			
44	67 (2 ⁵ / ₈)	1405 (55 ¹ / ₄)	1245 (49)	1315 (51 ³ / ₄)	40	42 (1 ⁵ / ₈)	38 (1 ¹ / ₂)	6.4 (0.25)	a	b	c			
42	67 (2 ⁵ / ₈)	1345 (53)	1195 (47)	1255 (49 ¹ / ₂)	36	42 (1 ⁵ / ₈)	38 (1 ¹ / ₂)	6.2 (0.25)	a	b	c			
40	65 (2 ¹ / ₂)	1290 (50 ³ / ₄)	1125 (44 ¹ / ₄)	1200 (47 ¹ / ₄)	36	42 (1 ⁵ / ₈)	38 (1 ¹ / ₂)	6.0 (0.25)	a	b	c			
38	60 (2 ³ / ₈)	1240 (48 ³ / ₄)	1075 (42 ¹ / ₄)	1150 (45 ¹ / ₄)	32	42 (1 ⁵ / ₈)	38 (1 ¹ / ₂)	6.8 (0.25)	a	b	c			
36	60 (2 ³ / ₈)	1170 (46)	1020 (40 ¹ / ₄)	1085 (42 ³ / ₄)	32	42 (1 ⁵ / ₈)	38 (1 ¹ / ₂)	6.6 (0.25)	a	b	c			
34	59 (2 ⁵ / ₁₆)	1110 (43 ³ / ₄)	960 (37 ³ / ₄)	1030 (40 ¹ / ₂)	32	42 (1 ⁵ / ₈)	38 (1 ¹ / ₂)	6.4 (0.25)	a	b	c			
32	57 (2 ¹ / ₄)	1060 (41 ³ / ₄)	910 (35 ³ / ₄)	980 (38 ¹ / ₂)	28	42 (1 ⁵ / ₈)	38 (1 ¹ / ₂)	6.2 (0.25)	a	b	c			
30	54 (2 ¹ / ₈)	985 (38 ³ / ₄)	855 (33 ³ / ₄)	915 (36)	28	33 (1 ³ / ₈)	30 (1 ¹ / ₄)	6.0 (0.25)	a	b	c			
28	52 (2 ¹ / ₁₆)	925 (36 ¹ / ₂)	795 (31 ¹ / ₄)	865 (34)	28	33 (1 ³ / ₈)	30 (1 ¹ / ₄)	6.8 (0.25)	a	b	c			
26	50 (2)	870 (34 ¹ / ₄)	745 (29 ¹ / ₄)	805 (31 ³ / ₄)	24	33 (1 ³ / ₈)	30 (1 ¹ / ₄)	6.6 (0.25)	a	b	c			
24	48 (1 ⁷ / ₈)	815 (32)	690 (27 ¹ / ₄)	750 (29 ¹ / ₂)	20	33 (1 ³ / ₈)	30 (1 ¹ / ₄)	4.4 (0.19)	a	b	c			
22	46 (1 ¹³ / ₁₆)	750 (29 ¹ / ₂)	640 (25 ¹ / ₄)	690 (27 ¹ / ₄)	20	33 (1 ³ / ₈)	30 (1 ¹ / ₄)	5.2 (0.19)	a	b	c			
20	43 (1 ¹¹ / ₁₆)	700 (27 ¹ / ₂)	585 (23)	635 (25)	20	30 (1 ¹ / ₄)	27 (1 ¹ / ₈)	5.0 (0.19)	a	b	c			
18	40 (1 ⁹ / ₁₆)	635 (25)	535 (21)	580 (22 ³ / ₄)	16	30 (1 ¹ / ₄)	27 (1 ¹ / ₈)	4.8 (0.19)	a	b	c			
16	36 (1 ⁷ / ₁₆)	595 (23 ¹ / ₂)	470 (18 ¹ / ₂)	540 (21 ¹ / ₄)	16	27 (1 ¹ / ₈)	24 (1)	4.6 (0.19)	a	b	c			
14	35 (1 ³ / ₈)	535 (21)	415 (16 ¹ / ₄)	475 (18 ³ / ₄)	12	27 (1 ¹ / ₈)	24 (1)	4.4 (0.19)	a	b	c			
12	32 (1 ¹ / ₄)	485 (19)	380 (15)	430 (17)	12	25 (1)	22 (7/8)	3.15 (0.13)	a	b	c			
10	30 (1 ³ / ₁₆)	405 (16)	325 (12 ³ / ₄)	360 (14 ¹ / ₄)	12	25 (1)	22 (7/8)	2.95 (0.13)	a	b	c			
8	28 (1 ¹ / ₈)	345 (13 ¹ / ₂)	270 (10 ⁵ / ₈)	300 (11 ³ / ₄)	8	23 (7/8)	20 (3/4)	2.92 (0.10)	a	b	c			
6	25 (1)	280 (11)	216 (8 ¹ / ₂)	240 (9 ¹ / ₂)	8	23 (7/8)	20 (3/4)	2.72 (0.10)	a	b	c			
4	24 (1 ⁵ / ₁₆)	230 (9)	157 (6 ³ / ₁₆)	190 (7 ¹ / ₂)	8	19 (3/4)	16 (5/8)	1.7 (0.06)	a	b	c			
3	24 (1 ⁵ / ₁₆)	190 (7 ¹ / ₂)	127 (5)	152 (6)	4	19 (3/4)	16 (5/8)	1.1 (0.06)	a	b	c			
2	20 (3/4)	150 (6)	92 (3 ⁵ / ₈)	121 (4 ³ / ₄)	4	19 (3/4)	16 (5/8)	1.68 (0.07)	a	b	c			
1 ¹ / ₂	17 (1 ¹ / ₁₆)	125 (5)	73 (2 ⁷ / ₈)	98 (3 ⁷ / ₈)	4	16 (5/8)	12 (1/2)	1.74 (0.07)	a	b	c			

^aB₁ = inside diameter of pipe.

^bE = outside diameter of pipe + 2t_n.

^cE₁ = outside diameter of pipe.

- ^dCorrosion allowance, if specified, need not be added to flange and cover thicknesses complying with ASME B16.5 Class 150, ASME B16.1 Class 125, and ASME B16.47 flanges.

Note: See Figure 5-8. The facing dimensions for slip-on and welding-neck flanges in NPS 1¹/₂ through 20 and NPS 24 are identical to those specified in ASME B16.5 for Class 150 steel flanges. The facing dimensions for flanges in NPS 30, 36, 42, and 48 are in agreement with ASME B16.1 for Class 125 cast iron flanges. The dimensions for large flanges may conform to Series B of ASME B16.47.

Table 5-9—Dimensions for Flush-Type Cleanout Fittings (mm [in.])

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11
Height of Opening <i>h</i>	Width of Opening <i>b</i>	Arc Width of Shell Reinforcing Plate <i>W</i>	Upper Corner Radius of Opening <i>r</i> ₁	Upper Corner Radius of Shell Reinforcing Plate <i>r</i> ₂	Edge Distance of Bolts <i>e</i>	Flange Width ^a (Except at Bottom) <i>f</i> ₃	Bottom Flange Width <i>f</i> ₂	Special Bolt Spacing ^b <i>g</i>	Number of Bolts	Diameter of Bolts
200 (8)	400 (16)	1170 (46)	100 (4)	360 (14)	32 (1 ¹ / ₄)	100 (4)	90 (3 ¹ / ₂)	80 (3 ¹ / ₄)	22	20 (3 ³ / ₄)
600 (24)	600 (24)	1830 (72)	300 (12)	740 (29)	40 (1 ¹ / ₂)	100 (4)	95 (3 ³ / ₄)	90 (3 ¹ / ₂)	36	20 (3 ³ / ₄)
900 (36)	1200 (48)	2700 (106)	450 ^c (18)	1040 (41)	40 (1 ¹ / ₂)	115 (4 ¹ / ₂)	120 (4 ³ / ₄)	110 (4 ¹ / ₄)	46	24 (1)
1200 ^d (48)	1200 (48)	3200 (125)	600 (24)	1310 (51 ¹ / ₂)	40 (1 ¹ / ₂)	115 (4 ¹ / ₂)	125 (5)	115 (4 ¹ / ₂)	52	24 (1)

^aFor neck thicknesses greater than 40 mm (1⁹/₁₆ in.), increase *f*₃ as necessary to provide a 1.5 mm (1¹/₁₆ in.) clearance between the required neck-to-flange weld and the head of the bolt.

^bRefers to spacing at the lower corners of the cleanout-fitting flange.

• ^cFor Groups IV, IVA, V, and VI, 600 mm (24 in.).

^dOnly for Group I, II, III, or IIIA shell materials (see 5.7.7.2).

Note: See Figure 5-12.

Table 5-10—Minimum Thickness of Cover Plate, Bolting Flange, and Bottom Reinforcing Plate for Flush-Type Cleanout Fittings (mm [in.])

Maximum Design Liquid Level m (ft) <i>H</i>	Equivalent Pressure ^a kPa (psi)	Size of Opening <i>h</i> × <i>b</i> (Height × Width)							
		200 × 400 (8 × 16)		600 × 600 (24 × 24)		900 × 1200 (36 × 48)		1200 × 1200 (48 × 48)	
		Thickness of Bolting Flange and Cover Plate <i>t</i> _c	Thickness of Bottom Reinforcing Plate ^b <i>t</i> _b	Thickness of Bolting Flange and Cover Plate <i>t</i> _c	Thickness of Bottom Reinforcing Plate ^c <i>t</i> _b	Thickness of Bolting Flange and Cover Plate <i>t</i> _c	Thickness of Bottom Reinforcing Plate ^d <i>t</i> _b	Thickness of Bolting Flange and Cover Plate <i>t</i> _c	Thickness of Bottom Reinforcing Plate ^e <i>t</i> _b
6.1 (20)	60 (8.7)	10 (3 ⁸ / ₈)	13 (1 ² / ₂)	10 (3 ⁸ / ₈)	13 (1 ² / ₂)	16 (5 ⁸ / ₈)	21 (13 ¹⁶ / ₁₆)	16 (5 ⁸ / ₈)	22 (7 ⁸ / ₈)
10 (34)	98 (14.7)	10 (3 ⁸ / ₈)	13 (1 ² / ₂)	13 (1 ² / ₂)	13 (1 ² / ₂)	19 (3 ⁴ / ₄)	25 (1)	21 (13 ¹⁶ / ₁₆)	28 (1 ⁸ / ₈)
12 (41)	118 (17.8)	10 (3 ⁸ / ₈)	13 (1 ² / ₂)	13 (1 ² / ₂)	14 (9 ¹⁶ / ₁₆)	22 (7 ⁸ / ₈)	28 (1 ⁸ / ₈)	22 (7 ⁸ / ₈)	30 (13 ¹⁶ / ₁₆)
16 (53)	157 (23)	10 (3 ⁸ / ₈)	13 (1 ² / ₂)	14 (9 ¹⁶ / ₁₆)	16 (5 ⁸ / ₈)	24 (15 ¹⁶ / ₁₆)	32 (1 ⁴ / ₄)	25 (1)	33 (15 ¹⁶ / ₁₆)
18 (60)	177 (26)	11 (7 ¹⁶ / ₁₆)	13 (1 ² / ₂)	16 (5 ⁸ / ₈)	18 (11 ¹⁶ / ₁₆)	25 (1)	33 (15 ¹⁶ / ₁₆)	28 (1 ⁸ / ₈)	35 (13 ⁸ / ₈)
20 (64)	196 (27.8)	11 (7 ¹⁶ / ₁₆)	13 (1 ² / ₂)	16 (5 ⁸ / ₈)	18 (11 ¹⁶ / ₁₆)	27 (1 ¹⁶ / ₁₆)	35 (13 ⁸ / ₈)	28 (1 ⁸ / ₈)	36 (17 ¹⁶ / ₁₆)
22 (72)	216 (31.2)	11 (7 ¹⁶ / ₁₆)	13 (1 ² / ₂)	18 (11 ¹⁶ / ₁₆)	19 (3 ⁴ / ₄)	28 (1 ⁸ / ₈)	36 (17 ¹⁶ / ₁₆)	30 (13 ¹⁶ / ₁₆)	38 (1 ² / ₂)

^aEquivalent pressure is based on water loading.

^bMaximum of 25 mm (1 in.).

^cMaximum of 28 mm (1¹/₈ in.).

^dMaximum of 38 mm (1¹/₂ in.).

^eMaximum of 45 mm (1³/₄ in.).

Note: See Figure 5-12.

Table 5-11—Thicknesses and Heights of Shell Reinforcing Plates for Flush-Type Cleanout Fittings (mm [in.])

Thickness of Lowest Shell Course <i>t</i> , <i>t</i> _d ^a mm (ft)	Maximum Design Liquid Level ^c <i>H</i> m (ft)	Height of Shell Reinforcing Plate for Size of Opening <i>h</i> × <i>b</i> (Height × Width) mm (ft)			
		200 × 400 (8 × 16)	600 × 600 (24 × 24)	900 × 1200 (36 × 48)	1200 × 1200 (48 × 48)
All	< 22 (72)	350 (14)	915 (36)	1372 (54)	1830 (72)

Notes:

^aDimensions *t*_d and *L* may be varied within the limits defined in 5.7.7.

^b1200 × 1200 (48 × 48) flush-type cleanout fittings are not permitted for tanks with greater than 38 mm (1¹/₂ in.) lowest shell course thickness.

^cSee 5.6.3.2.

Table 5-12—Dimensions for Flush-Type Shell Connections (mm [in.])

Class 150 Nominal Height of Flange Size	Height of Opening h	Width of Opening b	Arc Width of Shell Reinforcing Plate W	Upper Corner Radius of Opening r_1	Lower Corner Radius of Shell Reinforcing Plate r_2
8	200 (8 ^{5/8})	200 (8 ^{5/8})	950 (38)	100 (4) ^a	350 (14)
12	300 (12 ^{3/4})	300 (12 ^{3/4})	1300 (52)	150 (4) ^a	450 (18)
16	300 (12)	500 (20)	1600 (64)	150 (6)	450 (18)
18	300 (12)	550 (22)	1650 (66)	150 (6)	450 (18)
20	300 (12)	625 (25)	1725 (69)	150 (6)	450 (18)
24	300 (12)	900 (36)	2225 (89)	150 (6)	450 (18)

^aFor circular openings, this value will be $1/2$ of the ID based on the nozzle neck specified.
Note: See Figure 5-14.

- 07 | c. The portion of the neck of the fitting that may be considered as reinforcement according to 5.7.2.4.
- d. Excess shell-plate thickness. Reinforcement may be provided by any shell-plate thickness in excess of the thickness required by the governing load condition within a vertical distance above and below the centerline of the hole in the shell equal to the vertical dimension of the hole in the tank shell plate as long as the extra shell-plate thickness is the actual plate thickness used less the required thickness, calculated at the applicable opening, considering all load conditions and the corrosion allowance.
- e. The material in the nozzle neck. The strength of the material in the nozzle neck used for reinforcement should preferably be the same as the strength of the tank shell, but lower strength material is permissible as reinforcement as long as the neck material has minimum specified yield and tensile strengths not less than 70% and 80%, respectively, of the shell-plate minimum specified yield and tensile strengths. When the material strength is greater than or equal to the 70% and 80% minimum values, the area in the neck available for reinforcement shall be reduced by the ratio of the allowable stress in the neck, using the governing stress factors, to the allowable stress in the attached shell plate. No credit may be taken for the additional strength of any reinforcing material that has a higher allowable stress than that of the shell plate. Neck material that has a yield or tensile strength less than the 70% or 80% minimum values may be used, provided that no neck area is considered as effective reinforcement.
- 07 | **5.7.2.4** The following portions of the neck of a fitting may be considered part of the area of reinforcement, except where prohibited by 5.7.2.3, Item e:
- The portion extending outward from the outside surface of the tank shell plate to a distance equal to four times the neck-wall thickness or, if the neck-wall thickness is reduced within this distance, to the point of transition.
 - The portion lying within the shell-plate thickness.
 - The portion extending inward from the inside surface of the tank shell plate to the distance specified in Item a.
- 5.7.2.5** The aggregate strength of the weld attaching a fitting to the shell plate, an intervening reinforcing plate, or both shall at least equal the proportion of the forces passing through the entire reinforcement that is calculated to pass through the fitting.
- 5.7.2.6** The aggregate strength of the welds attaching any intervening reinforcing plate to the shell plate shall at least equal the proportion of the forces passing through the entire reinforcement that is calculated to pass through the reinforcing plate.
- 07 | **5.7.2.7** The attachment weld to the shell along the outer periphery of a reinforcing plate or proprietary connection that lap welds to the shell shall be considered effective only for the parts lying outside the area bounded by vertical lines drawn tangent to the shell opening; however, the outer peripheral weld shall be applied completely around the reinforcement. See 5.7.2.8 for allowable stresses. All of the inner peripheral weld shall be considered effective. The strength of the effective attachment weld shall be considered as the weld's shear resistance at the stress value given for fillet welds in 5.7.2.8. The size of the outer peripheral weld shall be equal to the thickness of the shell plate or reinforcing plate, whichever is thinner, but shall not be greater than 38 mm (1 $\frac{1}{2}$ in.). When low-type nozzles are used with a reinforcing plate that extends to the tank bottom (see Figure 5-8), the size of the portion of the peripheral weld that attaches the reinforcing plate to the bottom plate shall conform to 5.1.5.7. The inner peripheral weld shall be large enough to sustain the remainder of the loading.

5.7.2.8 The reinforcement and welding shall be configured to provide the required strength for the forces covered in 5.7.2.5 and 5.7.2.6.

The allowable stresses for the attachment elements are:

- For outer reinforcing plate-to-shell and inner reinforcing plate-to-nozzle neck fillet welds: $S_d \times 0.60$.
- For tension across groove welds: $S_d \times 0.875 \times 0.70$
- For shear in the nozzle neck: $S_d \times 0.80 \times 0.875$

where

S_d = the maximum allowable design stress (the lesser value of the base materials joined) permitted by 5.6.2.1 for carbon steel, or by Table S-2 for stainless steel.

Stress in fillet welds shall be considered as shear on the throat of the weld. The throat of the fillet shall be assumed to be 0.707 times the length of the shorter leg. Tension stress in the groove weld shall be considered to act over the effective weld depth.

5.7.2.9 When two or more openings are located so that the outer edges (toes) of their normal reinforcing-plate fillet welds are closer than eight times the size of the larger of the fillet welds, with a minimum of 150 mm (6 in.), they shall be treated and reinforced as follows:

- All such openings shall be included in a single reinforcing plate that shall be proportioned for the largest opening in the group.
- If the normal reinforcing plates for the smaller openings in the group, considered separately, fall within the area limits of the solid portion of the normal plate for the largest opening, the smaller openings may be included in the normal plate for the largest opening without an increase in the size of the plate, provided that if any opening intersects the vertical centerline of another opening, the total width of the final reinforcing plate along the vertical centerline of either opening is not less than the sum of the widths of the normal plates for the openings involved.
- If the normal reinforcing plates for the smaller openings in the group, considered separately, do not fall within the area limits of the solid portion of the normal plate for the largest opening, the group reinforcing-plate size and shape shall include the outer limits of the normal reinforcing plates for all the openings in the group. A change in size from the outer limits of the normal plate for the largest opening to the outer limits of that for the smaller opening farthest from the largest opening shall be accomplished by uniform straight taper unless the normal plate for any intermediate opening would extend beyond these limits, in which case uniform straight tapers shall join the outer limits of the several normal plates. The provisions of Item b with respect to openings on the same or adjacent vertical centerlines also apply in this case.

5.7.2.10 Reinforcing plates for shell openings, or each segment of the plates if they are not made in one piece, shall be provided with a 6 mm ($1/4$ in.) diameter telltale hole. Such holes shall be located on the horizontal centerline and shall be open to the atmosphere.

5.7.3 Spacing of Welds around Connections

See Figure 5-6 for spacing requirements listed in 5.7.3.1 through 5.7.3.4.

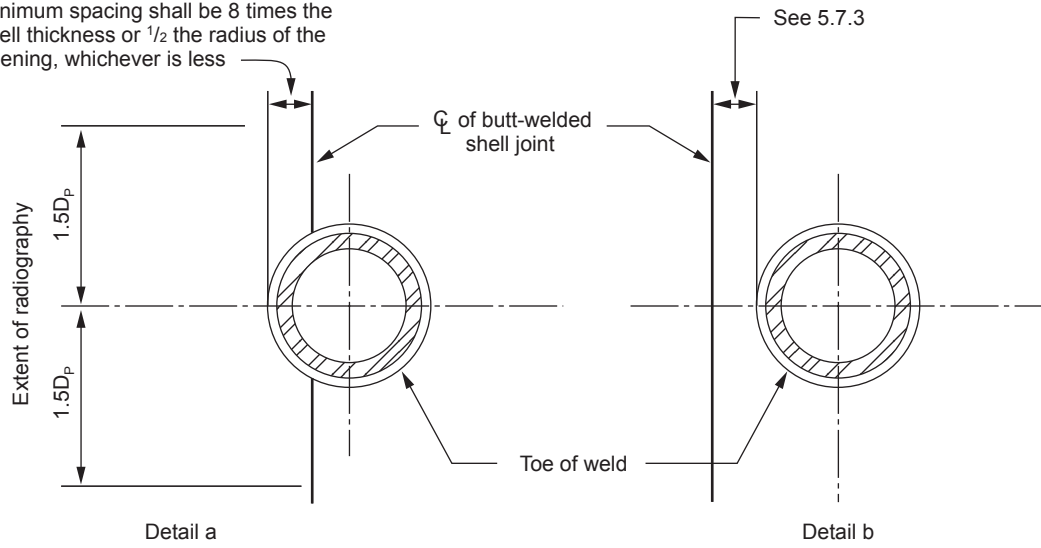
Note 1: Additional weld spacing requirements exist in this Standard. Other paragraphs and tables dealing with nozzles and manholes may increase the minimum spacing.

Note 2: Whenever stress relief or thermal stress relief is used in this Standard, it shall mean post-weld heat treatment.

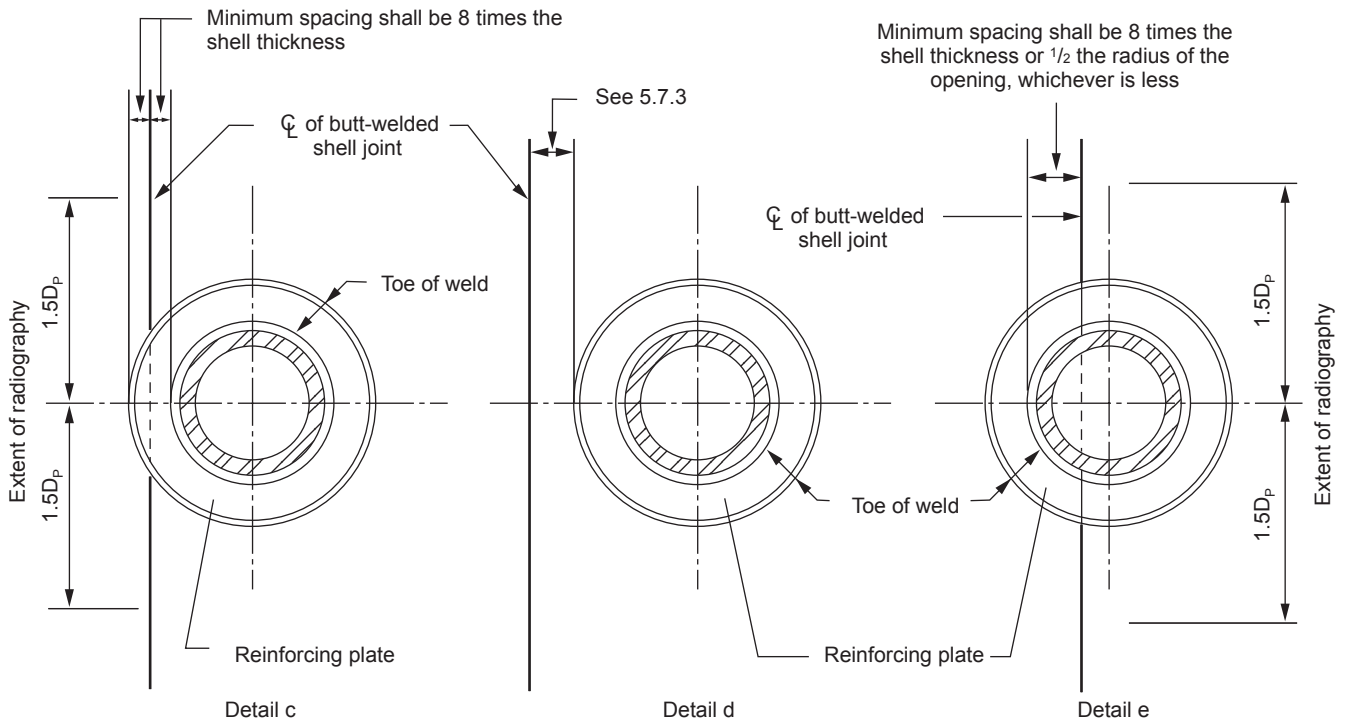
5.7.3.1 For non-stress-relieved welds on shell plates over 12.5 mm ($1/2$ in.) thick, the minimum spacing between penetration connections and adjacent shell-plate joints shall be governed by the following:

- The outer edge or toe of fillet around a penetration, around the periphery of a thickened insert plate, or around the periphery of a reinforcing plate shall be spaced at least the greater of eight times the weld size or 250 mm (10 in.) from the centerline of any butt-welded shell joints.
- The welds around the periphery of a thickened insert plate, around a reinforcing insert plate, or around a reinforcing plate shall be spaced at least the greater of eight times the larger weld size or 150 mm (6 in.) from each other.

Minimum spacing shall be 8 times the shell thickness or $\frac{1}{2}$ the radius of the opening, whichever is less



PENETRATION WITHOUT REINFORCING PLATE



PENETRATION WITH REINFORCING PLATE

Note: D_p = diameter of opening.

Figure 5-9—Minimum Spacing of Welds and Extent of Related Radiographic Examination

5.7.3.2 Where stress-relieving of the periphery weld has been performed prior to welding of the adjacent shell joint or where a non-stress-relieved weld is on a shell plate less than or equal to 12.5 mm ($1/2$ in.) thick, the spacing may be reduced to 150 mm (6 in.) from vertical joints or to the greater of 75 mm (3 in.) or $2^{1/2}$ times the shell thickness from horizontal joints. The spacing between the welds around the periphery of a thickened insert plate or around a reinforcing plate shall be the greater of 75 mm (3 in.) or $2^{1/2}$ times the shell thickness.

5.7.3.3 The rules in 5.7.3.1 and 5.7.3.2 shall also apply to the bottom-to-shell joint unless, as an alternative, the insert plate or reinforcing plate extends to the bottom-to-shell joint and intersects it at approximately 90 degrees. A minimum distance of 75 mm (3 in.) shall be maintained between the toe of a weld around a nonreinforced penetration (see 5.7.2.1) and the toe of the shell-to-bottom weld.

- **5.7.3.4** Nozzles and manholes should not be placed in shell weld seams and reinforcing pads for nozzles and manholes should not overlap plate seams (i.e., Figure 5-9, Details a, c, and e should be avoided). If there is no other feasible option and the Purchaser accepts the design, circular shell openings and reinforcing plates (if used) may be located in a horizontal or vertical butt-welded shell joint provided that the minimum spacing dimensions are met and a radiographic examination of the welded shell joint is conducted. The welded shell joint shall be fully radiographed for a length equal to three times the diameter of the opening, but the weld seam being removed need not be radiographed. Radiographic examination shall be in accordance with 8.1.3 through 8.1.8.

5.7.4 Thermal Stress Relief

5.7.4.1 All flush-type cleanout fittings and flush-type shell connections shall be thermally stress-relieved as an assembly prior to installation in the tank shell or after installation into the tank shell if the entire tank is stress-relieved. The stress relief shall be carried out within a temperature range of 600°C – 650°C (1100°F – 1200°F) (see 5.7.4.3 for quenched and tempered materials) for 1 hour per 25 mm (1 in.) of shell thickness. The assembly shall include the bottom reinforcing plate (or annular plate) and the flange-to-neck weld.

5.7.4.2 When the shell material is Group I, II, III, or IIIA, all opening connections NPS 12 or larger in nominal diameter in a shell plate or thickened insert plate more than 25 mm (1 in.) thick shall be prefabricated into the shell plate or thickened insert plate, and the prefabricated assembly shall be thermally stress-relieved within a temperature range of 600°C – 650°C (1100°F – 1200°F) for 1 hour per 25 mm (1 in.) of thickness prior to installation. The stress-relieving requirements need not include the flange-to-neck welds or other nozzle-neck and manhole-neck attachments, provided the following conditions are fulfilled:

- a. The welds are outside the reinforcement (see 5.7.2.4).
- b. The throat dimension of a fillet weld in a slip-on flange does not exceed 16 mm ($5/8$ in.), or the butt joint of a welding-neck flange does not exceed 19 mm ($3/4$ in.). If the material is preheated to a minimum temperature of 90°C (200°F) during welding, the weld limits of 16 mm ($5/8$ in.) and 19 mm ($3/4$ in.) may be increased to 32 mm and 38 mm ($1^{1/4}$ in. and $1^{1/2}$ in.), respectively.

5.7.4.3 When the shell material is Group IV, IVA, V, or VI, all opening connections requiring reinforcement in a shell plate or thickened insert plate more than 12.5 mm ($1/2$ in.) thick shall be prefabricated into the shell plate or thickened insert plate, and the prefabricated assembly shall be thermally stress relieved within a temperature range of 600°C – 650°C (1100°F – 1200°F) for 1 hour per 25 mm (1 in.) of thickness prior to installation.

When connections are installed in quenched and tempered material, the maximum thermal stress-relieving temperature shall not exceed the tempering temperature for the materials in the prefabricated stress-relieving assembly. The stress-relieving requirements do not apply to the weld to the bottom annular plate, but they do apply to flush-type cleanout openings when the bottom reinforcing plate is an annular-plate section. The stress-relieving requirements need not include the flange-to-neck welds or other nozzle-neck and manhole-neck attachments, provided the conditions of 5.7.4.2 are fulfilled.

5.7.4.4 Examination after stress relief shall be in accordance with 7.2.3.6 or 7.2.3.7.

07 **5.7.4.5** When it is impractical to stress relieve at a minimum temperature of 600°C (1100°F), it is permissible, subject to the Purchaser's agreement, to carry out the stress-relieving operation at lower temperatures for longer periods of time in accordance with the tabulation below. The lower temperature/longer time PWHT may not provide material toughness and residual stresses equivalent to that using the higher temperature/shorter time PWHT; therefore, a review by a knowledgeable metallurgist and possible verification by mill testing of heat-treated coupons and/or testing of welded plates shall be considered. See Line 23 of the Data Sheet for any Purchaser-specified requirements applicable to this heat-treatment option.

Minimum Stress-Relieving Temperature		Holding Time (hours per 25 mm [1 in.] of thickness)	See Note
(°C)	(°F)		
600	1100	1	1
570	1050	2	1
540	1000	4	1
510	950	10	1, 2
480 (min.)	900 (min.)	20	1, 2

Notes:

1. For intermediate temperatures, the time of heating shall be determined by straight line interpolation.
2. Stress relieving at these temperatures is not permitted for A 537 Class 2 material.

5.7.4.6 When used in stress-relieved assemblies, the material of quenched and tempered steels A 537, Cl 2 and A 678, Grade B, and of TMCP steel A 841 shall be represented by test specimens that have been subjected to the same heat treatment as that used for the stress relieved assembly.

5.7.5 Shell Manholes

5.7.5.1 Shell manholes shall conform to Figures 5-7A and 5-7B and Tables 5-3 through 5-5 (or Tables 5-6 through 5-8), but other shapes are permitted by 5.7.1.8. Manhole reinforcing plates or each segment of the plates if they are not made in one piece shall be provided with a 6 mm ($\frac{1}{4}$ in.) diameter telltale hole (for detection of leakage through the interior welds). Each hole shall be located on the horizontal centerline and shall be open to the atmosphere.

- **5.7.5.2** Manholes shall be of built-up welded construction. The dimensions are listed in Tables 5-3 through 5-5. The dimensions are based on the minimum neck thicknesses listed in Table 5-4. When corrosion allowance is specified to be applied to shell manholes, corrosion allowance is to be added to the minimum neck, cover plate, and bolting flange thicknesses of Tables 5-3 and 5-4.

5.7.5.3 The maximum diameter D_p of a shell cutout shall be as listed in Column 3 of Table 5-7. Dimensions for required reinforcing plates are listed in Table 5-6.

07 **5.7.5.4** The gasket materials shall meet service requirements based on the product stored, maximum design temperature, and fire resistance. Gasket dimensions, when used in conjunction with thin-plate flanges described in Figure 5-7A, have proven effective when used with soft gaskets, such as non-asbestos fiber with suitable binder. When using hard gaskets, such as solid metal, corrugated metal, metal-jacketed, and spiral-wound metal, the gasket dimensions, manhole flange, and manhole cover shall be designed per API Std 620, Sections 3.20 and 3.21. See 4.9 for additional requirements.

5.7.5.5 In lieu of using Figure 5-7A or design per API Std 620, forged flanges and forged blind flanges may be furnished per 4.6.

5.7.6 Shell Nozzles and Flanges

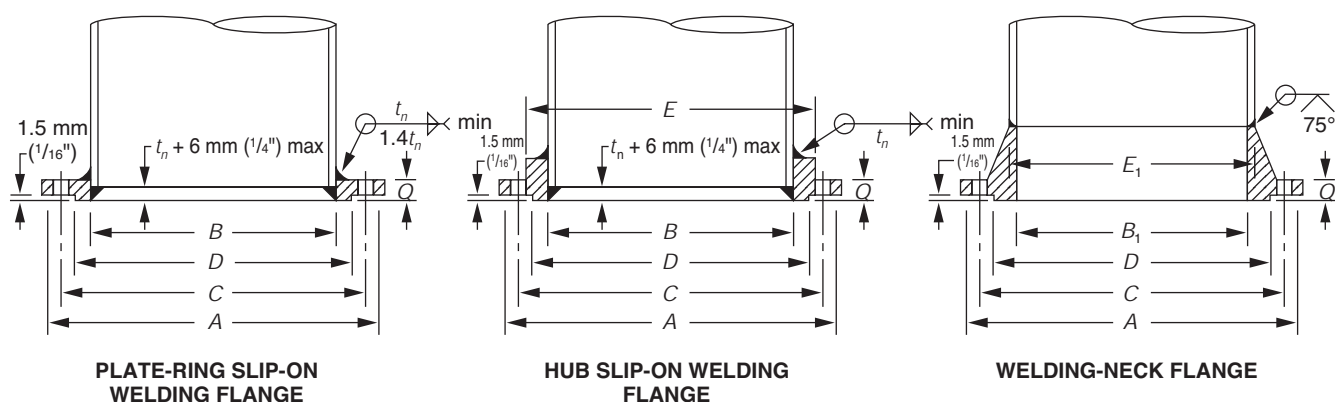
07 **5.7.6.1.a** Unless otherwise specified, shell nozzle flanges, excluding manholes, in sizes NPS 1 $\frac{1}{2}$ through NPS 20 and NPS 24 shall meet the requirements of ASME B16.5. For sizes larger than NPS 24 but not greater than NPS 60, flanges shall meet the requirements of ASME B16.47, Series A or Series B. Series A and Series B flanges are not compatible in all sizes and must be carefully selected to match the mating flange. If diameters, materials of construction, and flange styles of ASME B16.47 are unavailable, fabricated flanges with drilling template (bolt circle diameter, number of holes, and hole diameter) matching Series A or Series B shall be used. These fabricated flanges shall be designed in accordance with the ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1, Section UG-34 and Appendix 2. The allowable stresses for design shall be a matter of agreement between the Purchaser and the Manufacturer. Bolt holes shall straddle the vertical centerline of the flange.

- **5.7.6.1.b** Shell nozzles (and flanges, if specified by the Purchaser as an alternate to a. above) shall conform to Figures 5-7B, 5-8, and 5-10 and Tables 5-6 through 5-8, but other shapes are permitted by 5.7.1.8. An alternative connection design is permissible for the nozzle end that is not welded to the shell, if it provides equivalent strength, toughness, leak tightness, and utility and if the Purchaser agrees to its use in writing.
- **5.7.6.2** Unless shell nozzles are specified to be flush on the inside of the tank shell by the Purchaser, shell nozzles without internal piping in a tank without a floating roof may be supplied flush or with an internal projection at the option of the Manufacturer. In floating roof tanks, shell nozzles without internal piping within operating range of the floating roof shall be supplied flush on the inside of the tank shell unless agreed otherwise between the Manufacturer and the Purchaser.
- **5.7.6.3** The details and dimensions specified in this Standard are for nozzles installed with their axes perpendicular to the shell plate. A nozzle may be installed at an angle other than 90 degrees to the shell plate in a horizontal plane, provided the width of the reinforcing plate (W or D_o in Figure 5-8 and Table 5-6) is increased by the amount that the horizontal chord of the opening cut in the shell plate (D_p in Figure 5-8 and Table 5-7) increases as the opening is changed from circular to elliptical for the angular installation. In addition, nozzles not larger than NPS 3—for the insertion of thermometer wells, for sampling connections, or for other purposes not involving the attachment of extended piping—may be installed at an angle of 15 degrees or less off perpendicular in a vertical plane without modification of the nozzle reinforcing plate.
- **5.7.6.4** The minimum as-built thickness of nozzle necks to be used shall be equal to the required thickness as identified by the term t_n in Table 5-6, Column 3.

07

5.7.7 Flush-Type Cleanout Fittings

- **5.7.7.1** Flush-type cleanout fittings shall conform to the requirements of 5.7.7.2 through 5.7.7.12 and to the details and dimensions shown in Figures 5-12 and 5-13 and Tables 5-9 through 5-11. When a size intermediate to the sizes given in Tables 5-9 through 5-11 is specified by the Purchaser, the construction details and reinforcements shall conform to the next larger opening listed in the tables. The size of the opening or tank connection shall not be larger than the maximum size given in the appropriate table.
- **5.7.7.2** The opening shall be rectangular, but the upper corners of the opening shall have a radius equal to one-half the greatest height of the clear opening. When the shell material is Group I, II, III, or IIIA, the width or height of the clear opening shall not exceed 1200 mm (48 in.); when the shell material is Group IV, IVA, V, or VI, the height shall not exceed 900 mm (36 in.).
- **5.7.7.3** The reinforced opening shall be completely preassembled into a shell plate, and the completed unit, including the shell plate at the cleanout fitting, shall be thermally stress-relieved as described in 5.7.4 (regardless of the thickness or strength of the material).



Note: The t_n designated for weld thickness is the nominal pipe wall thickness (see Tables 5-6 and 5-7).

Figure 5-10—Shell Nozzle Flanges (See Table 5-8)

Vertical axis in SI units:

$$\left[\frac{(H + 8.8)D + 71.5}{1.408h} \right] \left[\frac{123t}{4.9D(H - 0.3)} \right]^{0.5}$$

Vertical axis in US Customary units:

$$\left[\frac{(H + 29)D + 770}{385h} \right] \left[\frac{17,850t}{2.6D(H - 1)} \right]^{0.5}$$

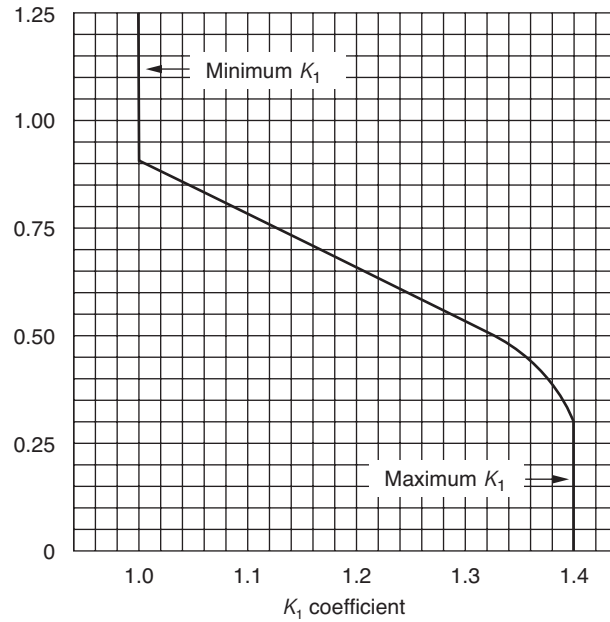


Figure 5-11—Area Coefficient for Determining Minimum Reinforcement of Flush-Type Cleanout Fittings

5.7.7.4 The cross-sectional area of the reinforcement over the top of the opening shall be calculated as follows:

$$A_{cs} \geq \frac{K_1 h t}{2}$$

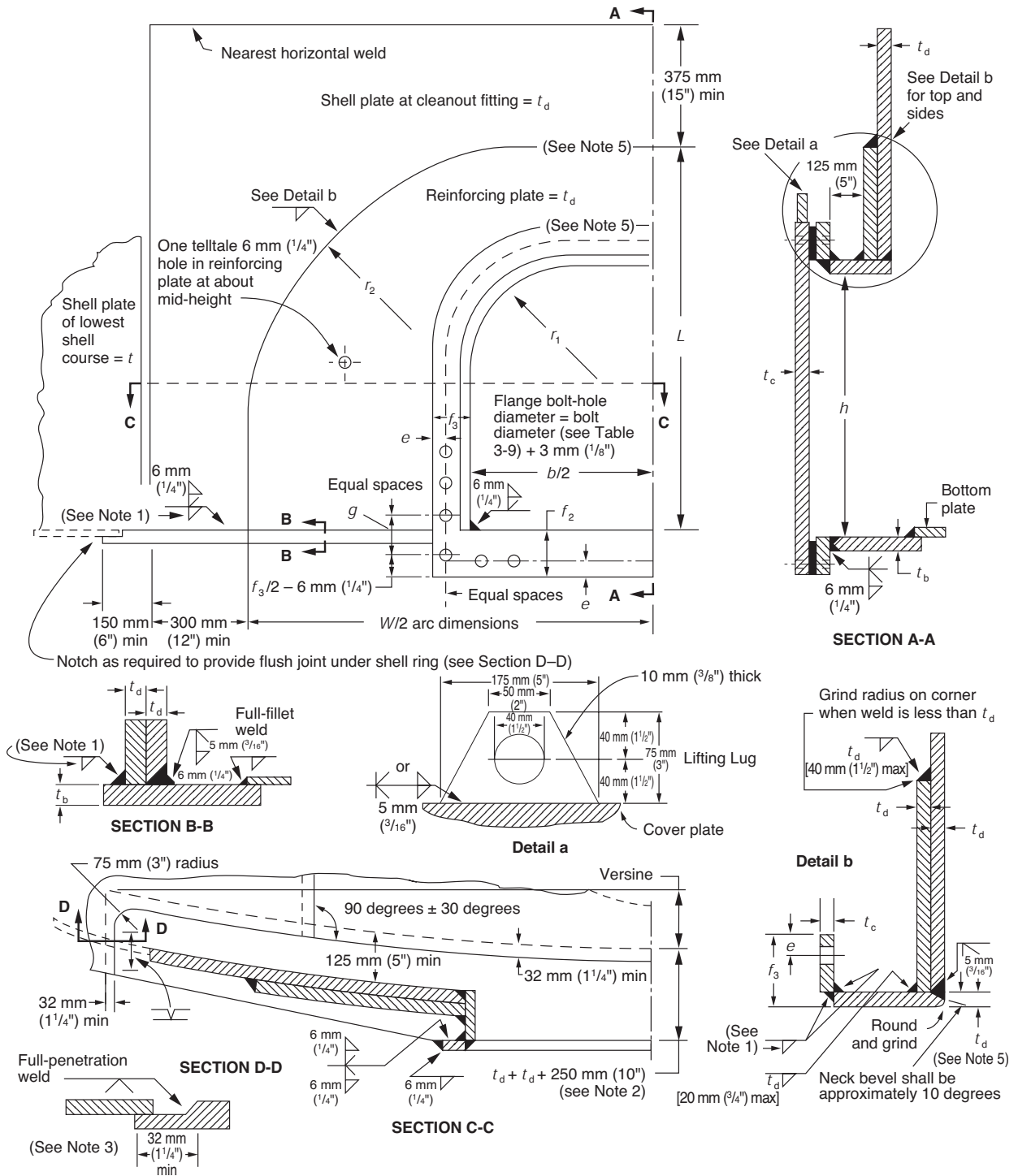
where

- A_{cs} = cross-sectional area of the reinforcement over the top of the opening, in mm² (in.²),
- K_1 = area coefficient from Figure 5-11,
- h = vertical height of clear opening, in mm (in.),
- t = calculated thickness of the lowest shell course, in mm (in.), required by the formulas of 5.6.3, 5.6.4, or A.4.1 but exclusive of any corrosion allowance.

5.7.7.5 The thickness of the shell plate in the flush-type cleanout fitting assembly shall be at least as thick as the adjacent shell plate in the lowest shell course. The thickness of the shell reinforcing plate and the neck plate shall be the same as the thickness of the shell plate in the cleanout-opening assembly.

The reinforcement in the plane of the shell shall be provided within a height L above the bottom of the opening. L shall not exceed $1.5h$ except that, in the case of small openings, $L - h$ shall not be less than 150 mm (6 in.). Where this exception results in an L that is greater than $1.5h$, only the portion of the reinforcement that is within the height of $1.5h$ shall be considered effective. The reinforcement required may be provided by any one or any combination of the following:

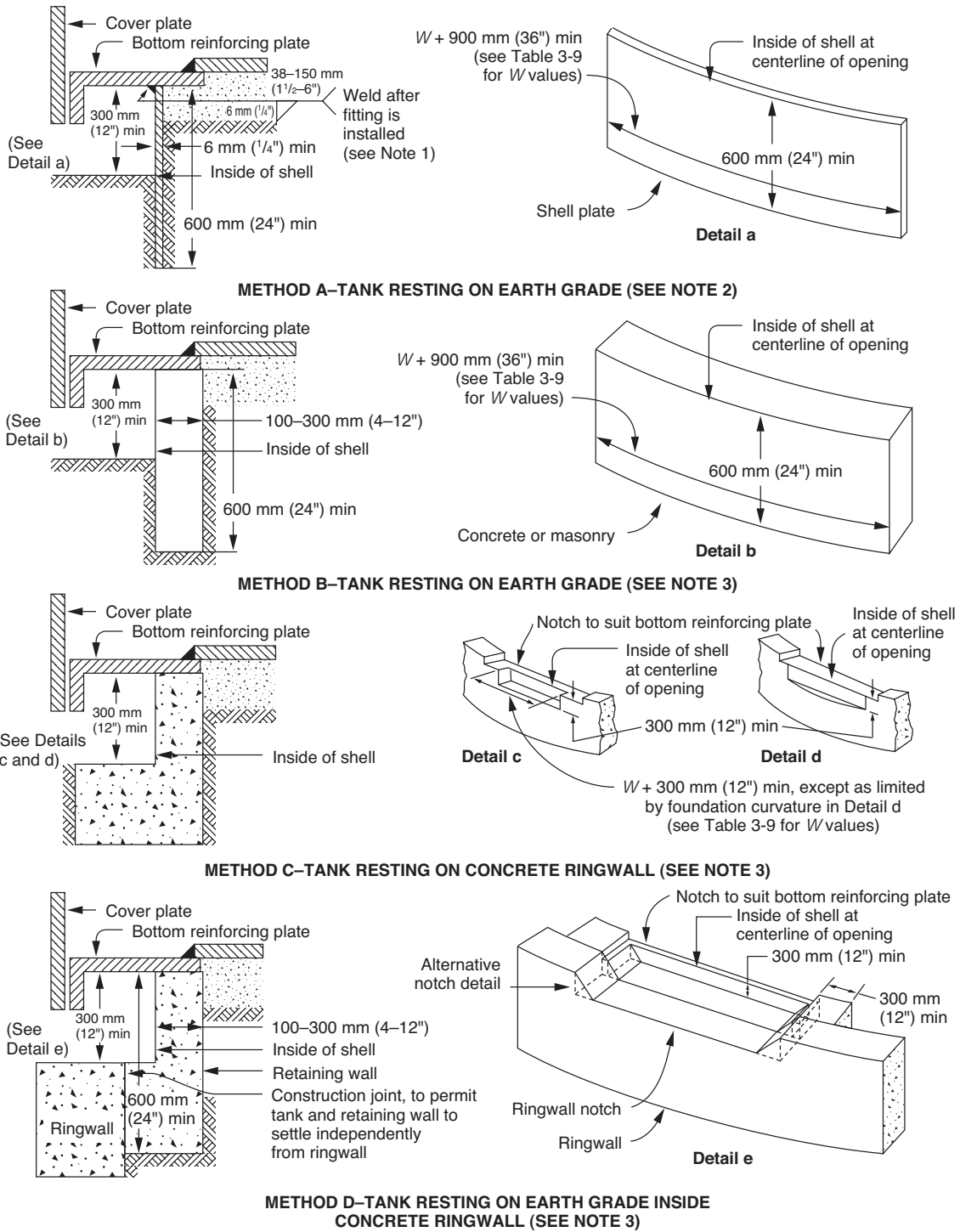
- a. The shell reinforcing plate.
- b. Any thickness of the shell plate in the flush-type cleanout fitting assembly that is greater than the thickness of the adjacent plates in the lowest shell course.
- c. The portion of the neck plate having a length equal to the thickness of the reinforcing plate.



Notes:

1. Thickness of thinner plate joined (13 mm [1/2 in.] maximum).
2. When an annular plate is provided, the reinforcing plate shall be regarded as a segment of the annular plate and shall be the same width as the annular plate.
3. When the difference between the thickness of the annular ring and that of the bottom reinforcing plate is less than 6 mm (1/4 in.), the radial joint between the annular ring and the bottom reinforcing plate may be butt-welded with a weld joint suitable for complete penetration and fusion.
4. Gasket material shall be specified by the Purchaser. The gasket material shall meet service requirements based on product stored, design metal temperature, maximum design temperature and fire resistance.
5. The thickness (t_d) of the shell plate at the cleanout opening, the reinforcing plate, and the neck plate, shall be equal to or greater than the thickness (t) of the shell plate of the lowest shell course.

Figure 5-12—Flush-Type Cleanout Fittings (See Tables 5-9, 5-10, and 5-11)



Notes:

1. This weld is not required if the earth is stabilized with portland cement at a ratio of not more than 1:12 or if the earth fill is replaced with concrete for a lateral distance and depth of at least 300 mm (12 in.).
2. When Method A is used, before the bottom plate is attached to the bottom reinforcing plate, (a) a sand cushion shall be placed flush with the top of the bottom reinforcing plate, and (b) the earth fill and sand cushion shall be thoroughly compacted.

3. When Method B, C, or D is used, before the bottom plate is attached to the bottom reinforcing plate, (a) a sand cushion shall be placed flush with the top of the bottom reinforcing plate, (b) the earth fill and sand cushion shall be thoroughly compacted, and (c) grout shall be placed under the reinforcing plate (if needed) to ensure a firm bearing.

Figure 5-13—Flush-Type Cleanout-Fitting Supports (See 5.7.7)

5.7.7.6 The minimum width of the tank-bottom reinforcing plate at the centerline of the opening shall be 250 mm (10 in.) plus the combined thickness of the shell plate in the cleanout-opening assembly and the shell reinforcing plate. The minimum thickness of the bottom reinforcing plate shall be determined by the following equation:

In SI units:

$$t_b = \frac{h^2}{360,000} + \frac{b}{170} \sqrt{HG}$$

where

t_b = minimum thickness of the bottom reinforcing plate, in mm,

h = vertical height of clear opening, in mm,

b = horizontal width of clear opening, in mm,

H = maximum design liquid level (see 5.6.3.2), in m,

G = specific gravity, not less than 1.0.

In US Customary units:

$$t_b = \frac{h^2}{14,000} + \frac{b}{310} \sqrt{HG}$$

where

t_b = minimum thickness of the bottom reinforcing plate, (in.),

h = vertical height of clear opening, (in.),

b = horizontal width of clear opening, (in.),

H = maximum design liquid level (see 5.6.3.2), (ft),

G = specific gravity, not less than 1.0.

5.7.7.7 The dimensions of the cover plate, bolting flange, bolting, and bottom-reinforcing plate shall conform to Tables 5-9 and 5-10.

5.7.7.8 All materials in the flush-type cleanout fitting assembly shall conform to the requirements in Section 4. The shell plate containing the cleanout assembly, the shell reinforcing plate, the neck plate, and the bottom reinforcing plate shall meet the impact test requirements of 4.2.9 and Figure 4-1 for the respective thickness involved at the design metal temperature for the tank. The notch toughness of the bolting flange and the cover plate shall be based on the governing thickness as defined in 4.5.5.3 using Table 4-3(a), Table 4-3(b), and Figure 4-1. Additionally, the yield strength and the tensile strength of the shell plate at the flush-type cleanout fitting, the shell reinforcing plate, and the neck plate shall be equal to, or greater than, the yield strength and the tensile strength of the adjacent lowest shell course plate material.

5.7.7.9 The dimensions and details of the cleanout-opening assemblies covered by this section are based on internal hydrostatic loading with no external-piping loading.

5.7.7.10 When a flush-type cleanout fitting is installed on a tank that is resting on an earth grade without concrete or masonry walls under the tank shell, provision shall be made to support the fitting and retain the grade by either of the following methods:

- a. Install a vertical steel bulkhead plate under the tank, along the contour of the tank shell, symmetrical with the opening, as shown in Figure 5-13, Method A.
- b. Install a concrete or masonry retaining wall under the tank with the wall's outer face conforming to the contour of the tank shell as shown in Figure 5-13, Method B.

5.7.7.11 When a flush-type cleanout fitting is installed on a tank that is resting on a ringwall, a notch with the dimensions shown in Figure 5-13, Method C, shall be provided to accommodate the cleanout fitting.

5.7.7.12 When a flush-type cleanout fitting is installed on a tank that is resting on an earth grade inside a foundation retaining wall, a notch shall be provided in the retaining wall to accommodate the fitting, and a supplementary inside retaining wall shall be provided to support the fitting and retain the grade. The dimensions shall be as shown in Figure 5-13, Method D.

5.7.8 Flush-Type Shell Connections

- **5.7.8.1** Tanks may have flush-type connections at the lower edge of the shell. Each connection may be made flush with the flat bottom under the following conditions (see Figure 5-14):

- The shell uplift from the internal design and test pressures (see Appendix F) and wind and earthquake loads (see Appendix E) shall be counteracted so that no uplift will occur at the cylindrical-shell/flat-bottom junction.
- The vertical or meridional membrane stress in the cylindrical shell at the top of the opening for the flush-type connection shall not exceed one-tenth of the circumferential design stress in the lowest shell course containing the opening.
- The maximum width, b , of the flush-type connection opening in the cylindrical shell shall not exceed 900 mm (36 in.).
- The maximum height, h , of the opening in the cylindrical shell shall not exceed 300 mm (12 in.).
- The thickness, t_a , of the bottom-transition plate in the assembly shall be 12.5 mm ($1/2$ in.) minimum or, when specified, the same as the thickness of the tank annular plate.

5.7.8.2 The details of the connection shall conform to those shown in Figure 5-14, and the dimensions of the connection shall conform to Table 5-12 and to the requirements of 5.7.8.3 through 5.7.8.11.

5.7.8.3 The reinforced connection shall be completely preassembled into a shell plate. The completed assembly, including the shell plate containing the connection, shall be thermally stress-relieved at a temperature of 600°C – 650°C (1100°F – 1200°F) for 1 hour per 25 mm (1 in.) of shell-plate thickness, t_d (see 5.7.4.1 and 5.7.4.2).

5.7.8.4 The reinforcement for a flush-type shell connection shall meet the following requirements:

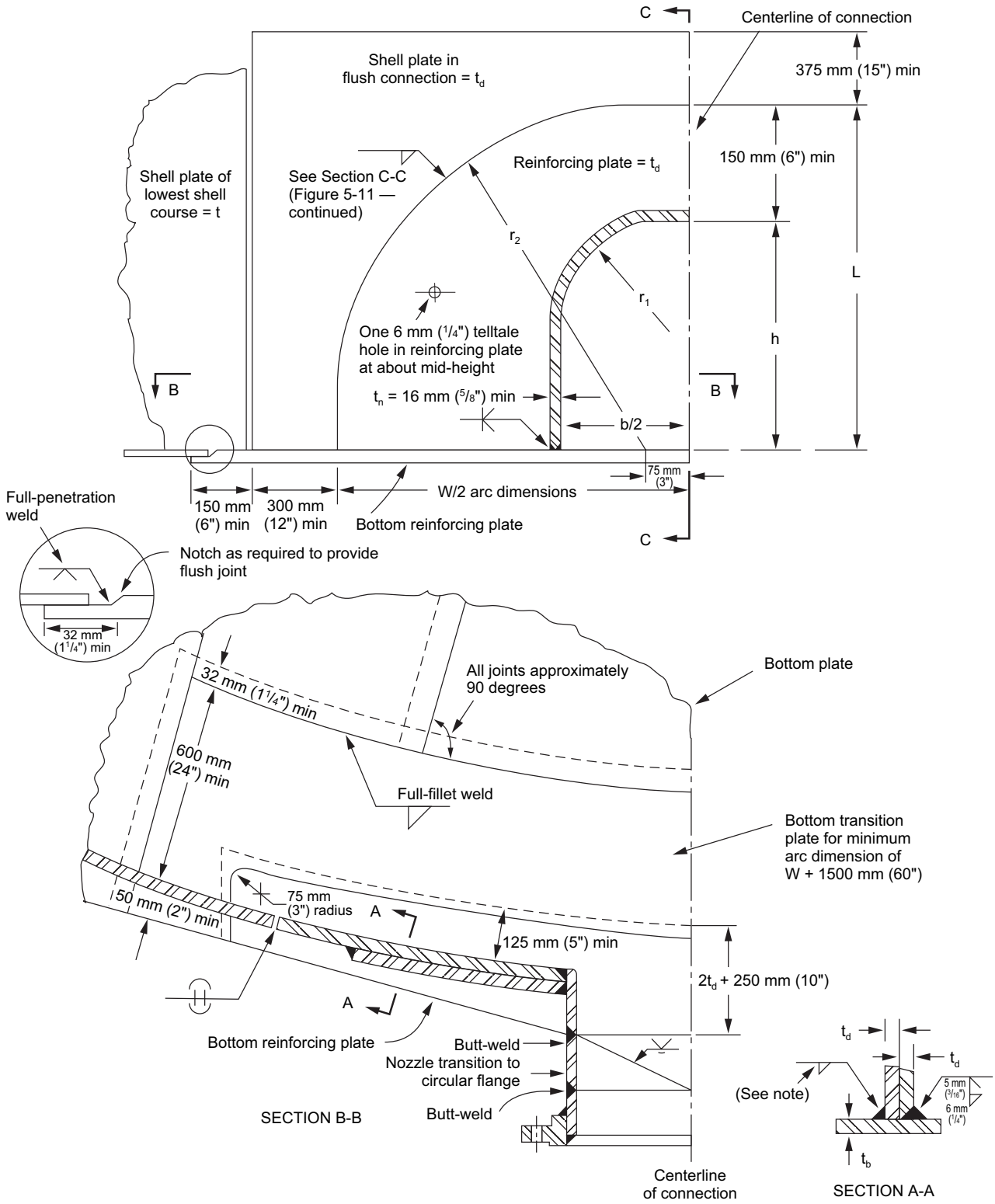
- The cross-sectional area of the reinforcement over the top of the connection shall not be less than $K_1ht/2$ (see 5.7.7.4).
- The thickness of the shell plate, t_d , for the flush-connection assembly shall be at least as thick as the adjacent shell plate, t , in the lowest shell course.
- The thickness of the shell reinforcing plate shall be the same as the thickness of the shell plate in the flush-connection assembly.
- The reinforcement in the plane of the shell shall be provided within a height L above the bottom of the opening. L shall not exceed $1.5h$ except that, in the case of small openings, $L - h$ shall not be less than 150 mm (6 in.). Where this exception results in an L that is greater than $1.5h$, only the portion of the reinforcement that is within the height of $1.5h$ shall be considered effective.
- The required reinforcement may be provided by any one or any combination of the following: (1) the shell reinforcing plate, (2) any thickness of the shell plate in the assembly that is greater than the thickness of the adjacent plates in the lowest shell course, and (3) the portion of the neck plate having a length equal to the thickness of the reinforcing plate.
- The width of the tank-bottom reinforcing plate at the centerline of the opening shall be 250 mm (10 in.) plus the combined thickness of the shell plate in the flush-connection assembly and the shell reinforcing plate. The thickness of the bottom reinforcing plate shall be calculated by the following equation (see 5.7.7.6):

In SI units:

$$t_b = \frac{h^2}{360,000} + \frac{b}{170} \sqrt{HG}$$

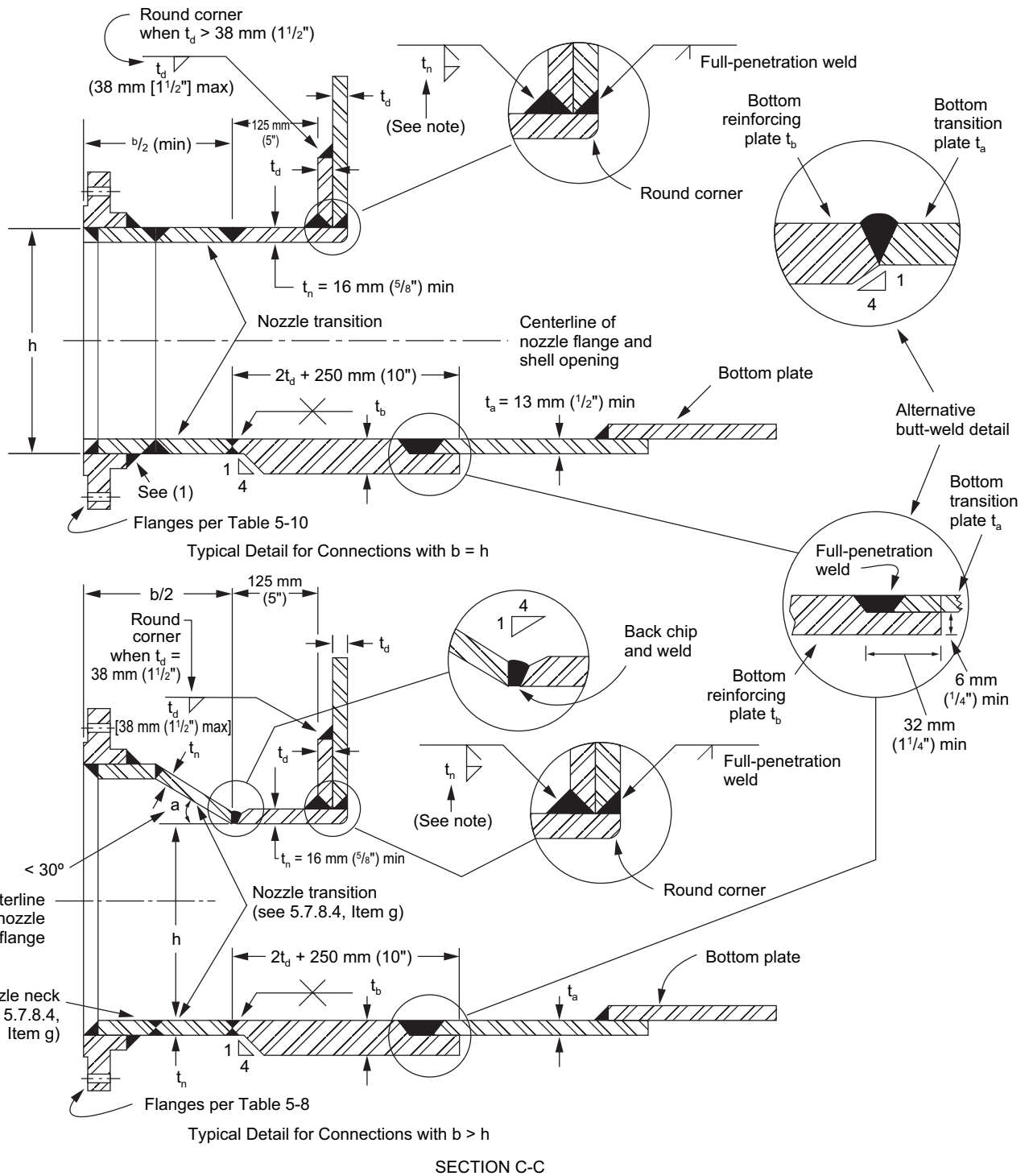
where

- t_b = minimum thickness of the bottom reinforcing plate, in mm,
- h = vertical height of clear opening, in mm,
- b = horizontal width of clear opening, in mm,
- H = maximum design liquid level (see 5.6.3.2), in m,
- G = specific gravity, not less than 1.0.



Note: Thickness of thinner plate joined 13 mm ($1/2$ in.) maximum.

Figure 5-14—Flush-Type Shell Connection



Notes:
 Thickness of thinner plate joined 13 mm ($\frac{1}{2}$ in.) maximum.
 (1) Flange weld sizes shall be the smaller of available hub material or t_n .

Figure 5-14—Flush-Type Shell Connection (continued)

In US Customary units:

$$t_b = \frac{h^2}{14,000} + \frac{b}{310} \sqrt{HG}$$

where

t_b = minimum thickness of the bottom reinforcing plate, (in.),

h = vertical height of clear opening, (in.),

b = horizontal width of clear opening, (in.),

H = maximum design liquid level (see 5.6.3.2), (ft),

G = specific gravity, not less than 1.0.

The minimum value of t_b shall be:

16 mm ($5/8$ in.) for $HG \leq 14.4$ m (48 ft)

17 mm ($11/16$ in.) for 14.4 m (48 ft) $< HG \leq 16.8$ m (56 ft)

19 mm ($3/4$ in.) for 16.8 m (56 ft) $< HG \leq 19.2$ m (64 ft)

g. The minimum thickness of the nozzle neck and transition piece, t_n , shall be 16 mm ($5/8$ in.). External loads applied to the connection may require t_n to be greater than 16 mm ($5/8$ in.).

5.7.8.5 All materials in the flush-type shell connection assembly shall conform to the requirements in Section 4. The material of the shell plate in the connection assembly, the shell reinforcing plate, the nozzle neck attached to the shell, the transition piece, and the bottom reinforcing plate shall conform to 4.2.9 and Figure 4-1 for the respective thickness involved at the design metal temperature for the tank. The notch toughness of the bolting flange and the nozzle neck attached to the bolting flange shall be based on the governing thickness as defined in 4.5.5.3 and used in Figure 4-1. Additionally, the yield strength and the tensile strength of the shell plate at the flush-type shell connection and the shell reinforcing plate shall be equal to, or greater than, the yield strength and the tensile strength of the adjacent lowest shell course plate material.

5.7.8.6 The nozzle transition between the flush connection in the shell and the circular pipe flange shall be designed in a manner consistent with the requirements of this Standard. Where this Standard does not cover all details of design and construction, the Manufacturer shall provide details of design and construction that will be as safe as the details provided by this Standard.

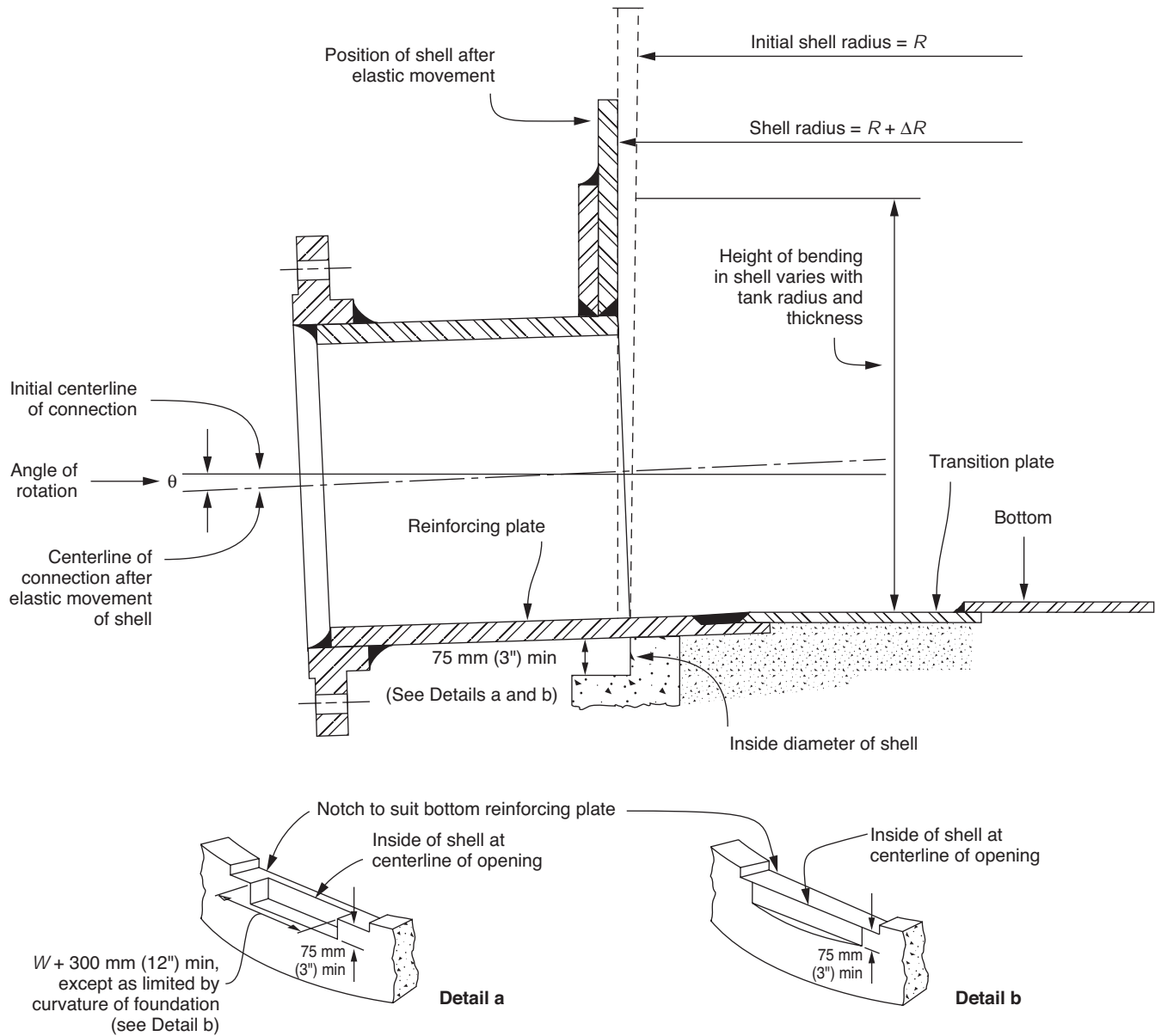
5.7.8.7 Where anchoring devices are required by Appendices E and F to resist shell uplift, the devices shall be spaced so that they will be located immediately adjacent to each side of the reinforcing plates around the opening.

5.7.8.8 Adequate provision shall be made for free movement of connected piping to minimize thrusts and moments applied to the shell connection. Allowance shall be made for the rotation of the shell connection caused by the restraint of the tank bottom-to-shell expansion from stress and temperature as well as for the thermal and elastic movement of the piping. Rotation of the shell connection is shown in Figure 5-15.

5.7.8.9 The foundation in the area of a flush-type connection shall be prepared to support the bottom reinforcing plate of the connection. The foundation for a tank resting on a concrete ringwall shall provide uniform support for both the bottom reinforcing plate and the remaining bottom plate under the tank shell. Different methods of supporting the bottom reinforcing plate under a flush-type connection are shown in Figure 5-13.

5.7.8.10 Flush-type connections may be installed using a common reinforcing pad; however, when this construction is employed, the minimum distance between nozzle centerlines shall not be less than $1.5[b_1 + b_2 + 65 \text{ mm } (2\frac{1}{2} \text{ in.})]$, where b_1 and b_2 are the widths of adjacent openings, or 600 mm (24 in.), whichever is greater. The width of each opening, b , shall be obtained from Table 5-12 for the respective nominal flange size. Adjacent shell flush-type connections that do not share a common reinforcing plate shall have at least a 900 mm (36 in.) clearance between the ends of their reinforcing plates.

5.7.8.11 All longitudinal butt-welds in the nozzle neck and transition piece, if any, and the first circumferential butt-weld in the neck closest to the shell, excluding neck-to-flange weld, shall receive 100% radiographic examination (see 8.1). The nozzle-to-tank-shell and reinforcing plate welds and the shell-to-bottom reinforcing plate welds shall be examined for their complete length by magnetic particle examination (see 8.2). The magnetic particle examination shall be performed on the root pass, on every



DETAILS OF NOTCH IN RINGWALL

Figure 5-15—Rotation of Shell Connection

12.5 mm ($1/2$ in.) of deposited weld metal while the welds are made, and on the completed welds. The completed welds shall also be visually examined. The examination of the completed welds shall be performed after stress-relieving but before hydrostatic testing (see 8.2 and 8.5 for the appropriate inspection and repair criteria).

5.8 SHELL ATTACHMENTS AND TANK APPURTENANCES

5.8.1 Shell Attachments

5.8.1.1 Shell attachments shall be made, inspected, and removed in conformance with Section 7.

a. Permanent attachments are items welded to the shell that will remain while the tank is in its intended service. These include items such as wind girders, stairs, gauging systems, davits, walkways, tank anchors, supports for internal items such as heating coils and other piping supports, ladders, floating roof supports welded to the shell, exterior piping supports, grounding clips, insu-

lation rings, and electrical conduit and fixtures. Items installed above the maximum liquid level of the tank are not permanent attachments.

b. Temporary attachments are items welded to the shell that will be removed prior to the tank being commissioned into its intended service. These include items such as alignment clips, fitting equipment, stabilizers, and lifting lugs.

5.8.1.2 When attachments are made to shell courses of material in Group IV, IVA, V, or VI, the movement of the shell (particularly the movement of the bottom course) under hydrostatic loading shall be considered, and the attachments shall meet the following requirements:

a. Permanent attachments may be welded directly to the shell with fillet welds having a maximum leg dimension of 13 mm ($1/2$ in.). The edge of any permanent attachment welds shall be at least 75 mm (3 in.) from the horizontal joints of the shell and at least 150 mm (6 in.) from the vertical joints, insert-plate joints, or reinforcing-plate fillet welds. Permanent attachment welds may cross shell horizontal or vertical butt welds providing the welds are continuous within these limits and the angle of incidence between the two welds is greater than or equal to 45 degrees. Additionally, any splice weld in the permanent attachment shall be located a minimum of 150 mm (6 in.) from any shell weld unless the splice weld is kept from intersecting the shell weld by acceptable modifications to the attachment.

b. The welding and inspection of permanent attachments to these shell courses shall conform to 7.2.3.5.

c. Temporary attachments to shell courses shall preferably be made prior to welding of the shell joints. Weld spacing for temporary attachments made after welding of the shell joints shall be the same as that required for permanent attachments. Temporary attachments to shell courses shall be removed, and any resulting damage shall be repaired and ground to a smooth profile.

• 5.8.2 Bottom Connections

Connections to the tank bottom are permitted subject to agreement between the Purchaser and the Manufacturer with respect to details that provide strength, tightness, and utility equal to the details of shell connections specified in this Standard.

5.8.3 Cover Plates

5.8.3.1 Unreinforced openings less than or equal to NPS 2 pipe size are permissible in flat cover plates without increasing the cover plate thickness if the edges of the openings are not closer to the center of the cover plate than one-fourth the height or diameter of the opening. Requirements for openings NPS 2 pipe size and smaller that do not satisfy the location requirement and for larger reinforced openings are given in 5.8.3.2 through 5.8.3.4.

5.8.3.2 Reinforced openings in the cover plates of shell manholes shall be limited to one-half the diameter of the manhole opening but shall not exceed NPS 12 pipe size. The reinforcement added to an opening may be a reinforcing plate or an increased thickness of the cover plate, but in either case, the reinforcement shall provide an added reinforcing area no less than the cutout area of the opening in the cover plate.

A cover plate with a nozzle attachment for product-mixing equipment shall have a thickness at least 1.4 times greater than the thickness required by Table 5-3. The added thickness (or pad plate) for replacement of the opening cutout in the cover plate shall be based on Table 5-3. The 40% increase in thickness within a radius of one diameter of the opening may be included as part of the area of replacement required. The mixer-nozzle attachment to the cover plate shall be a full-penetration weld. The manhole bolting-flange thickness shall not be less than 1.4 times the thickness required by Table 5-3. The manhole nozzle neck shall be designed to support the mixer forces with a minimum thickness not less than the requirements of Table 5-4 without comparison to the increased bolting-flange thickness noted in this section.

5.8.3.3 When cover plates (or blind flanges) are required for shell nozzles, the minimum thickness shall be that given for flanges in Table 5-8. Reinforced openings in the cover plates (or blind flanges) of shell nozzles shall be limited to one-half the diameter of the nozzle. The reinforcement added to an opening may be an added pad plate or an increased thickness of the cover plate, but in either case, the reinforcement shall provide an added reinforcing area no less than 50% of the cutout area of the opening in the cover plate. Mixer nozzles may be attached to cover plates.

5.8.3.4 Openings in the cover plates of flush-type cleanout fittings shall be limited to NPS 2 pipe size in accordance with 5.8.3.1.

5.8.3.5 Shell manhole covers shall have two handles. Those covers weighing more than 34 kg (75 lb) shall be equipped with either a hinge or davit to facilitate the handling of the manhole cover plate. The davit support arm shall not be welded directly to the shell without a reinforcing plate.

5.8.4 Roof Manholes

Roof manholes shall conform to Figure 5-16 and Table 5-13. If work is expected to be carried on through the manhole opening while the tank is in use, the roof structure around the manhole shall be reinforced.

5.8.5 Roof Venting

5.8.5.1 Tanks designed in accordance with this Standard and having a fixed roof shall be vented for both normal conditions (resulting from operational requirements, including maximum filling and emptying rates, and atmospheric temperature changes) and emergency conditions (resulting from exposure to an external fire). Tanks with both a fixed roof and a floating roof satisfy these requirements when they comply with the circulation venting requirements of Appendix H. All other tanks designed in accordance with this Standard and having a fixed roof shall meet the venting requirements of 5.8.5.2 and 5.8.5.3.

5.8.5.2 Normal venting shall be adequate to prevent internal or external pressure from exceeding the corresponding tank design pressures and shall meet the requirements specified in API Std 2000 for normal venting.

• **5.8.5.3** Emergency venting requirements are satisfied if the tank is equipped with a weak roof-to-shell attachment (frangible joint) in accordance with 5.10.2.6, or if the tank is equipped with pressure relief devices meeting the requirements specified in API Std 2000 for emergency venting. When pressure relief devices are used to satisfy the emergency venting requirements, they shall achieve the flow rates specified in API Std 2000 without exceeding the following limits on internal pressure:

a. For unanchored tanks, the pressure relief devices shall be adequate to prevent internal pressure from exceeding the tank design pressure as determined in F.4.1 (subject to the limitations in F.4.2 and F.4.3, as applicable). In calculating limitations per F.4.2, use $M = 0$.

b. For anchored tanks, except those designed to F.1.3, the pressure relief devices shall be adequate to prevent internal pressure from exceeding the tank design pressure as determined in F.4.1 (subject to the limitations in F.4.3, as applicable).

c. For tanks designed to F.1.3 (anchored tanks), the pressure relief devices shall be adequate to prevent internal pressure from exceeding the design pressure specified by the Purchaser.

• **5.8.5.4** The filling and emptying rates are specified on the Data Sheet, Line 7. See the Data Sheet, Table 3 for venting devices, which shall be specified by the Purchaser and verified by the Manufacturer.

5.8.5.5 Corrosion-resistant coarse-mesh bird screens (13 mm [$1/2$ in.] nominal openings) shall protect all free vents.

5.8.5.6 Flanged roof nozzles shall conform to Figure 5-19 and Table 5-14. Slip-on flanges and weld neck flanges shall conform to the requirements of ASME B16.5 for Class 150 plate-ring flanges shall conform to all of the dimensional requirements for slip-on welding flanges with the exception that it is acceptable to omit the extended hub on the back of the slip-on or weld neck flanges. Raised face flanges shall be provided for nozzles with attached piping. Flat face flanges shall be provided for roof nozzles used for the mounting of tank accessories.

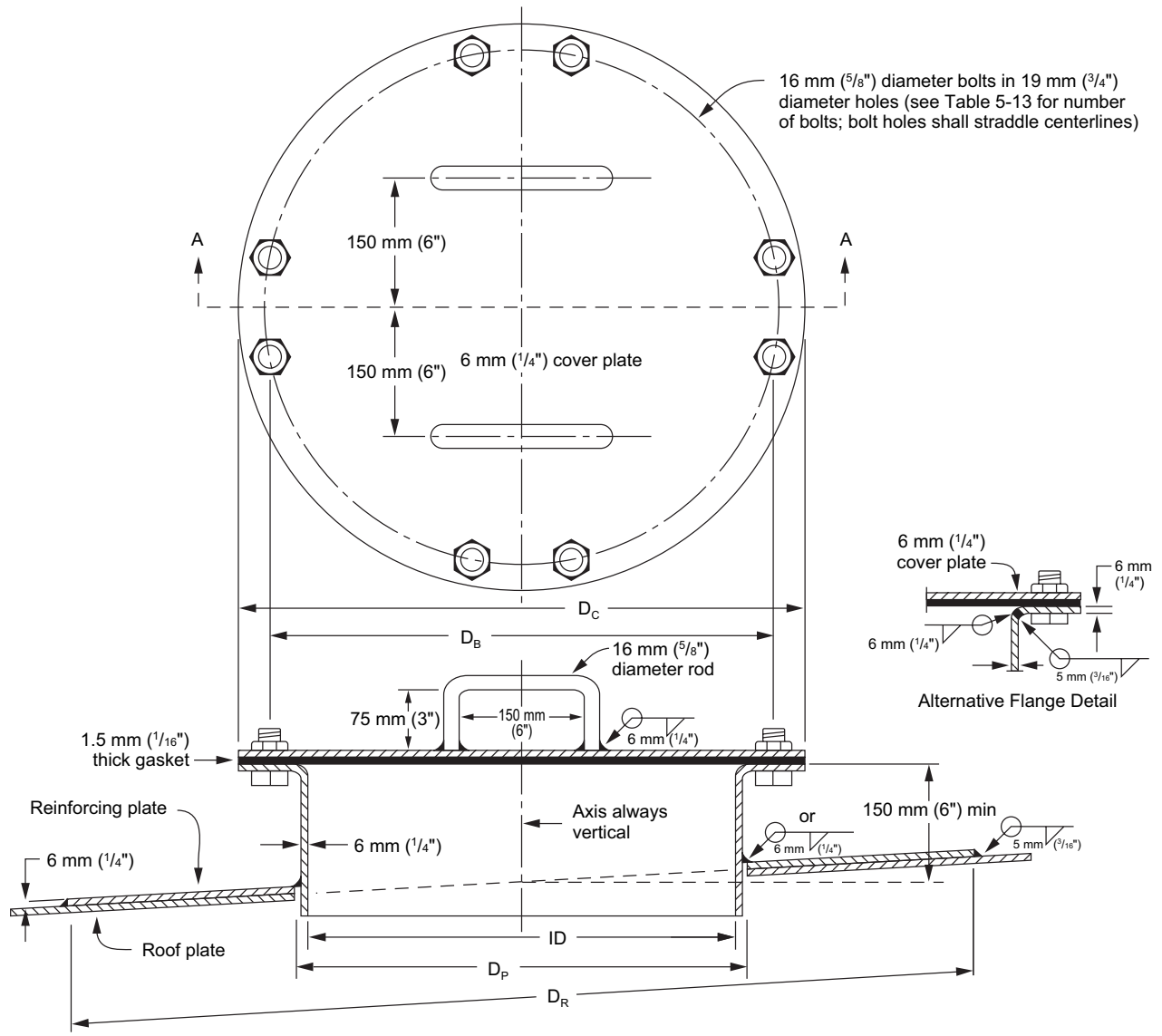
5.8.5.7 Threaded roof nozzles shall conform to Figure 5-20 and Table 5-15.

5.8.6 Rectangular Roof Openings

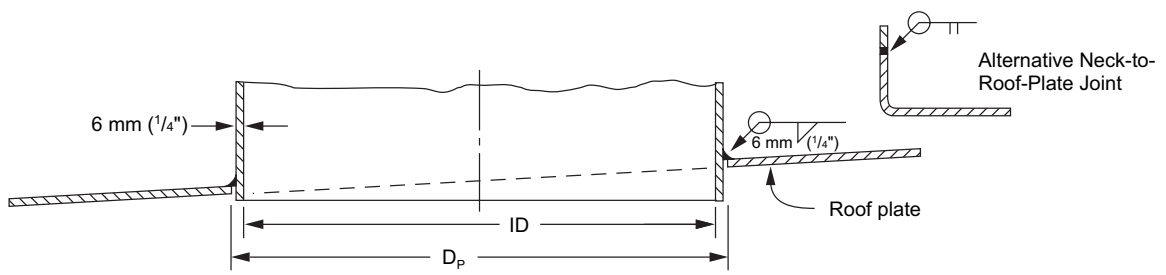
5.8.6.1 Rectangular roof openings in supported roofs shall conform to Figure 5-17 or 5-18 and/or this section. If work is expected to be carried on through the roof opening, while the tank is in use, the roof structure around the roof opening shall be reinforced.

5.8.6.2 The cover plate thickness and/or structural support shall be designed to limit maximum fiber stresses in accordance with this Standard, however, cover plate thickness shall not be less than 5 mm ($3/16$ in.). In addition to other expected design loads, consider a 112 kg (250 lb) person standing in the center of the installed/closed cover. The designer shall consider wind in the design of hinged openings and how removed covers will be handled without damage (adequate rigidity).

5.8.6.3 Rectangular openings, other than shown in Figures 5-17 and 5-18, and openings larger than indicated shall be designed by an engineer experienced in tank design in accordance with this Standard. Hinged covers prescribed in Figure 5-18 may not be used on roofs designed to contain internal pressure. Flanged covers prescribed in Figure 5-17 may not be used on tanks with internal pressures (acting across the cross sectional area of the tank roof) that exceed the weight of the roof plates. This section applies only to fixed steel roofs.



SECTION A-A—ROOF MANHOLE WITH REINFORCING PLATE



BASE FOR ROOF MANHOLE WITHOUT REINFORCING PLATE

Figure 5-16—Roof Manholes (See Table 5-13)

Table 5-13—Dimensions for Roof Manholes (mm [in.])

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
Size of Manhole	Diameter of Neck ID^a	Diameter of Cover Plate D_C	Diameter of Bolt Circle D_B	Number of Bolts	Diameter of Gasket		Diameter of Hole in Roof Plate or Reinforcing Plate D_P	Outside Diameter of Reinforcing Plate D_R
					Inside	Outside		
500 (20)	500 (20)	650 (26)	590 (23 ¹ / ₂)	16	500 (20)	650 (26)	515 (20 ⁵ / ₈)	1050 (42)
600 (24)	600 (24)	750 (30)	690 (27 ¹ / ₂)	20	600 (24)	750 (30)	615 (24 ⁵ / ₈)	1150 (46)

^aPipe may be used for neck, providing the minimum nominal wall thickness is 6 mm (¹/₄ in.). (ID and D_P shall be adjusted accordingly.)
Note: See Figure 5-18.

Table 5-14—Dimensions for Flanged Roof Nozzles (mm [in.])

Column 1	Column 2	Column 3	Column 4	Column 5
Nozzle NPS	Outside Diameter of Pipe Neck	Diameter of Hole in Roof Plate or Reinforcing Plate D_P	Minimum Height of Nozzle H_R	Outside Diameter of Reinforcing Plate ^a D_R
1 ¹ / ₂	48.3 (1.900)	50 (2)	150 (6)	125 (5)
2	60.3 (2 ³ / ₈)	65 (2 ¹ / ₂)	150 (6)	175 (7)
3	88.9 (3 ¹ / ₂)	92 (3 ⁵ / ₈)	150 (6)	225 (9)
4	114.3 (4 ¹ / ₂)	120 (4 ⁵ / ₈)	150 (6)	275 (11)
6	168.3 (6 ⁵ / ₈)	170 (6 ³ / ₄)	150 (6)	375 (15)
8	219.1 (8 ⁵ / ₈)	225 (8 ⁷ / ₈)	150 (6)	450 (18)
10	273.0 (10 ³ / ₄)	280 (11)	200 (8)	550 (22)
12	323.8 (12 ³ / ₄)	330 (13)	200 (8)	600 (24)

^aReinforcing plates are not required on nozzles NPS 6 or smaller but may be used if desired.
Note: See Figure 5-19.

• 5.8.7 Water Drawoff Sumps

Water drawoff sumps shall be as specified in Figure 5-21 and Table 5-16, unless otherwise specified by the Purchaser.

5.8.8 Scaffold-Cable Support

The scaffold-cable support shall conform to Figure 5-22. Where seams or other attachments are located at the center of the tank roof, the scaffold support shall be located as close as possible to the center.

5.8.9 Threaded Connections

Threaded piping connections shall be female and tapered. The threads shall conform to the requirements of ASME B1.20.1 for tapered pipe threads.

Table 5-15—Dimensions for Threaded Roof Nozzles (mm [in.])

Column 1	Column 2	Column 3	Column 4
Nozzle NPS	Coupling NPS	Diameter of Hole in Roof Plate or Reinforcing Plate D_P	Outside Diameter of Reinforcing Plate ^a D_R
3/4	3/4	36 (1 ⁷ / ₁₆)	100 (4)
1	1	44 (1 ²³ / ₃₂)	110 (4 ¹ / ₂)
1 ¹ / ₂	1 ¹ / ₂	60 (2 ¹¹ / ₃₂)	125 (5)
2	2	76 (3)	175 (7)
3	3	105 (4 ¹ / ₈)	225 (9)
4	4	135 (5 ¹¹ / ₃₂)	275 (11)
6	6	192 (7 ¹⁷ / ₃₂)	375 (15)
8	8	250 (9 ⁷ / ₈)	450 (18)
10	10	305 (12)	550 (22)
12	12	360 (14 ¹ / ₄)	600 (24)

^aReinforcing plates are not required on nozzles NPS 6 or smaller but may be used if desired.
Note: See Figure 5-20.

5.8.10 Platforms, Walkways, and Stairways

- Platforms, walkways, and stairways shall be in accordance with Tables 5-17, 5-18, and 5-19 and OSHA 29 *CFR* 1910, Subpart D, or equivalent national safety standard and the requirements herein, except as noted herein.
 - For examples of acceptable details, see Process Industry Practices standard details PIP STF05501, PIP STF05520, and PIP STF05521 (see www.pip.org).
- Unless declined on the Data Sheet, Line 24, a roof edge landing or gauger's platform shall be provided at the top of all tanks.

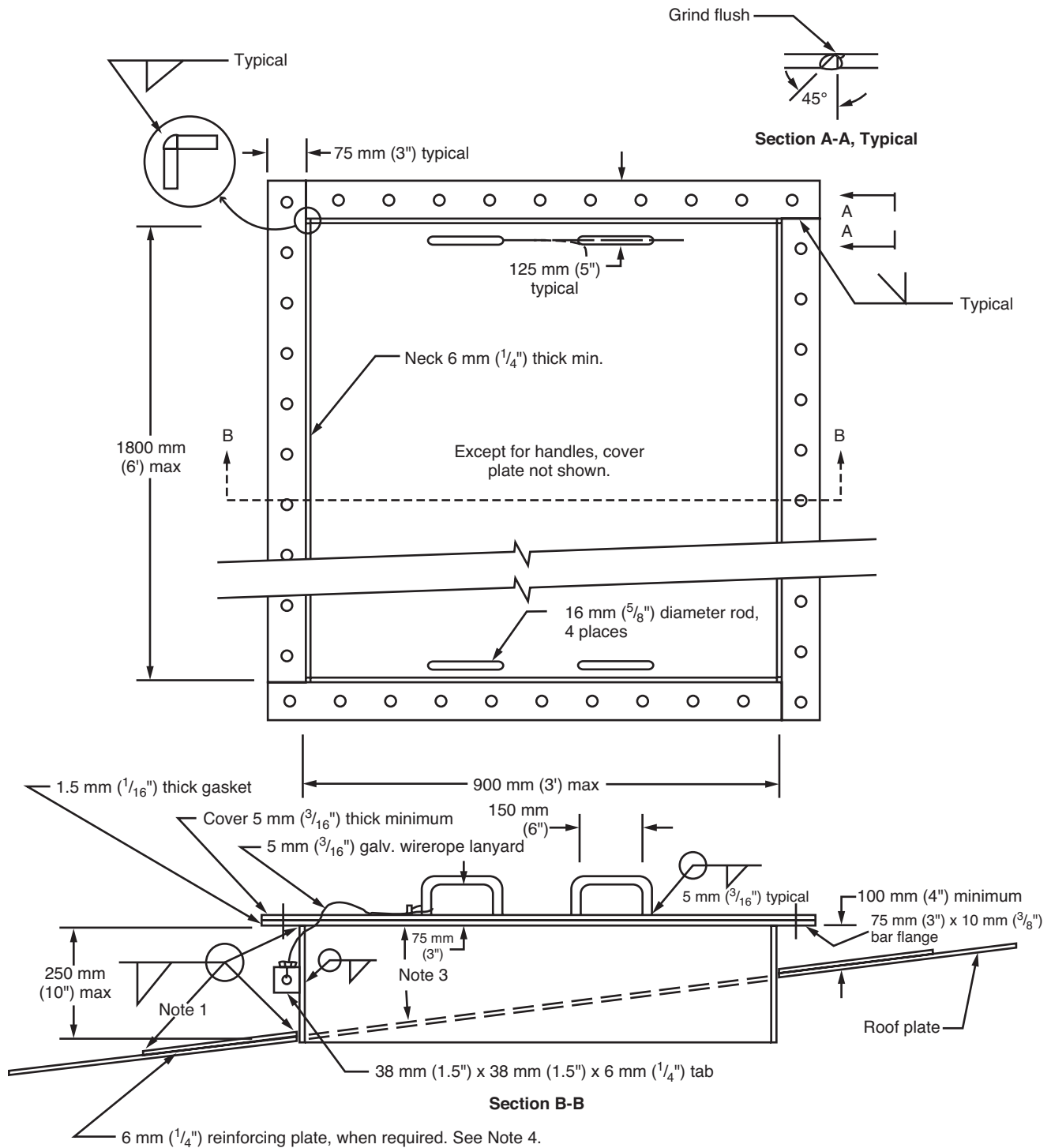
5.8.11 Other Appurtenances and Attachments

5.8.11.1 Floating suction lines shall be provided when specified on the Data Sheet, Table 4. Floating suction lines using rigid articulated (having one or more swing joints) pipe shall be designed to travel in a vertical plane and prevent damage to the floating roof and the suction line through its design range of travel. These lines shall be designed so that the vertical plane is as close as possible to, and in no case greater than 10 degrees off, a radial line from the tank centerline to the nozzle. Adjustments shall be made to clear internal structures.

- 5.8.11.2** Inlet diffusers shall be provided if requested in the Other Tank Appurtenances section of the Data Sheet, Table 4. (See API RP 2003 and Appendix H for additional information.)
- 5.8.11.3** If required by the Purchaser, grounding lugs shall be provided in the quantity specified on the Data Sheet, Table 4, and comply with Figure 5-23. The lugs shall be equally spaced around the base of the tank. Provide a minimum of four lugs. The suggested maximum lug spacing is 30 m (100 ft).

Note: Tanks that rest directly on a foundation of soil, asphalt or concrete are inherently grounded for purposes of dissipation of electrostatic charges. The addition of grounding rods or similar devices will not reduce the hazard associated with electrostatic charges in the stored product. API RP 2003 and NFPA-780 contain additional information about tank grounding issues as well as comments about lightning protection.

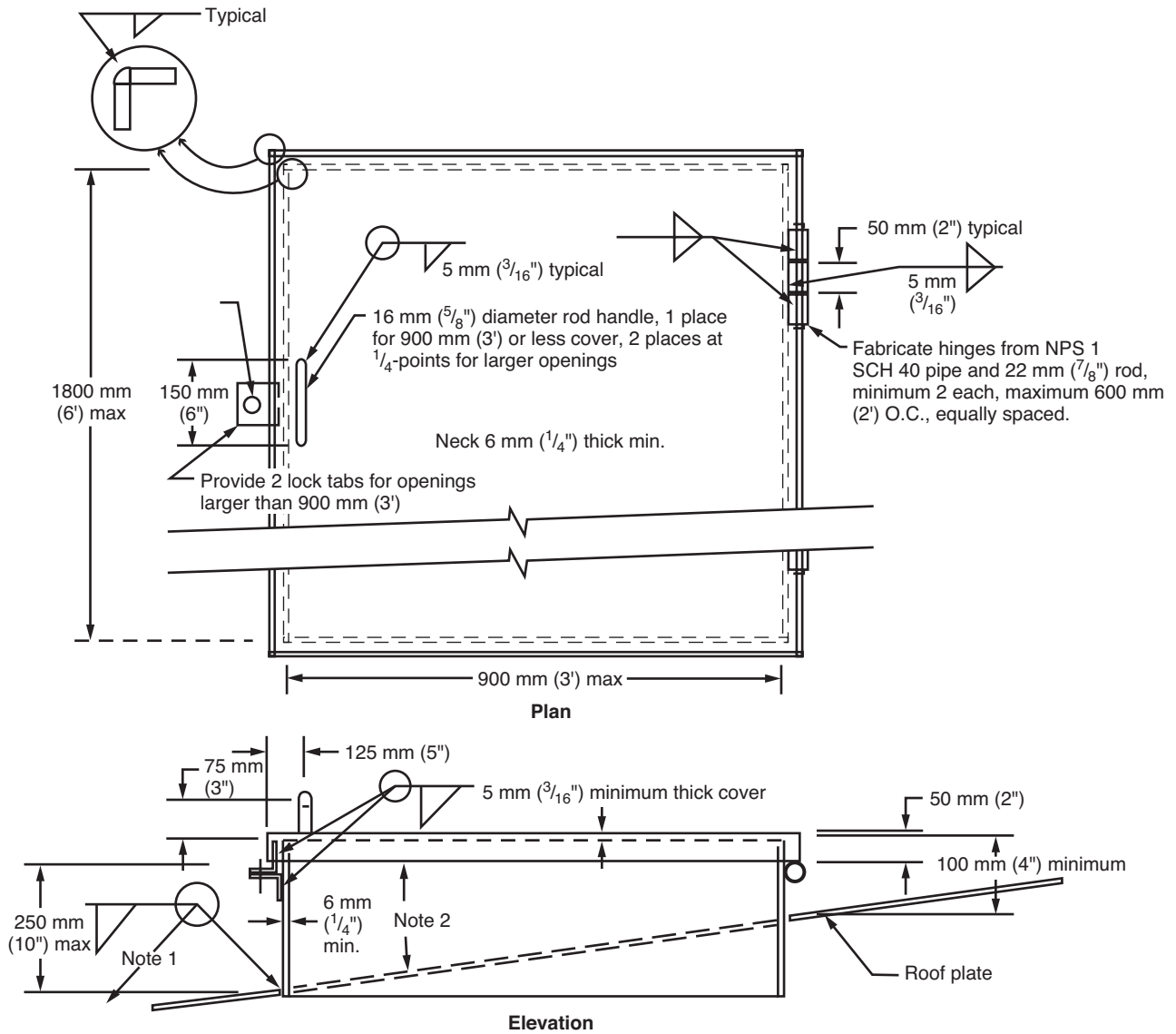
5.8.11.4 All non-circular miscellaneous pads shall have rounded corners with a minimum radius of 50 mm (2 in.). Pads that must cover shell seams shall be provided with a 6 mm (¹/₄ in.) telltale hole (see 5.7.3.4).



Notes:

1. Weld size shall be the smaller of the plate thicknesses being joined.
2. Cover may be either parallel to roof or horizontal. Opening may be oriented as desired.
3. Bolts shall be 16-mm (5/8-in.) diameter in 20-mm (3/4-in.) holes, which shall be equally spaced and shall not exceed 125-mm (5 in.) on center.
4. When required, provide 6-mm (1/4-in.) reinforcing plate. Width at least 1/2 smallest opening dimension. Round outside corners with 75 mm (3 in.) radius, minimum. Seams shall be square groove butt-welded.

Figure 5-17—Rectangular Roof Openings with Flanged Covers



Notes:

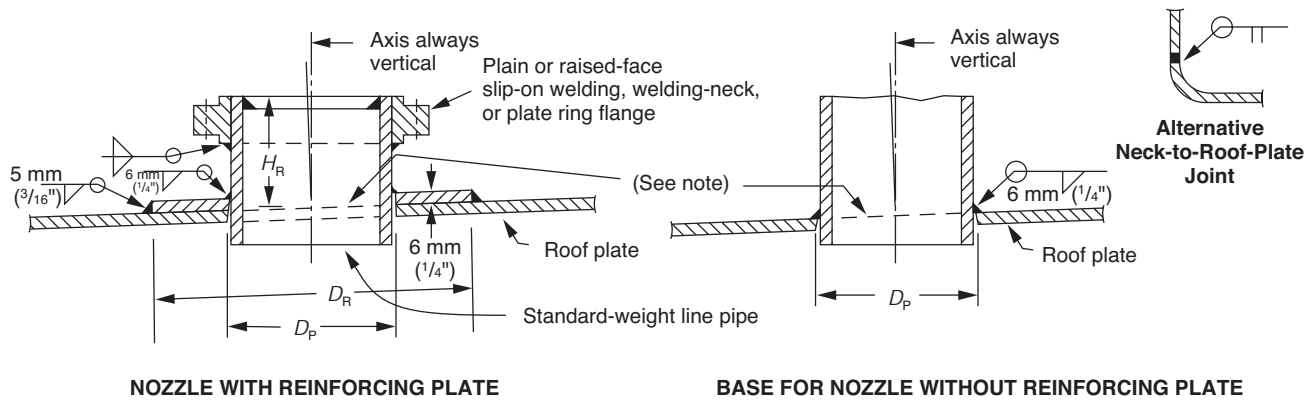
1. Weld size shall be the smaller of the plate thicknesses being joined.
2. Cover may be either parallel to roof or horizontal. Opening may be oriented as desired.
3. Reinforcement, when required, shall be as shown in Figure 5-19.
4. Not for use on roofs designed to contain internal pressure.

Figure 5-18—Rectangular Roof Openings with Hinged Cover

5.9 TOP AND INTERMEDIATE STIFFENING RINGS

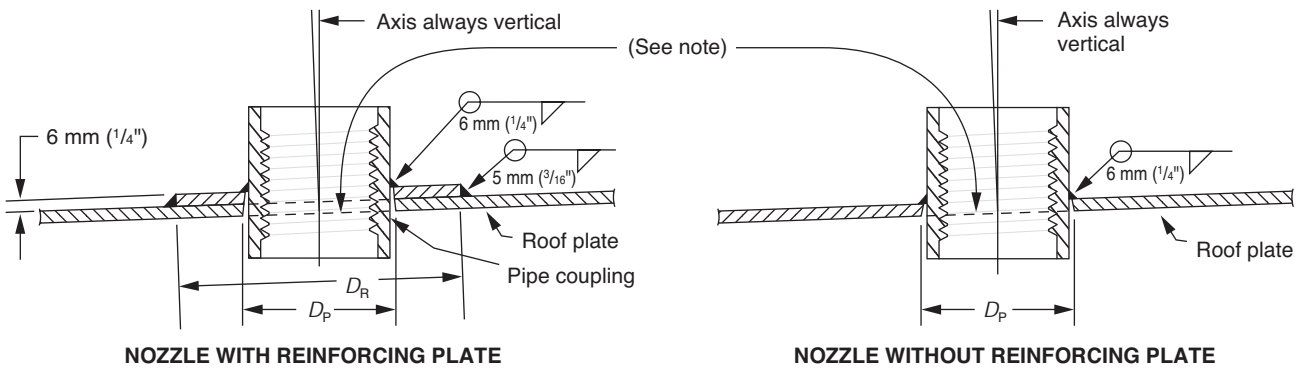
5.9.1 General

An open-top tank shall be provided with stiffening rings to maintain roundness when the tank is subjected to wind loads. The stiffening rings shall be located at or near the top of the top course, preferably on the outside of the tank shell. This design for rings used as wind girders also applies to floating-roof tanks covered in Appendix C. The top angle and the wind girders shall conform, in material and size, to the requirements of this Standard.



Note: When the roof nozzle is used for venting, the neck shall be trimmed flush with the roofline.

Figure 5-19—Flanged Roof Nozzles (See Table 5-14)



Note: See 5.8.9 for requirements for threaded connections. When the roof nozzle is used for venting, the neck shall be trimmed flush with the roofline.

Figure 5-20—Threaded Roof Nozzles (See Table 5-15)

5.9.2 Types of Stiffening Rings

Stiffening rings may be made of structural sections, formed plate sections, sections built up by welding, or combinations of such types of sections assembled by welding. The outer periphery of stiffening rings may be circular or polygonal (see Figure 5-24).

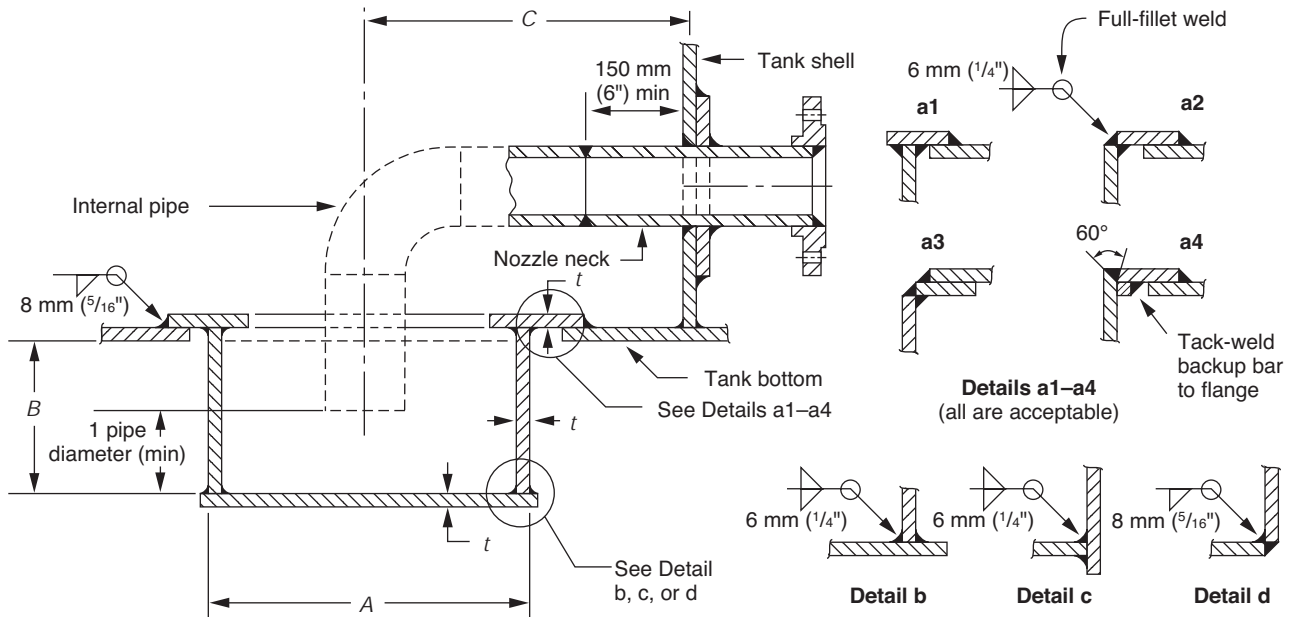
5.9.3 Restrictions on Stiffening Rings

5.9.3.1 The minimum size of angle for use alone or as a component in a built-up stiffening ring shall be $64 \times 64 \times 6.4$ mm ($2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{4}$ in.). The minimum nominal thickness of plate for use in formed or built-up stiffening rings shall be 6 mm ($\frac{1}{4}$ in.).

5.9.3.2 When the stiffening rings are located more than 0.6 m (2 ft) below the top of the shell, the tank shall be provided with a $64 \times 64 \times 4.8$ mm ($2\frac{1}{2} \times 2\frac{1}{2} \times \frac{3}{16}$ in.) top curb angle for shells 5 mm ($\frac{3}{16}$ in.) thick, with a $76 \times 76 \times 6.4$ mm ($3 \times 3 \times \frac{1}{4}$ in.) angle for shells more than 5 mm ($\frac{3}{16}$ in.) thick, or with other members of equivalent section modulus.

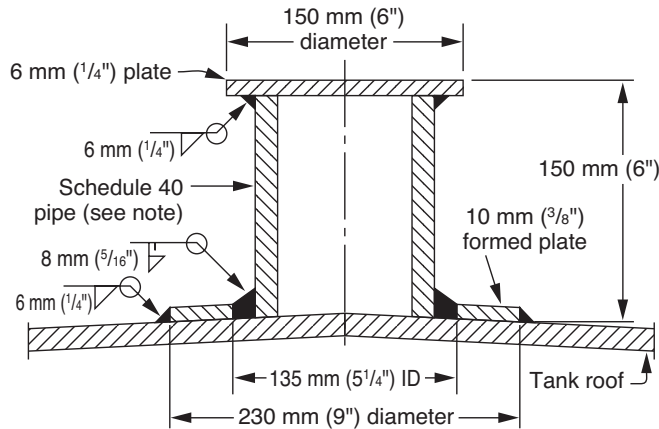
5.9.3.3 Rings that may trap liquid shall be provided with adequate drain holes. Uninsulated tanks having rings shall have small water-shedding slopes and/or drain holes or slots unless the Purchaser approves an alternate means of drainage. If drain holes are provided, they shall be at least 25 mm (1 in.) diameter (or slot width) on 2400 mm (8 ft) centers or less. Insulated tanks where the rings function as insulation closures shall have no drain holes or slots.

5.9.3.4 Welds joining stiffening rings to the tank shell may cross vertical tank seam welds. Any splice weld in the ring shall be located a minimum of 150 mm (6 in.) from any vertical shell weld. Stiffening rings may also cross vertical tank seam welds with the use of coping (rat hole) of the stiffening ring at the vertical tank seam. Where the coping method is used, the required section modulus of the stiffening ring and weld spacing must be maintained.



Note: The erection procedure shall include the following steps: (a) a hole shall be cut in the bottom plate or a sump shall be placed in the foundation before bottom placement; (b) a neat excavation shall be made to conform to the shape of the drawoff sump, the sump shall be put in place, and the foundation shall be compacted around the sump after placement; and (c) the sump shall be welded to the bottom.

Figure 5-21—Drawoff Sump (See Table 5-16)



Note: NPS 4 Schedule 40 pipe (wall thickness = 6.02 mm [0.237 in.]; outside diameter = 114.3 mm [4.5 in.]).

Figure 5-22—Scaffold Cable Support

Table 5-16—Dimensions for Drawoff Sumps

NPS	Diameter of Sump mm (in.) <i>A</i>	Depth of Sump mm (in.) <i>B</i>	Distance from Center Pipe to Shell m (ft) <i>C</i>	Thickness of Plates in Sump mm (in.) <i>t</i>	Minimum Internal Pipe Thickness mm (in.)	Minimum Nozzle Neck Thickness mm (in.)
2	610 (24)	300 (12)	1.1 (3 ¹ / ₂)	8 (5/16)	5.54 (0.218)	5.54 (0.218)
3	910 (36)	450 (18)	1.5 (5)	10 (3/8)	6.35 (0.250)	7.62 (0.300)
4	1220 (48)	600 (24)	2.1 (6 ³ / ₄)	10 (3/8)	6.35 (0.250)	8.56 (0.337)
6	1520 (60)	900 (36)	2.6 (8 ¹ / ₂)	11 (7/16)	6.35 (0.250)	10.97 (0.432)

Note: See Figure 5-19.

Table 5-17—Requirements for Platforms and Walkways

	1. All parts shall be made of metal.
07	2. The minimum width of the walkway shall be 610 mm (24 in.), after making adjustments at all projections.
	3. Flooring shall be made of grating or nonslip material.
	4. The height of the top railing above the floor shall be 1070 mm (42 in.). ^a
	5. The minimum height of the toeboard shall be 75 mm (3 in.).
	6. The maximum space between the top of the floor and the bottom of the toeboard shall be 6 mm (¹ / ₄ in.).
	7. The height of the midrail shall be approximately one-half the distance from the top of the walkway to the top of the railing.
	8. The maximum distance between railing posts shall be 2400 mm (96 in.).
	9. The completed structure shall be capable of supporting a moving concentrated load of 4450 N (1000 lbf), and the handrail structure shall be capable of withstanding a load of 900 N (200 lbf) applied in any direction at any point on the top rail.
	10. Handrails shall be on both sides of the platform but shall be discontinued where necessary for access.
	11. At handrail openings, any space wider than 150 mm (6 in.) between the tank and the platform should be floored.
	12. A tank runway that extends from one part of a tank to any part of an adjacent tank, to the ground, or to another structure shall be supported so that free relative movement of the structures joined by the runway is permitted. This may be accomplished by firm attachment of the runway to one tank and the use of a slip joint at the point of contact between the runway and the other tank. (This method permits either tank to settle or be disrupted by an explosion without the other tank being endangered.)
07	^a This handrail height is required by OSHA specifications.

Table 5-18—Requirements for Stairways

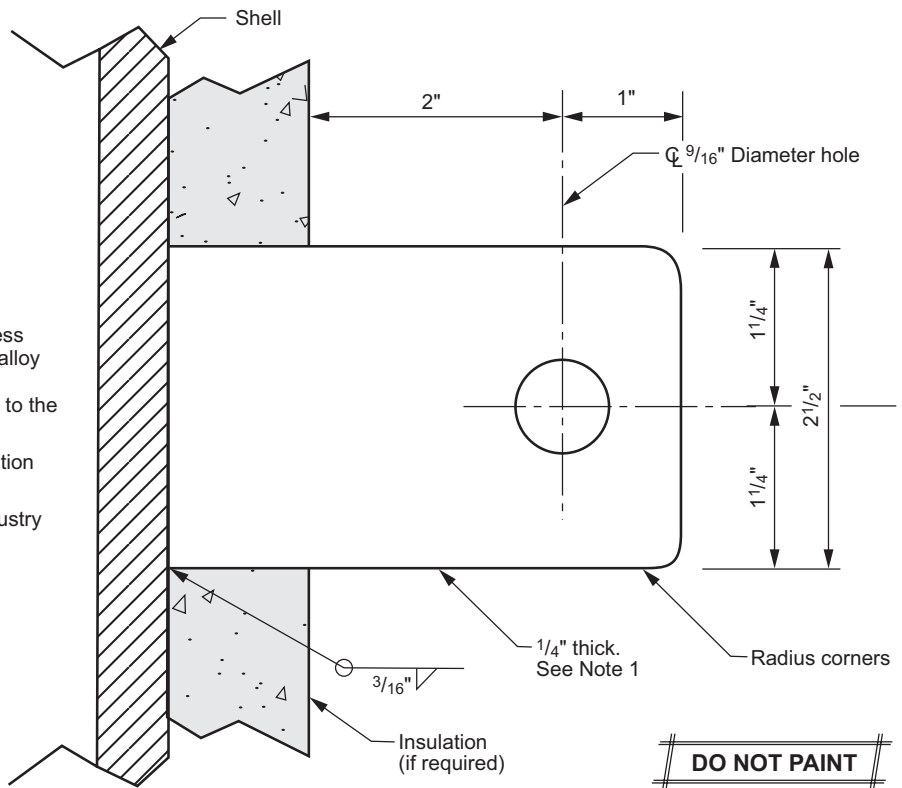
	1. All parts shall be made of metal.
07	2. The minimum width of the stairs shall be 710 mm (28 in.).
	3. The maximum angle ^a of the stairway with a horizontal line shall be 50 degrees.
	4. The minimum width of the stair treads shall be 200 mm (8 in.). (The sum of twice the rise of the stair treads plus the run [defined as the horizontal distance between the noses of successive tread pieces] shall not be less than 610 mm [24 in.] or more than 660 mm [26 in.]. Rises shall be uniform throughout the height of the stairway.)
	5. Treads shall be made of grating or nonslip material.
	6. The top railing shall join the platform handrail without offset, and the height measured vertically from tread level at the nose of the tread shall be 760 mm – 860 mm (30 in. – 34 in.).
	7. The maximum distance between railing posts, measured along the slope of the railing, shall be 2400 mm (96 in.).
	8. The completed structure shall be capable of supporting a moving concentrated load of 4450 N (1000 lbf), and the handrail structure shall be capable of withstanding a load of 900 N (200 lbf) applied in any direction at any point on the top rail.
	9. Handrails shall be on both sides of straight stairs; handrails shall also be on both sides of circular stairs when the clearance between the tank shell and the stair stringer exceeds 200 mm (8 in.).
07	10. Circumferential stairways shall be completely supported on the shell of the tank, and the ends of the stringers shall be clear of the ground. Stairways shall extend from the bottom of the tank up to a roof edge landing or gauger's platform.
	^a It is recommended that the same angle be employed for all stairways in a tank group or plant area.

Table 5-19—Rise, Run, and Angle Relationships for Stairways

Height of Rise mm (in.) <i>R</i>	$2R + r = 610 \text{ mm (24 in.)}$			$2R + r = 660 \text{ mm (26 in.)}$		
	Width of Run mm (in.) <i>r</i>	Angle		Width of Run mm (in.) <i>r</i>	Angle	
		Degrees	Minutes		Degrees	Minutes
135 (5 ¹ / ₄)	340 (13 ¹ / ₂)	21	39	—	—	—
140 (5 ¹ / ₂)	330 (13)	22	59	380 (15)	20	13
145 (5 ³ / ₄)	320 (12 ¹ / ₂)	24	23	370 (14 ¹ / ₂)	21	24
150 (6)	310 (12)	25	49	360 (14)	22	37
155 (6 ¹ / ₄)	300 (11 ¹ / ₂)	27	19	350 (13 ¹ / ₂)	23	53
165 (6 ¹ / ₂)	280 (11)	30	31	330 (13)	26	34
170 (6 ³ / ₄)	270 (10 ¹ / ₂)	32	12	320 (12 ¹ / ₂)	27	59
180 (7)	250 (10)	35	45	300 (12)	30	58
185 (7 ¹ / ₄)	240 (9 ¹ / ₂)	37	38	290 (11 ¹ / ₂)	32	32
190 (7 ¹ / ₂)	230 (9)	39	34	280 (11)	34	10
195 (7 ³ / ₄)	220 (8 ¹ / ₂)	41	33	270 (10 ¹ / ₂)	35	50
205 (8)	200 (8)	45	42	250 (10)	39	21
210 (8 ¹ / ₄)	190 (7 ¹ / ₂)	47	52	240 (9 ¹ / ₂)	41	11
215 (8 ¹ / ₂)	—	—	—	230 (9)	43	4
220 (8 ³ / ₄)	—	—	—	220 (8 ¹ / ₂)	45	0
225 (9)	—	—	—	210 (8)	46	58

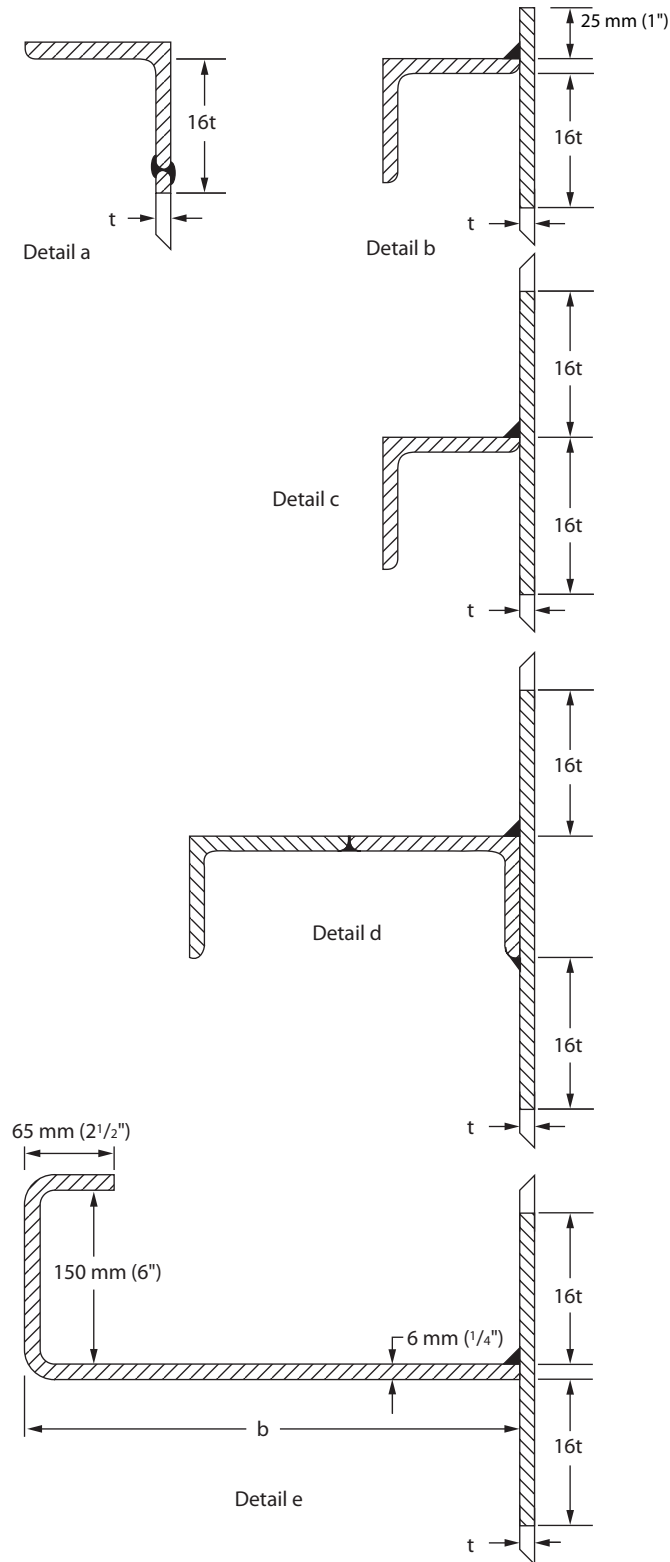
Notes:

1. Lug material shall be austenitic stainless steel when attached to carbon or low alloy steel parts. When attached to other materials, lug material shall be similar to the material to which attached.
2. See tank drawing/data sheet for elevation and orientation.
3. Drawing courtesy of PIP (Process Industry Practices).



[SI units omitted for clarity]

Figure 5-23—Grounding Lug



Note: The section moduli given in Table 5-20 for Details c and d are based on the longer leg being located horizontally (perpendicular to the shell) when angles with uneven legs are used.

Figure 5-24—Typical Stiffening-Ring Sections for Tank Shells (See Table 5-20)

Table 5-20—Section Moduli (cm³ [in.³]) of Stiffening-Ring Sections on Tank Shells

Column 1		Column 2	Column 3	Column 4	Column 5	Column 6
Member Size		Shell Thickness (mm [in.])				
mm	in.	5 (3/16)	6 (1/4)	8 (5/16)	10 (3/8)	11 (7/16)
Top Angle: Figure 5-24, Detail a						
64 × 64 × 6.4	2 1/2 × 2 1/2 × 1/4	6.86 (0.41)	7.01 (0.42)	—	—	—
64 × 64 × 7.9	2 1/2 × 2 1/2 × 5/16	8.30 (0.51)	8.48 (0.52)	—	—	—
76 × 76 × 9.5	3 × 3 × 3/8	13.80 (0.89)	14.10 (0.91)	—	—	—
Curb Angle: Figure 5-24, Detail b						
64 × 64 × 6.4	2 1/2 × 2 1/2 × 1/4	27.0 (1.61)	28.3 (1.72)	—	—	—
64 × 64 × 7.9	2 1/2 × 2 1/2 × 1/16	31.1 (1.89)	32.8 (2.04)	—	—	—
76 × 76 × 6.4	3 × 3 × 1/4	38.1 (2.32)	39.9 (2.48)	—	—	—
76 × 76 × 9.5	3 × 3 × 3/8	43.0 (2.78)	52.6 (3.35)	—	—	—
102 × 102 × 6.4	4 × 4 × 1/4	57.6 (3.64)	71.4 (4.41)	—	—	—
102 × 102 × 9.5	4 × 4 × 3/8	65.6 (4.17)	81.4 (5.82)	—	—	—
One Angle: Figure 5-24, Detail c (See Note)						
64 × 64 × 6.4	2 1/2 × 2 1/2 × 1/4	28.5 (1.68)	29.6 (1.79)	31.3 (1.87)	32.7 (1.93)	33.4 (2.00)
64 × 64 × 7.9	2 1/2 × 2 1/2 × 5/16	33.1 (1.98)	34.6 (2.13)	36.9 (2.23)	38.7 (2.32)	39.5 (2.40)
102 × 76 × 6.4	4 × 3 × 1/4	58.3 (3.50)	60.8 (3.73)	64.2 (3.89)	66.6 (4.00)	67.7 (4.10)
102 × 76 × 7.9	4 × 3 × 5/16	68.3 (4.14)	71.6 (4.45)	76.2 (4.66)	79.4 (4.82)	80.8 (4.95)
127 × 76 × 7.9	5 × 3 × 5/16	90.7 (5.53)	95.2 (5.96)	102.0 (6.25)	106.0 (6.47)	108.0 (6.64)
127 × 89 × 7.9	5 × 3 1/2 × 5/16	101.0 (6.13)	106.0 (6.60)	113.0 (6.92)	118.0 (7.16)	120.0 (7.35)
127 × 89 × 9.5	5 × 3 1/2 × 3/8	116.0 (7.02)	122.0 (7.61)	131.0 (8.03)	137.0 (8.33)	140.0 (8.58)
152 × 102 × 9.5	6 × 4 × 3/8	150.0 (9.02)	169.0 (10.56)	182.0 (11.15)	191.0 (11.59)	194.0 (11.93)
Two Angles: Figure 5-24, Detail d (See Note)						
102 × 76 × 7.9	4 × 3 × 5/16	186 (11.27)	191 (11.78)	200 (12.20)	207 (12.53)	210 (12.81)
102 × 76 × 9.5	4 × 3 × 3/8	216 (13.06)	222 (13.67)	233 (14.18)	242 (14.60)	245 (14.95)
127 × 76 × 7.9	5 × 3 × 5/16	254 (15.48)	262 (16.23)	275 (16.84)	285 (17.34)	289 (17.74)
127 × 76 × 9.5	5 × 3 × 3/8	296 (18.00)	305 (18.89)	321 (19.64)	333 (20.26)	338 (20.77)
127 × 89 × 7.9	5 × 3 1/2 × 5/16	279 (16.95)	287 (17.70)	300 (18.31)	310 (18.82)	314 (19.23)
127 × 89 × 9.5	5 × 3 1/2 × 3/8	325 (19.75)	334 (20.63)	350 (21.39)	363 (22.01)	368 (22.54)
152 × 102 × 9.5	6 × 4 × 3/8	456 (27.74)	468 (28.92)	489 (29.95)	507 (30.82)	514 (31.55)
Formed Plate: Figure 5-24, Detail e						
b = 250	b = 10	—	341 (23.29)	375 (24.63)	392 (25.61)	399 (26.34)
b = 300	b = 12	—	427 (29.27)	473 (31.07)	496 (32.36)	505 (33.33)
b = 350	b = 14	—	519 (35.49)	577 (37.88)	606 (39.53)	618 (40.78)
b = 400	b = 16	—	615 (42.06)	687 (45.07)	723 (47.10)	737 (48.67)
b = 450	b = 18	—	717 (48.97)	802 (52.62)	846 (55.07)	864 (56.99)
b = 500	b = 20	—	824 (56.21)	923 (60.52)	976 (63.43)	996 (65.73)
b = 550	b = 22	—	937 (63.80)	1049 (68.78)	1111 (72.18)	1135 (74.89)
b = 600	b = 24	—	1054 (71.72)	1181 (77.39)	1252 (81.30)	1280 (84.45)
b = 650	b = 26	—	1176 (79.99)	1317 (86.35)	1399 (90.79)	1432 (94.41)
b = 700	b = 28	—	1304 (88.58)	1459 (95.66)	1551 (100.65)	1589 (104.77)
b = 750	b = 30	—	1436 (97.52)	1607 (105.31)	1709 (110.88)	1752 (115.52)
b = 800	b = 32	—	1573 (106.78)	1759 (115.30)	1873 (121.47)	1921 (126.66)
b = 850	b = 34	—	1716 (116.39)	1917 (125.64)	2043 (132.42)	2096 (138.17)
b = 900	b = 36	—	1864 (126.33)	2080 (136.32)	2218 (143.73)	2276 (150.07)
b = 950	b = 38	—	2016 (136.60)	2248 (147.35)	2398 (155.40)	2463 (162.34)
b = 1000	b = 40	—	2174 (147.21)	2421 (158.71)	2584 (167.42)	2654 (174.99)

Note: The section moduli for Details c and d are based on the longer leg being located horizontally (perpendicular to the shell) when angles with uneven legs are used.

5.9.4 Stiffening Rings as Walkways

A stiffening ring or any portion of it that is specified as a walkway shall have a width not less than 710 mm (28 in.) clear of projections including the angle on the top of the tank shell. The clearance around local projections shall not be less than 610 mm (24 in.). Unless the tank is covered with a fixed roof, the stiffening ring (used as a walkway) shall be located 1100 mm (42 in.) below the top of the curb angle and shall be provided with a standard railing on the unprotected side and at the ends of the section used as a walkway.

5.9.5 Supports for Stiffening Rings

Supports shall be provided for all stiffening rings when the dimension of the horizontal leg or web exceeds 16 times the leg or web thickness. The supports shall be spaced at the intervals required for the dead load and vertical live load; however, the spacing shall not exceed 24 times the width of the outside compression flange.

5.9.6 Top Wind Girder

5.9.6.1 The required minimum section modulus of the stiffening ring shall be determined by the following equation:

In SI units:

$$Z = \frac{D^2 H_2}{17} \left(\frac{V}{190} \right)^2$$

where

- Z = required minimum section modulus (cm³),
- D = nominal tank diameter (m),
- H_2 = height of the tank shell (m), including any freeboard provided above the maximum filling height as a guide for a floating roof,
- V = design wind speed (3-sec gust) (km/h) (see 5.2.1[j]).

In US Customary units:

$$Z = 0.0001 D^2 H_2 \left(\frac{V}{120} \right)^2$$

where

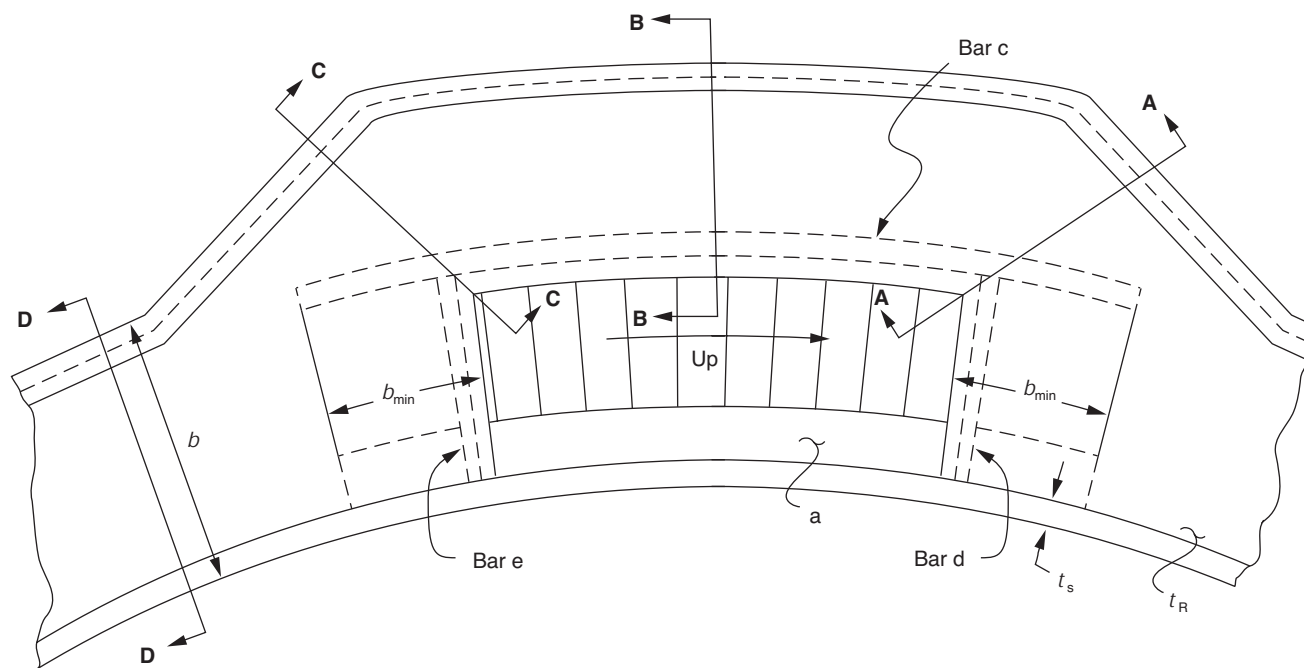
- Z = required minimum section modulus (in.³),
- D = nominal tank diameter (ft),
- H_2 = height of the tank shell (ft), including any freeboard provided above the maximum filling height as a guide for a floating roof,
- V = design wind speed (3-sec gust) (mph) (see 5.2.1[j]).

- Note: For tank diameters over 60 m (200 ft), the section modulus required by the equation may be reduced by agreement between the Purchaser and the Manufacturer, but the modulus may not be less than that required for a tank diameter of 60 m (200 ft). (A description of the loads on the tank shell that are included in the design wind speed can be found in Item a of the note to 5.9.7.1.)

5.9.6.2 The section modulus of the stiffening ring shall be based on the properties of the applied members and may include a portion of the tank shell for a distance of 16 plate thicknesses below and, if applicable, above the shell-ring attachment. When curb angles are attached to the top edge of the shell ring by butt-welding, this distance shall be reduced by the width of the vertical leg of the angle (see Figure 5-24 and Table 5-22).

5.9.6.3 When a stair opening is installed through a stiffening ring, the section modulus of the portion of the ring outside the opening, including the transition section, shall conform to the requirements of 5.9.6.1. The shell adjacent to the opening shall be stiffened with an angle or a bar, the wide side of which is placed in a horizontal plane. The other sides of the opening shall also be stiffened with an angle or a bar, the wide side of which is placed in a vertical plane. The cross-sectional area of these rim stiffeners shall be greater than or equal to the cross-sectional area of the portion of shell included in the section-modulus calculations for the stiffening ring. These rim stiffeners or additional members shall provide a suitable toe board around the opening.

The stiffening members shall extend beyond the end of the opening for a distance greater than or equal to the minimum depth of the regular ring sections. The end stiffening members shall frame into the side stiffening members, and the end and side stiffening members shall be connected to ensure that their full strength is developed. Figure 5-25 shows the opening described in this section. Alternative details that provide a load-carrying capacity equal to that of the girder cross-section away from the opening may be provided.



Notes:

1. The cross-sectional area of a, c, d, and e must equal $32t_s^2$. The section of the figure designated "a" may be a bar or an angle whose wide leg is horizontal. The other sections may be bars or angles whose wide legs are vertical.
2. Bars c, d, and e may be placed on the top of the girder web, provided they do not create a tripping hazard.
3. The section modulus of Sections A-A, B-B, C-C, and D-D shall conform to 5.9.6.1.
4. The stairway may be continuous through the wind girder or may be offset to provide a landing.
5. See 5.9.6.3 for toeboard requirements.

Figure 5-25—Stairway Opening through Stiffening Ring

5.9.7 Intermediate Wind Girders

5.9.7.1 The maximum height of the unstiffened shell shall be calculated as follows:

In SI units:

$$H_1 = 9.47t \sqrt{\left(\frac{t}{D}\right)^3 \left(\frac{190}{V}\right)^2}$$

where

H_1 = vertical distance, in m, between the intermediate wind girder and the top angle of the shell or the top wind girder of an open-top tank,

- t = as ordered thickness, unless otherwise specified, of the top shell course (mm) (see Note 1),
- D = nominal tank diameter (m),
- V = design wind speed (3-sec gust) (km/h) (see 5.2.1[j]).

In US Customary units:

$$H_1 = 600,000t \sqrt{\left(\frac{t}{D}\right)^3 \left(\frac{120}{V}\right)^2}$$

where

H_1 = vertical distance, in ft, between the intermediate wind girder and the top angle of the shell or the top wind girder of an open-top tank,

- t = as ordered thickness, unless otherwise specified, of the top shell course (in.) (see Note 1),
- D = nominal tank diameter (ft),
- V = design wind speed (3-sec gust) (mph) (see 5.2.1[j]).

Note 1: The structural stability check of wind girder stiffened shells in accordance with 5.9.6 and 5.9.7, shall be based upon nominal dimensions of the shell course and the wind girders irrespective of specified corrosion allowances whenever the “No” option is selected for “Check Buckling in Corroded Cond.?” on the Data Sheet, Line 9. Whenever the “Yes” option is selected, the check must be based upon the nominal dimensions minus the specified corrosion allowance.

Note 2: This formula is intended to cover tanks with either open tops or closed tops and is based on the following factors (for the background for the factors given in this note, see ASCE 7 and R. V. McGrath’s “Stability of API Standard 650 Tank Shells”):¹⁹

a. The velocity pressure is:

$$p = 0.00256K_z K_{zt} K_d V^2 I G = 1.48 \text{ kPa (31 lbf/ft}^2\text{)}$$

where

K_z = velocity pressure exposure coefficient = 1.04 for exposure C at a height of 40 ft,

K_{zt} = 1.0 for all structures except those on isolated hills or escarpments,

K_d = directionality factor = 0.95 for round tanks,

V = 3-second gust design wind speed = 190 km/h (120 mph) at 10 m (33 ft) above ground (see 5.2.1[j]),

I = importance factor = 1.0 for Category II structures,

G = gust factor = 0.85 for exposure C.

A 0.24 kPa (5 lbf/ft²) internal vacuum is added for inward drag on open-top tanks or for external pressure on closed top tanks for a total of 1.72 kPa (36 lbf/ft²).

b. The wind pressure is uniform over the theoretical buckling mode of the tank shell, which eliminates the need for a shape factor for the wind loading.

c. The modified U.S. Model Basin formula for the critical uniform external pressure on thin-wall tubes free from end loadings, subject to the total pressure specified in Item a.

- d. When other factors are specified by the Purchaser that are greater than the factors in Items a – c, the total load on the shell shall be modified accordingly, and H_1 shall be decreased by the ratio of 1.72 kPa (36 lbf/ft²) to the modified total pressure.

5.9.7.2 After the maximum height of the unstiffened shell, H_1 , has been determined, the height of the transformed shell shall be calculated as follows:

a. With the following equation, change the actual width of each shell course into a transposed width of each shell course having the top shell thickness:

$$W_{tr} = W \sqrt[5]{\left(\frac{t_{\text{uniform}}}{t_{\text{actual}}}\right)^5}$$

where

W_{tr} = transposed width of each shell course, mm (in.),

W = actual width of each shell course, mm (in.),

- t_{uniform} = as ordered thickness, unless otherwise specified, of the top shell course, mm (in.),
- t_{actual} = as ordered thickness, unless otherwise specified, of the shell course for which the transposed width is being calculated, mm (in.).

¹⁹R.V. McGrath, “Stability of API Standard 650 Tank Shells,” *Proceedings of the American Petroleum Institute, Section III—Refining*, American Petroleum Institute, New York, 1963, Vol. 43, pp. 458 – 469.

b. Add the transposed widths of the courses. The sum of the transposed widths of the courses will give the height of the transformed shell.

5.9.7.3 If the height of the transformed shell is greater than the maximum height H_1 , an intermediate wind girder is required.

5.9.7.3.1 For equal stability above and below the intermediate wind girder, the girder should be located at the mid-height of the transformed shell. The location of the girder on the actual shell should be at the same course and same relative position as the location of the girder on the transformed shell, using the thickness relationship in 5.9.7.2.

5.9.7.3.2 Other locations for the girder may be used, provided the height of unstiffened shell on the transformed shell does not exceed H_1 (see 5.9.7.5).

5.9.7.4 If half the height of the transformed shell exceeds the maximum height H_1 , a second intermediate girder shall be used to reduce the height of unstiffened shell to a height less than the maximum.

5.9.7.5 Intermediate wind girders shall not be attached to the shell within 150 mm (6 in.) of a horizontal joint of the shell. When the preliminary location of a girder is within 150 mm (6 in.) of a horizontal joint, the girder shall preferably be located 150 mm (6 in.) below the joint; however, the maximum unstiffened shell height shall not be exceeded.

5.9.7.6 The required minimum section modulus of an intermediate wind girder shall be determined by the following equation:

In SI units:

$$Z = \frac{D^2 H_1}{17} \left(\frac{V}{190} \right)^2$$

where

Z = required minimum section modulus (cm^3),

D = nominal tank diameter (m),

H_1 = vertical distance (m), between the intermediate wind girder and the top angle of the shell or the top wind girder of an open-top tank,

V = design wind speed (3-sec gust) (km/h) (see 5.2.1[j]).

In US Customary units:

$$Z = \frac{D^2 H_1}{10\,000} \left(\frac{V}{120} \right)^2$$

where

Z = required minimum section modulus (in^3),

D = nominal tank diameter (ft),

H_1 = vertical distance (ft), between the intermediate wind girder and the top angle of the shell or the top wind girder of an open-top tank,

V = design wind speed (3-sec gust) (mph) (see 5.2.1[j]).

Note: A description of the loads on the tank shell that are included in the design wind speed can be found in Item a of the note to 5.9.7.1.

5.9.7.6.1 Where the use of a transformed shell permits the intermediate wind girder to be located at a height that is less than H_1 calculated by the formula in 5.9.7.1, the spacing to the mid-height of the transformed shell, transposed to the height of the actual shell, may be substituted for H_1 in the calculation for the minimum section modulus if the girder is attached at the transposed location.

5.9.7.6.2 The section modulus of the intermediate wind girder shall be based on the properties of the attached members and may include a portion of the tank shell for a distance above and below the attachment to the shell, in mm (in.), of:

In SI units:

$$13.4 (D_t)^{0.5}$$

where

D = nominal tank diameter (m),

t = shell thickness at the attachment (mm).

In US Customary units:

$$1.47 (D_t)^{0.5}$$

where

D = nominal tank diameter (ft),

t = shell thickness at the attachment (in.).

- 07 | **5.9.7.7** An opening for a stairway in an intermediate stiffener is unnecessary when the intermediate stiffener extends no more than 150 mm (6 in.) from the outside of the shell and the nominal stairway width is at least 710 mm (28 in.). For greater outward extensions of a stiffener, the stairway shall be increased in width to provide a minimum clearance of 450 mm (18 in.) between the outside of the stiffener and the handrail of the stairway, subject to the Purchaser's approval. If an opening is necessary, it may be designed in a manner similar to that specified in 5.9.6.3 for a top wind girder with the exception that only a 560 mm (22 in.) width through the stiffener need be provided.

5.10 ROOFS

5.10.1 Definitions

- 07 | The following definitions apply to roof designs but shall not be considered as limiting the type of roof permitted by 5.10.2.8.
- A supported cone roof is a roof formed to approximately the surface of a right cone that is supported principally either by rafters on girders and columns or by rafters on trusses with or without columns.
 - A self-supporting cone roof is a roof formed to approximately the surface of a right cone that is supported only at its periphery.
 - A self-supporting dome roof is a roof formed to approximately a spherical surface that is supported only at its periphery.
 - A self-supporting umbrella roof is a modified dome roof formed so that any horizontal section is a regular polygon with as many sides as there are roof plates that is supported only at its periphery.

5.10.2 General

5.10.2.1 All roofs and supporting structures shall be designed for load combinations (a), (b), (c), (e), and (f) of Appendix R.

- 07 | **5.10.2.2** Roof plates shall have a minimum nominal thickness of 5 mm (³/₁₆ in.) or 7-gauge sheet. Thicker roof plates may be required for self-supporting roofs (see 5.10.5 and 5.10.6). Any required corrosion allowance for the plates of self-supporting roofs shall be added to the calculated thickness unless otherwise specified by the Purchaser. Any corrosion allowance for the plates of supported roofs shall be added to the minimum nominal thickness. For frangible roof tanks, where a corrosion allowance is specified, the design must have frangible characteristics in the as-built (uncorroded) condition.

5.10.2.3 Roof plates of supported cone roofs shall not be attached to the supporting members unless otherwise approved by the Purchaser. Continuously attaching the roof to cone supporting members may be beneficial when interior coating systems are required, however, the tank roof cannot be considered frangible (see 5.10.2.6).

- **5.10.2.4** All internal and external structural members shall have a minimum nominal thickness of 4.3 mm (0.17 in.) in any component. The method of providing a corrosion allowance, if any, for the structural members shall be a matter of agreement between the Purchaser and the Manufacturer.
- **5.10.2.5** Roof plates shall be attached to the top angle of the tank with a continuous fillet weld on the top side only.
- **5.10.2.6** A roof is considered frangible (see 5.8.5 for emergency venting requirement) if the roof-to-shell joint will fail prior to the shell-to-bottom joint in the event of excessive internal pressure. When a Purchaser specifies a tank with a frangible roof, the tank design shall comply with all of the following:
 - a. The tank shall be 15.25 m (50 ft) diameter²⁰ or greater.
 - b. The slope of the roof at the top angle attachment does not exceed 2 in 12.
 - c. The roof is attached to the top angle with a single continuous fillet weld that does not exceed 5mm (³/₁₆ in.).
 - d. The roof support members shall not be attached to the roof plate.
 - e. The roof-to-top-angle compression ring is limited to details a – e in Figure F-2.
 - f. The top angle may be smaller than that required by 5.1.5.9.e.
 - g. All members in the region of the roof-to-shell junction, including insulation rings considered as contributing to the cross-sectional area (A).
 - h. The cross sectional area (A) of the roof-to-shell junction is less than the limit shown below:

In SI units:

$$A = \frac{D_{LS}}{1390 \tan \theta}$$

In US Customary units:

$$A = \frac{D_{LS}}{201,000 \tan \theta}$$

Note: The terms for the equation above are defined in Appendix F.

- **5.10.2.7** For all types of roofs, the plates may be stiffened by sections welded to the plates but may not be stiffened by sections welded to the supporting rafters or girders.
- **5.10.2.8** These rules cannot cover all details of tank roof design and construction. With the approval of the Purchaser, the roof need not comply with 5.10.5, 5.10.6, and 5.10.7. The Manufacturer shall provide a roof designed and constructed to be as safe as otherwise provided for in this Standard. In the roof design, particular attention should be given to preventing failure through instability.

5.10.3 Allowable Stresses

● 5.10.3.1 General

All parts of the roof structure shall be proportioned so that the sum of the maximum static and dynamic stresses shall not exceed the limitations specified in the AISC Specification for Structural Steel Buildings or with the agreement of the Purchaser an equivalent structural design code recognized by the government of the country where the tank is located. The portion of the specification, “Allowable Stress Design,” shall be used in determining allowable unit stresses. Use of Part 5, Chapter N—“Plastic Design,” is specifically not allowed.²⁰

²⁰See API Publ 937 *Evaluation of the Design Criteria for Storage Tanks with Frangible Roofs*. Ongoing API research evaluating the relative strength of the shell-to-bottom and roof-to-shell joints may permit extending the minimum diameter below 15.25 m (50 ft).

5.10.3.2 Minimum Thicknesses

The minimum thickness of any structural member, including any corrosion allowance on the exposed side or sides, shall not be less than 6 mm (0.250 in.) for columns, knee braces and beams or stiffeners which by design normally resist axial compressive forces or 4 mm (0.17 in.) for any other structural member.

5.10.3.3 Maximum Slenderness Ratios

For columns, the value L/r_c shall not exceed 180. For other compression members, the value L/r shall not exceed 200. For all other members, except tie rods whose design is based on tensile force, the value L/r shall not exceed 300.

where

L = unbraced length, mm (in.),

r_c = least radius of gyration of column, mm (in.),

r = governing radius of gyration, mm (in.).

• 5.10.3.4 Columns

When the Purchaser does not specify lateral loads that will be imposed on the roof-supporting columns and the column member is not considered to be a slender element section by the AISC Specification, the following formula for allowable compression may be used in lieu of the formulas in the AISC Specification when l/r exceeds 120 and the yield stress of column (F_y) is less than or equal to 250 MPa (36,000 lbf/in.²). When the Purchaser specifies lateral loads that will be imposed on the roof-supporting columns, the columns must be proportioned to meet the requirements for combined axial compression and bending as specified in 5.10.3.

When l/r is less than or equal to C_c :

$$F_a = \frac{\left[\frac{\left[1 - \frac{(l/r)^2}{2C_c^2} \right] F_y}{\frac{5}{3} + \frac{3(l/r)}{8C_c} - \frac{(l/r)^3}{8C_c^3}} \right]}{\left[1.6 - \frac{l}{200r} \right]}$$

where

$$C_c = \sqrt{\frac{2\pi^2 E}{F_y}}$$

When l/r exceeds C_c :

$$F_a = \frac{\left[\frac{12\pi^2 E}{23(l/r)^2} \right]}{\left[1.6 - \frac{l}{200r} \right]}$$

where

F_a = allowable compression stress, MPa (lbf/in.²),

F_y = yield stress of material, MPa (lbf/in.²),

E = modulus of elasticity, MPa (lbf/in.²),

l = unbraced length of the column, mm (in.),

r = least radius of gyration of column, mm (in.).

5.10.4 Supported Cone Roofs

- **5.10.4.1** The slope of the roof shall be 1:16 or greater if specified by the Purchaser. If the rafters are set directly on chord girders, producing slightly varying rafter slopes, the slope of the flattest rafter shall conform to the specified or ordered roof slope. 07

5.10.4.2 Main supporting members, including those supporting the rafters, may be rolled or fabricated sections or trusses. Although these members may be in contact with the roof plates, the compression flange of a member or the top chord of a truss shall be considered as receiving no lateral support from the roof plates and shall be laterally braced, if necessary, by other acceptable methods. The allowable stresses in these members shall be governed by 5.10.3.

5.10.4.3 Structural members serving as rafters may be rolled or fabricated sections but in all cases shall conform to the rules of 5.10.2, 5.10.3, and 5.10.4. Rafters shall be designed for the dead load of the rafters and roof plates with the compression flange of the rafter considered as receiving no lateral support from the roof plates and shall be laterally braced if necessary (see 5.10.4.2). When considering additional dead loads or live loads, the rafters in direct contact with the roof plates applying the loading to the rafters may be considered as receiving adequate lateral support from the friction between the roof plates and the compression flanges of the rafters, with the following exceptions:

- Trusses and open-web joints used as rafters.
- Rafters with a nominal depth greater than 375 mm (15 in.).
- Rafters with a slope greater than 1:6.

- **5.10.4.4** Rafters shall be spaced so that in the outer ring, their centers are not more than 0.6π m (2π ft [6.28 ft]) apart measured along the circumference of the tank. Spacing on inner rings shall not be greater than 1.7 m (5.5 ft).
- **5.10.4.5** Roof columns shall be made from either pipe or structural shapes as selected on the Data Sheet, Line 11. Pipe columns shall either be sealed or have openings on both the top and bottom of the column.

5.10.4.6 Rafter clips for the outer row of rafters shall be welded to the tank shell.

5.10.4.7 Roof support columns shall be provided at their bases with details that provide for the following:

a. *Load Distribution:* Column loads shall be distributed over a bearing area based on the specified soil bearing capacity or foundation design. Where an unstiffened horizontal plate is designed to distribute the load, it shall be a minimum of 12 mm (¹/₂ in.) thick. Alternatively, the column load may be distributed by an assembly of structural beams. The plate or members shall be designed to distribute the load without exceeding allowable stresses prescribed in 5.10.3.1. 07

b. *Corrosion and Abrasion Protection:* At each column a wear plate with a minimum 6 mm (¹/₄ in.) thickness shall be welded to the tank bottom with a 6 mm (¹/₄ in.) minimum fillet weld. A single adequate thickness plate may be designed for the dual functions of load distribution and corrosion/abrasion protection.

c. *Vertical Movement:* The design shall allow the columns to move vertically relative to the tank bottom without restraint in the event of tank overpressure or bottom settlement.

d. *Lateral Movement:* The columns shall be effectively guided at their bases to prevent lateral movement. The guides shall remain effective in the event of vertical movement of columns relative to tank bottom of up to 75 mm (3 in.). The guides shall be located such that they are not welded directly to the tank bottom plates.

5.10.4.8 Three acceptable arrangements to provide the functions required by 5.10.4.7 are illustrated in Figure 5-26.

5.10.4.9 For Appendix F tanks, when supporting members are attached to the roof plate, consideration shall be given to the design of the supporting members and their attachment details when considering internal pressure.

- **5.10.5 Self-Supporting Cone Roofs**

Note: Self-supporting roofs whose roof plates are stiffened by sections welded to the plates need not conform to the minimum thickness requirements, but the thickness of the roof plates shall not be less than 5 mm (³/₁₆ in.) when so designed by the Manufacturer, subject to the approval of the Purchaser.

5.10.5.1 Self-supporting cone roofs shall conform to the following requirements:

$$\theta \leq 37 \text{ degrees (slope} = 9:12)$$

$$\theta \geq 9.5 \text{ degrees (slope} = 2:12)$$

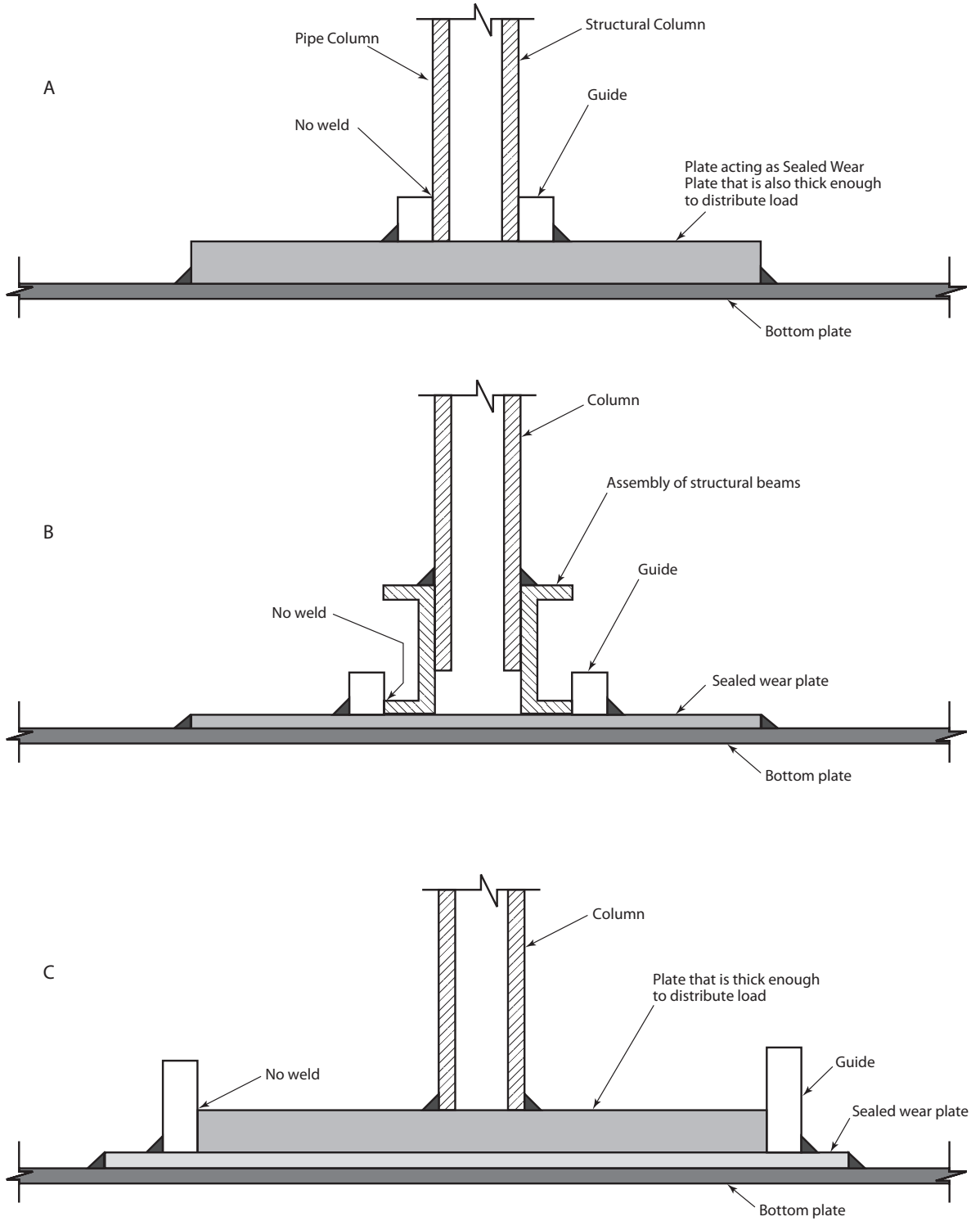


Figure 5-26—Some Acceptable Column Base Details

In SI units:

$$\text{Minimum thickness} = \frac{D}{4.8 \sin \theta} \sqrt{\frac{T}{2.2}} \geq 5 \text{ mm}$$

Maximum thickness = 12.5 mm, exclusive of corrosion allowance

where

D = nominal diameter of the tank shell (m),

T = greater of load combinations (e)(1) and (e)(2) of Appendix R (kPa),

θ = angle of cone elements to the horizontal (deg).

In US Customary units:

$$\text{Minimum thickness} = \frac{D}{400 \sin \theta} \sqrt{\frac{T}{45}} \geq 3/16 \text{ in.}$$

Maximum thickness = 1/2 in., exclusive of corrosion allowance

where

D = nominal diameter of the tank shell (ft),

T = greater of load combinations (e)(1) and (e)(2) of Appendix R (lbf/ft²),

θ = angle of cone elements to the horizontal (deg).

5.10.5.2 The participating area at the roof-to-shell junction shall be determined using Figure F-2 and shall equal or exceed the following:

In SI units:

$$\frac{D^2}{0.432 \sin \theta} \left(\frac{T}{2.2} \right)$$

where

D = nominal diameter of the tank shell (m),

T = greater of load combinations (e)(1) and (e)(2) of Appendix R (kPa),

θ = angle of cone elements to the horizontal (deg).

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

In US Customary units:

$$\frac{D^2}{3000 \sin \theta} \left(\frac{T}{45} \right)$$

where

D = nominal diameter of the tank shell (ft),

T = greater of load combinations (e)(1) and (e)(2) of Appendix R (lbf/ft²),

θ = angle of cone elements to the horizontal (deg).

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

● 5.10.6 Self-Supporting Dome and Umbrella Roofs

Note: Self-supporting roofs whose roof plates are stiffened by sections welded to the plates need not conform to the minimum thickness requirements, but the thickness of the roof plates shall not be less than 5 mm ($3/16$ in.) when so designed by the Manufacturer, subject to the approval of the Purchaser.

5.10.6.1 Self-supporting dome and umbrella roofs shall conform to the following requirements:

Minimum radius = $0.8D$ (unless otherwise specified by the Purchaser)

Maximum radius = $1.2D$

In SI units:

$$\text{Minimum thickness} = \frac{r_r}{2.4} \sqrt{\frac{T}{2.2}} + \text{C.A.} \geq 5 \text{ mm}$$

Maximum thickness = 12.5 mm, exclusive of corrosion allowance

where

D = nominal diameter of the tank shell (m),

T = greater of load combinations (e)(1) and (e)(2) of Appendix R (kPa),

r_r = roof radius (m).

In US Customary units:

$$\text{Minimum thickness} = \frac{r_r}{200} \sqrt{\frac{T}{45}} + \text{C.A.} \geq 3/16 \text{ in.}$$

Maximum thickness = $1/2$ in., exclusive of corrosion allowance

where

D = nominal diameter of the tank shell (ft),

T = greater of load combinations (e)(1) and (e)(2) of Appendix R (lbf/ft²),

r_r = roof radius (ft).

5.10.6.2 The participating area, in mm², at the roof-to-shell junction shall be determined using Figure F-2, and shall equal or exceed the following:

$$\frac{Dr_r}{0.216} \left(\frac{T}{2.2} \right)$$

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

In US Customary units:

The participating area, in in.², at the roof-to-shell junction shall be determined using Figure F-2 and shall equal or exceed the following:

$$\frac{Dr_r}{1500} \left(\frac{T}{45} \right)$$

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

5.10.7 Top-Angle Attachment for Self-Supporting Roofs

Information and certain restrictions on types of top-angle joints are provided in Item c of 5.1.5.9. Details of welding are provided in 7.2.

5.11 WIND LOAD ON TANKS (OVERTURNING STABILITY)

5.11.1 Wind Pressure

Overturning stability shall be calculated using the wind pressures given in 5.2.1(j).

5.11.2 Unanchored Tanks

Unanchored tanks shall satisfy both of the following uplift criteria:

1. $0.6M_w + M_{Pi} < M_{DL} / 1.5$
2. $M_w + 0.4M_{Pi} < (M_{DL} + M_F) / 2$

where

M_{Pi} = moment about the shell-to-bottom joint from design internal pressure,

M_w = overturning moment about the shell-to-bottom joint from horizontal plus vertical wind pressure,

M_{DL} = moment about the shell-to-bottom joint from the weight of the shell and roof supported by the shell,

M_F = moment about the shell-to-bottom joint from liquid where weight of liquid is w_a defined in E.2.2 using a specific gravity of 0.7 and a height of one half the design liquid height H , so in SI units, $w_a = 59t_b\sqrt{F_{by}H}$ and in US Customary units $w_a = 4.67t_b\sqrt{F_{by}H}$ (see Figure 5-27).

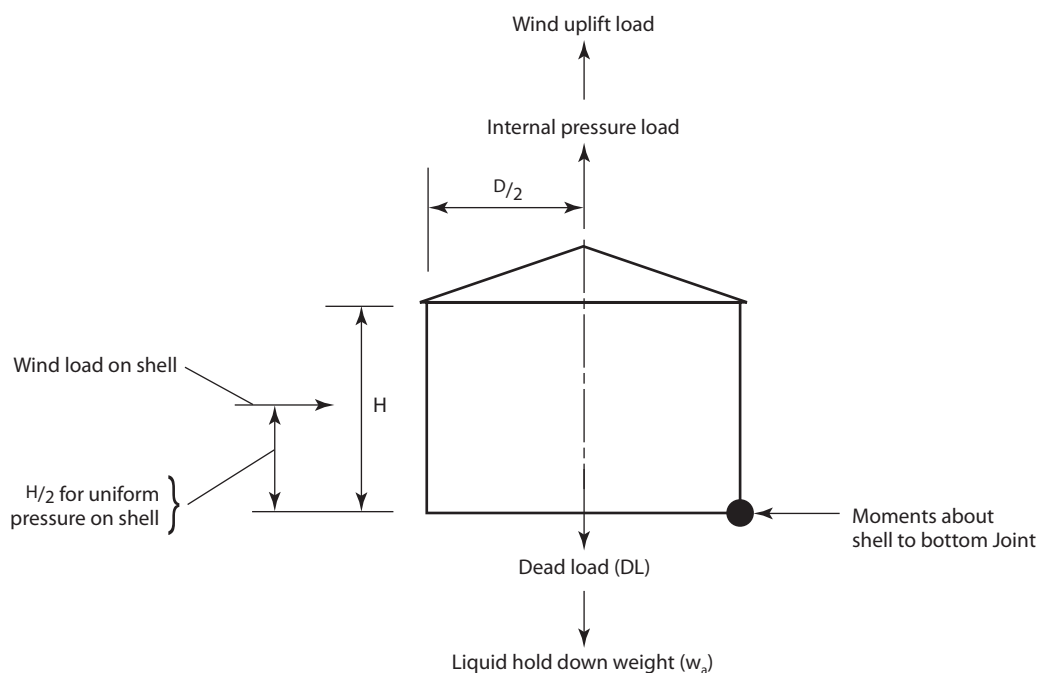


Figure 5-27—Overturning Check for Unanchored Tanks

5.11.3 Anchored Tanks

When anchors are required, the design tension load per anchor shall be calculated as follows:

$$t_b = 4M_w/dN - W/N$$

where

t_b = design tension load per anchor (N) (lbf),

d = diameter of the anchor circle (m) (ft),

N = number of anchors,

W = weight of the shell plus roof supported by the shell less 0.4 times the uplift from internal pressure.

5.11.4 Sliding Friction

Unless otherwise required, tanks that may be subject to sliding due to wind shall use a maximum allowable sliding friction of 0.40 multiplied by the force against the tank bottom.

5.12 TANK ANCHORAGE

5.12.1 When a tank is required to be anchored per 5.11, Appendix E, Appendix F, or when a tank is anchored for any other reason, the following minimum requirements shall be met.

5.12.2 Anchorage shall be provided to resist each of the uplift load cases listed in Table 5-21. The load per anchor shall be:

$$t_b = U/N$$

where

t_b = load per anchor,

U = net uplift load per Table 5-21,

N = number of anchors (a minimum of 4 is required),

5.12.3 The spacing between anchors shall not exceed 3 m (10 ft).

5.12.4 Allowable stresses for anchor bolts shall be in accordance with Table 5-21 for each load case. The allowable stress shall apply to the net (root) area of the anchor bolt.

- **5.12.5** The Purchaser shall specify any corrosion allowance that is to be added to the anchor dimensions. Unless otherwise specified, corrosion allowance for anchor bolts shall be applied to the nominal diameter. The minimum anchor bolt diameter is 1 in. plus any specified corrosion allowance.

- **5.12.6** Attachment of the anchor bolts to the shell shall be through stiffened chair-type assemblies or anchor rings of sufficient size and height. An acceptable procedure for anchor chair design is given in AISI E-1, Volume II, Part VII "Anchor Bolt Chairs." When acceptable to the Purchaser, anchor straps may be used if the shell attachment is via chair-type assemblies or anchor rings of sufficient size and height.

5.12.7 Other evaluations of anchor attachments to the shell may be made to ensure that localized stresses in the shell will be adequately handled. An acceptable evaluation technique is given in ASME Section VIII Division 2, Appendix 4, using the allowable stresses given in this section for S_m . The method of attachment shall take into consideration the effect of deflection and rotation of the shell.

5.12.8 Allowable stresses for anchorage parts shall be in accordance with 5.10.3. A 33% increase of the allowable stress may be used for wind or seismic loading conditions.

5.12.9 The maximum allowable local stress in the shell at the anchor attachment shall be in accordance with Table 5-21 unless an alternate evaluation is made in accordance with 5.12.7.

Table 5-21a—Uplift Loads (SI Units)

Uplift Load Case	Net Uplift Formula, U (N)	Allowable Anchor Bolt Stress (MPa)	Allowable Shell Stress at Anchor Attachment (MPa)
Design Pressure	$[(P - 0.08t_h) \times D^2 \times 0.785] - W_1$	105	140
Test Pressure	$[(P_t - 0.08t_h) \times D^2 \times 0.785] - W_1$	140	170
Failure Pressure ^a	$[(1.5 \times P_f - 0.08t_h) \times D^2 \times 0.785] - W_3$	F_y	F_{ty}
Wind Load	$[4 \times M_w/D] - W_2$	$0.8 \times F_y$	170
Seismic Load	$[4 \times M_s/D] - W_2$	$0.8 \times F_y$	170
Design Pressure + Wind	$[(P - 0.08t_h) \times D^2 \times 0.785] + [4 M_w/D] - W_1$	140	170
Design Pressure + Seismic	$[(P - 0.08t_h) \times D^2 \times 0.785] + [4 M_s/D] - W_1$	$0.8 \times F_y$	170

where

D = tank diameter in (m)

F_{ty} = minimum yield strength of the bottom shell course (MPa)

P = design pressure in (kPa) (see Appendix F)

P_t = test pressure in (kPa) (see Appendix F)

P_f = failure pressure in (kPa) (see Appendix F)

t_h = roof plate thickness (mm)

M_w = wind moment in (N-m) (see 5.11)

M_s = seismic moment in (N-m) (see Appendix E)

W_1 = dead load of shell minus any corrosion allowance and any dead load other than roof plate acting on the shell minus any corrosion allowance (N)

W_2 = dead load of shell minus any corrosion allowance and any dead load including roof plate acting on the shell minus any corrosion allowance (N)

W_3 = dead load of the shell using as-built thicknesses and any dead load other than roof plate acting on the shell using as-built thicknesses (N)

^aFailure pressure applies to tanks falling under F.1.3 only. The failure pressure shall be calculated using as-built thicknesses.

Table 5-21b—Uplift Loads (US Customary Units)

Uplift Load Case	Net Uplift Formula, U (lbf)	Allowable Anchor Bolt Stress (lbf/in. ²)	Allowable Anchor Stress at Anchor Attachment (lbf/in. ²)
Design Pressure	$[(P - 8t_h) \times D^2 \times 4.08] - W_1$	15,000	20,000
Test Pressure	$[(P_t - 8t_h) \times D^2 \times 4.08] - W_1$	20,000	25,000
Failure Pressure ^a	$[(1.5 \times P_f - 8t_h) \times D^2 \times 4.08] - W_3$	F_y	F_{ty}
Wind Load	$[4 \times M_w/D] - W_2$	$0.8 \times F_y$	25,000
Seismic Load	$[4 \times M_s/D] - W_2$	$0.8 \times F_y$	25,000
Design Pressure + Wind	$[(P - 8t_h) \times D^2 \times 4.08] + [4 M_w/D] - W_1$	20,000	25,000
Design Pressure + Seismic	$[(P - 8t_h) \times D^2 \times 4.08] + [4 M_s/D] - W_1$	$0.8 \times F_y$	25,000

where

D = tank diameter in ft

F_{ty} = minimum yield strength of the bottom shell course (psi)

P = design pressure in inches of water column (see Appendix F)

P_t = test pressure in inches of water column (see Appendix F)

P_f = failure pressure in inches of water column (see Appendix F)

t_h = roof plate thickness in inches

M_w = wind moment in ft-lbs (see 5.11)

M_s = seismic moment in ft-lbs (see Appendix E)

W_1 = dead load of shell minus any corrosion allowance and any dead load other than roof plate acting on the shell minus any corrosion allowance (lbf)

W_2 = dead load of shell minus any corrosion allowance and any dead load including roof plate acting on the shell minus any corrosion allowance (lbf)

W_3 = dead load of the shell using as-built thicknesses and any dead load other than roof plate acting on the shell using as-built thicknesses (lbf)

^aFailure pressure applies to tanks falling under F.1.3 only. The failure pressure shall be calculated using as-built thicknesses.

- **5.12.10** When specified by the Purchaser, the anchors shall be designed to allow for thermal expansion of the tank resulting from a temperature greater than 93°C (200°F).
- 5.12.11** Any anchor bolts shall be uniformly tightened to a snug fit, and any anchor straps shall be welded while the tank is filled with test water but before any pressure is applied on top of the water. Measures such as peening the threads or adding locking nuts, shall be taken to prevent the nuts from backing off the threads.
- 5.12.12** The embedment strength of the anchor in the foundation shall be sufficient to develop the specified minimum yield strength of the anchor. Hooked anchors or end plates may be used to resist pullout.
- 5.12.13** The foundation shall provide adequate counterbalancing weight to resist the design uplift loads in accordance with the following:
 - 5.12.13.1** The counterbalancing weight, such as a concrete ringwall, shall be designed so that the resistance to net uplift is in accordance with Table 5-21. When considering uplift due to a wind or seismic moment, an evaluation shall be made to insure overturning stability of the foundation and to insure soil-bearing pressures are within allowable stress levels as determined using the recommendations of Appendix B.
 - 5.12.13.2** When a footing is included in the ringwall design, the effective weight of the soil above the footing may be included in the counterbalancing weight.

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SECTION 6—FABRICATION

6.1 GENERAL

6.1.1 Workmanship

- **6.1.1.1** All work of fabricating API Std 650 tanks shall be done in accordance with this Standard and with the permissible alternatives specified in the Purchaser's inquiry or order. The workmanship and finish shall be first class in every respect and subject to the closest inspection by the Manufacturer's inspector even if the Purchaser has waived any part of the inspection.

6.1.1.2 When material requires straightening, the work shall be done by pressing or another noninjurious method prior to any layout or shaping. Heating or hammering is not permissible unless the material is maintained at forging temperature during straightening.

6.1.1.3 Materials used to aid in the fabrication of tanks shall not have a detrimental effect on the structural integrity of the tank. Lubricants, crayons, adhesives, and anti-weld spatter compounds shall not contain materials that will be detrimental to the tank, e.g., sulfur and chloride compounds for stainless steel materials. Attachments that will be welded to the pressure boundary shall not have a zinc or cadmium coating in the weld area within 12 mm (0.5 in.) of the weld.

6.1.2 Finish of Plate Edges

The edges of plates may be sheared, machined, chipped, or machine gas cut. Shearing shall be limited to plates less than or equal to 10 mm ($3/8$ in.) thick used for butt-welded joints and to plates less than or equal to 16 mm ($5/8$ in.) thick used for lap-welded joints.

- Note: With the Purchaser's approval, the shearing limitation on plates used for butt-welded joints may be increased to a thickness less than or equal to 16 mm ($5/8$ in.).

When edges of plates are gas cut, the resulting surfaces shall be uniform and smooth and shall be freed from scale and slag accumulations before welding. After cut or sheared edges are wire brushed, the fine film of rust adhering to the edges need not be removed before welding. Circumferential edges of roof and bottom plates may be manually gas cut.

6.1.3 Shaping of Shell Plates

Figure 6-1 provides criteria for shaping of plates to the curvature of the tank prior to installation in the tank. Shaping of plates concurrently with installation in the tank shell is permitted if the tank diameter exceeds the limit in Figure 6-1 or if the Manufacturer's alternate procedure for any diameter has been accepted by the Purchaser.

6.1.4 Marking

All special plates that are cut to shape before shipment as well as roof-supporting structural members shall be marked as shown on the Manufacturer's drawings.

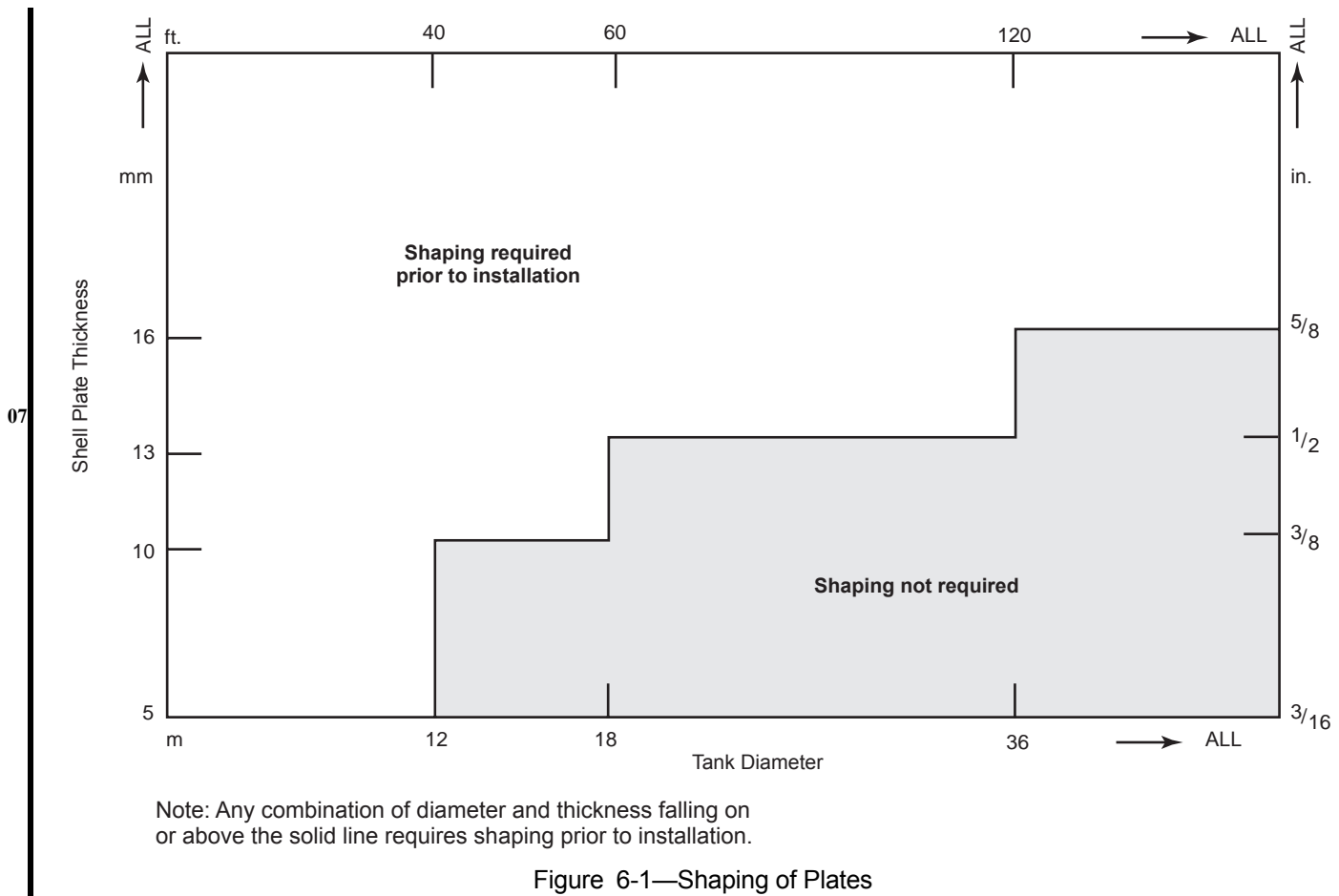
6.1.5 Shipping

Plates and tank material 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. All flange faces and other machined surfaces shall be protected against corrosion and from physical damage.

6.2 SHOP INSPECTION

- **6.2.1** The Purchaser's inspector shall be permitted free entry to all parts of the Manufacturer's plant that are concerned with the contract whenever any work under the contract is being performed. The Manufacturer shall afford the Purchaser's inspector all reasonable facilities to assure the inspector that the material is being furnished in accordance with this Standard. Also, the Manufacturer shall furnish samples or specimens of materials for the purpose of qualifying welders in accordance with 9.3.

Unless otherwise specified, inspection shall be made at the place of manufacture prior to shipment. The Manufacturer shall give the Purchaser ample notice of when the mill will roll the plates and when fabrication will begin so that the Purchaser's inspector may be present when required. The usual mill test of plates shall be deemed sufficient to prove the quality of the steel furnished



(except as noted in 6.2.2). Mill test reports or certificates of compliance, as provided for in the material specification, shall be furnished to the Purchaser only when the option is specified in the original contract that they be provided.

6.2.2 Mill and shop inspection shall not release the Manufacturer from responsibility for replacing any defective material and for repairing any defective workmanship that may be discovered in the field.

- **6.2.3** Any material or workmanship that in any way fails to meet the requirements of this Standard may be rejected by the Purchaser's inspector, and the material involved shall not be used under the contract. Material that shows injurious defects subsequent to its acceptance at the mill, subsequent to its acceptance at the Manufacturer's works, or during erection and testing of the tank will be rejected. The Manufacturer will be notified of this in writing and will be required to furnish new material promptly and make the necessary replacements or suitable repairs.

- **6.2.4**
 - a. The Manufacturer shall visually inspect all edges of shell and roof plates before installing the plates in the tank or before inserting a nozzle into the plate to determine if laminations are present. If a lamination is visually detected, the Manufacturer shall ultrasonically test the area to determine the extent of the laminations and shall reject the plate or make repairs in accordance with 6.2.4b.
 - b. For laminations found not exceeding 75 mm (3 in.) in length or 25 mm (1 in.) in depth, repairs may be made by edge gouging and rewelding to seal the lamination. The Manufacturer shall submit the edge repair procedure for Purchaser acceptance prior to the start of fabrication. For laminations exceeding these limits, the Manufacturer shall either reject the plate or repair the plate by entirely removing the lamination. Before making such repairs the Manufacturer shall document the extent of the lamination and submit a case-specific repair procedure for Purchaser approval.

SECTION 7—ERECTION

7.1 GENERAL

- **7.1.1** Required foundation and grade work shall be supplied by the Purchaser, unless otherwise specified in the Contract. The Manufacturer shall check level tolerances and contour before starting work, and shall notify the Purchaser of any deficiency discovered that might affect the quality of the finished work. Deficiencies noted shall be rectified by the Purchaser unless otherwise agreed by the Manufacturer.
- 7.1.2** After the Purchaser has turned the tank foundation over to the Manufacturer, the Manufacturer shall maintain the grade under the tank in true profile and free of foreign materials such as clay, coal, cinders, metal scraps, or animal or vegetable matter of any sort. The Manufacturer shall repair any damage to either the foundation or grade surface caused by the Manufacturer's operations.
- 7.1.3** Coating or foreign material shall not be used between surfaces in contact in the construction of the tank, except as permitted by 7.2.1.9.
- **7.1.4** Coating or other protection for structural work inside and outside of the tank shall be as specified in the contract and shall be applied by competent workers.
- 7.1.5** All temporary attachments welded to the exterior of the tank shall be removed and any noticeable projections of weld metal shall be ground smooth with the surface of the plate. In the event of inadvertent tearing of the plate when attachments are removed, the damaged area shall be repaired by welding and subsequent grinding of the surface to a smooth condition.
- 7.1.6** All temporary attachments welded to the interior of the tank, including the shell, roof, tank bottom, roof columns and other internal structures shall be removed and any noticeable projections of weld metal shall be ground smooth. In the event of inadvertent tearing of the plate when attachments are removed, the damaged area shall be repaired by welding and subsequent grinding of the surface to a smooth condition. This work must be completed before the application of internal coatings, the air raising of a fixed roof, the initial floating of a floating roof, and any other circumstance whereby projections may cause damage.

7.2 DETAILS OF WELDING

7.2.1 General

- **7.2.1.1** Tanks and their structural attachments shall be welded by the shielded metal-arc, gas metal-arc, gas tungsten-arc, oxy-fuel, flux-cored arc, submerged-arc, electroslag, or electrogas process using suitable equipment. Use of the oxyfuel, electroslag, or electrogas process shall be by agreement between the Manufacturer and the Purchaser. Use of the oxyfuel process is not permitted when impact testing of the material is required. All tank welding shall be performed in accordance with the requirements of Section 9 of this Standard and welding procedure specifications as described in Section IX of the ASME *Code*. Welding shall be performed in a manner that ensures complete fusion with the base metal.
- 7.2.1.2** No welding of any kind shall be performed when the surfaces 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 the work are properly shielded. Also, pre-heat shall be applied when metal temperature is below the temperature required by Table 7-1. In that case the base metal shall be heated to at least the temperature indicated in Table 7-1 within 75 mm (3 in.) of the place where welding is to be started and maintained 75 mm (3 in.) ahead of the arc.

Table 7-1—Minimum Preheat Temperatures

Material Group per Table 2-3	Thickness (<i>t</i>) of Thicker Plate mm (in.)	Minimum Preheat Temperature
Groups I, II, III & IIIA	$t \leq 32$ ($t \leq 1.25$)	0°C (32°F)
	$32 < t \leq 38$ ($1.25 < t \leq 1.50$)	10°C (50°F)
	$t > 38$ ($t > 1.50$)	93°C (200°F)
Groups IV, IVA, V & VI	$t \leq 32$ ($t \leq 1.25$)	10°C (50°F)
	$32 < t \leq 38$ ($1.25 < t \leq 1.50$)	40°C (100°F)
	$t > 38$ ($t > 1.50$)	93°C (200°F)

7-1

7.2.1.3 Each layer of weld metal or multilayer welding shall be cleaned of slag and other deposits before the next layer is applied.

7.2.1.4 The edges of all welds shall merge smoothly with the surface of the plate without a sharp angle.

7.2.1.5 All welding shall be free from coarse ripples, grooves, overlaps, abrupt ridges, and valleys that interfere with interpretation of NDE results.

7.2.1.6 During the welding operation, plates shall be held in close contact at all lap joints.

- **7.2.1.7** The method proposed by the Manufacturer for holding the plates in position for welding shall be submitted to the Purchaser's inspector for approval if approval has not already been given in writing by the Purchaser.

7.2.1.8 Tack welds used during the assembly of vertical joints of tank shells shall be removed and shall not remain in the finished joints when the joints are welded manually. When such joints are welded by the submerged-arc process, the tack welds shall be thoroughly cleaned of all welding slag but need not be removed if they are sound and are thoroughly fused into the subsequently applied weld beads.

Whether tack welds are removed or left in place, they shall be made using a fillet-weld or butt-weld procedure qualified in accordance with Section IX of the ASME *Code*. Tack welds to be left in place shall be made by welders qualified in accordance with Section IX of the ASME *Code* and shall be visually examined for defects, which shall be removed if found (see 8.5 for criteria for visual examination).

7.2.1.9 If protective coatings are to be used on surfaces to be welded, the coatings shall be included in welding-procedure qualification tests for the brand formulation and maximum thickness of coating to be applied.

7.2.1.10 Low-hydrogen electrodes shall be used for all manual metal-arc welds in annular rings and shell courses, including the attachment of the first shell course to bottom or annular plates, as follows:

- a. Where the plates are thicker than 12.5 mm ($1/2$ in.) (based on the thickness of the thicker member being joined) and made of material from Groups I–III.
- b. For all thicknesses when the plates are made of material from Groups IV, IVA, V and VI.

7.2.1.11 Non-structural small attachments such as insulation clips, studs and pins but not insulation support rings or bars may be welded by the arc stud, capacitor discharge or shielded metal arc process to the exterior of the shell including reinforcing plates or PWHT assemblies and roof either before or after hydrostatic testing is performed, but before the tank will be filled with product provided:

- a. The attachment locations meet the spacing requirements of 5.8.1.2a.
- b. The arc stud welding process is limited to 10 mm ($3/8$ in.) maximum diameter studs or equivalent cross-section.
- c. The maximum shielded metal arc electrode is limited to 3 mm ($1/8$ in.) diameter and shall be a low-hydrogen type.
- d. The attachment welds, except for those made by the capacitor discharge method, shall be inspected per 7.2.3.5. The attachment welds made by the capacitor discharge method shall be visually examined for all types and groups of shell materials.
- e. All stud welding and capacitor discharge procedures have been qualified in accordance with ASME Section IX. Capacitor discharge procedures do not require procedure qualification provided the power output is 125 watt-sec or less.

The shielded metal arc weld procedures shall meet the requirements of Section 9 for qualification for use.

7.2.2 Bottoms

7.2.2.1 After the bottom plates are laid out and tacked, they shall be joined by welding the joints in a sequence that the Manufacturer has found to result in the least distortion from shrinkage and thus to provide as nearly as possible a plane surface.

7.2.2.2 The welding of the shell to the bottom shall be practically completed before the welding of bottom joints that may have been left open to compensate for shrinkage of any welds previously made is completed.

7.2.2.3 Shell plates may be aligned by metal clips attached to the bottom plates, and the shell may be tack welded to the bottom before continuous welding is started between the bottom edge of the shell plate and the bottom plates.

7.2.3 Shells

7.2.3.1 Plates to be joined by butt welding shall be matched accurately and retained in position during the welding operation. Misalignment in completed vertical joints for plates greater than 16 mm ($\frac{5}{8}$ in.) thick shall not exceed 10% of the plate thickness or 3 mm ($\frac{1}{8}$ in.), whichever is less; misalignment for plates less than or equal to 16 mm ($\frac{5}{8}$ in.) thick shall not exceed 1.5 mm ($\frac{1}{16}$ in.).

7.2.3.2 In completed horizontal butt joints, the upper plate shall not project beyond the face of the lower plate at any point by more than 20% of the thickness of the upper plate, with a maximum projection of 3 mm ($\frac{1}{8}$ in.); however, for upper plates less than 8 mm ($\frac{5}{16}$ in.) thick, the maximum projection shall be limited to 1.5 mm ($\frac{1}{16}$ in.).

- **7.2.3.3** The reverse side of double-welded butt joints shall be thoroughly cleaned in a manner that will leave the exposed surface satisfactory for fusion of the weld metal to be added, prior to the application of the first bead to the second side. This cleaning may be done by chipping; grinding; melting out; or where the back of the initial bead is smooth and free from crevices that might entrap slag, another method that, upon field inspection, is acceptable to the Purchaser.

7.2.3.4 For circumferential and vertical joints in tank shell courses constructed of material more than 38 mm ($1\frac{1}{2}$ in.) thick (based on the thickness of the thicker plate at the joint), multipass weld procedures are required, with no pass over 19 mm ($\frac{3}{4}$ in.) thick permitted.

7.2.3.5 The requirements of this section shall be followed when welding to Group IV, IVA, V, and VI materials. Permanent and temporary attachments (see 7.2.1.10 for information on shell-to-bottom welds) shall be welded with low-hydrogen electrodes. Both permanent and temporary attachments shall be welded in accordance with a procedure that minimizes the potential for underbead cracking. The welds of permanent attachments (not including shell-to-bottom welds) and areas where temporary attachments are removed, shall be examined visually and by either the magnetic particle method or by the liquid penetrant method (see 8.2, 8.4, or 8.5 for the appropriate inspection criteria).

7.2.3.6 Completed welds of stress-relieved assemblies shall be examined by visual, as well as by magnetic particle or penetrant methods, after stress relief, but before hydrostatic test.

7.2.3.7 Flush-type connections shall be inspected according to 5.7.8.11.

7.2.4 Shell-to-Bottom Welds

- **7.2.4.1** The initial weld pass inside the shell shall have all slag and non-metals removed from the surface of the weld and then examined for its entire circumference prior to welding the first weld pass outside the shell (temporary weld fit-up tacks excepted), both visually and by one of the following methods to be agreed to by Purchaser and the Manufacturer:

- a. Magnetic particle.
- b. Applying a solvent liquid penetrant to the weld and then applying a developer to the gap between the shell and the bottom and examining for leaks after a minimum dwell time of one hour.
- c. Applying a water-soluble liquid penetrant to either side of the joint and then applying a developer to the other side of the joint and examining for leaks after a minimum dwell time of one hour.
- d. Applying a high flash-point penetrating oil such as light diesel to the gap between the shell and the bottom, letting stand for at least four hours, and examining the weld for evidence of wicking.

Note: Residual oil may remain on the surfaces yet to be welded even after the cleaning required below and contamination of the subsequent weld is possible.

- e. Applying a bubble-forming solution to the weld, using a right angle vacuum box, and examining for bubbles.

Thoroughly clean all residual examination materials from the as yet to be welded surfaces and from the unwelded gap between the shell and bottom. Remove defective weld segments and reweld as required. Reexamine the repaired welds and a minimum of 150 mm (6 in.) to either side in the manner described above. Repeat this clean-remove-repair-examine-and-clean process until there is no evidence of leaking. Complete all welding passes of the joint both inside and outside the shell. Visually examine the finished weld surfaces of the joint both inside and outside the shell for their entire circumference.

7.2.4.2 As an alternative to 7.2.4.1, the initial weld passes, inside and outside of the shell, shall have all slag and non-metals removed from the surface of the welds and the welds shall be examined visually. Additionally, after the completion of the inside and outside fillet or partial penetration welds, the welds may be tested by pressurizing the volume between the inside and outside

welds with air pressure to 103 kPa (15 lbf/in.² gauge) and applying a solution film to both welds. To assure that the air pressure reaches all parts of the welds, a sealed blockage in the annular passage between the inside and outside welds must be provided by welding at one or more points. Additionally, a small pipe coupling communicating with the volume between the welds must be connected at one end and a pressure gauge connected to a coupling on the other end of the segment under test.

- **7.2.4.3** By agreement between the Purchaser and the Manufacturer, the examinations of 7.2.4.1 may be waived if the following examinations are performed on the entire circumference of the weld(s):
 - a. Visually examine the initial weld pass (inside or outside).
 - b. Visually examine the finished joint welded surfaces, both inside and outside the shell.
 - c. Examine either side of the finished joint weld surfaces by magnetic particle, or liquid penetrant, or right angle vacuum box.

7.2.5 Roofs

Except for the stipulation that the structural framing (such as the rafters and girders) of the roof must be reasonably true to line and surface, this Standard does not include special stipulations for erection of the roof.

7.3 INSPECTION, TESTING, AND REPAIRS

7.3.1 General

7.3.1.1 The Purchaser's inspector shall at all times have free entry to all parts of the job while work under the contract is being performed. The Manufacturer shall afford the Purchaser's inspector reasonable facilities to assure the inspector that the work is being performed in accordance with this Standard.

7.3.1.2 Any material or workmanship shall be subject to the replacement requirements of 6.2.3.

- **7.3.1.3** Material that is damaged by defective workmanship or that is otherwise defective will be rejected. The Manufacturer will be notified of this in writing and will be required to furnish new material promptly or to correct defective workmanship.

7.3.1.4 Before acceptance, all work shall be completed to the satisfaction of the Purchaser's inspector, and the entire tank, when filled with oil, shall be tight and free from leaks.

7.3.2 Inspection of Welds

● 7.3.2.1 Butt-Welds

Complete penetration and complete fusion are required for welds joining shell plates to shell plates. Inspection for the quality of the welds shall be made using either the radiographic method specified in 8.1 or alternatively, by agreement between the Purchaser and the Manufacturer, using the ultrasonic method specified in 8.3.1 (see Appendix U). In addition to the radiographic or ultrasonic examination, these welds shall also be visually examined. Furthermore, the Purchaser's inspector may visually inspect all butt-welds for cracks, arc strikes, excessive undercut, surface porosity, incomplete fusion, and other defects. Acceptance and repair criteria for the visual method are specified in 8.5.

7.3.2.2 Fillet Welds

Fillet welds shall be inspected by the visual method. The final weld shall be cleaned of slag and other deposits prior to inspection. Visual examination acceptance and repair criteria are specified in 8.5.

● 7.3.2.3 Responsibility

The Manufacturer shall be responsible for making radiographs and any necessary repairs; however, if the Purchaser's inspector requires radiographs in excess of the number specified in Section 6, or requires chip-outs of fillet welds in excess of one per 30 m (100 ft) of weld and no defect is disclosed the additional inspections and associated work shall be the responsibility of the Purchaser.

7.3.3 Examination and Testing of the Tank Bottom

Upon completion of welding of the tank bottom, the bottom welds and plates shall be examined visually for any potential defects and leaks. Particular attention shall apply to areas such as sumps, dents, gouges, three-plate laps, bottom plate breakdowns, arc

strikes, temporary attachment removal areas, and welding lead arc burns. Visual examination acceptance and repair criteria are specified in 6.5. In addition, all welds shall be tested by one of the following methods:

- a. A vacuum-box test in accordance with 8.6.
- b. A tracer gas test in accordance with 8.6.11.
- c. After at least the lowest shell course has been attached to the bottom, water (to be supplied by the Purchaser) shall be pumped underneath the bottom. A head of 150 mm (6 in.) of liquid shall be maintained using a temporary dam to hold that depth around the edge of the bottom. The line containing water for testing may be installed temporarily by running it through a manhole to one or more temporary flange connections in the bottom of the tank, or the line may be installed permanently in the subgrade beneath the tank. The method of installation should be governed by the nature of the subgrade. Reasonable care shall be taken to preserve the prepared subgrade under the tank.

7.3.4 Inspection of Reinforcing-Plate Welds

After fabrication is completed but before the tank is filled with test water, the reinforcing plates shall be tested by the Manufacturer by applying up to 100 kPa (15 lbf/in.²) gauge pneumatic pressure between the tank shell and the reinforcement plate on each opening using the telltale hole specified in 5.7.5.1. While each space is subjected to such pressure, a soap film, linseed oil, or another material suitable for the detection of leaks shall be applied to all attachment welding around the reinforcement, both inside and outside the tank.

• 7.3.5 Testing of the Shell

After the entire tank and roof structure is completed, the shell (except for the shell of tanks designed in accordance with Appendix F) shall be tested by one of the following methods, as specified on the Data Sheet, Line 14:

- 1. If water is available for testing the shell, the tank shall be filled with water as follows: (1) to the maximum design liquid level, *H*; (2) for a tank with a tight roof, to 50 mm (2 in.) above the weld connecting the roof plate or compression bar to the top angle or shell; (3) to a level lower than that specified in Subitem 1 or 2 when restricted by overflows, an internal floating roof, or other freeboard by agreement between the Purchaser and the Manufacturer, or 4) to a level of seawater producing a bottom of shell hoop stress equal to that produced by a full-height fresh water test. The tank shall be inspected frequently during the filling operation, and any welded joints above the test-water level shall be examined in accordance with Item b. This test shall be conducted before permanent external piping is connected to the tank. Attachments to the shell defined in 5.8.1.1, located at least 1 m (3 ft) above the water level, and roof appurtenances may be welded during the filling of the tank. After completion of the hydro-test, only non-structural small attachments may be welded to the tank in accordance with 7.2.1.11.
- 2. If sufficient water to fill the tank is not available, the tank may be tested by (1) painting all of the joints on the inside with a highly penetrating oil, such as automobile spring oil, and carefully examining the outside of the joints for leakage; (2) applying vacuum to either side of the joints or applying internal air pressure as specified for the roof test in 7.3.7 and carefully examining the joints for leakage; or (3) using any combination of the methods stipulated in 7.3.5, Subitems 1 and 2.

7.3.6 Hydrostatic Testing Requirements

7.3.6.1 This hydrostatic test of the tank shall be conducted before permanent external piping is connected to the tank. Attachments to the shell defined in 5.8.1.1, located at least 1 m (3 ft) above the water level, and roof appurtenances may be welded during the filling of the tank. After completion of the hydro-test, only non-structural small attachments may be welded to the tank in accordance with 7.2.1.11. Any welded joints above the test-water level shall be examined for leakage by one of the following methods:

1. coating all of the joints on the inside with a highly penetrating oil, such as automobile spring oil, and carefully examining the outside of the joints for leakage;
2. applying vacuum to either side of the joints or applying internal air pressure as specified for the roof test in 7.3.7 and carefully examining the joints for leakage; or
3. using any combination of the methods stipulated in Subitems 1 and 2.

7.3.6.2 The Manufacturer shall be responsible for:

1. Preparing the tank for testing. This shall include removal of all trash, debris, grease, oil, weld scale, weld spatter, and any other foreign matter from the interior and the roof(s) of the tank.
- 2. Furnishing, laying, and removing all lines from the water source tie-in location and to the water disposal point as prescribed on the Data Sheet, Line 14.
- 3. Filling and emptying the tank. (See 1.3 for Purchaser responsibility to obtain any required permits for disposal of water.)
- 4. Cleaning, rinsing, drying, or other prescribed activity, if specified on Data Sheet, Line 14, following the hydro-test to make the tank ready for operation.
- 5. Taking settlement measurements (unless explicitly waived by the Purchaser on the Data Sheet, Line 14).
6. Furnishing all other test materials and facilities, including blinds, bolting, and gaskets (see 4.9).
- 7. Checking the wind girders for proper drainage during or following the hydro-test. If water is retained, additional drainage shall be provided subject to the Purchaser's approval.

• **7.3.6.3** The Purchaser shall be responsible for:

1. Furnishing and disposing of the water for hydro-testing the tank from the water source tie-in location as designated on the Data Sheet, Line 14. If biocide or caustic additions are specified to the Manufacturer, the Purchaser is responsible for determining or identifying disposal restrictions on the treated water.
2. Specifying the test water quality. Potable water is preferred for hydro-testing. This does not preclude the use of condensate, reverse osmosis water, well water, river water, or sea water. The Purchaser shall consider issues such as low temperature brittle fracture, freeze damage; amount of suspended solids, sanitation issues, animal/plant incubation and/or growth, acidity, general corrosion, pitting, protecting against cathodic cells, microbiologically-induced corrosion, material dependent sensitivity to trace chemical attack, disposal, rinsing, and residuals left in the tank after emptying. If the Purchaser-supplied test water causes corrosion, the Purchaser is responsible for the required repairs.
3. For the following metallurgies, describe on the Data Sheet, Line 14, (using a Supplemental Specification) any additional restrictions on the water quality:
 - a. Carbon Steel—For carbon steel equipment where water contact exceeds 14 days, including filling and draining (e.g., consider adding an oxygen scavenger and a biocide, and raise the pH by the addition of caustic).
 - b. Stainless Steel—See Appendix S.
 - c. Aluminum Components—See Appendix H.

7.3.6.4 For carbon and low-alloy steel tanks, the tank metal temperature during hydrostatic testing shall not be colder than the design metal temperature per Figure 4-1, as long as the water is prevented from freezing. The Manufacturer is responsible for heating the test water, if heating is required, unless stated otherwise on the Data Sheet, Line 14.

- **7.3.6.5** The minimum fill and discharge rate, if any, shall be specified by the Purchaser on the Data Sheet, Line 23. When settlement measurements are specified by the Purchaser, the maximum filling rates shall be as follows, unless otherwise restricted by the requirements in 5.8.5:

Water Filling Rate		
Bottom Course Thickness	Tank Portion	Maximum Filling Rate
Less than 22 mm ($7/8$ in.)	– Top course	300 mm (12 in.)/hr
	– Below top course	460 mm (18 in.)/hr
22 mm ($7/8$ in.) and thicker	– Top third of tank	230 mm (9 in.)/hr
	– Middle third of tank	300 (12 in.)/hr
	– Bottom third of tank	460 (18 in.)/hr

Filling may continue while elevation measurements are being made as long as the change in water elevation for a set of readings does not exceed 300 mm (12 in.). Unless waived on the Data Sheet, the Manufacturer shall make shell elevation measurements in accordance with the following:

1. Shell elevation measurements shall be made at equally-spaced intervals around the tank circumference not exceeding 0.8 m (32 ft). The minimum number of shell measurement points shall be eight.
2. Observed elevations shall be referred to a permanent benchmark. The level instrument shall be set up at least $1\frac{1}{2}$ times tank diameter away from the tank when tank elevation readings are taken. Six sets of settlement readings are required:
 - a. Before start of the hydrostatic test
 - b. With tank filled to $\frac{1}{4}$ test height (± 600 mm [2 ft])
 - c. With tank filled to $\frac{1}{2}$ test height (± 600 mm [2 ft])
 - d. With tank filled to $\frac{3}{4}$ test height (± 600 mm [2 ft])
 - e. At least 24 hours after the tank has been filled to the maximum test height. This 24-hour period may be increased to duration specified on the data sheet if the Purchaser so requires for conditions such as:
 - i. The tank is the first one in the area.
 - ii. The tank has a larger capacity than any other existing tank in the area.
 - iii. The tank has a higher unit bearing load than any other existing tank in the area.
 - iv. There is a question regarding the rate or magnitude of settlement that will take place.
 - f. After tank has been emptied of test water

- Note: The three sets of settlement readings described in paragraphs b, c, and d above may be omitted if specified by the Purchaser.

7.3.6.6 If settlement measurements are specified by the Purchaser, any differential settlement greater than 13 mm per 10 m ($\frac{1}{2}$ in. per 32 ft) of circumference or a uniform settlement over 50 mm (2 in.) shall be reported to the Purchaser for evaluation. Filling of the tank shall be stopped until cleared by the Purchaser.

7.3.6.7 For floating-roof tanks, the maximum and minimum annular space between the shell and the roof rim plate prior to initial flotation and at the maximum test fill height shall be measured and recorded.

7.3.6.8 Internal bottom elevation measurements shall be made before and after hydrostatic testing. Measurements shall be made at maximum intervals of 3 m (10 ft) measured on diametrical lines across the tank. The diametrical lines shall be spaced at equal angles, with a maximum separation measured at the tank circumference of 10 m (32 ft). A minimum of four diametrical lines shall be used.

7.3.6.9 All elevation measurements shall be included in the Manufacturer's Post-Construction Document Package (see W.1.5).

7.3.7 Testing of the Roof

7.3.7.1 Upon completion, the roof of a tank designed to be gas-tight (except for roofs designed under 7.3.7.2, F.4.4, and F.7.6) shall be tested by one of the following methods:

- a. Applying internal air pressure not exceeding the weight of the roof plates and applying to the weld joints a bubble solution or other material suitable for the detection of leaks.
- b. Vacuum testing the weld joints in accordance with 8.6 to detect any leaks.

- **7.3.7.2** Upon completion, the roof of a tank not designed to be gas-tight, such as a tank with peripheral circulation vents or a tank with free or open vents, shall receive only visual inspection of its weld joints, unless otherwise specified by the Purchaser.

7.4 REPAIRS TO WELDS

- **7.4.1** All defects found in welds shall be called to the attention of the Purchaser'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 Purchaser's inspector. Acceptance criteria are specified in 8.2, 8.4, and 8.5, as applicable.

7.4.2 Pinhole leaks or porosity in a tank bottom joint may be repaired by applying an additional weld bead over the defective area. Other defects or cracks in tank bottom or tank roof (including floating roofs in Appendix C) joints shall be repaired as required by 8.1.7. Mechanical caulking is not permitted.

7.4.3 All defects, cracks, or leaks in shell joints or the shell-to-bottom joint shall be repaired in accordance with 8.1.7.

- **7.4.4** Repairs of defects discovered after the tank has been filled with water for testing shall be made with the water level at least 0.3 m (1 ft) below any point being repaired or, if repairs have to be made on or near the tank bottom, with the tank empty. Welding shall not be done on any tank unless all connecting lines have been completely blinded. Repairs shall not be attempted on a tank that is filled with oil or that has contained oil until the tank has been emptied, cleaned, and gas freed. Repairs on a tank that has contained oil shall not be attempted by the Manufacturer unless the manner of repair has been approved in writing by the Purchaser and the repairs are made in the presence of the Purchaser's inspector.

7.5 DIMENSIONAL TOLERANCES

• 7.5.1 General

The purpose of the tolerances given in 7.5.2 through 7.5.7 is to produce a tank of acceptable appearance and to permit proper functioning of floating roofs. Measurements shall be taken prior to the hydrostatic water test. Unless waived or modified by the Purchaser on Data Sheet, Line 15, or established separately by agreement between the Purchaser and the Manufacturer, the following tolerances apply:

7.5.2 Plumbness

- The maximum out-of-plumbness of the top of the shell relative to the bottom of the shell shall not exceed 1/200 of the total tank height. The out-of-plumbness in one shell course shall not exceed the permissible variations for flatness and waviness as specified in ASTM A 6M/A 6, ASTM A 20M/A 20, or ASTM A 480M/A 480, whichever is applicable.
- The maximum out-of-plumbness of roof columns, guide poles, or other vertical internal components shall not exceed 1/200 of the total height. The 1/200 criteria shall also apply to fixed roof columns. For tanks with internal floating roofs, apply the criteria of this section or Appendix H, whichever is more stringent.

7.5.3 Roundness

Radii measured at 0.3 m (1 ft) above the bottom corner weld shall not exceed the following tolerances:

Tank Diameter m (ft)	Radius Tolerance mm (in.)
< 12 (40)	± 13 (1/2)
From 12 (40) to < 45 (150)	± 19 (3/4)
From 45 (150) to < 75 (250)	± 25 (1)
≥ 75 (250)	± 32 (1 1/4)

7.5.4 Local Deviations

Local deviations from the theoretical shape (for example, weld discontinuities and flat spots) shall be limited as follows:

- Deviations (peaking) at vertical weld joints shall not exceed 13 mm (1/2 in.). Peaking at vertical weld joints shall be determined using a horizontal sweep board 900 mm (36 in.) long. The sweep board shall be made to the nominal radius of the tank.
- Deviations (banding) at horizontal weld joints shall not exceed 13 mm (1/2 in.). Banding at horizontal weld joints shall be determined using a straight edge vertical sweep board 900 mm (36 in.) long.
- Flat spots measured in the vertical plane shall not exceed the appropriate plate flatness and waviness requirements given in 7.5.2.

7.5.5 Foundations

7.5.5.1 To achieve the tolerances specified in 7.5.2 through 7.5.4, it is essential that a foundation true to the plane be provided for the tank erection. The foundation should have adequate bearing to maintain the trueness of the foundation (see Appendix B).

7.5.5.2 Where foundations true to a horizontal plane are specified, tolerances shall be as follows:

- a. Where a concrete ringwall is provided under the shell, the top of the ringwall shall be level within ± 3 mm ($1/8$ in.) in any 9 m (30 ft) of the circumference and within ± 6 mm ($1/4$ in.) in the total circumference measured from the average elevation.
- b. Where a concrete ringwall is not provided, the foundation under the shell shall be level within ± 3 mm ($1/8$ in.) in any 3 m (10 ft) of the circumference and within ± 13 mm ($1/2$ in.) in the total circumference measured from the average elevation.
- c. Where a concrete slab foundation is provided, the first 0.3 m (1 ft) of the foundation (or width of the annular ring), measured from the outside of the tank radially towards the center, shall comply with the concrete ringwall requirement. The remainder of the foundation shall be within ± 13 mm ($1/2$ in.) of the design shape.

7.5.5.3 Where a sloping foundation is specified, elevation differences about the circumference shall be calculated from the specified high point. Actual elevation differences about the circumference shall be determined from the actual elevation of the specified high point. The actual elevation differences shall not deviate from the calculated differences by more than the following tolerances:

- a. Where a concrete ringwall is provided, ± 3 mm ($1/8$ in.) in any 9 m (30 ft) of circumference and ± 6 mm ($1/4$ in.) in the total circumference.
- b. Where a concrete ringwall is not provided, ± 3 mm ($1/8$ in.) in any 3 m (10 ft) of circumference and ± 13 mm ($1/2$ in.) in the total circumference.

7.5.6 Nozzles

Nozzles (excluding manholes) shall be installed within the following tolerances:

- a. Specified projection from outside of tank shell to extreme face of flange: ± 5 mm ($3/16$ in.)
- b. Elevation of shell nozzle or radial location of a roof nozzle: ± 6 mm ($1/4$ in.)
- c. Flange tilt in any plane, measured on the flange face:
 - $\pm 1/2$ degree for nozzles greater than NPS 12 in nominal diameter
 - ± 3 mm ($1/8$ in.) at the outside flange diameter for nozzles NPS 12 and smaller
- d. Flange bolt hole orientation: ± 3 mm ($1/8$ in.)

7.5.7 Shell Manholes

Manholes shall be installed within the following tolerances:

- a. Specified projection from outside of shell to extreme face of flange, ± 3 mm ($1/2$ in.)
- b. Elevation and angular location, ± 13 mm ($1/2$ in.)
- c. Flange tilt in any plane, measured across the flange diameter, ± 13 mm ($1/2$ in.)

SECTION 8—METHODS OF INSPECTING JOINTS

Note: In this Standard, the term inspector, as used in Sections V and VIII of the ASME *Code*, shall be interpreted to mean the Purchaser's inspector.

8.1 RADIOGRAPHIC METHOD

For the purposes of this paragraph, plates shall be considered of the same thickness when the difference in their specified or design thickness does not exceed 3 mm ($1/8$ in.).

8.1.1 Application

Radiographic inspection is required for shell butt-welds (see 8.1.2.2, 8.1.2.3, and 8.1.2.4), annular-plate butt-welds (see 8.1.2.9), and flush-type connections with butt-welds (see 5.7.8.11). Radiographic inspection is not required for the following: roof-plate welds, bottom-plate welds, welds joining the top angle to either the roof or shell, welds joining the shell plate to the bottom plate, welds in nozzle and manway necks made from plate, or appurtenance welds to the tank.

8.1.2 Number and Location of Radiographs

8.1.2.1 Except when omitted under the provisions of A.3.4, radiographs shall be taken as specified in 8.1.2 through 8.1.9.

8.1.2.2 The following requirements apply to vertical joints:

a. For butt-welded joints in which the thinner shell plate is less than or equal to 10 mm ($3/8$ in.) thick, one spot radiograph shall be taken in the first 3 m (10 ft) of completed vertical joint of each type and thickness welded by each welder or welding operator. The spot radiographs taken in the vertical joints of the lowest course may be used to meet the requirements of Note 3 in Figure 8-1 for individual joints. Thereafter, without regard to the number of welders or welding operators, one additional spot radiograph shall be taken in each additional 30 m (100 ft) (approximately) and any remaining major fraction of vertical joint of the same type and thickness. At least 25% of the selected spots shall be at junctions of vertical and horizontal joints, with a minimum of two such intersections per tank. In addition to the foregoing requirements, one random spot radiograph shall be taken in each vertical joint in the lowest course (see the top panel of Figure 8-1).

b. For butt-welded joints in which the thinner shell plate is greater than 10 mm ($3/8$ in.) but less than or equal to 25 mm (1 in.) in thickness, spot radiographs shall be taken according to Item a. In addition, all junctions of vertical and horizontal joints in plates in this thickness range shall be radiographed; each film shall clearly show not less than 75 mm (3 in.) of vertical weld and 50 mm (2 in.) of weld length on each side of the vertical intersection. In the lowest course, two spot radiographs shall be taken in each vertical joint: one of the radiographs shall be as close to the bottom as is practicable, and the other shall be taken at random (see the center panel of Figure 8-1).

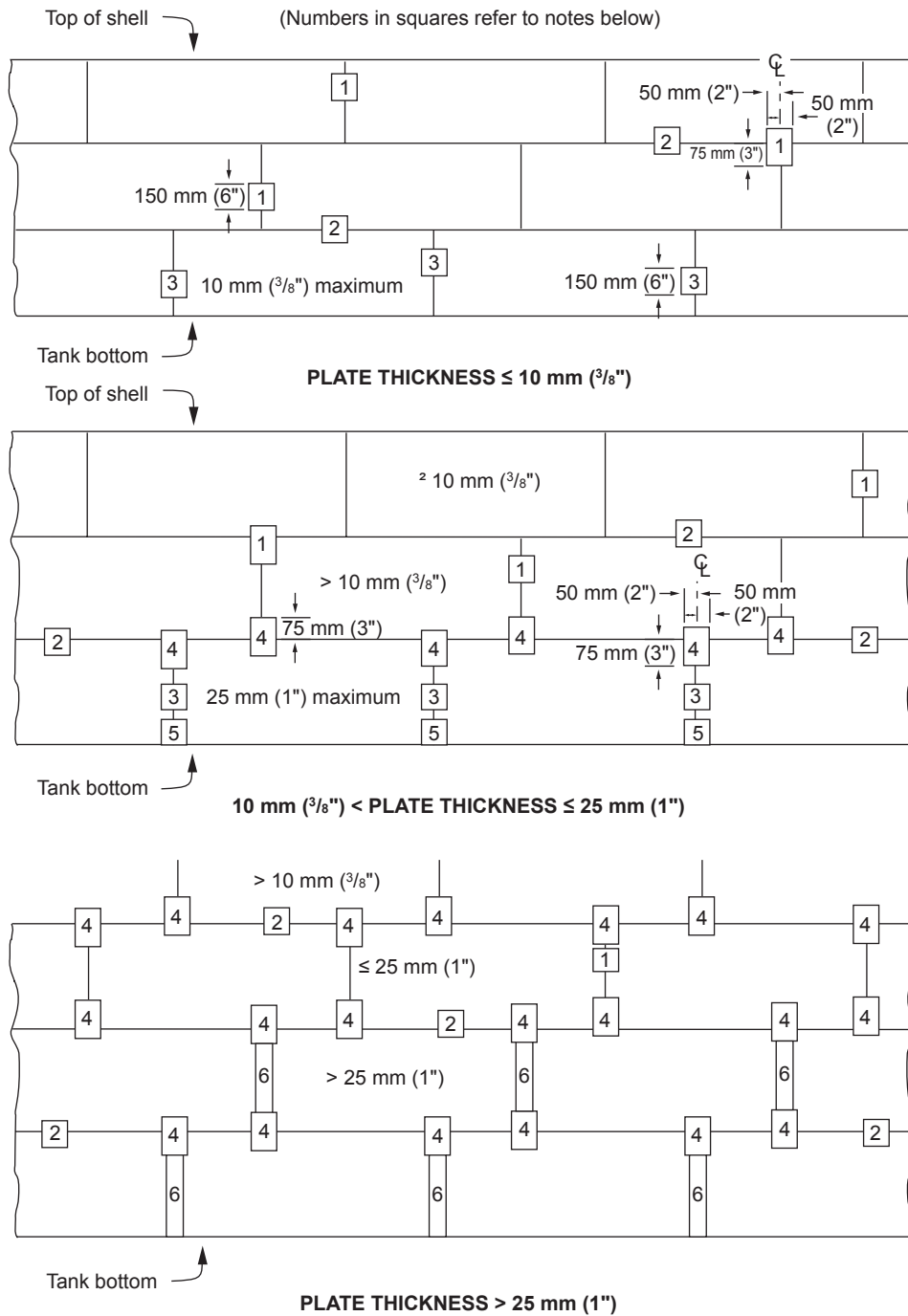
c. Vertical joints in which the shell plates are greater than 25 mm (1 in.) thick shall be fully radiographed. All junctions of vertical and horizontal joints in this thickness range shall be radiographed; each film shall clearly show not less than 75 mm (3 in.) of vertical weld and 50 mm (2 in.) of weld length on each side of the vertical intersection (see the bottom panel of Figure 8-1).

d. The butt-weld around the periphery of an insert manhole or nozzle shall be completely radiographed.

8.1.2.3 One spot radiograph shall be taken in the first 3 m (10 ft) of completed horizontal butt joint of the same type and thickness (based on the thickness of the thinner plate at the joint) without regard to the number of welders or welding operators. Thereafter, one radiograph shall be taken in each additional 60 m (200 ft) (approximately) and any remaining major fraction of horizontal joint of the same type and thickness. These radiographs are in addition to the radiographs of junctions of vertical joints required by Item c of 8.1.2.2 (see Figure 8-1).

8.1.2.4 The number of spot radiographs required herein shall be applicable on a per tank basis, irrespective of the number of tanks being erected concurrently or continuously at any location.

8.1.2.5 It is recognized that in many cases the same welder or welding operator does not weld both sides of a butt joint. If two welders or welding operators weld opposite sides of a butt joint it is permissible to inspect their work with one spot radiograph. If the radiograph is rejected, additional spot radiographs shall be taken to determine whether one or both of the welders or welding operators are at fault.



Notes:

1. Vertical spot radiograph in accordance with 8.1.2.2, Item a: one in the first 3 m (10 ft) and one in each 30 m (100 ft) thereafter, 25% of which shall be at intersections.
2. Horizontal spot radiograph in accordance with 8.1.2.3: one in the first 3 m (10 ft) and one in each 60 m (200 ft) thereafter.
3. Vertical spot radiograph in each vertical seam in the lowest course (see 8.1.2.2, Item b). Spot radiographs that satisfy the requirements of Note 1 for the lowest course may be used to satisfy this requirement.
4. Spot radiographs of all intersections over 10 mm ($\frac{3}{8}$ in.) (see 8.1.2.2, Item b).
5. Spot radiograph of bottom of each vertical seam in lowest shell course over 10 mm ($\frac{3}{8}$ in.) (see 8.1.2.2, Item b).
6. Complete radiograph of each vertical seam over 25 mm (1 in.). The complete radiograph may include the spot radiographs of the intersections if the film has a minimum width of 100 mm (4 in.) (see 8.1.2.2, Item c).

Figure 8-1—Radiographic Requirements for Tank Shells

8.1.2.6 An equal number of spot radiographs shall be taken from the work of each welder or welding operator in proportion to the length of joints welded.

- **8.1.2.7** As welding progresses, radiographs shall be taken as soon as it is practicable. The locations where spot radiographs are to be taken may be determined by the Purchaser's inspector.

8.1.2.8 Each radiograph shall clearly show a minimum of 150 mm (6 in.) 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) penetrameter.

8.1.2.9 When bottom annular plates are required by 5.5.1, or by M.4.1, the radial joints shall be radiographed as follows: (a) For double-welded butt joints, one spot radiograph shall be taken on 10% of the radial joints; (b) For single-welded butt joints with permanent or removable back-up bar, one spot radiograph shall be taken on 50% of the radial joints. Extra care must be exercised in the interpretation of radiographs of single-welded joints that have a permanent back-up bar. In some cases, additional exposures taken at an angle may determine whether questionable indications are acceptable. The minimum radiographic length of each radial joint shall be 150 mm (6 in.). Locations of radiographs shall preferably be at the outer edge of the joint where the shell plate and annular plate join.

8.1.3 Technique

8.1.3.1 Except as modified in this section, the radiographic examination method employed shall be in accordance with Section V, Article 2, of the ASME *Code*.

8.1.3.2 Personnel who perform and evaluate radiographic examinations according to this section shall be qualified and certified by the Manufacturer as meeting the requirements of certification as generally outlined in Level II or Level III of ASNT SNT-TC-1A (including applicable supplements). Level-I personnel may be used if they are given written acceptance/rejection procedures prepared by Level-II or Level-III personnel. These written procedures shall contain the applicable requirements of Section V, Article 2, of the ASME *Code*. In addition, all Level-I personnel shall be under the direct supervision of Level-II or Level-III personnel.

8.1.3.3 The requirements of T-285 in Section V, Article 2, of the ASME *Code* are to be used only as a guide. Final acceptance of radiographs shall be based on whether the prescribed penetrameter image and the specified hole can be seen.

8.1.3.4 The finished surface of the weld reinforcement at the location of the radiograph shall either be flush with the plate or have a reasonably uniform crown not to exceed the following values:

Plate Thickness mm (in.)	Maximum Thickness of Reinforcement mm (in.)
≤ 13 (1/2)	1.5 (1/16)
> 13 (1/2) to 25 (1)	2.5 (3/32)
> 25 (1)	3 (1/8)

• 8.1.4 Submission of Radiographs

Before any welds are repaired, the radiographs shall be submitted to the inspector with any information requested by the inspector regarding the radiographic technique used.

8.1.5 Radiographic Standards

Welds examined by radiography shall be judged as acceptable or unacceptable by the standards of Paragraph UW-51(b) in Section VIII of the ASME *Code*.

• 8.1.6 Determination of Limits of Defective Welding

When a section of weld is shown by a radiograph to be unacceptable under the provisions of 8.1.5 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 75 mm (3 in.) 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 8.1.5, additional spots shall be examined until the limits of unacceptable welding are determined, or the

erector may replace all of the welding performed by the welder or welding operator on that joint. If the welding is replaced, the inspector shall have the option of requiring that one radiograph be taken at any selected location on any other joint on which the same welder or welding operator has welded. If any of these additional spots fail to comply with the requirements of 8.1.5, the limits of unacceptable welding shall be determined as specified for the initial section.

8.1.7 Repair of Defective Welds

8.1.7.1 Defects in welds shall be repaired by chipping or melting out the defects from one side or both sides of the joint, as required, and rewelding. Only the cutting out of defective joints that is necessary to correct the defects is required.

- **8.1.7.2** All repaired welds in joints shall be checked by repeating the original inspection procedure and by repeating one of the testing methods of 7.3, subject to the approval of the Purchaser.

8.1.8 Record of Radiographic Examination

8.1.8.1 The Manufacturer shall prepare an as-built radiograph map showing the location of all radiographs taken along with the film identification marks.

- **8.1.8.2** After the structure is completed, the films shall be the property of the Purchaser unless otherwise agreed upon by the Purchaser and the Manufacturer.

8.2 MAGNETIC PARTICLE EXAMINATION

8.2.1 When magnetic particle examination is specified, the method of examination shall be in accordance with Section V, Article 7, of the ASME *Code*.

8.2.2 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 Section V of the ASME *Code*.

8.2.3 The Manufacturer shall determine that each magnetic particle examiner meets the following requirements:

- Has vision (with correction, if necessary) to be able to read a Jaeger Type 2 standard chart at a distance of not less than 300 mm (12 in.) and is capable of distinguishing and differentiating contrast between the colors used. Examiners shall be checked annually to ensure that they meet these requirements.
- Is competent in the technique of the magnetic particle examination method, including performing the examination and interpreting and evaluating the results; however, where the examination method consists of more than one operation, the examiner need only be qualified for one or more of the operations.

8.2.4 Acceptance standards and the removal and repair of defects shall be in accordance with Section VIII, Appendix 6, Paragraphs 6-3, 6-4, and 6-5, of the ASME *Code*.

8.3 ULTRASONIC EXAMINATION

8.3.1 Ultrasonic Examination in Lieu of Radiography

When ultrasonic examination is applied in order to fulfill the requirement of 7.3.2.1, the provisions of Appendix U shall apply.

8.3.2 Ultrasonic Examination NOT in Lieu of Radiography

8.3.2.1 When the radiographic method is applied in order to fulfill the requirement of 7.3.2.1, then any ultrasonic examination specified shall be in accordance with this section.

8.3.2.2 The method of examination shall be in accordance with Section V, Article 5, of the ASME *Code*.

8.3.2.3 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 Section V of the ASME *Code*.

8.3.2.4 Examiners who perform ultrasonic examinations under this section shall be qualified and certified by the Manufacturers as meeting the requirements of certification as generally outlined in Level II or Level III of ASNT SNT-TC-1A (including applicable supplements). Level-I personnel may be used if they are given written acceptance/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.

- **8.3.2.5** Acceptance standards shall be agreed upon by the Purchaser and the Manufacturer.

8.4 LIQUID PENETRANT EXAMINATION

8.4.1 When liquid penetrant examination is specified, the method of examination shall be in accordance with Section V, Article 6, of the ASME Code.

8.4.2 Liquid penetrant 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 Section V of the ASME Code.

8.4.3 The Manufacturer shall determine and certify that each liquid penetrant examiner meets the following requirements:

a. Has vision (with correction, if necessary) to enable him to read a Jaeger Type 2 standard chart at a distance of not less than 300 mm (12 in.) and is capable of distinguishing and differentiating contrast between the colors used. Examiners shall be checked annually to ensure that they meet these requirements.

b. Is competent in the technique of the liquid penetrant examination method for which he is certified, including making the examination and interpreting and evaluating the results; however, where the examination method consists of more than one operation, the examiner may be certified as being qualified for one or more of the operations.

8.4.4 Acceptance standards and the removal and repair of defects shall be in accordance with Section VIII, Appendix 8, Paragraphs 8-3, 8-4, and 8-5, of the ASME Code.

8.5 VISUAL EXAMINATION

8.5.1 A weld shall be acceptable by visual inspection if the inspection shows the following:

a. There are no crater cracks, other surface cracks or arc strikes in or adjacent to the welded joints.

b. Maximum permissible undercut is 0.4 mm ($1/64$ in.) in depth for vertical butt joints, vertically oriented permanent attachments, attachment welds for nozzles, manholes, flush-type openings, and the inside shell-to-bottom welds. For horizontal butt joints, horizontally oriented permanent attachments, and annular-ring butt joints, the maximum permissible undercut is 0.8 mm ($1/32$ in.) in depth.

c. The frequency of surface porosity in the weld does not exceed one cluster (one or more pores) in any 100 mm (4 in.) of length, and the diameter of each cluster does not exceed 2.5 mm ($3/32$ in.).

d. The reinforcement of the welds on all butt joints on each side of the plate shall not exceed the following thicknesses:

Plate Thickness mm (in.)	Maximum Reinforcement Thickness mm (in.)	
	Vertical Joints	Horizontal Joints
≤ 13 ($1/2$)	2.5 ($3/32$)	3 ($1/8$)
> 13 ($1/2$) to 25 (1)	3 ($1/8$)	5 ($3/16$)
> 25 (1)	5 ($3/16$)	6 ($1/4$)

The reinforcement need not be removed except to the extent that it exceeds the maximum acceptable thickness or unless its removal is required by 8.1.3.4 for radiographic examination.

8.5.2 A weld that fails to meet the criteria given in 8.5.1 shall be reworked before hydrostatic testing as follows:

a. Any defects shall be removed by mechanical means or thermal gouging processes. Arc strikes discovered in or adjacent to welded joints shall be repaired by grinding and rewelding as required. Arc strikes repaired by welding shall be ground flush with the plate.

b. Rewelding is required if the resulting thickness is less than the minimum required for design or hydrostatic test conditions. All defects in areas thicker than the minimum shall be feathered to at least a 4:1 taper.

c. The repair weld shall be visually examined for defects.

Notes:

1. Vertical spot radiograph in accordance with 8.1.2.2, Item a: one in the first 3 m (10 ft) and one in each 30 m (100 ft) thereafter, 25% of which shall be at intersections.

2. Horizontal spot radiograph in accordance with 8.1.2.3: one in the first 3 m (10 ft) and one in each 60 m (200 ft) thereafter.
3. Vertical spot radiograph in each vertical seam in the lowest course (see 8.1.2.2, Item b). Spot radiographs that satisfy the requirements of Note 1 for the lowest course may be used to satisfy this requirement.
4. Spot radiographs of all intersections over 10 mm ($3/8$ in.) (see 8.1.2.2, Item b).
5. Spot radiograph of bottom of each vertical seam in lowest shell course over 10 mm ($3/8$ in.) (see 8.1.2.2, Item b).
6. Complete radiograph of each vertical seam over 25 mm (1 in.). The complete radiograph may include the spot radiographs of the intersections if the film has a minimum width of 100 mm (4 in.) (see 8.1.2.2, Item c).

8.6 VACUUM TESTING

8.6.1 Vacuum testing is performed using a testing box approximately 150 mm (6 in.) wide by 750 mm (30 in.) long with a clear window in the top, which provides proper visibility to view the area under inspection. During testing, illumination shall be adequate for proper evaluation and interpretation of the test. The open bottom shall be sealed against the tank surface by a suitable gasket. Connections, valves, lighting and gauges, as required, shall be provided. A soap film solution or commercial leak detection solution, applicable to the conditions, shall be used.

8.6.2 Vacuum testing shall be performed in accordance with a written procedure prepared by the Manufacturer of the tank. The procedure shall require:

- a. Performing a visual examination of the bottom and welds prior to performing the vacuum-box test;
 - b. Verifying the condition of the vacuum box and its gasket seals;
 - c. Verifying that there is no quick bubble or spitting response to large leaks; and
 - d. Applying the film solution to a dry area, such that the area is thoroughly wetted and a minimum generation of application bubbles occurs.
- **8.6.3** A partial vacuum of 21 kPa (3 lbf/in.²/₆ in. Hg) to 35 kPa (5 lbf/in.²/₁₀ in. Hg) gauge shall be used for the test. If specified by the Purchaser, a second partial vacuum test of 56 kPa (8 lbf/in.²/₁₆ in. Hg) to 70 kPa (10 lbf/in.²/₂₀ in. Hg) shall be performed for the detection of very small leaks.

8.6.4 The Manufacturer shall determine that each vacuum-box operator meets the following requirements:

- a. Has vision (with correction, if necessary) to be able to read a Jaeger Type 2 standard chart at a distance of not less than 300 mm (12 in.). Operators shall be checked annually to ensure that they meet this requirement; and
- b. Is competent in the technique of the vacuum-box testing, including performing the examination and interpreting and evaluating the results; however, where the examination method consists of more than one operation, the operator performing only a portion of the test need only be qualified for that portion the operator performs.

8.6.5 The vacuum-box test shall have at least 50 mm (2 in.) overlap of previously viewed surface on each application.

8.6.6 The metal surface temperature limits shall be between 4°C (40°F) and 52°C (125°F), unless the film solution is proven to work at temperatures outside these limits, either by testing or Manufacturer's recommendations.

8.6.7 A minimum light intensity of 1000 Lux (100 fc) at the point of examination is required during the application of the examination and evaluation for leaks.

8.6.8 The vacuum shall be maintained for the greater of either at least 5 seconds or the time required to view the area under test.

8.6.9 The presence of a through-thickness leak indicated by continuous formation or growth of a bubble(s) or foam, produced by air passing through the thickness, is unacceptable. The presence of a large opening leak, indicated by a quick bursting bubble or spitting response at the initial setting of the vacuum box is unacceptable. Leaks shall be repaired and retested.

07 | • **8.6.10** A record or report of the test including a statement addressing temperature and light intensity shall be completed and furnished to the Purchaser upon request.

- **8.6.11** As an alternate to vacuum-box testing, a suitable tracer gas and compatible detector can be used to test the integrity of welded bottom joints for their entire length. Where tracer gas testing is employed as an alternate to vacuum-box testing, it shall meet the following requirements:

- a. Tracer gas testing shall be performed in accordance with a written procedure which has been reviewed and approved by the Purchaser and which shall address as a minimum: the type of equipment used, surface cleanliness, type of tracer gas, test pressure, soil permeability, soil moisture content, satisfactory verification of the extent of tracer gas permeation, and the method or technique to be used including scanning rate and probe standoff distance.
- b. The technique shall be capable of detecting leakage of 1×10^{-4} Pa m³/s (1×10^{-3} std cm³/s) or smaller
- c. The test system parameters (detector, gas, and system pressure, i.e., level of pressure under bottom) shall be calibrated by placing the appropriate calibrated capillary leak, which will leak at a rate consistent with (b) above, in a temporary or permanent fitting in the tank bottom away from the tracer gas pressurizing point. Alternatively, by agreement between the Purchaser and the Manufacturer, the calibrated leak may be placed in a separate fitting pressurized in accordance with the system parameters.
- d. While testing for leaks in the welded bottom joints, system parameters shall be unchanged from those used during calibration.

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SECTION 9—WELDING PROCEDURE AND WELDER QUALIFICATIONS

9.1 DEFINITIONS

In this Standard, terms relating to welding shall be interpreted as defined in Section IX of the ASME *Code*. Additional terms are defined in 9.1.1 and 9.1.2.

9.1.1 An angle joint is a joint between two members that intersect at an angle between 0 degrees (a butt joint) and 90 degrees (a corner joint).

9.1.2 Porosity refers to gas pockets or voids in metal.

9.2 QUALIFICATION OF WELDING PROCEDURES

9.2.1 General Requirements

- **9.2.1.1** The erection Manufacturer and the fabrication Manufacturer if other than the erection Manufacturer, shall prepare welding procedure specifications and shall perform tests documented by procedure qualification records to support the specifications, as required by Section IX of the ASME *Code* and any additional provisions of this Standard. If the Manufacturer is part of an organization that has, to the Purchaser's satisfaction, established effective operational control of the qualification of welding procedures and of welder performance for two or more companies of different names, then separate welding procedure qualifications are not required, provided all other requirements of 9.2, 9.3, and Section IX of the ASME *Code* are met. Welding procedures for ladder and platform assemblies, handrails, stairways, and other miscellaneous assemblies, but not their attachments to the tank, shall comply with either AWS D1.1, AWS D1.6, or Section IX of the ASME *Code*, including the use of standard WPSs.

9.2.1.2 The welding procedures used shall produce weldments with the mechanical properties required by the design.

9.2.1.3 Material specifications listed in Section 4 of this Standard but not included in Table QW-422 of Section IX of the ASME *Code* shall be considered as P1 material with group numbers assigned as follows according to the minimum tensile strength specified:

- a. Less than or equal to 485 MPa (70 ksi)—Group 1.
- b. Greater than 485 MPa (70 ksi) but less than 550 MPa (80 ksi)—Group 2.
- c. Greater than or equal to 550 MPa (80 ksi)—Group 3.

Separate welding procedures and performance qualifications shall be conducted for A 841M/A 841 material.

9.2.1.4 Welding variables (including supplementary essential variables when impact tests are required by 9.2.2), as defined by QW-250 of Section IX of the ASME *Code*, shall be used to determine the welding procedure specifications and the procedure qualification records to be instituted. In addition, when impact tests of the heat-affected zone are required, the heat-treated condition of the base material shall be a supplementary essential variable. If a protective coating has been applied to weld edge preparations, the coating shall be included as an essential variable of the welding procedure specification, as required by 7.2.1.9.

9.2.2 Impact Tests

9.2.2.1 Impact tests for the qualification of welding procedures shall comply with the applicable provisions of 4.2.8 and shall be made at or below the design metal temperature.

9.2.2.2 When impact testing of a material is required by 4.2.8, 4.2.9, or 4.5.5, impact tests of the heat-affected zone shall be made for all automatic and semiautomatic welding procedures.

9.2.2.3 For all materials to be used at a design metal temperature below 10°C (50°F), the qualification of the welding procedure for vertical joints shall include impact tests of the weld metal. If vertical joints are to be made by an automatic or semiautomatic process, impact tests of the heat-affected zone shall also be made.

9.2.2.4 When the design metal temperature is below -7°C (20°F), impact tests of the weld metal shall be made for all procedures used for welding the components listed in 4.2.9.1, for welding attachments to these components, and for fabricating shell nozzles and manholes from pipe and forgings listed in 4.5.

9.2.2.5 Impact tests shall show minimum values for acceptance in accordance with 4.2.8.3 and the following:

- a. For P1, Group 1, materials—20 J (15 ft-lbf), average of three specimens.
- b. For P1, Group 2, materials—27 J (20 ft-lbf), average of three specimens.
- c. For P1, Group 3, materials—34 J (25 ft-lbf), average of three specimens.

For shell plates thicker than 40 mm (1½ in.), these values shall be increased by 7 J (5 ft-lbf) for each 12.5 mm (½ in.) over 40 mm (1½ in.). Interpolation is permitted.

9.2.2.6 Weld-metal impact specimens shall be taken across the weld with one face substantially parallel to and within 1.5 mm (1/16 in.) of the surface of the material. The notch shall be cut normal to the original material surface and with the weld metal entirely within the fracture zone.

9.2.2.7 Heat-affected-zone impact specimens shall be taken across the weld and as near the surface of the material as is practicable. Each specimen shall be etched to locate the heat-affected zone, and the notch shall be cut approximately normal to the original material surface and with as much heat-affected-zone material as possible included in the fracture zone.

9.2.2.8 Production welding shall conform to the qualified welding procedure, but production-weld test plates need not be made.

9.3 QUALIFICATION OF WELDERS

9.3.1 The erection Manufacturer and the fabrication Manufacturer, if other than the erection Manufacturer, shall conduct tests for all welders assigned to manual and semiautomatic welding and all operators assigned to automatic welding to demonstrate the welders' and operators' ability to make acceptable welds. Tests conducted by one Manufacturer shall not qualify a welder or welding operator to do work for another Manufacturer.

9.3.2 The welders and welding operators who weld pressure parts and join nonpressure parts, such as all permanent and temporary clips and lugs, to pressure parts shall be qualified in accordance with Section IX of the ASME *Code*.

9.3.3 The records of the tests for qualifying welders and welding operators shall include the following:

- a. Each welder or welding operator shall be assigned an identifying number, letter, or symbol by the fabrication or erection Manufacturer.
- b. The fabrication or erection Manufacturer shall maintain a record of the welders or welding operators employed that shows the date and results of the tests for each welder or operator and the identifying mark assigned to each welder or operator. This record shall be certified by the fabrication or erection Manufacturer and shall be accessible to the inspector.

9.4 IDENTIFICATION OF WELDED JOINTS

The welder or welding operator's identification mark shall be hand- or machine-stamped adjacent to and at intervals not exceeding 1 m (3 ft) along the completed welds. In lieu of stamping, a record may be kept that identifies the welder or welding operator employed for each welded joint; these records shall be accessible to the inspector. Roof plate welds and flange-to-nozzle-neck welds do not require welder identification.

SECTION 10—MARKING

10.1 NAMEPLATES

10.1.1 A tank made in accordance with this Standard shall be identified by a nameplate similar to that shown in Figure 10-1. The nameplate shall indicate, by means of letters and numerals not less than 4 mm ($\frac{5}{32}$ in.) high, the following information:

- a. API Standard 650.
- b. The applicable appendix to API Standard 650.
- c. The year the tank was completed.
- d. The date of the edition and the addendum number of API Standard 650.
- e. The nominal diameter and nominal height, in meters (ft and in.) (unless other units are specified by the Purchaser).
- f. The maximum capacity (see 5.2.6.2), in m³ (42-gallon barrels) (unless other units are specified by the Purchaser).
- g. The design liquid level (see 5.6.3.2), in meters (ft and in.) (unless other units are specified by the Purchaser).
- h. The design specific gravity of the liquid.
- i. The design pressure, which shall be shown as atmospheric unless Appendix F or Appendix V applies. If Appendix V applies, design pressure shall be shown as a negative number. If both Appendices F and V apply, the positive and negative pressures shall be separated by a forward slash and shall be followed by consistent units of measurement.
- j. The design metal temperature as described in 1.4 in °C (°F), unless other units are specified by the Purchaser.
- k. The maximum design temperature, in °C (°F) (unless other units are specified by the Purchaser), which shall not exceed 93°C (200°F) except in cases where Appendix M applies.
- l. The name of the fabrication Manufacturer if other than the erection Manufacturer. The Manufacturer's serial number or contract number shall be from the erection Manufacturer.
- m. The material specification number for each shell course.
- n. When stress relief is applied to a part in accordance with the requirements of 5.7.4, the letters "SR."
- o. The Purchaser's tank number.

API STANDARD 650			
APPENDIX	<input type="text"/>	YEAR COMPLETED	<input type="text"/>
EDITION	<input type="text"/>	ADDENDUM NO.	<input type="text"/>
NOMINAL DIAMETER	<input type="text"/>	NOMINAL HEIGHT	<input type="text"/>
MAXIMUM CAPACITY	<input type="text"/>	DESIGN LIQUID LEVEL	<input type="text"/>
DESIGN SPECIFIC GRAVITY	<input type="text"/>	DESIGN METAL TEMP.	<input type="text"/>
DESIGN PRESSURE	<input type="text"/>	MAXIMUM DESIGN TEMP.	<input type="text"/>
MANUFACTURER'S SERIAL NO.	<input type="text"/>	PARTIAL STRESS RELIEF	<input type="text"/>
		PURCHASER'S TANK NO.	<input type="text"/>
FABRICATED BY	<input type="text"/>		
ERECTED BY	<input type="text"/>		
SHELL COURSE		MATERIAL	

- Note: At the Purchaser's request or at the erection Manufacturer's discretion, additional pertinent information may be shown on the nameplate, and the size of the nameplate may be increased proportionately.

Figure 10-1—Manufacturer's Nameplate

10.1.2 The nameplate shall be attached to the tank shell adjacent to a manhole or to a manhole reinforcing plate immediately above a manhole. A nameplate that is placed directly on the shell plate or reinforcing plate shall be attached by continuous welding or brazing all around the nameplate. A nameplate that is riveted or otherwise permanently attached to an auxiliary plate of ferrous material shall be attached to the tank shell plate or reinforcing plate by continuous welding. The nameplate shall be of corrosion-resistant metal.

10.1.3 When a tank is fabricated and erected by a single organization, that organization's name shall appear on the nameplate as both fabricator and erector.

10.1.4 When a tank is fabricated by one organization and erected by another, the names of both organizations shall appear on the nameplate, or separate nameplates shall be applied by each.

10.2 DIVISION OF RESPONSIBILITY

Unless otherwise agreed upon, when a tank is fabricated by one Manufacturer and erected by another, the erection Manufacturer shall be considered as having the primary responsibility. The erection Manufacturer shall make certain that the materials used in the fabrication of the components and in the construction of the tank are in accordance with all applicable requirements.

10.3 CERTIFICATION

The Manufacturer shall certify to the Purchaser, by a letter such as that shown in Figure 10-2, that the tank has been constructed in accordance with the applicable requirements of this Standard. An as-built data sheet in accordance with Appendix L shall be attached to the certification letter.

- Note: At the Purchaser's request or at the erection Manufacturer's discretion, additional pertinent information may be shown on the nameplate, and the size of the nameplate may be increased proportionately.

MANUFACTURER'S CERTIFICATION FOR A TANK BUILT TO API STANDARD 650	
To	_____
	<small>(name and address of Purchaser)</small>

We hereby certify that the tank constructed for you at	_____
	<small>(location)</small>

and described as follows:	_____
	<small>(serial or contract number, diameter, height, capacity, floating or fixed roof)</small>

meets all applicable requirements of API Standard 650, _____ Edition, _____ Revision, Appendix _____, dated _____, including the requirements for design, materials, fabrication, and erection.	
The tank is further described on the attached as-built data sheet dated _____.	

Manufacturer	

Authorized Representative	

Date	

Figure 10-2—Manufacturer's Certification Letter

APPENDIX A—OPTIONAL DESIGN BASIS FOR SMALL TANKS

A.1 Scope

- **A.1.1** This appendix provides requirements for field-erected tanks of relatively small capacity in which the stressed components have a maximum nominal thickness of 12.5 mm ($1/2$ in.), including any corrosion allowance specified by the Purchaser. The stressed components include the shell and reinforcing plates, shell reinforcing plates for flush-type cleanout fittings and flush-type shell connections, and bottom plates that are welded to the shell. The maximum nominal thickness of 12.5 mm ($1/2$ in.) does not apply to:
 1. bottom plates not welded to the shell,
 2. the bottom reinforcing plate of flush-type cleanouts and flush-type shell connections,
 3. flanges and cover plates of flush-type cleanouts,
 4. flush-type shell connection necks attached to shell and flanges and cover plates of flush-type shell connections,
 5. nozzle and manhole necks, their flanges and cover plates,
 6. anchor bolt chair components and shell compression ring.
- **A.1.2** This appendix is applicable only when specified by the Purchaser and is limited to design metal temperatures above -30°C (-20°F) (above -40°C [-40°F] when killed, fine-grain material is used).
- A.1.3** This appendix is applicable to any of the Section 4 materials, although the single allowable stress does not provide any advantage to higher strength steels.
- A.1.4** This appendix states only the requirements that differ from the basic rules in this Standard. When differing requirements are not stated, the basic rules must be followed; however, the overturning effect of a wind load should be considered.
- A.1.5** Typical sizes, capacities, and shell-plate thicknesses are listed in Tables A-1 through A-4 for a design in accordance with A.4 (joint efficiency = 0.85; specific gravity = 1.0; and corrosion allowance = 0).

A.2 Materials

- A.2.1** Shell-plate materials shall not be more than 12.5 mm ($1/2$ in.) thick, as stated in A.1.1.
- A.2.2** For stressed components, the Group-I and Group-II materials listed in Table 4-3 may be used above a design metal temperature of -30°C (-20°F) but need not conform to the toughness requirements of 4.2.9, Figure 4-1, and 9.2.2. Group-III and Group-IIIA materials may be used above a design metal temperature of -40°C (-40°F) and shall conform to impact requirements of 9.2.2.
- A.2.3** Material used for shell nozzle and manhole necks and flanges shall conform to 4.5, 4.6, and Table 4-3 but need not conform to the toughness requirements of 4.2.9, 4.5.5, and Figure 4-1.
- A.2.4** Bottom reinforcing plates in flush-type cleanouts and flush-type shell connections, and flush-type fitting necks attached to shell shall conform to toughness requirements of 4.2.9 and Figure 4-1 at design metal temperature.

A.3 Design

- A.3.1** The maximum tensile stress before the joint efficiency factor is applied shall be 145 MPa (21,000 lbf/in.²).
- A.3.2** Stresses shall be computed on the assumption that the tank is filled with water (specific gravity = 1.0) or with the liquid to be stored if it is heavier than water.
- A.3.3** The tension in each ring shall be computed 300 mm (12 in.) above the centerline of the lower horizontal joint of the course in question. When these stresses are computed, the tank diameter shall be taken as the nominal diameter of the bottom course.
- **A.3.4** The joint efficiency factor shall be 0.85 with the spot radiography required by A.5.3. By agreement between the Purchaser and the Manufacturer, the spot radiography may be omitted, and a joint efficiency factor of 0.70 shall be used.

Table A-1a—Typical Sizes and Corresponding Nominal Capacities (m³)
for Tanks with 1800-mm Courses

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11
Tank Diameter m	Capacity per m of Height m ³	Tank Height (m) / Number of Courses in Completed Tank								
		3.6 / 2	5.4 / 3	7.2 / 4	9 / 5	10.8 / 6	12.6 / 7	14.4 / 8	16.2 / 9	18 / 10
3	7.07	25	38	51	64	76	—	—	—	—
4.5	15.9	57	86	115	143	172	—	—	—	—
6	28.3	102	153	204	254	305	356	407	—	—
7.5	44.2	159	239	318	398	477	557	636	716	795
9	63.6	229	344	458	573	687	802	916	1,031	1,145
10.5	86.6	312	468	623	779	935	1,091	1,247	1,403	1,559
12	113	407	611	814	1,018	1,221	1,425	1,629	1,832	2,036
13.5	143	515	773	1,031	1,288	1,546	1,804	2,061	2,319	2,576
15	177	636	954	1,272	1,590	1,909	2,227	2,545	2,863	3,181
18	254	916	1,374	1,832	2,290	2,748	3,206	3,664	4,122	4,580
										<i>D = 18</i>
21	346	1,247	1,870	2,494	3,117	3,741	4,364	4,988	5,089	—
24	452	1,629	2,443	3,257	4,072	4,886	5,700	5,474	<i>D = 20</i>	—
27	573	2,061	3,092	4,122	5,153	6,184	6,690	<i>D = 22</i>	—	—
30	707	2,545	3,817	5,089	6,362	7,634	<i>D = 26</i>	—	—	—
36	1,018	3,664	5,497	7,329	9,161	<i>D = 30</i>	—	—	—	—
						<i>D = 36</i>				
42	1,385	4,988	7,481	9,975	—	—	—	—	—	—
48	1,810	6,514	9,772	11,966	—	—	—	—	—	—
54	2,290	8,245	12,367	<i>D = 46</i>	—	—	—	—	—	—
60	2,827	10,179	15,268	—	—	—	—	—	—	—
66	3,421	12,316	16,303	—	—	—	—	—	—	—
			<i>D = 62</i>							

Note: The nominal capacities given in this table were calculated using the following formula:

In SI units:

$$C = 0.785D^2H$$

where

- C = capacity of tank, in m³,
- D = diameter of tank, in m (see A.4.1),
- H = height of tank, in m (see A.4.1).

The capacities and diameters in italics (Columns 4 – 11) are the maximums for the tank heights given in the column heads, based on a maximum permissible shell-plate thickness of 12.5 mm, a maximum allowable design stress of 145 MPa, a joint efficiency of 0.85, and no corrosion allowance (see A.4.1).

Table A-1b—Typical Sizes and Corresponding Nominal Capacities (barrels) for Tanks with 72-in. Courses

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11
Tank Diameter ft	Capacity per ft of Height barrels	Tank Height (ft) / Number of Courses in Completed Tank								
		12 / 2	18 / 3	24 / 4	30 / 5	36 / 6	42 / 7	48 / 8	54 / 9	60 / 10
10	14.0	170	250	335	420	505	—	—	—	—
15	31.5	380	565	755	945	1,130	—	—	—	—
20	56.0	670	1,010	1,340	1,680	2,010	2,350	2,690	—	—
25	87.4	1,050	1,570	2,100	2,620	3,150	3,670	4,200	4,720	5,250
30	126	1,510	2,270	3,020	3,780	4,530	5,290	6,040	6,800	7,550
35	171	2,060	3,080	4,110	5,140	6,170	7,200	8,230	9,250	10,280
40	224	2,690	4,030	5,370	6,710	8,060	9,400	10,740	12,100	13,430
45	283	3,400	5,100	6,800	8,500	10,200	11,900	13,600	15,300	17,000
50	350	4,200	6,300	8,400	10,500	12,600	14,700	16,800	18,900	21,000
60	504	6,040	9,060	12,100	15,110	18,130	21,150	24,190	37,220	28,260
										<i>D = 58</i>
70	685	8,230	12,340	16,450	20,580	24,700	28,800	32,930	30,970	—
80	895	10,740	16,120	21,500	26,880	32,260	37,600	35,810	<i>D = 64</i>	—
90	1,133	13,600	20,400	27,220	34,030	40,820	40,510	<i>D = 73</i>	—	—
100	1,399	16,800	25,200	33,600	42,000	48,400	<i>D = 83</i>	—	—	—
120	2,014	24,190	36,290	48,380	58,480	<i>D = 98</i>	—	—	—	—
						<i>D = 118</i>				
140	2,742	32,930	49,350	65,860	—	—	—	—	—	—
160	3,581	43,000	64,510	74,600	—	—	—	—	—	—
180	4,532	54,430	81,650	<i>D = 149</i>	—	—	—	—	—	—
200	5,595	67,200	100,800	—	—	—	—	—	—	—
220	6,770	81,310	102,830	—	—	—	—	—	—	—
										<i>D = 202</i>

Note: The nominal capacities given in this table were calculated using the following formula:

In US Customary units:

$$C = 0.14D^2H,$$

where

- C = capacity of tank, in 42-gal barrels,
- D = diameter of tank, in ft (see A.4.1),
- H = height of tank, in ft (see A.4.1).

The capacities and diameters in italics (Columns 4 – 11) are the maximums for the tank heights given in the column heads, based on a maximum permissible shell-plate thickness of 1/2 in., a maximum allowable design stress of 21,000 lbf/in.², a joint efficiency of 0.85, and no corrosion allowance (see A.4.1).

Table A-2a—Shell-Plate Thicknesses (mm) for Typical Sizes of Tanks with 1800-mm Courses

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12
Tank Diameter m	Tank Height (m) / Number of Courses in Completed Tank										Maximum Allowable Height for Diameter ^a m
	1.8 / 1	3.6 / 2	5.4 / 3	7.2 / 4	9 / 5	10.8 / 6	12.6 / 7	14.4 / 8	16.2 / 9	18 / 10	
3	5.0	5.0	5.0	5.0	5.0	5.0	—	—	—	—	—
4.5	5.0	5.0	5.0	5.0	5.0	5.0	—	—	—	—	—
6	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	—	—	—
7.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.3	—
9	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.7	6.3	—
10.5	5.0	5.0	5.0	5.0	5.0	5.0	5.1	5.9	6.6	7.4	—
12	5.0	5.0	5.0	5.0	5.0	5.0	5.9	6.7	7.6	8.4	—
13.5	5.0	5.0	5.0	5.0	5.0	5.6	6.6	7.6	8.5	9.5	—
15	6.0	6.0	6.0	6.0	6.0	6.3	7.3	8.4	9.5	10.6	—
18	6.0	6.0	6.0	6.0	6.2	7.5	8.8	10.1	11.4	—	17.8
21	6.0	6.0	6.0	6.0	7.3	8.8	10.3	11.8	—	—	15.3
24	6.0	6.0	6.0	6.6	8.3	10.0	11.7	—	—	—	13.4
27	6.0	6.0	6.0	7.4	9.3	11.3	—	—	—	—	11.9
30	6.0	6.0	6.0	8.2	10.4	12.5	—	—	—	—	10.8
36	8.0	8.0	8.0	9.9	12.5	—	—	—	—	—	9.0
42	8.0	8.0	8.5	11.5	—	—	—	—	—	—	7.8
48	8.0	8.0	9.7	—	—	—	—	—	—	—	6.9
54	8.0	8.0	10.9	—	—	—	—	—	—	—	6.1
60	8.0	8.0	12.2	—	—	—	—	—	—	—	5.5
66	10.0	10.0	—	—	—	—	—	—	—	—	5.1

^aBased on a maximum permissible shell-plate thickness of 12.5 mm, a maximum allowable design stress of 145 MPa, a joint efficiency of 0.85, and no corrosion allowance.

Note: The plate thicknesses shown in this table are based on a maximum allowable design stress of 145 MPa, a joint efficiency of 0.85, and no corrosion allowance (see A.4.1).

Table A-2b—Shell-Plate Thicknesses (in.) for Typical Sizes of Tanks with 72-in. Courses

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12
Tank Diameter ft	Tank Height (ft) / Number of Courses in Completed Tank										Maximum Allowable Height for Diameter ^a ft
	6 / 1	12 / 2	18 / 3	24 / 4	30 / 5	36 / 6	42 / 7	48 / 8	54 / 9	60 / 10	
10	3/16	3/16	3/16	3/16	3/16	3/16	—	—	—	—	—
15	3/16	3/16	3/16	3/16	3/16	3/16	—	—	—	—	—
20	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16	—	—	—
25	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16	0.20	0.22	—
30	3/16	3/16	3/16	3/16	3/16	3/16	3/16	0.21	0.24	0.26	—
35	3/16	3/16	3/16	3/16	3/16	3/16	0.21	0.24	0.27	0.30	—
40	3/16	3/16	3/16	3/16	3/16	0.21	0.24	0.28	0.31	0.35	—
45	3/16	3/16	3/16	3/16	3/16	0.23	0.27	0.31	0.35	0.38	—
50	1/4	1/4	1/4	1/4	1/4	0.26	0.30	0.35	0.39	0.43	—
60	1/4	1/4	1/4	1/4	0.26	0.31	0.36	0.41	0.47	—	58.2
70	1/4	1/4	1/4	1/4	0.30	0.36	0.42	0.48	—	—	50.0
80	1/4	1/4	1/4	0.27	0.34	0.41	0.48	—	—	—	43.9
90	1/4	1/4	1/4	0.31	0.38	0.46	—	—	—	—	39.1
100	1/4	1/4	1/4	0.34	0.43	—	—	—	—	—	35.3
120	5/16	5/16	5/16	0.41	—	—	—	—	—	—	29.6
140	5/16	5/16	0.35	0.47	—	—	—	—	—	—	25.5
160	5/16	5/16	0.40	—	—	—	—	—	—	—	22.5
180	5/16	5/16	0.45	—	—	—	—	—	—	—	20.1
200	5/16	0.32	0.50	—	—	—	—	—	—	—	18.2
220	3/8	3/8	—	—	—	—	—	—	—	—	16.6

^aBased on a maximum permissible shell-plate thickness of 1/2 in., a maximum allowable design stress of 21,000 lbf/in.², a joint efficiency of 0.85, and no corrosion allowance.

Note: The plate thicknesses shown in this table are based on a maximum allowable design stress of 21,000 lbf/in.², a joint efficiency of 0.85, and no corrosion allowance (see A.4.1).

Table A-3a—Typical Sizes and Corresponding Nominal Capacities (m³)
for Tanks with 2400-mm Courses

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
Tank Diameter m	Capacity per m of Height m ³	Tank Height (m) / Number of Courses in Completed Tank						
		4.8 / 2	7.2 / 3	9.6 / 4	12 / 5	14.4 / 6	16.8 / 7	19.2 / 8
3	7.07	34	51	68	—	—	—	—
4.5	15.9	76	115	153	191	—	—	—
6	28.3	136	204	272	339	407	—	—
7.5	44.2	212	318	424	530	636	742	848
9	63.6	305	458	610	763	916	1,069	1,221
10.5	86.6	416	623	831	1,039	1,247	1,455	1,663
12	113	543	814	1085	1,357	1,629	1,900	2,171
13.5	143	687	1,031	1373	1,718	2,061	2,405	2,748
15	177	848	1,272	1696	2,121	2,545	2,969	3,393
18	254	1,221	1,832	2442	3,054	3,664	4,275	4,358
								<i>D = 17</i>
21	346	1,663	2,494	3323	4,156	4,988	4,763	—
24	452	2,171	3,257	4341	5,429	5,474	<i>D = 19</i>	—
27	573	2,748	4,122	5494	6,871	<i>D = 22</i>	—	—
30	707	3,393	5,089	6782	<i>D = 27</i>	—	—	—
36	1,018	4,886	7,329	8712	—	—	—	—
				<i>D = 34</i>				
42	1,385	6,650	9,975	—	—	—	—	—
48	1,810	8,686	<i>11,966</i>	—	—	—	—	—
54	2,290	10,993	<i>D = 46</i>	—	—	—	—	—
60	2,827	13,572	—	—	—	—	—	—
66	3,421	16,422	—	—	—	—	—	—

Note: The nominal capacities given in this table were calculated using the following formula:

In SI units:

$$C = 0.785D^2H$$

where

- C = capacity of tank, in m³,
- D = diameter of tank, in m (see A.4.1),
- H = height of tank, in m (see A.4.1).

The capacities and diameters in italics (Columns 4 – 9) are the maximums for the tank heights given in the column heads, based on a maximum permissible shell-plate thickness of 12.5 mm, a maximum allowable design stress of 145 MPa, a joint efficiency of 0.85, and no corrosion allowance (see A.4.1).

Table A-3b—Typical Sizes and Corresponding Nominal Capacities (barrels) for Tanks with 96-in. Courses

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
Tank Diameter ft	Capacity per ft of Height barrels	Tank Height (ft) / Number of Courses in Completed Tank						
		16 / 2	24 / 3	32 / 4	40 / 5	48 / 6	56 / 7	64 / 8
10	14.0	225	335	450	—	—	—	—
15	31.5	505	755	1,010	1,260	—	—	—
20	56.0	900	1,340	1,790	2,240	2,690	—	—
25	87.4	1,400	2,100	2,800	3,500	4,200	4,900	5,600
30	126	2,020	3,020	4,030	5,040	6,040	7,050	8,060
35	171	2,740	4,110	5,480	6,850	8,230	9,600	10,980
40	224	3,580	5,370	7,160	8,950	10,740	12,540	14,340
45	283	4,530	6,800	9,060	11,340	13,600	15,880	18,140
50	350	5,600	8,400	11,200	14,000	16,800	19,600	22,400
60	504	8,060	12,100	16,130	20,160	24,190	28,220	<i>26,130</i>
								<i>D = 54</i>
70	685	10,960	16,450	21,950	27,440	32,930	<i>30,140</i>	—
80	895	14,320	21,500	28,670	35,840	<i>35,810</i>	<i>D = 62</i>	—
90	1,133	18,130	27,220	36,290	<i>45,360</i>	<i>D = 73</i>	—	—
100	1,399	22,380	33,600	44,800	<i>D = 88</i>	—	—	—
120	2,014	32,250	48,380	<i>54,200</i>	—	—	—	—
				<i>D = 110</i>				
140	2,742	43,900	65,860	—	—	—	—	—
160	3,581	57,340	<i>74,600</i>	—	—	—	—	—
180	4,532	72,570	<i>D = 149</i>	—	—	—	—	—
200	5,595	89,600	—	—	—	—	—	—
220	6,770	108,410	—	—	—	—	—	—

Note: The nominal capacities given in this table were calculated using the following formula:

In US Customary units:

$$C = 0.14D^2H,$$

where

- C = capacity of tank, in 42-gal barrels,
- D = diameter of tank, in ft (see A.4.1),
- H = height of tank, in ft (see A.4.1).

The capacities and diameters in italics (Columns 4 – 9) are the maximums for the tank heights given in the column heads, based on a maximum permissible shell-plate thickness of 1/2 in., a maximum allowable design stress of 21,000 lbf/in.², a joint efficiency of 0.85, and no corrosion allowance (see A.4.1).

Table A-4a—Shell-Plate Thicknesses (mm) for Typical Sizes of Tanks
with 2400-mm Courses

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10
Tank Height Diameter m	Tank Height (m) / Number of Courses in Completed Tank								Maximum Allowable Height for Diameter ^a m
	2.4 / 1	4.8 / 2	7.2 / 3	9.6 / 4	12 / 5	14.4 / 6	16.8 / 7	19.2 / 8	
3	5.0	5.0	5.0	5.0	—	—	—	—	—
4.5	5.0	5.0	5.0	5.0	5.0	—	—	—	—
6	5.0	5.0	5.0	5.0	5.0	5.0	—	—	—
7.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	—
9	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	—
10.5	5.0	5.0	5.0	5.0	5.0	5.0	5.1	5.9	—
12	5.0	5.0	5.0	5.0	5.0	5.0	5.9	6.7	—
13.5	5.0	5.0	5.0	5.0	5.0	5.6	6.6	7.6	—
15	6.0	6.0	6.0	6.0	6.0	6.3	7.3	8.4	—
18	6.0	6.0	6.0	6.0	6.2	7.5	8.8	10.1	17.8
21	6.0	6.0	6.0	6.0	7.3	8.8	10.3	11.8	15.3
24	6.0	6.0	6.0	6.6	8.3	10.0	11.7	—	13.4
27	6.0	6.0	6.0	7.4	9.3	11.3	—	—	11.9
30	6.0	6.0	6.1	8.2	10.4	12.5	—	—	10.8
36	8.0	8.0	8.0	9.9	12.5	—	—	—	9.0
42	8.0	8.0	8.5	11.5	—	—	—	—	7.8
48	8.0	8.0	9.7	—	—	—	—	—	6.9
54	8.0	8.0	10.9	—	—	—	—	—	6.1
60	8.0	8.0	12.2	—	—	—	—	—	5.5
66	10.0	10.0	—	—	—	—	—	—	5.1

^aBased on a maximum permissible shell-plate thickness of 12.5 mm, a maximum allowable design stress of 145 MPa, a joint efficiency of 0.85, and no corrosion allowance.

Note: The plate thicknesses shown in this table are based on a maximum allowable design stress of 145 MPa, a joint efficiency of 0.85, and no corrosion allowance (see A.4.1).

Table A-4b—Shell-Plate Thicknesses (in.) for Typical Sizes of Tanks with 96-in. Courses

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10
Tank Height Diameter ft	Tank Height (ft) / Number of Courses in Completed Tank								Maximum Allowable Height for Diameter ^a ft
	8 / 1	16 / 2	24 / 3	32 / 4	40 / 5	48 / 6	56 / 7	64 / 8	
10	3/16	3/16	3/16	3/16	—	—	—	—	—
15	3/16	3/16	3/16	3/16	3/16	—	—	—	—
20	3/16	3/16	3/16	3/16	3/16	3/16	—	—	—
25	3/16	3/16	3/16	3/16	3/16	3/16	0.20	0.23	—
30	3/16	3/16	3/16	3/16	3/16	0.21	0.24	0.28	—
35	3/16	3/16	3/16	3/16	0.20	0.24	0.28	0.33	—
40	3/16	3/16	3/16	3/16	0.23	0.28	0.32	0.37	—
45	3/16	3/16	3/16	0.21	0.26	0.31	0.36	0.42	—
50	1/4	1/4	1/4	0.25	0.29	0.35	0.40	0.46	—
60	1/4	1/4	1/4	0.27	0.34	0.41	0.48	—	58.2
70	1/4	1/4	1/4	0.32	0.40	0.48	—	—	50.0
80	1/4	1/4	0.27	0.37	0.46	—	—	—	43.9
90	1/4	1/4	0.31	0.41	—	—	—	—	39.1
100	1/4	1/4	0.34	0.46	—	—	—	—	35.3
120	5/16	5/16	0.41	—	—	—	—	—	29.6
140	5/16	5/16	0.47	—	—	—	—	—	25.5
160	5/16	0.35	—	—	—	—	—	—	22.5
180	5/16	0.40	—	—	—	—	—	—	20.1
200	5/16	0.44	—	—	—	—	—	—	18.2
220	3/8	0.48	—	—	—	—	—	—	16.6

^aBased on a maximum permissible shell-plate thickness of 1/2 in., a maximum allowable design stress of 21,000 lbf/in.², a joint efficiency of 0.85, and no corrosion allowance.

Note: The plate thicknesses shown in this table are based on a maximum allowable design stress of 21,000 lbf/in.², a joint efficiency of 0.85, and no corrosion allowance (see A.4.1).

A.4 Thickness of Shell Plates

A.4.1 The minimum thicknesses of shell plates shall be computed from the stress on the vertical joints, using the following formula:

In SI units:

$$t = \frac{4.9D(H-0.3)G}{(E)(145)} + CA$$

where

t = minimum thickness, in mm (see 5.6.1.1),

D = nominal diameter of the tank, in m (see 5.6.1.1, Note 1),

H = design liquid level, in m (see 5.6.3.2),

- G = specific gravity of the liquid to be stored, as specified by the Purchaser. The specific gravity shall not be less than 1.0,
- E = joint efficiency, which is either 0.85 or 0.70 (see A.3.4),
- CA = corrosion allowance, in mm, as specified by the Purchaser (see 5.3.2).

In US Customary units:

$$t = \frac{2.6D(H-1)G}{(E)(21,000)} + CA$$

where

t = minimum thickness (in.) (see 5.6.1.1),

D = nominal diameter of the tank (ft) (see 5.6.1.1, Note 1),

H = design liquid level (ft) (see 5.6.3.2),

- G = specific gravity of the liquid to be stored, as specified by the Purchaser. The specific gravity shall not be less than 1.0,
- E = joint efficiency, which is either 0.85 or 0.70 (see A.3.4),
- CA = corrosion allowance (in.), as specified by the Purchaser (see 5.3.2).

A.4.2 The nominal thickness of shell plates (including shell extensions for floating roofs) shall not be less than that listed in 3.6.1.1. The nominal thickness of shell plates refers to the tank shell as constructed. The nominal thicknesses given in 5.6.1.1 are based on erection requirements.

A.5 Tank Joints

A.5.1 Vertical and horizontal joints in the shell, bottom joints, shell-to-bottom joints, wind-girder joints, and roof and top-angle joints shall conform to 5.1.5.

A.5.2 The requirements of 5.7.3 for the spacing of welds do not apply except for the requirement that the spacing between the toes of welds around a connection shall not be less than $2\frac{1}{2}$ times the shell thickness at the connection.

A.5.3 When radiographic inspection is required (joint efficiency = 0.85), the spot radiographs of vertical joints shall conform to 8.1.2.2, Item a only, excluding the 10 mm ($\frac{3}{8}$ in.) shell-thickness limitation in Item a and excluding the additional random spot radiograph required by Item a. The spot radiographs of horizontal joints shall conform to 8.1.2.3.

- **A.6 Intermediate Wind Girders**

Calculations for and installation of intermediate wind girders are not required unless specified by the Purchaser.

A.7 Shell Manholes and Nozzles

A.7.1 Except for other designs and shapes permitted by 5.7.1.2, shell manholes shall conform to 5.7.5, Figures 5-7A and 5-7B, and Tables 5-3 through 5-5.

A.7.2 Shell nozzles and flanges shall conform to 5.7.6; Figures 5-7B, 5-8, and 5-10; and Tables 5-6 through 5-8.

A.7.3 The radiographic requirements of 5.7.3.4 do not apply.

A.8 Flush-Type Cleanout Fittings

A.8.1 The details and dimensions of flush-type cleanout fittings shall conform to 5.7.7, Figures 5-12 and 5-13, and Tables 5-9 through 5-11.

- **A.8.2** The provisions for stress relief specified in 5.7.4 and 5.7.7.3 are not required unless they are specified by the Purchaser or unless any plate in the unit has a thickness greater than 16 mm ($5/8$ in.).

A.9 Flush-Type Shell Connections

A.9.1 The details and dimensions of flush-type shell connections shall conform to 5.7.8, Figure 5-14, and Table 5-12.

- **A.9.2** The provisions for stress relief specified in 5.7.4 and 5.7.8.3 are not required unless they are specified by the Purchaser or unless any plate in the assembly has a thickness greater than 16 mm ($5/8$ in.).

1

APPENDIX B—RECOMMENDATIONS FOR DESIGN AND CONSTRUCTION OF FOUNDATIONS FOR ABOVEGROUND OIL STORAGE TANKS

B.1 Scope

B.1.1 This appendix provides important considerations for the design and construction of foundations for aboveground steel oil storage tanks with flat bottoms. Recommendations are offered to outline good practice and to point out some precautions that should be considered in the design and construction of storage tank foundations.

B.1.2 Since there is a wide variety of surface, subsurface, and climatic conditions, it is not practical to establish design data to cover all situations. The allowable soil loading and the exact type of subsurface construction to be used must be decided for each individual case after careful consideration. The same rules and precautions shall be used in selecting foundation sites as would be applicable in designing and constructing foundations for other structures of comparable magnitude.

B.2 Subsurface Investigation and Construction

B.2.1 At any tank site, the subsurface conditions must be known to estimate the soil bearing capacity and settlement that will be experienced. This information is generally obtained from soil borings, load tests, sampling, laboratory testing, and analysis by an experienced geotechnical engineer familiar with the history of similar structures in the vicinity. The subgrade must be capable of supporting the load of the tank and its contents. The total settlement must not strain connecting piping or produce gauging inaccuracies, and the settlement should not continue to a point at which the tank bottom is below the surrounding ground surface. The estimated settlement shall be within the acceptable tolerances for the tank shell and bottom.

B.2.2 When actual experience with similar tanks and foundations at a particular site is not available, the following ranges for factors of safety should be considered for use in the foundation design criteria for determining the allowable soil bearing pressures. (The owner or geotechnical engineer responsible for the project may use factors of safety outside these ranges.)

- a. From 2.0 to 3.0 against ultimate bearing failure for normal operating conditions.
- b. From 1.5 to 2.25 against ultimate bearing failure during hydrostatic testing.
- c. From 1.5 to 2.25 against ultimate bearing failure for operating conditions plus the maximum effect of wind or seismic loads.

B.2.3 Some of the many conditions that require special engineering consideration are as follows:

- a. Sites on hillsides, where part of a tank may be on undisturbed ground or rock and part may be on fill or another construction or where the depth of required fill is variable.
- b. Sites on swampy or filled ground, where layers of muck or compressible vegetation are at or below the surface or where unstable or corrosive materials may have been deposited as fill.
- c. Sites underlain by soils, such as layers of plastic clay or organic clays, that may support heavy loads temporarily but settle excessively over long periods of time.
- d. Sites adjacent to water courses or deep excavations, where the lateral stability of the ground is questionable.
- e. Sites immediately adjacent to heavy structures that distribute some of their load to the subsoil under the tank sites, thereby reducing the subsoil's capacity to carry additional loads without excessive settlement.
- f. Sites where tanks may be exposed to flood waters, possibly resulting in uplift, displacement, or scour.
- g. Sites in regions of high seismicity that may be susceptible to liquefaction.
- h. Sites with thin layers of soft clay soils that are directly beneath the tank bottom and that can cause lateral ground stability problems.

B.2.4 If the subgrade is inadequate to carry the load of the filled tank without excessive settlement, shallow or superficial construction under the tank bottom will not improve the support conditions. One or more of the following general methods should be considered to improve the support conditions:

- a. Removing the objectionable material and replacing it with suitable, compacted material.
- b. Compacting the soft material with short piles.
- c. Compacting the soft material by preloading the area with an overburden of soil. Strip or sand drains may be used in conjunction with this method.
- d. Stabilizing the soft material by chemical methods or injection of cement grout.

- e. Transferring the load to a more stable material underneath the subgrade by driving piles or constructing foundation piers. This involves constructing a reinforced concrete slab on the piles to distribute the load of the tank bottom.
- f. Constructing a slab foundation that will distribute the load over a sufficiently large area of the soft material so that the load intensity will be within allowable limits and excessive settlement will not occur.
- g. Improving soil properties by vibro-compaction, vibro-replacement, or deep dynamic-compaction.
- h. Slow and controlled filling of the tank during hydrostatic testing. When this method is used, the integrity of the tank may be compromised by excessive settlements of the shell or bottom. For this reason, the settlements of the tank shall be closely monitored. In the event of settlements beyond established ranges, the test may have to be stopped and the tank releveled.

B.2.5 The fill material used to replace muck or other objectionable material or to build up the grade to a suitable height shall be adequate for the support of the tank and product after the material has been compacted. The fill material shall be free of vegetation, organic matter, cinders, and any material that will cause corrosion of the tank bottom. The grade and type of fill material shall be capable of being compacted with standard industry compaction techniques to a density sufficient to provide appropriate bearing capacity and acceptable settlements. The placement of the fill material shall be in accordance with the project specifications prepared by a qualified geotechnical engineer.

B.3 Tank Grades

B.3.1 The grade or surface on which a tank bottom will rest should be constructed at least 0.3 m (1 ft) above the surrounding ground surface. This will provide suitable drainage, help keep the tank bottom dry, and compensate for some small settlement that is likely to occur. If a large settlement is expected, the tank bottom elevation shall be raised so that the final elevation above grade will be a minimum of 150 mm (6 in.) after settlement.

B.3.2 There are several different materials that can be used for the grade or surface on which the tank bottom will rest. To minimize future corrosion problems and maximize the effect of corrosion prevention systems such as cathodic protection, the material in contact with the tank bottom should be fine and uniform. Gravel or large particles shall be avoided. Clean washed sand 75 mm – 100 mm (3 in. – 4 in.) deep is recommended as a final layer because it can be readily shaped to the bottom contour of the tank to provide maximum contact area and will protect the tank bottom from coming into contact with large particles and debris. Large foreign objects or point contact by gravel or rocks could cause corrosion cells that will cause pitting and premature tank bottom failure.

During construction, the movement of equipment and materials across the grade will mar the graded surface. These irregularities should be corrected before bottom plates are placed for welding.

Adequate provisions, such as making size gradients in sublayers progressively smaller from bottom to top, should be made to prevent the fine material from leaching down into the larger material, thus negating the effect of using the fine material as a final layer. This is particularly important for the top of a crushed rock ringwall.

Note: For more information on tank bottom corrosion and corrosion prevention that relates to the foundation of a tank, see API RP 651.

- **B.3.3** Unless otherwise specified by the Purchaser, the finished tank grade shall be crowned from its outer periphery to its center at a slope of 1 in. in 10 ft. The crown will partly compensate for slight settlement, which is likely to be greater at the center. It will also facilitate cleaning and the removal of water and sludge through openings in the shell or from sumps situated near the shell. Because crowning will affect the lengths of roof-supporting columns, it is essential that the tank Manufacturer be fully informed of this feature sufficiently in advance. (For an alternative to this paragraph, see B.3.4.)
- **B.3.4** As an alternative to B.3.3, the tank bottom may be sloped toward a sump. The tank Manufacturer must be advised as required in B.3.3.

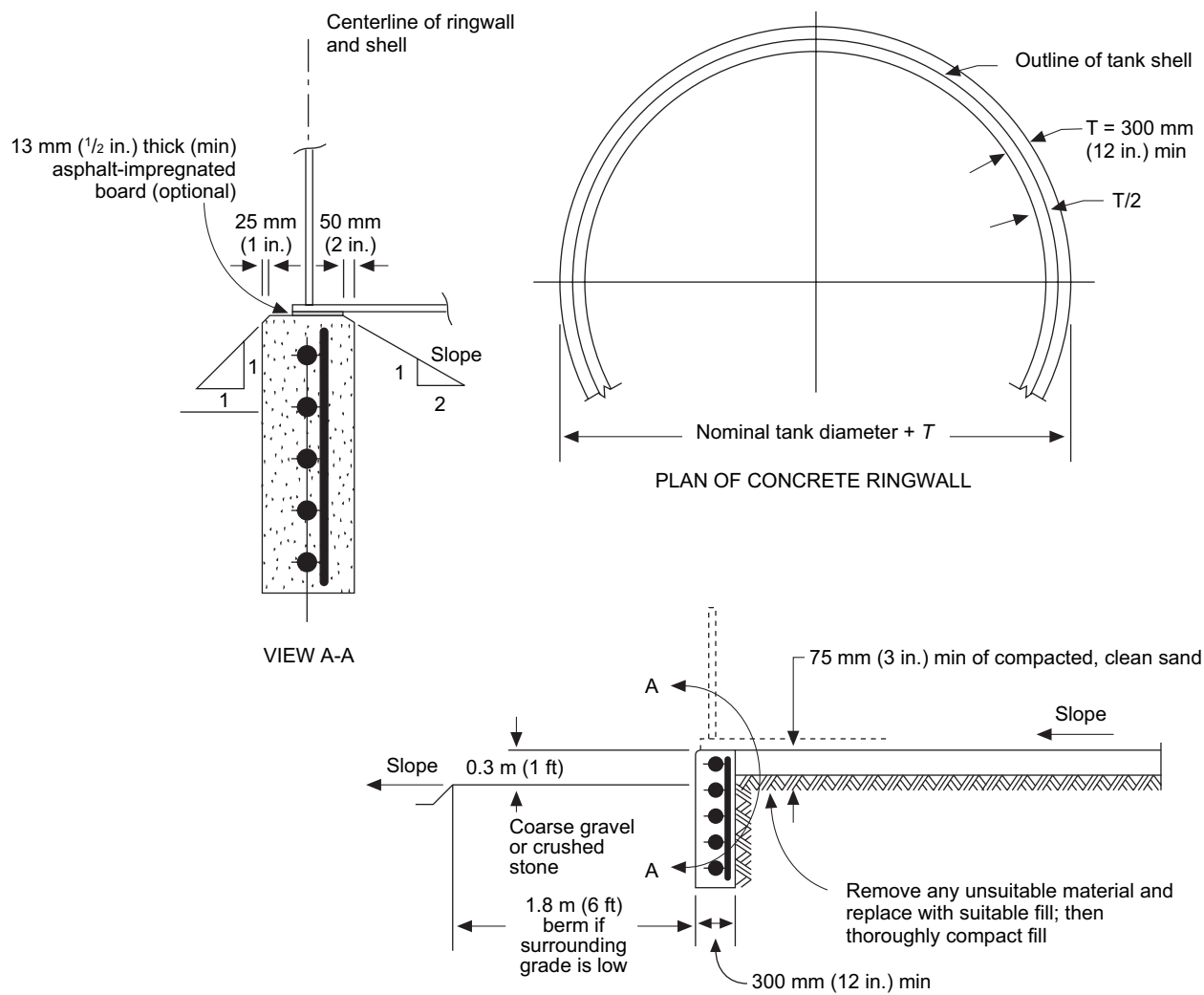
B.4 Typical Foundation Types

B.4.1 EARTH FOUNDATIONS WITHOUT A RINGWALL

B.4.1.1 When an engineering evaluation of subsurface conditions that is based on experience and/or exploratory work has shown that the subgrade has adequate bearing capacity and that settlements will be acceptable, satisfactory foundations may be constructed from earth materials. The performance requirements for earth foundations are identical to those for more extensive foundations. Specifically, an earth foundation should accomplish the following:

- a. Provide a stable plane for the support of the tank.
- b. Limit overall settlement of the tank grade to values compatible with the allowances used in the design of the connecting piping.
- c. Provide adequate drainage.
- d. Not settle excessively at the perimeter due to the weight of the shell wall.

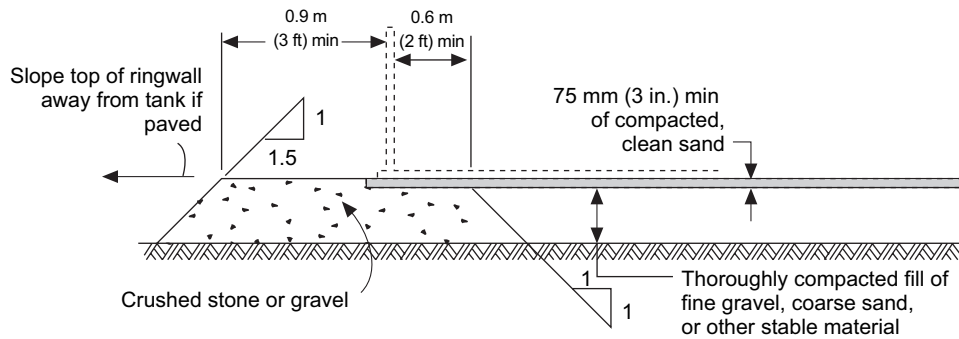
B.4.1.2 Many satisfactory designs are possible when sound engineering judgment is used in their development. Three designs are referred to in this appendix on the basis of their satisfactory long-term performance. For smaller tanks, foundations can consist of compacted crushed stone, screenings, fine gravel, clean sand, or similar material placed directly on virgin soil. Any unstable material must be removed, and any replacement material must be thoroughly compacted. Two recommended designs that include ringwalls are illustrated in Figures B-1 and B-2 and described in B.4.2 and B.4.3.



Notes:

1. See B.4.2.3 for requirements for reinforcement.
2. The top of the concrete ringwall shall be smooth and level. The concrete strength shall be at least 20 MPa (3000 lbf/in.²) after 28 days. Reinforcement splices must be staggered and shall be lapped to develop full strength in the bond. If staggering of laps is not possible, see ACI 318 for additional development requirements.
3. Ringwalls that exceed 300 mm (12 in.) in width shall have rebar distributed on both faces.
4. See B.4.2.2 for the position of the tank shell on the ringwall.

Figure B-1—Example of Foundation with Concrete Ringwall



Note: Any unsuitable material shall be removed and replaced with suitable fill; the fill shall then be thoroughly compacted.

Figure B-2—Example of Foundation with Crushed Stone Ringwall

B.4.2 EARTH FOUNDATIONS WITH A CONCRETE RINGWALL

B.4.2.1 Large tanks and tanks with heavy or tall shells and/or self-supported roofs impose a substantial load on the foundation under the shell. This is particularly important with regard to shell distortion in floating-roof tanks. When there is some doubt whether a foundation will be able to carry the shell load directly, a concrete ringwall foundation should be used. As an alternative to the concrete ringwall noted in this section, a crushed stone ringwall (see B.4.3) may be used. A foundation with a concrete ringwall has the following advantages:

- It provides better distribution of the concentrated load of the shell to produce a more nearly uniform soil loading under the tank.
- It provides a level, solid starting plane for construction of the shell.
- It provides a better means of leveling the tank grade, and it is capable of preserving its contour during construction.
- It retains the fill under the tank bottom and prevents loss of material as a result of erosion.
- It minimizes moisture under the tank.

A disadvantage of concrete ringwalls is that they may not smoothly conform to differential settlements. This disadvantage may lead to high bending stresses in the bottom plates adjacent to the ringwall.

B.4.2.2 When a concrete ringwall is designed, it shall be proportioned so that the allowable soil bearing is not exceeded. The ringwall shall not be less than 300 mm (12 in.) thick. The centerline diameter of the ringwall should equal the nominal diameter of the tank; however, the ringwall centerline may vary if required to facilitate the placement of anchor bolts or to satisfy soil bearing limits for seismic loads or excessive uplift forces. The depth of the wall will depend on local conditions, but the depth must be sufficient to place the bottom of the ringwall below the anticipated frost penetration and within the specified bearing strata. As a minimum, the bottom of the ringwall, if founded on soil, shall be located 0.6 m (2 ft) below the lowest adjacent finish grade. Tank foundations must be constructed within the tolerances specified in 7.5.5. Recesses shall be provided in the wall for flush-type cleanouts, drawoff sumps, and any other appurtenances that require recesses.

B.4.2.3 A ringwall should be reinforced against temperature changes and shrinkage and reinforced to resist the lateral pressure of the confined fill with its surcharge from product loads. ACI 318 is recommended for design stress values, material specifications, and rebar development and cover. The following items concerning a ringwall shall be considered:

- The ringwall shall be reinforced to resist the direct hoop tension resulting from the lateral earth pressure on the ringwall's inside face. Unless substantiated by proper geotechnical analysis, the lateral earth pressure shall be assumed to be at least 50% of the vertical pressure due to fluid and soil weight. If a granular backfill is used, a lateral earth pressure coefficient of 30% may be used.
- The ringwall shall be reinforced to resist the bending moment resulting from the uniform moment load. The uniform moment load shall account for the eccentricities of the applied shell and pressure loads relative to the centroid of the resulting soil pressure. The pressure load is due to the fluid pressure on the horizontal projection of the ringwall inside the shell.
- The ringwall shall be reinforced to resist the bending and torsion moments resulting from lateral, wind, or seismic loads applied eccentrically to it. A rational analysis, which includes the effect of the foundation stiffness, shall be used to determine these moments and soil pressure distributions.

- d. The total hoop steel area required to resist the loads noted above shall not be less than the area required for temperature changes and shrinkage. The hoop steel area required for temperature changes and shrinkage is 0.0025 times the vertical cross-sectional area of the ringwall or the minimum reinforcement for walls called for in ACI 318, Chapter 14.
- e. For ringwalls, the vertical steel area required for temperature changes and shrinkage is 0.0015 times the horizontal cross-sectional area of the ringwall or the minimum reinforcement for walls called for in ACI 318, Chapter 14. Additional vertical steel may be required for uplift or torsional resistance. If the ring foundation is wider than its depth, the design shall consider its behavior as an annular slab with flexure in the radial direction. Temperature and shrinkage reinforcement shall meet the ACI 318 provisions for slabs. (See ACI 318, Chapter 7.)
- f. When the ringwall width exceeds 460 mm (18 in.), using a footing beneath the wall should be considered. Footings may also be useful for resistance to uplift forces.
- g. Structural backfill within and adjacent to concrete ringwalls and around items such as vaults, undertank piping, and sumps requires close field control to maintain settlement tolerances. Backfill should be granular material compacted to the density and compacting as specified in the foundation construction specifications. For other backfill materials, sufficient tests shall be conducted to verify that the material has adequate strength and will undergo minimal settlement.

B.4.3 EARTH FOUNDATIONS WITH A CRUSHED STONE AND GRAVEL RINGWALL

B.4.3.1 A crushed stone or gravel ringwall will provide adequate support for high loads imposed by a shell. A foundation with a crushed stone or gravel ringwall has the following advantages:

- It provides better distribution of the concentrated load of the shell to produce a more nearly uniform soil loading under the tank.
- It provides a means of leveling the tank grade, and it is capable of preserving its contour during construction.
- It retains the fill under the tank bottom and prevents loss of material as a result of erosion.
- It can more smoothly accommodate differential settlement because of its flexibility.

A disadvantage of the crushed stone or gravel ringwall is that it is more difficult to construct it to close tolerances and achieve a flat, level plane for construction of the tank shell.

B.4.3.2 For crushed stone or gravel ringwalls, careful selection of design details is necessary to ensure satisfactory performance. The type of foundation suggested is shown in Figure B-2. Significant details include the following:

- The 0.9 m (3 ft) shoulder and berm shall be protected from erosion by being constructed of crushed stone or covered with a permanent paving material.
- Care shall be taken during construction to prepare and maintain a smooth, level surface for the tank bottom plates.
- The tank grade shall be constructed to provide adequate drainage away from the tank foundation.
- The tank foundation must be true to the specified plane within the tolerances specified in 7.5.5.

B.4.4 SLAB FOUNDATIONS

- B.4.4.1** When the soil bearing loads must be distributed over an area larger than the tank area or when it is specified by the owner, a reinforced concrete slab shall be used. Piles beneath the slab may be required for proper tank support.

B.4.4.2 The structural design of the slab, whether on grade or on piles, shall properly account for all loads imposed upon the slab by the tank. The reinforcement requirements and the design details of construction shall be in accordance with ACI 318.

B.5 Tank Foundations for Leak Detection

Appendix I provides recommendations on the construction of tank and foundation systems for the detection of leaks through the bottoms of storage tanks.

APPENDIX C—EXTERNAL FLOATING ROOFS

• C.1 Scope

C.1.1 This appendix provides minimum requirements that, unless otherwise qualified in the text, apply to single-deck pontoon-type and double-deck-type floating roofs. See Section 2 for the definition of these roof types. This appendix is intended to limit only those factors that affect the safety and durability of the installation and that are considered to be consistent with the quality and safety requirements of this Standard. Numerous alternative details and proprietary appurtenances are available; however, agreement between the Purchaser and the Manufacturer is required before they are used.

C.1.2 The type of roof and seal to be provided shall be as specified on the Data Sheet, Line 30. If the type is not specified, the Manufacturer shall provide a roof and seal that is cost-effective and suitable for the specified service. Pan-type floating roofs shall not be used.

C.1.3 The Purchaser is required to provide all applicable jurisdictional requirements that apply to external floating roofs (see 1.3).

C.1.4 See Appendix W for bid requirements pertaining to external floating roofs.

C.2 Material

The material requirements of Section 4 shall apply unless otherwise stated in this appendix. Castings shall conform to any of the following specifications:

- a. ASTM A 27M, grade 405-205 (ASTM A 27, grade 60-30), fully annealed.
- b. ASTM A 27M, grade 450-240 (ASTM A 27, grade 65-35), fully annealed or normalized and tempered, or quenched and tempered.
- c. ASTM A 216M (ASTM A 216) WCA, WCB, or WCC grades annealed and normalized, or normalized and tempered.

C.3 Design

C.3.1 GENERAL

- **C.3.1.1** The roof and accessories shall be designed and constructed so that the roof is allowed to float to the maximum design liquid level and then return to a liquid level that floats the roof well below the top of the tank shell without damage to any part of the roof, tank, or appurtenances. During such an occurrence, no manual attention shall be required to protect the roof, tank, or appurtenances. If a windskirt or top-shell extension is used, it shall contain the roof seals at the highest point of travel. The Purchaser shall provide appropriate alarm devices to indicate a rise of the liquid in the tank to a level above the normal and overflow protection levels (see NFPA 30 and API RP 2350). Overflow slots shall not be used as a primary means of detecting an overflow incident. If specified by the Purchaser (Table 4 of the Data Sheet), emergency overflow openings may be provided to protect the tank and floating roof from damage.
- **C.3.1.2** The application of corrosion allowances shall be a matter of agreement between the Purchaser and the Manufacturer. Corrosion allowance shall be added to the required minimum nominal thickness or, when no minimum nominal thickness is required, added to the minimum thickness required for functionality.
- **C.3.1.3** Sleeves and fittings that penetrate the single deck or lower decks of annular pontoons or lower decks of double-deck roofs, except for automatic bleeder vents, rim space vents, and leg sleeves, shall have a minimum wall thickness of “Standard Wall” for pipe NPS 6 and larger and 6 mm ($1/4$ in.) for all other pipe and plate construction unless otherwise specified on the Data Sheet, Table 5. Such penetrations shall extend into the liquid.
- **C.3.1.4** The annular space between the roof outer rim of the floating roof and the product side of the tank shell shall be designed for proper clearance of the peripheral seal (see C.3.13). All appurtenances and internal components of the tank shall have adequate clearance for the proper operation of the completed roof assembly.
- **C.3.1.5** For tanks greater than 60 m (200 ft) in diameter, the deck portion of single-deck pontoon floating roofs shall be designed to avoid flexural fatigue failure caused by design wind loads. Such designs shall be a matter of agreement between the Purchaser and the Manufacturer, using techniques such as underside stitch welding.

C.3.1.6 All conductive parts of the external floating roof shall be electrically interconnected and bonded to the outer tank structure. Bonding (grounding) shunts shall be provided on the external floating roof and shall be located above the uppermost seal. Shunts shall be 50-mm (2-in.) wide by 28-gauge (0.4-mm [$1/64$ -in.] thick) austenitic stainless steel as a minimum, or shall provide equivalent corrosion resistance and current carrying capacity as stated in NFPA 780 and API RP 2003. Shunt spacing shall be no more than 3 m (10 ft). All movable cover accessories (hatches, manholes, pressure relief devices, and other openings) on the external floating roof shall be electrically bonded to the external floating roof to prevent static electricity sparking when they are opened.

C.3.2 JOINTS

C.3.2.1 Joints shall be designed as described in 5.1.

C.3.2.2 If the underside of the roof is to be coated, all coated joints shall be seal-welded.

C.3.3 DECKS

C.3.3.1 Roofs in corrosive service, such as covering sour crude oil, should be the contact type designed to eliminate the presence of any air-vapor mixture under the deck.

- **C.3.3.2** Unless otherwise specified by the Purchaser, all deck plates shall have a minimum nominal thickness of 5 mm ($3/16$ in.) (permissible ordering basis—37.4 kg/m², 7.65 lbf/ft² of plate, 0.180-in. plate, or 7-gauge sheet).

C.3.3.3 Deck plates shall be joined by continuous full-fillet welds on the top side. On the bottom side, where flexure can be anticipated adjacent to girders, support legs, or other relatively rigid members, full-fillet welds not less than 50 mm (2 in.) long on 250 mm (10 in.) centers shall be used on any plate laps that occur within 300 mm (12 in.) of any such members. A minimum of three fillet welds shall be made.

C.3.3.4 Top decks of double-deck roofs and of pontoon sections, which are designed with a permanent slope shall be designed, fabricated, and erected (with a minimum slope of 1 in 64) to minimize accumulation of standing water (e.g., pooling adjacent to a rolling ladder's track) when primary roof drains are open. This requirement is not intended to completely eliminate isolated puddles. When out of service, water shall flow freely to the primary roof drains. These decks shall preferably be lapped to provide the best drainage. Plate buckles shall be kept to a minimum.

C.3.3.5 The deck of single-deck pontoon floating roofs shall be designed to be in contact with the liquid during normal operation, regardless of service. The design shall accommodate deflection of the deck caused by trapped vapor.

C.3.3.6 All covers for roof openings, except roof drains and vents, shall have gaskets or other sealing surfaces and shall be provided with a liquid-tight cover.

C.3.4 PONTOON DESIGN

C.3.4.1 Floating roofs shall have sufficient buoyancy to remain afloat on liquid with a specific gravity of the lower of the product specific gravity or 0.7 and with primary drains inoperative for the following conditions:

- 250 mm (10 in.) of rainfall in a 24-hour period over the full horizontal tank area with the roofs intact. This condition does not apply to double-deck roofs provided with emergency drains designed to keep water to a lesser volume that the roofs will safely support. Such emergency drains shall not allow the product to flow onto the roof.

Note: The rainfall rate for sizing the roof drains in C.3.8 may result in a larger accumulated rainfall.

- **b.** Single-deck and any two adjacent pontoon compartments punctured and flooded in single-deck pontoon roofs and any two adjacent compartments punctured and flooded in double-deck roofs, both roof types with no water or live load.

With agreement by the Purchaser, Item b may be replaced by the following for floating roofs 6 m (20 ft) in diameter or less: Any one compartment punctured and flooded in single-deck pontoon roofs or double-deck roofs, both roof types with no water or live load.

- **C.3.4.2** The pontoon portions of single-deck pontoon-type roofs shall be designed to have adequate strength to prevent permanent distortion when the center deck is loaded by its design rainwater (C.3.4.1, Item a) or when the center deck and two adjacent pontoons are punctured (C.3.4.1, Item b). The allowable stress and stability criteria shall be jointly established by the Purchaser and the Manufacturer as part of the inquiry. Alternatively, a proof test simulating the conditions of C.3.4.1, with the roof floating on water, may be performed on the roof or on one of similar design that is of equal or greater diameter.

C.3.4.3 Any penetration of the floating roof shall not allow product to flow onto the roof under design conditions.

C.3.5 PONTOON OPENINGS

- Each compartment shall be provided with a liquid-tight manhole with a minimum nominal size of NPS 20. Manhole covers shall be provided with suitable hold-down fixtures (which may be of the quick-opening type) or with other means of preventing wind or fire-fighting hose streams from removing the covers. The top edge of the manhole necks shall be at an elevation that prevents liquid from entering the compartments under the conditions of C.3.4. With agreement by the Purchaser, floating roofs 6 m (20 ft) in diameter or less may be designed using a pontoon inspection port in place of a pontoon manhole.

Each compartment shall be vented to protect against internal or external pressure. Vents may be in the manhole cover, inspection port cover, or the top deck of the compartment. The vents shall be at an elevation that prevents liquid from entering the compartment under the conditions of C.3.4 and shall terminate in a manner that prevents entry of rain and fire-fighting liquids.

C.3.6 COMPARTMENTS

Compartment plates are radial or circumferential dividers forming compartments that provide flotation for the roof (see C.3.4). All internal compartment plates (or sheets) shall be single-fillet welded along all of their edges, and other welding shall be performed at junctions as required to make each compartment leak tight. Each compartment weld shall be tested for leak tightness using internal pressure or a vacuum box and a soap solution or penetrating oil.

C.3.7 LADDERS

- Unless otherwise specified by the Purchaser, the floating roof shall be supplied with a ladder that automatically adjusts to any roof position so that access to the roof is always provided. The ladder shall be designed for full-roof travel, regardless of the normal setting of the roof-leg supports. The ladder shall have full-length handrails on both sides and shall be designed for a 4450 N (1000 lbf) midpoint load with the ladder in any operating position. Step assemblies shall be of open type and have non-slip walking surfaces and self-leveling treads with a minimum width of 510 mm (20 in.) and a 860 mm (34 in.) high handrail at the nose of the tread. When the roof is in its extreme low position, the slope of the rolling ladder shall not be less than 35 degrees to vertical, unless specified otherwise by the Purchaser. Wheels shall be provided at the lower end of the ladder, sized to prevent binding of the ladder, and provided with maintenance-free bearings. Ladders shall be grounded to both the roof and the gauger's platform with at least an AWG (American Wire Gage) 2/0 (67 sq. mm [0.104 sq. in.]), non-tangling cable. Cable shall be configured so that it will not freeze to adjacent surfaces in cold weather. Ladder and track design shall minimize ponding by using trussed runways or other details considering fatigue and stiffening effects resulting from supports. The Purchaser may elect to add requirements such as a wider stair width, lateral roof loading, and alternate runway designs that reduce ponding under the ladder.

C.3.8 ROOF DRAINS

C.3.8.1 Primary Roof Drains

- 1. Primary roof drains shall be sized and positioned to accommodate the rainfall rates specified on the Data Sheet, Line 33, while preventing the roof from accumulating a water level greater than design, without allowing the roof to tilt excessively or interfere with its operation. Roof drains shall be furnished attached to double-flanged, low-type nozzles on the tank shell with valves to be supplied by the Purchaser. A swing-type check valve shall be provided at the inlet of drains unless otherwise specified on the Data Sheet, Line 32. The drains shall be removable, if required by the Purchaser. Primary roof drains shall not be smaller than NPS 3 for roofs with a diameter less than or equal 36 m (120 ft) or smaller than NPS 4 for roofs with a diameter greater than 36 m (120 ft).
- 2. Primary roof drains shall be resistant to the tank's contents, or suitably coated, and shall be free from floating, kinking, or catching on any internal appurtenance or obstruction during operation, and from being crushed by landing legs on the bottom.
- 3. The Purchaser shall specify, on the Data Sheet, Line 32, the required primary roof drain. Acceptable types of primary roof drains are:
 - Manufacturer's standard drain,
 - Steel swing or pivot-jointed pipe drains, designed and packed for external pressure,
 - Stainless steel armored hose.

4. If supplied, rigid segments of drain piping attached to the bottom or the roof shall be guided, not rigidly attached, to allow for differential thermal expansion and plate flexing. The design shall avoid being damaged by the roof support legs or other obstructions.
5. Siphon-type and non-armored hose-type drains are not acceptable as primary roof drains.
6. Double-deck floating roofs up to 60 m (200 ft) in diameter shall have either a single center sump or a reversed-slope, top-center deck with multiple sumps connected to a single drain line, depending on the design rainfall quantity and the roof configuration. Double-deck floating roofs larger than 60 m (200 ft) in diameter shall have a reversed-slope, top-center deck with multiple roof sumps having individual drain lines.
7. Inlets to single-deck primary roof drains shall have guarded trash stops or screens to stop debris from entering and obstructing the drain system. The Manufacturer shall provide isolation valves to stop product flow onto the roof when the check valve fails, unless specified otherwise on the Data Sheet, Line 32. Cut-off valves for this purpose shall have extension handles to permit actuation when puddles obstruct access to the valve.
8. When specified on the Data Sheet, Line 32, drains, sumps, check valves, and cut-off valves shall be protected from freeze damage by using special equipment designs. Any mechanically actuated cut-off valve shall permit actuation when the drain pipe is partially obstructed by chunk ice or slush (e.g., a ram valve or a metal-seated ball valve).

07 • C.3.8.2 Emergency Roof Drains

Double-deck roofs shall have a minimum of three open-ended emergency roof drains designed to provide drainage to prevent sinking the roof during severe rainfall events. Emergency drains are prohibited on single-deck floating roofs. Elevation of the emergency overflow drains shall be such that the outer rim cannot be completely submerged. These drains shall discharge at least 300 mm (1 ft) below the bottom of the roof and shall consist of open-ended pipes, braced as necessary to the roof structure. The drains shall be sized to handle the rainfall specified by the Purchaser, with a minimum diameter of NPS 4. The drains shall be sealed with a slit fabric seal or similar device that covers at least 90% of the opening that will reduce the product-exposed surfaces while permitting rainwater passage. The drains shall be fabricated from Schedule 80 pipe, or heavier, and fittings with 6 mm ($1/4$ -in.) thick roof deck reinforcing plates.

C.3.8.3 Out-of-Service Supplementary Drains

- Threaded pipe couplings and plugs with a 600-mm (24-in.) extension “T-bar” handle shall be provided as supplementary drains when the roof is resting on its legs and when the primary drains are inoperative. The number of drains shall be based on the specified rainfall rate (see Line 33 of the Data Sheet) and tank size. Fittings shall be at least NPS 4. Plugs shall have threads coated with a non-stick coating or anti-seize paste such as tetrafluoroethylene. One supplementary drain shall be located adjacent to the ladder track.

C.3.9 VENTS

To prevent overstressing of the roof deck or seal membrane, automatic bleeder vents (vacuum breakers) shall be furnished for venting air to or from the underside of the deck when filling or emptying the tank. The Manufacturer shall determine and recommend the number and sizes of bleeder vents to be provided based on maximum filling and emptying rates specified. Each automatic bleeder vent (vacuum breaker vent) shall be closed at all times, except when required to be open to relieve excess pressure or vacuum, in accordance with the manufacturer's design. Each automatic bleeder vent (vacuum breaker vent) shall be equipped with a gasketed lid, pallet, flapper, or other closure device.

07 C.3.10 SUPPORTING LEGS

- **C.3.10.1** Floating roofs shall be provided with either removable or non-removable legs. If removable legs are specified on the Data Sheet, Line 32, the legs shall be adjustable from the top side of the roof, and designed to be inserted through either fixed low legs or leg sleeves. Both low and high legs shall have cutouts (minimum of 19 mm [$3/4$ in.] wide) at the bottom to permit drainage of trapped product. Removable covers shall be provided for leg sleeves or fixed low legs when the adjustable legs are removed. Adjustable legs shall be capped on top. If specified on the Data Sheet, Line 32, removable legs shall be provided with storage rack(s) on the top of the pontoon or deck appropriate for leg storage during normal operation or during maintenance. Rack quantity and location shall be determined by the Manufacturer to balance the roof live load and shall take into account the weight of the rolling ladder. The materials of construction shall be tabulated on the Data Sheet, Table 5. Removable legs shall be no smaller

than NPS 2. High legs shall have a stop to prevent their dropping through the low legs during installation. See C.1.3 regarding Purchaser specification of jurisdictional requirements.

C.3.10.2 The legs and attachments shall be designed to support the roof and a uniform live load of at least 1.2 kPa (25 lbf/ft²). Where possible, the roof load shall be transmitted to the legs through bulkheads or diaphragms. Leg attachments to single decks shall be given particular attention to prevent failures at the points of attachment.

C.3.10.3 Legs shall have settings for at least two levels:

a. A minimum setting determined by the Manufacturer to support the roof in the low-roof position while clearing mixers, nozzles, shell manholes, seals, and other components inside the tank by at least 75 mm (3 in.), and

- b. The minimum clearance of the roof in the high-roof position specified on the Data Sheet, Line 32.

When specified on the Data Sheet, Line 33, the two settings shall be field-adaptable to allow for uneven tank bottom settlement (i.e., constructed to permit small variations from the required positions for each leg).

- **C.3.10.4** Legs shall be Schedule 80 minimum and sleeves shall be Schedule 40 minimum unless specified otherwise on the Data Sheet, Table 5.

C.3.10.5 Roof legs shall have matching steel landing pads continuous full-fillet welded to the tank bottom with minimum dimensions of 10-mm (³/₈-in.) thickness by 350-mm (14-in.) diameter. The centerline of the legs shall coincide with the centerline of the landing pads.

C.3.10.6 Roof support legs sleeves shall be installed plumb. Fixed legs or leg sleeves through single decks shall be reinforced.

C.3.10.7 All fixed leg or leg sleeve penetrations through the deck plate (top and bottom for pontoon and double-deck roofs) shall be attached to the deck plate(s) with continuous fillet welds made from the top side, as a minimum.

- **C.3.10.8** If specified (see C.1.3 regarding Purchaser specification of jurisdictional requirements), covers and seals shall be provided at all openings.
- **C.3.10.9** When side entry mixers are specified and there is inadequate clearance between the roof and mixer components, rather than increasing the leg lengths, the pontoon (or double deck) shall be notched with a recessed pocket providing at least 75 mm (3 in.) mixer component clearance at the low-roof position.

C.3.11 ROOF MANHOLES

Roof manholes shall be provided for access to the tank interior and for ventilation when the tank is empty. Manholes shall be located around the roof to provide an effective pattern for access, lighting, and ventilation of the product storage interior. Each manhole shall have a minimum nominal diameter of 600 mm (24 in.) and shall have a liquid-tight gasketed, bolted cover equivalent to the cover shown in Figure 5-16.

The minimum number of manholes shall be as follows:

Nominal Tank Diameter <i>D</i> , m (ft)	Minimum Number
$D \leq 61$ (200)	2
61 (200) $< D \leq 91$ (300)	3
91 (300) $< D$	4

C.3.12 CENTERING AND ANTI-ROTATION DEVICES

C.3.12.1 A guide pole shall be provided as an anti-rotation device for the floating roof. Locate the guide pole near the gauger's platform. The guide pole shall be capable of resisting the lateral forces imposed by the roof ladder, unequal snow loads, and wind loads.

C.3.12.2 Guide pole sections shall be welded with full penetration butt welds. Backing strips are not permitted. Provision must be made for draining and venting of unslotted pipe. See 7.5.2 for guide pole erection tolerance requirements.

- **C.3.12.3** The guide pole shall have all required emission control devices around the well opening where it penetrates the roof, such as those described in C.3.14.1, Item (1) and specified on the Data Sheet, Line 32. (See C.1.3 regarding Purchaser specification of jurisdictional requirement.)

C.3.13 PERIPHERAL SEALS

C.3.13.1 See H.4.4 for descriptions of peripheral seal types, selection guidelines, and additional requirements. Peripheral seals are also referred to as rim seals.

- **C.3.13.2** The Purchaser shall specify the seal materials in the Data Sheet, Table 5.
- **C.3.13.3** See C.1.3 regarding Purchaser specification of jurisdictional requirements. All seals shall be installed such that gaps between the seal and the shell of the tank meet the gap requirements of the jurisdiction for new construction, if any, and the Purchaser's gap requirements.

C.3.13.4 Installation and removal of peripheral seals shall not require draining the tank.

C.3.13.5 The specific requirements for external floating roof peripheral seals are:

07 • Primary Seal

The type of primary seal may be controlled by jurisdiction regulations. Types generally used are mechanical shoe seals and liquid-mounted (envelope) seals. Unless specified otherwise on the Data Sheet, Line 31, primary seals shall be the mechanical shoe type and shall be supplied and installed by the roof Manufacturer.

• Secondary Seal

The type of secondary seal may be controlled by jurisdiction regulations. If required by the Purchaser, a secondary seal shall be provided by the roof Manufacturer as specified on the Data Sheet, Line 31. Unless specified otherwise, secondary seals shall be the wiper type and shall be supplied and installed by the roof Manufacturer. The design of the secondary seal shall permit inspection of the primary seal without removal.

Mechanical Shoe Seals

The following additional requirements apply to mechanical shoe seals, if used, and which may be used as primary or secondary seals:

The metal band (shoe) is typically formed as a series of sheets that are overlapped or joined together to form a ring that is held against the shell by a series of mechanical devices. For external floating roofs only, the mechanical shoe seal shoes shall extend at least 610 mm (24 in.) above and at least 100 mm (4 in.) into the liquid at the design flotation level, except when this type of seal is the secondary seal, installed above a primary seal. The "design flotation level" is defined as the roof position (under dead load conditions) for the specific gravity range from 0.7 to the design specific gravity on the Data Sheet.

C.3.14 GAUGING DEVICE

- **C.3.14.1** Each roof shall be provided with gauging ports with caps (gauging wells or hatches) as indicated on the Data Sheet, Line 32 (see C.1.3 regarding Purchaser specification of jurisdictional requirement), with one port located adjacent to the gauger's platform and remote from regions of turbulent flow. These ports may be as follows:

- 1. Slotted guide pole gauge wells: These are vertical anti-rotation pipes that can be used for gauging. Unless specified otherwise by the Purchaser, the pipe shall have two rows of 25-mm by 300-mm (1-in. by 12-in.) vertical slots on staggered 280-mm (11-in.) centers located 180 degrees apart. Slots shall range from the maximum fill height to near the tank bottom. Holes may be provided in lieu of slots if holes are required by the Purchaser. Well and pole shall be equipped with all required emission control devices, which may include items such as a gasketed sliding well cover, and a pole wiper, as well as either a pole sleeve or a pole float and float wiper (see API *MPMS* 19.2 for requirements and illustrations of some of these devices). If there are no slots or holes located so as to allow the stored liquid to flow into the pole at liquid levels above the lowest operating level, then the pole is not considered slotted for purposes of air regulation compliance (even if there are slots or holes located below the lowest operating level).
- 2. Non-guide pole gauge wells: These shall be NPS 8 pipes projecting at least 150 mm (6 in.) above the roof's outer rim. For sample hatches without gauging apparatus, see C.3.15.3.

- **C.3.14.2** Each gauge well shall have a B16.5 Class 150 bolt pattern, flat-face pipe flange with a full-face gasket at its top, and shall be attached to a non-sparking cap. See C.1.3 regarding Purchaser specification of jurisdictional requirements.

C.3.14.3 Each gauge well shall have a permanent gauge mark or tab just inside the cap on the pipe wall called a “reference point” or “knife edge.”

- **C.3.14.4** When specified on the Data Sheet, Line 32, a datum plate shall be attached to the bottom of the slotted guide pole at the distance designated by the Purchaser.
- **C.3.14.5** If striking plates are specified on the Data Sheet, Line 32, they shall be provided on the tank bottom beneath the guide pole or under the gauge well if no guide pole is specified.
- **C.3.14.6** A gauger’s platform shall be located at an elevation that remains above and clear of the roof, its sealing system, and foam dam even during an overflow event. The Purchaser shall specify the platform location on the Data Sheet Plan. The direction is typically upwind of the direction of the prevailing wind.

C.3.15 OTHER ROOF ACCESSORIES

C.3.15.1 Wax Scrapers

If wax scrapers are specified on the Data Sheet, Line 31, they shall be located such that the scraping action occurs below the liquid surface. Design of wax scrapers shall not interfere with bottom shell course accessories.

C.3.15.2 Foam Dams

- A foam dam, if specified on the Data Sheet, Line 32, shall be installed on top plates of pontoon or roof deck at least 300 mm (12 in.) but no more than 600 mm (24 in.) from the tank shell to contain foam fire-fighting solution. The foam dam shall be a minimum of 300 mm (12 in.) high and extend at least 50 mm (2 in.) above the lower of the secondary seal or any burnout panel, measured at its highest contact point with the shell. The dam shall be fabricated from 10 gauge (0.134 in.) or thicker steel plate with support braces installed on the side of the foam dam closest to the center of the tank at a circumferential spacing of approximately 1.5 m (5 ft) on center. Bottom of plate shall have 10-mm ($3/8$ -in.) slotted weep holes. The dam shall be attached to the top deck plate by a continuous fillet weld on the foam side. See NFPA 11 for additional information regarding foam dams.

C.3.15.3 Sample Hatches

If specified on the Data Sheet, Line 32, the Manufacturer shall install an NPS 8 sample hatch with funnel on the roof deck with remote access from the gauging platform. Manufacturer shall install a recoil reel on the gauging platform. The hatch shall be equipped with a self-closing liquid-tight cover that can be opened and closed from the gauger’s platform.

C.3.15.4 Automatic Level Gauge

- a. Tanks shall have a ground-level reading, automatic float-level gauge, unless otherwise specified on the Data Sheet, Table 4.
- b. Access for maintenance and repair shall be considered.
- c. Level gauge shall be located such that the float well is away from any appurtenances that produce turbulence.
- d. The bottom of the float well shall be approximately 150 mm (6 in.) above the tank bottom when the floating roof is at its lowest position.
- e. Gauge float wells shall be equipped with a gasketed cover that is bolted closed. See C.1.3 regarding Purchaser specification of jurisdictional requirements.

C.3.15.5 Side Entry Mixers

- a. Mixers shall conform to the Data Sheet, Line 26.
- b. Each mixer shall be installed in cover plates in dedicated shell nozzles or manholes.

C.4 Fabrication, Erection, Welding, Inspection, and Testing

C.4.1 The applicable fabrication, erection, welding, inspection, and testing requirements of this Standard shall apply.

C.4.2 Deck seams and other joints that are required to be liquid- or vapor-tight shall be tested for leaks by means of penetrating oil or any other method consistent with the methods described in this Standard for testing cone-roof seams and tank-bottom seams.

C.4.3 The roof shall be given a flotation test while the tank is being filled with water and emptied. During this test, the upper side of the lower deck shall be examined for leaks. The appearance of a damp spot on the upper side of the lower deck shall be considered evidence of leakage.

C.4.4 The upper side of the upper decks of pontoon and double-deck roofs shall be visually inspected for pinholes and defective welding.

C.4.5 Drainpipe and hose systems of primary drains shall be tested with water at a pressure of 350 kPa (50 lbf/in.²) gauge. During the flotation test, the roof drain valves shall be kept open and observed for leakage of the tank contents into the drain lines.

APPENDIX D—TECHNICAL INQUIRIES

D.1 Introduction

API will consider written requests for interpretations of API Std 650. API staff will make such interpretations in writing after consulting, if necessary, with the appropriate committee officers and committee members. The API committee responsible for maintaining API Std 650 meets regularly to consider written requests for interpretations and revisions and to develop new criteria dictated by technological development. The committee's activities in this regard are limited strictly to interpretations of the Std and to the consideration of revisions to the present standard on the basis of new data or technology. As a matter of policy, API does not approve, certify, rate, or endorse any item, construction, proprietary device, or activity, and accordingly, inquiries that require such consideration will be returned. Moreover, API does not act as a consultant on specific engineering problems or on the general understanding or application of the Standard. If, based on the inquiry information submitted, it is the opinion of the committee that the inquirer should seek other assistance, the inquiry will be returned with the recommendation that such assistance be obtained. All inquiries that cannot be understood because they lack information will be returned.

D.2 Inquiry Format

D.2.1 Inquiries shall be limited strictly to requests for interpretation of the current standard or to the consideration of revisions to the standard on the basis of new data or technology. Inquiries shall be submitted in the format described in D.2.2 through D.2.5.

D.2.2 The scope of an inquiry shall be limited to a single subject or a group of closely related subjects. An inquiry concerning two or more unrelated subjects will be returned.

D.2.3 An inquiry shall start with a background section that states the purpose of the inquiry, which would be either to obtain an interpretation of the Standard or to propose a revision to the Standard. The background section shall concisely provide the information needed for the committee's understanding of the inquiry (with sketches as necessary) and shall cite the applicable edition, revision, paragraphs, figures, and tables.

D.2.4 After the background section, an inquiry's main section shall state the inquiry as a condensed, precise question, omitting superfluous background information and, where appropriate, posing the question so that the reply could take the form of "yes" or "no" (perhaps with provisos). This inquiry statement should be technically and editorially correct. The inquirer shall state what he or she believes the Standard requires. If the inquirer believes a revision to the Standard is needed, he or she shall provide recommended wording.

D.2.5 The inquirer shall include his or her name and mailing address. The inquiry should be typed; however, legible handwritten inquiries will be considered. Inquiries should be submitted to the general manager of the Downstream Segment, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005. Inquiries complying with the above format may be submitted by electronic mail to: standards@api.org.

D.3 Technical Inquiry Responses

Following are selected responses to requests for interpretation API Std 650 requirements. A more extensive listing of interpretations can be found on the API website at www.api.org in the "Committees/Standards" section. The current version of API Std 650 may differ from the following inquiries, which were developed against prior editions/addenda, making the following inquiries possibly invalid. The paragraph references in the following have not been revised to reflect the new paragraph numbering issued in the 11th Edition of API Std 650.

SECTION 1.1 SCOPE

07 | 650-I-03/00 (Note: See 1.1.3 in the 11th Edition for revised rules pertaining to the use of SI units within the Standard.)

Question 1: Regarding the use of SI units, does API 650 allow either of the following?

- (1) Use of SI units throughout the design process.
- (2) Use the original U.S. Customary units with a hard conversion to SI units as a final step to the design process.

Reply 1: Yes, both are allowed.

Question 2: When SI units are used, does API 650 require different dimensional details compared to previous API 650 Editions or USC unit details now specified in the 10th Edition?

Reply 2: The committee currently has an agenda item to study this question. Any changes resulting from this agenda item will appear in a future addendum or edition to API 650.

Question 3: When SI units are used, does API 650 require material thickness, material properties, configurations, etc. based solely on the SI units for a particular tank?

Reply 3: The committee currently has an agenda item to study this question. Any changes resulting from this agenda item will appear in a future addendum or edition to API 650.

Question 4: Does the wording of the Foreword to API 650 require a separate check of the USC results when SI unit are specified and after making such a check using the USC results if more restrictive?

Reply 4: No.

SECTION 2.2 PLATES

650-I-09/01

07 | Question: For plate material certified by the Manufacturer to meet more than one specification, such as A 516 Grade 60 and A 516 Grade 70, which specification should be used when applying the rules in Table 2-3, Figure 2-1, and Section 2.2.9 of API 650?

Reply: Dual certification of material is not addressed in API 650, except in 2.1.4 and Appendix S.

650-I-11/01

Question: Does API 650 require that the material in the bottom shell course and the annular plate be the same material specification?

Reply: API 650, Section 2.2.9.1, requires bottom plates welded to the shell to comply with Figure 2-1, but does not require the bottom shell course and annular plate to be the same material specification.

650-I-33/03

Question: Are roof materials required to meet the toughness requirements in 2.2.9?

Reply: No. Refer to 2.2.9.1.

650-I-06/04

Question 1: Does the 0.01 in. thickness tolerance specified for plate in API 650, 2.2.1.2.3 apply to carbon and stainless coil product?

Reply 1: Yes. All requirements of the base document apply to an Appendix S tank unless specifically changed or waived by a statement in Appendix S. Refer to S.1.5.

Question 2: When purchasing hot-rolled coil-processed steel for use as roof, shell, and/or bottom plate on a stainless tank, does the ASTM under-run tolerance apply?

Reply 2: The minimum of the ASTM tolerance or as specified in API 650, Sections 2.2.1.1, 2.2.1.2, or 2.2.1.3, shall apply.

SECTION 2.5 PIPING AND FORGINGS

650-I-15/00

Question: 1 For nozzles made from pipe materials, does API 650, Section 2.5.2 require that seamless pipe be used for nozzles in shells made from Group I, II, III, or IIIA materials?

Reply 1: Yes, unless ASTM A 671 pipe is used.

Question: 2 Does API 650, Section. 2.5.2 preclude the use of electric-resistance welded pipe meeting ASTM A 53, or electric-welded pipe meeting API 5L, for nozzles in shells made from Group IV, IVA, V, or VI materials, but allow use of electric-fusion-welded pipe nozzles made from ASTM A 671?

Reply 2: Yes.

SECTION 3.1 JOINTS

650-I-11/02

Question: Is there any allowance or provision to omit the top angle as required by API 650, 3.1.5.9e and 3.1.5.9f if we can show by calculation that the top compression area is sufficient.

Reply: No.

650-I-32/02

Question: Referring to API 650, Section 3.1.5.3b, does the phrase "...horizontal joints shall have a common vertical centerline" mean that the mid-thickness of the plates align vertically?

Reply: Yes. This is sometimes referred to as "centerline-stacked".

650-I-40/02

Question: Does the lap weld of two bottom plates on the butt-welded annular plates have to be 12 in. away from the annular plates butt welds?

Reply: No

650-I-37/03

Question: Is it the intent of 3.1.3.5 to limit the maximum lap of a double welded lap joint to 2 in. and a single welded lap joint to 1 in. If not, is there a maximum lap requirement for single welded lap joint bottoms and roofs? Would this constraint, if any, also apply to bottom or roof repair or replacements governed by API 653.

Reply: No

650-I-49/03

Question 1: Section 3.1.3.5 of API 650 specifies minimum lap joint dimensions. Is there any limit on the maximum width of a lap joint?

Reply 1: API Standard 650 does not address maximum lap.

Question 2: Can a lap joint consisting of two (2) $\frac{1}{4}$ in. plates be lapped 3 in.?

Reply 2: Yes. Any lap that exceeds the minimum is acceptable. Refer to 3.1.3.5.

SECTION 3.5 ANNULAR BOTTOM PLATES

650-I-49/00

Question: If a tank bottom slopes downward toward the center of the tank, are the annular plates required to lap over the bottom plates?

Reply: This is not covered by API 650. (5.1.5.4 in the 11th Edition covers this issue.)

650-I-22/03

Question: Section 3.5.2 states the annular bottom plates shall have at least a 50 mm projection outside the shell. Is the reference point to calculate the projection located on the outside or inside diameter of the shell?

Reply: The reference point is on the outside diameter of the shell plate, as stated in 3.5.2.

SECTION 3.6 SHELL DESIGN

650-I-02/02

Background: On one recent contract, corrosion allowance of 0.25 in. was specified only on first shell course. The tank is 250 ft (diameter) by 53 ft high, with a liquid height of 48 ft 0 in. (external floater) and design specific gravity = 0.968. Detail design per the current edition shows that the second course thickness is controlled by hydrostatic test condition, which is incorrect. Investigation has proven that the current rules in API 650 for the variable design point method are not valid for variable corrosion allowance. The second course thickness calculated is more than the one-foot method will calculate, however, this is not stated in API 650. It is not unusual for a customer to specify variable corrosion allowance. The variable design point method is used only for large tanks and in some cases, as I have discovered, the second course will be calculated $1/16$ in. thicker than needs to be when corrosion allowance is a significant percentage of first course. This extra thickness amounts to good some of money.

Question: Is the variable design point method of shell design covered under API 650, Section 3.6.4 valid for tanks with variable corrosion allowance (i.e., different corrosion for each shell course)?

Reply: No.

SECTION 3.7 SHELL OPENINGS

650-I-33/99

Question: Referring to API 650, Section 3.7.4, must all flush-type cleanouts and flush-type shell connections be stress-relieved regardless of the material used, the nozzle diameter, or the thickness of the shell insert plate?

Reply: Yes, see Section 3.7.4.1.

650-I-53/99

Question 1: Per Section 3.7.4.2, for shell openings over NPS 12, if insert plates are not used to reinforce the shell opening, is the shell thickness a factor in determining if PWHT of the assembly is required?

Reply 1: Yes.

Question 2: Regarding Section 3.7.4.2, is stress-relieving mandatory for the prefabricated assembly when the thickness of the thickened insert plate exceeds 1 in., irrespective of the shell opening size?

Reply 2: No. The requirement applies only to NPS 12 or larger connections.

650-I-01/00

Question: Does API 650, Section 3.7.4.3, allow stress-relieving nozzles, as described therein, after installation in the shell, using locally applied heaters?

Reply: No. The heat treatment must be performed prior to installation in the tank.

650-I-18/00

Question 1: Referencing Figure 3-14, does API 650 cover flush shell connections to be installed non-radially?

Reply 1: No.

Question 2: Referencing Figure 3-15, are flush-type shell connections smaller than 8 in. covered in API 650?

Reply 2: No.

650-I-20/00

Question: Does API 650, Section 3.7.4, require that all flush-type cleanout fittings be stress-relieved?

Reply: Yes, except as permitted by A.8.2.

650-I-32/00

Question: Are square or rectangular manways allowed per API 650? If no, what specific section limits them?

Reply: Yes. See Figure 3-14 for roof manway requirements.

650-I-34/00

Question: Does API 650, Section 3.7.4.2 require stress-relieving for materials in opening connections coming under Group I, II, III or III A, when the thickness of the shell is less than 1 in., but the sum of the shell plate thickness and the reinforcement plate thickness exceeds 1 in. for NPS 12 and larger?

Reply: No.

650-I-43/00

Question: Referring to API 650, Section 3.7.4.2, must a prefabricated manhole assembly be stress relieved if the material is Group II (A 131, Grade B), the shell plate is 3/8 in. thick, and the opening is a 24-in. diameter manhole?

Reply: No, because the shell is less than 1 in. thick.

650-I-47/00

Question: Does API 650, Section 3.7.6.1, permit making a hot tapping connection on a blind flange on a nozzle in a tank?

Reply: No. Refer to API 650, Section 3.8.3, for rules on installing a nozzle in a cover plate in a new tank. Refer to API 653, Section 7.14, for rules and guidance on hot tapping in an in-service tank.

650-I-48/00

Question: Does API 650 define a “neck” as piping or nozzle passing through the shell of the tank to the first flange, regardless of the length and configuration (such as an upturned pipe connected by an elbow and another short piece pipe to the first flange) of this pipe?

Reply: No. API does not define this term. Also, refer to Section 1.2, which defines the limits of applicability on piping.

650-I-07/02

Question: Given a 2 in. nominal bore non-reinforced nozzle in a non stress-relieved shell greater than 0.5 in. thickness. Are the minimum distances for: (1) the outer edge of nozzle attachment weld to center line of a shell butt weld, either vertical or horizontal, and (2) the toe-to-toe distance of the fillet to the shell-to-bottom weld, required to be 10 in. (or 8x weld thickness) and 3 in., respectively?

Reply: Yes, for new tanks, see API 650, sections 3.7.3.1, 3.7.3.3, and Figure 3-22.

650-I-28/02

Question: When stress relieving the assembly defined in API 650 Sections 3.7.4.1, 3.7.4.2, and 3.7.4.3, is it permissible to perform a local heat treatment that includes part of a shell plate, instead of the whole shell plate, i.e., the portion around the connection at full width of shell plate?

Reply: No, however, there is no rule against shortening the plate length circumferentially, prior to installation of the fitting or connection.

650-I-56/02

Question: Do the minimum thicknesses listed in Table 3-10, and calculated by the equations in section 3.7.7.6 have a corrosion allowance?

Reply: No. See Section 3.3.2.

650-I-07/04

Question: Regarding Section 3.7.2 as it applies to Appendix F, when calculating the required shell thickness at the nozzle location is it necessary to use the joint efficiency factor that was used for calculating the required tank shell thickness?

Reply: No.

650-I-09/04

Question 1: Section 3.7.1.8 states “Reinforcement of shell openings that comply with API Standard 620 are acceptable alternatives.” When using API 620 to calculate nozzle reinforcement does the entire API 620 standard apply?

Reply 1: No.

Question 2: API 620 limits the design temperature to 250°F. Can the rules for nozzle reinforcement be used for designing nozzle reinforcement for an API 650 Appendix M tank with a design temperature greater than 250°F?

Reply 2: Yes.

Question 3: Can the rules for nozzle reinforcement in API 620 be used for designing nozzle reinforcement for a stainless steel API 650 Appendix S tank?

Reply 3: Yes.

Question 4: When designing nozzle reinforcement for an API 650 tank using the rules of API 620, should the allowable stresses of API 650 be used?

Reply 4: Yes.

SECTION 3.8 SHELL ATTACHMENTS AND TANK APPURTENANCES

650-I-51/00

Question: API 650, Section 3.8.3.2, requires mixer manway bolting flanges to be 40% thicker than the values shown in Table 3-3. Footnote b under Table 3-4 requires the minimum manway neck thickness to be the lesser of the flange thickness or the shell plate. Is it therefore required that the minimum neck thickness on a mixer manway be the lesser of 140% of the flange thickness value in Table 3-3 or the shell thickness?

Reply: No.

650-I-53/00

Question: Referring to API 650, is magnetic particle testing applicable for inspecting permanent attachments to the shell and at temporary attachment removal areas, when the material group is of Group I (A 283, Grade C)?

Reply: No. See 3.8.1.2 and 5.2.3.5, in Addendum 1 to the 10th Edition of API 650.

650-I-14/02

Background: Section 3.8.3.2 states: “a cover plate with a nozzle attachment for product-mixing equipment shall have a thickness at least 1.4 times greater than the thickness required by Table 3-3.” Section 3.8.3.3 also states that “when cover plates (or blind flanges) are required for shell nozzles, the minimum thickness shall be that given for flanges in Table 3-8.” There seems to be a conflict between these two sections in that when the thickness specified by Table 3-3 (at max liquid level) is increased by 40%, it is still thinner than the thickness specified by Table 3-8.

Question 1: In determining the thickness of a cover plate and bolting flange in which product mixing equipment is installed, is there a conflict between 3.8.3.2 and 3.8.3.3.

Reply 1: No.

Question 2: If we are to adhere to 3.8.3.3, how are we to compute the new thickness of a cover plate whose integrity has been compromised by the addition of a hole into which a smaller adapter nozzle has been placed. Section 3.8.3.3 only

directs the reader to Table 3-8 to find the thickness of unadulterated cover plates. No mention is made in 3.8.3.3 regarding how to compute the new thickness after a nozzle has been added.

Reply 2: API does not provide consulting on specific engineering problems or on the general understanding of its standards. We can only provide interpretations requirements that are stated in an API Standard or consider revisions based on new data or technology.

SECTION 3.9 TOP AND INTERMEDIATE WIND GIRDERS

650-I-39/99

Question 1: Is it acceptable for the primary (upper) bottom, of an API 650 Appendix I double-bottom tank to not project through the shell and to be attached only to the inside of the shell?

Reply 1: No. API 650, Section 3.4.2 requires the bottom plate project at least 25 mm (1 in.) outside the toe of the outer shell-to-bottom weld. Section 3.5.2 requires the annular plate project at least 50 mm (2 in.) outside the shell. Furthermore, Section 3.1.5.7 requires the bottom be welded to the shell on both sides of the shell. The only way this can be accomplished is with a shell projection. Figure I-4 illustrates an acceptable double-bottom installation. (See the 11th Edition for revised rules.)

Question 2: What is the function of asphalt-impregnated board written as “optional”?

Reply 2: The function of the asphalt-impregnated board is to minimize water infiltration underneath the tank bottom and corrosion of the portion of the tank bottom in direct contact with the concrete ringwall.

Question 3: What is the expected effect on tank annular plates if the asphalt-impregnated board is not installed?

Reply 3: See reply to Question 1.

SECTION 3.10 ROOFS

650-I-51/99

Question 1: In API 650, Section 3.10.5, is the calculated minimum thickness the actual required thickness that takes into account the span of unstiffened cone plates with a total load of 45 lbf/ft²?

Reply 1: Yes, it is the minimum required thickness, exclusive of corrosion allowance, for the tank diameter and roof slope under consideration. It should be noted that the maximum allowable roof plate thickness limits the tank diameter as a function of the roof slope.

Question 2: How is the minimum thickness used?

Reply 2: API does not act as a consultant on specific engineering problems or on the general understanding or application of its standards. API's activities in regard to technical inquiries are limited strictly to interpretations of the standard and to the consideration of revisions to the present standard based on new data or technology.

650-I-52/99

Question: Is welding of the main roof support members to the roof plates allowed by the standard?

Reply: No, see API 650, Section 3.10.2.3 that states that roof plates of supported cone roofs shall not be attached to the supporting members.

SECTION 5.2 DETAILS OF WELDING

650-I-11/00

Question 1: Does API 650 Section 5.2.1.10 require the use of low hydrogen electrodes when making manual horizontal welds between two shell plates when both plates are in Groups I-III, one plate is greater than 12.5 mm (0.5 in.) thick and the other plate is 12.5 mm (0.5 in.) thick or less?

Reply 1: Yes.

Question 2: Does API 650 Section 5.2.1.10 require the use of low hydrogen electrodes when making manual welds between the shell and bottom plates when both plates are in Groups I-III, the shell plate is greater than 12.5 mm (0.5 in.) thick and the tank bottom plate is 12.5 mm (0.5 in.) thick or less?

07 | Reply 2: Yes. (The 11th Edition modifies these rules.)

Question 3: Does API 650 Section 5.2.1.10 require low hydrogen electrodes when making welds between two annular plates that are 12.5 mm thick or less and are made of material in Groups I-III.

Reply 3: No. This question will be referred to the appropriate Subcommittee to confirm this is the desired requirement.

650-I-28/00

Question 1: Referring to API 650, Section 5.2.2.1, is the tank Manufacturer allowed to set the sequence of welding the floor plates, if the sequence has been found by the Manufacturer to yield the least distortion from shrinkage?

Reply 1: Yes, see Section 5.2.2.1.

Question 2: If bottom plate seams are left open for shrinkage, then must the shell-to-bottom corner weld be practically complete prior to making the welds left open for shrinkage compensation?

Reply 2: Yes, see Section 5.2.2.2.

650-I-39/02

Question: Can a tank be constructed when the ambient air temperature is less than 0°F?

Reply: Yes, providing that the base metal temperature meets the requirements of section 5.2.1.2.

650-I-04/04

Question 1: Can E-7024 electrodes be used to weld the shell-to-bottom weld when the thickness of the shell and bottom plates are both less than ___” and both materials are from Groups I-III?

Reply 1: Yes. Refer to API 650, Section 5.2.1.10.

SECTION 5.3 INSPECTING, TESTING, AND REPAIRS

650-I-16/00

Question: Regarding the hydro-testing of a tank to be lined internally, does API 650 require the tank to be filled with water before and after the lining is installed, or only before the lining is installed, or only after the lining is installed?

Reply: API 650 does not cover this issue. API does not provide consulting advice on issues that are not addressed in API 650.

650-I-21/00

Question 1: Does API 650 require any additional testing beyond the hydrostatic (water) test specified in Section 5.3.5 for a tank designed for product with specific gravity greater than 1?

Reply 1: No. Section F.7.6 provides additional requirements for Appendix F tanks. The Purchaser may require more stringent testing as a supplemental requirement.

Question 2: Given the following conditions: nominal diameter of the tank–30 m, height of shell–18.4 m, roof–torospherical, specific gravity of content–1.32, top gauge pressure–0. Can the design calculation for test condition be executed on API 650 and Appendix F (design pressure on bottom level 233 CPA or more)?

Reply 2: API does not provide consulting on specific engineering problems or on the general understanding and application of its standards. We can only provide interpretations of API 650 requirements. Please refer to Appendix D and restate your inquiry so that it poses a question on the meaning of a requirement in API 650.

650-I-22/00

Question: Referring to 5.3.6 and 5.3.7, is it permissible to weld insulation clips or pins, using a stud welding procedure, on a tank shell and/or roof after the hydrostatic test?

Reply: No.

650-I-33/00

Question: Does API 650, Section 5.3.5, prohibit starting the water filling for hydrostatic testing while completing some welded attachments on the last shell ring above the water level?

Reply: No. (See 7.3.5(1) in the 11th Edition which gives new rules.)

650-I-12/01

Question 1: Does API 650 require that tolerances (plumbness/peaking bending/roundness) be checked after the construction of each shell course, rather than after the completion of the entire shell?

Reply 1: These tolerances must be measured by the Purchaser's inspector at anytime prior to the hydrostatic test. See Sections 4.2.3, 5.3.1.2, and 5.5.6 (7.5.1 in the 11th Edition).

Question 2: If repairs are required to meet the specified tolerances, when must the repairs be made?

Reply 2: API 650 does not address the timing of these repairs.

SECTION 5.4 REPAIRS TO WELDS

650-I-48/99

Question 1: If welds in a non-radiographed tank (e.g., per Appendix A) are examined by visual examination and determined to be defective, does API 650 permit the Purchaser to then require radiographic examination of the welds?

Reply 1: Section 5.4.1 requires that the Purchaser's inspector approve the plan to resolve the problem. The ramifications of any upgrade to the NDE procedure originally required, such as radiographing the welds in this case, become a contractual matter.

Question 2: For Purchaser-specified NDE, if required to resolve a visual finding, what acceptance criteria applies?

Reply 2: This is a contractual matter not covered by API 650.

SECTION 5.5 DIMENSIONAL TOLERANCES

650-I-24/00

Question: API 650 gives tolerances for plumbness and roundness, but these are related to the tank shell. Are there any defined tolerances on the tank roof, such as on the rim space dimension?

Reply: No.

650-I-29/00

Question: Does the phrase in Section 5.5.5.2.a of API 650, "the top of the ring wall shall be level within $\pm 3\text{mm}$ ($1/8$ in.) in any 9 m (30 ft) of the circumference", mean that the ring wall upper plane position is to be between two horizontal planes 6 mm apart or 3 mm apart?

Reply: 6 mm apart.

650-I-40/00

Question: For tanks built to API 650 and complying with Section 5.5 dimensional tolerances and subsequently commissioned, do the minimum requirements of API 650 with respect to plumbness, banding, etc., still apply after a tank has been placed in service?

Reply: No. API 650 covers the design and construction of new tanks. Any tolerance rules that might apply after the tank has been placed in service, typically API 653 plus any supplemental owner requirements, are to be determined by the local jurisdiction and the tank owner. See API 653, 1.1.1, Section 8, and 10.5.2, for further information and for some examples.

650-I-07/01

Question 1: API 650, Section 5.5.1, states that the tolerances as specified may be waived by (agreement between the Purchaser and the Manufacturer). If a tank does not meet the specified tolerance with regards to one specific area such as the roundness but has met the tolerance in relation to plumbness and local deviation as well as all the testing requirements such as radiography and hydro-testing, can the Manufacturer insist that the Purchaser accept the tank?

07 | Reply 1: No. Agreement by both parties is required. (The Purchaser's waiver is required in the 11th Edition.)

Question 2: Since Section 5.5.1 states that the purpose of the tolerances as specified is for appearance and to permit proper functioning of floating roofs, is it therefore correct to conclude that the Purchaser has no right to refuse to accept a tank which has passed all tests required by API 650 but may have some out-of-tolerance in one or more areas?

Reply 2: No.

Question 3: An inspection measurement shows a maximum out of roundness of 28 mm on the uppermost shell course at three locations in a tank. Is this detrimental to the structural integrity of the tank?

Reply 3: API can only provide interpretations of API 650 requirements or consider revisions to the standard based on new data or technology. API does not provide consulting on specific engineering problems or on the general understanding of its standards.

650-I-08/01

Question: Does the 10th Edition of API 650 specify tolerances for the elevation and orientation of shell nozzles?

07 | Reply: No. (See the 11th Edition for elevation tolerances.)

SECTION 6 METHODS OF INSPECTING JOINTS

650-I-47/99

Question: Does API 650 allow the Purchaser to require radiographic examination as a requirement for acceptance after fabrication on a tank that is not required to be radiographed per API 650 rules?

Reply: API 650 does not prohibit the Purchaser from specifying additional requirements. These are contractual issues outside the scope of the document.

SECTION 6.1 RADIOGRAPHIC METHOD

650-I-10/02

Question: For repaired regions made after spot radiography detects defective welding, is it correct that according to 6.1.7.2 that only the original spot radiography requirements apply no matter the number of original spot and tracer radiographs taken?

Reply: Yes, because the post-repair inspection procedure is spot radiography as was the original inspection requirement.

Section 7.2 Qualification of Welding Procedures

650-I-23/00

Question: Referring to 7.2.2, 2.2.8, and 2.2.9, for the fabrication and welding of shell nozzles made from pipe and forgings meeting toughness requirements of 2.5.5, is it mandatory to have impact tests on weld procedure qualifications for welding these components?

Reply: Yes, if these materials are welded to any of the components listed in 2.2.9.1 and the design metal temperature is below 20°F. See 7.2.2.4.

650-I-27/03

Question: For the purposes of determining radiographic requirements for tanks can tank shell plate thickness of 0.5 inch thickness be considered to be 0.375 inch thick as outlined in 6.1?

Reply: No. Refer to Section 6.1.2.2b.

650-I-34/03

Question: Do the requirements of API 650 section 6.1.2.2 apply to welds that will be in the vertical position when the tank is in service, but are made in the flat or horizontal position?

Reply: Yes. The requirements of 6.1.2.2 apply to welds that will be in the vertical position when the tank is in service.

650-I-42/03

Question 1: When annular plates are joined with single-welded butt joints, is one radiograph required at each of 50% of the total count of radial joints?

Reply 1: Yes. See Section 6.1.2.9 (b).

Question 2: When annular plates are joined with single-welded butt joints, is a radiograph required at each radial joint with the radiograph length covering 50% of the total length of the weld?

Reply 2: No. The 50% factor is applied to the number of joints, not the length of joint. See Section 6.1.2.9 (b).

SECTION 8.1 NAMEPLATES

650-I-49/00

Question: For a tank built to the 10th Edition, 1st Addendum, of API 650, is it acceptable to mark "November 1998" in the Edition box and "X" in the "Revision No." box on the nameplate?

Reply: No. The marks should be the "month and year" of the Edition in the first box, and the number of the addendum revision in the second box (e.g., 0, 1, 2).

SECTION 8.3 CERTIFICATION

650-I-16/02

Background: Secondary containment rules for petroleum tanks are almost universally applied. Most often these rules are satisfied by constructing dike or berm walls around a tank farm. However, due to space or other regulatory limitations, the owner may wish to install double wall tanks where the outer tank would contain the volume of the inner tank should a catastrophic failure occur. In this case, the outer wall would have to be designed to contain the hydrostatic pressure of the liquid from the inner tank. In addition, consideration of detailed design for piping flexibility passing through the outer wall would need to be made.

Question: Is it permissible to construct a tank within a tank and certify both tanks to API 650 Section 8.3?

Reply: Yes.

APPENDIX C EXTERNAL FLOATING ROOFS

650-I-12/2

Question 1: Referring to Section C.3.9, Must the thermal in-breathing/out-breathing requirements as per API Std 2000 also need to be considered during design of bleeder vents? (i.e., during deciding size and quantity of bleeder vents, so that there will not be any overstressing of roof deck or seal membrane).

Reply 1: No, C.3.9 does not require venting per API Std 2000.

Question 2: If answer to Question 1 is yes, would it not be worthwhile to clarify the same appropriately in Section C.3.9 of API 650?

Reply 2: See Reply 1.

APPENDIX E SEISMIC DESIGN OF STORAGE TANKS

07 | 650-I-44/99 (See Appendix E in the 11th Edition for new rules pertaining to seismic design.)

Question 1: Do the changes to Chapter 16, *Division IV Earthquake Design*, of the *1997 Uniform Building Code* affect API 650, Appendix E requirements?

Reply 1: The committee is currently considering changes to Appendix E as a result of the revisions to the *Uniform Building Code*. Approved changes will appear in future addenda of API 650.

Question 2: Why is the Seismic Zone Map of the United States shown in API 650, Appendix E slightly different for that shown on page 2-37 of the *1997 Uniform Building Code*, Figure 16-2?

07 | Reply 2: The committee is currently considering changes to Appendix E as a result of the revisions to the *Uniform Building Code*. Approved changes will appear in a future addendum or edition of API 650.

650-I-45/99 (See Appendix E in the 11th Edition for new rules pertaining to seismic design.)

Question: Is the value obtained from the equation in E.4.2 equal to the dimension measured radially inward from the interior face of the shell to the end of the annular plate (the “end of the annular plate” is defined here as the inner edge/perimeter of the typical lap joint between the bottom and the annular plate)? (See E.6.2.1.2 in the 11th Edition.)

Reply: No, the dimension is measured radially inward from the interior face of the shell to the end of the annular plate, defined as the inner edge of the annular plate. The extent of the overlap of the bottom plate on the annular plate is not a significant consideration.

07 | 650-I-25/00 (See Appendix E in the 11th Edition for new rules pertaining to seismic design.)

Question 1: Should the metric formula for calculating the natural period of the first sloshing mode in Section E.3.3.2 read:

$$T = k(D^{0.5})\left(\frac{1}{0.5521}\right)$$

07 | Reply 1: Yes. This correction will appear in Addendum 2 of API 650. (See E.4.5 in the 11th Edition.)

Question 2: Should the metric formula for calculating the width of the thicker plate under the shell in Section E.4.2 read:

$$0.1745 \times 10^{-3} w_L / GH(m)$$

Reply 2: Yes. This correction will appear in Addendum 2 of API 650.

Question 3: Is the following revision to Section E.5.1 appropriate?

“When $M/[D^2 (w_f + w_L)]$ is greater than 1.57 or when $b/1000t$ ($b/12t$) is greater than F_a (see E.5.3), the tank is structurally unstable.”

Reply 3: Yes. This correction will appear in Addendum 2 of API 650.

Question 4: Is the following revision to Section E.5.3 appropriate?

“The maximum longitudinal compressive stress in the shell $b/1000t$ ($b/12t$), shall not exceed the maximum allowable stress, F_a , determined by the following formulas for F_a , which take in to account...”

Reply 4: Yes. This correction was made in Addendum 1 of API 650, released in March 2000.

APPENDIX F DESIGN OF TANKS FOR SMALL INTERNAL PRESSURES

650-I-12/00

Question: Assume a tank is to be designed to API 650, Appendix F.1.2, (the internal pressure will be greater than the weight of the roof plates but less than the weight of the shell, roof and framing). In addition, assume anchors are to be added for some reason other than internal pressure, for example: seismic, wind, sliding, overturning or user mandated. Does the tank have to be designed to API 650 Section F.7?

Reply: No, only Sections F.2 through F.6 apply. Section 3.11 applies to anchors that resist wind overturning when specified by the Purchaser. Appendix E applies to anchors provided for seismic. API's Subcommittee on Pressure Vessels and Tanks is currently reviewing API 650 anchor requirements. (F.2 has been deleted.)

650-I-15/02

Question 1: Is the “ W ” in 3.10.2.5.3 referring to the same “ W ” in F.4.2?

Reply 1: Yes. (Paragraph 3.10.2.5.3 has been deleted.)

Question 2: Does “ W ” in F.4.2 include the weight of the bottom of the tank?

Reply 2: No. (“ W ” has been revised to “ D_{LS} ” in the 11th Edition.)

Question 3: Is the “ A ” in 3.10.2.5.3 referring to the same “ A ” in F.4.1 and cross-hatched area shown in Figure F-2?

Reply 3: Yes.

650-I-25/03

Question 1: If internal pressure inside tank does not exceed the weight of the shell, roof, and attached framing, but exceeds the weight of the roof plates (Basic Design plus Appendix F.1 to F.6), must H be increased by the quantity $P/12G$?

Reply 1: No.

650-I-30/03

Question: For an anchored tank, can the P_{max} calculation in F.4.2 be exceeded by the design pressure of the tank?

Reply: Yes.

APPENDIX H INTERNAL FLOATING ROOFS

650-I-50/99

Question 1: Does API 650 require that floating roof seals be installed prior to hydro-testing the tank?

Reply 1: No. (See H.4.4.4 in the 11th Edition for revised rules.)

Question 2: Is a roof seal considered a major component of the tank?

Reply 2: API 650 does not use the term “major component.”

650-I-10/00

Question: Does API 650 provide a way to obtain a frangible roof connection on a small tank describe as follows?

- Diameter: 8 ft
- Height: 10 ft
- Cross sectional area of the roof-to-shell junction “ A ”: larger than that allowed by the equation in Section 3.10.

Reply: No. The API Subcommittee on Pressure Vessels and Tanks is currently reviewing the design criteria for frangible roof joints. You may wish to review API Publ 937 *Evaluation of Design Criteria for Storage Tanks with Frangible Roof Joints*.

650-I-38/02

Question 1: Is the reference to NFPA 11 found in footnote number 1 under item H.2.1 meant to establish that non-perforated honeycomb floating roofs are the exclusively permitted type to be used if an H.2.2.f type floating roof is being considered?

Reply 1: No. The reference to NFPA 11 is solely related to the design of a fire suppression system (if used).

Question 2: Per H.4.1.7 “Inspection openings shall be located above the liquid level and closed compartments shall be capable of being resealed in the field after periodic inspection (to prevent liquid or vapor entry).” In the case of floating roofs type H.2.2.f, does “inspection openings” refer to screwed couplings, test plug or similar devices, or is it implied by “inspection openings” the disassembling in the field of flotation modules?

Reply 2: Yes, “inspection openings” in Section H.4.1.7 refers to screwed couplings, test plugs or similar devices and not to the disassembling in the field of flotation modules.

Question 3: Does note c of API 650 Table 3-6 allow the customer to locate nozzles lower than allowed by the weld spacing requirements of 3.7.3?

Reply 3: No.

650-I-09/03

Question: Does H.4.2.2 require internal floating roofs be designed to support a uniform load of 500 lbf/in.²?

Reply: The 500 lb force is to be applied as a moving concentrated load over one square foot located anywhere on the roof. Refer to H.4.2.5 for distributed uniform loading.

APPENDIX J SHOP-ASSEMBLED STORAGE TANKS

650-I-05/02

Question: Referencing Appendix J, does the roof plate material have to meet the same toughness requirements as the shell plate on tanks located in -40°F areas? (Assume F.7 is not applicable.)

Reply: This is not addressed in API 650.

650-I-18/02

Background: Many times small tanks with diameters less than 10 ft are specified for construction in accordance with API 650. A review of API 650, Section 3.6.1.1, shows the minimum thickness to be $\frac{3}{16}$ in. and 3.6.1.2 indicates that the minimum shell plate width is 72 in. Appendix J states that the maximum tank diameter of a tank constructed to API 650 is 20 ft.

Question: Is there a minimum diameter or height or volume for which new tanks constructed to API 650 apply?

Response: No.

650-I-36/02

Question: On an API 650 shop-fabricated tank (Appendix J), can a reinforcing plate cross a shell weld?

Reply: Yes. See J.3.6.1 and 3.7.

APPENDIX P ALLOWABLE EXTERNAL LOADS ON SHELL OPENINGS

650-I-12/04

Question 1: If the nozzle has a compensating pad to Table 3-6, does the code require a check to be made on stress levels at the edge of the pad and if so can WRC 297 be used with the stress reduction factor applied from P.3?

Reply 1: No.

Question 2: If the nozzle neck meets the requirements of Table 3-7, are any further checks required to find stress levels in the nozzle neck and if so can WRC 297 be used with the stress reduction factor applied from P.3?

Reply 2: No.

APPENDIX S AUSTENITIC STAINLESS STEEL STORAGE TANKS

650-I-19/00

Question: In my opinion, the formulas given for shell thickness calculation for stainless steel materials in Appendix S, Par. S.3.2 include the corrosion allowance (CA) at the wrong place. The formulas should consist of two parts, the second part should be the CA without the division by.

Reply: Yes, you are correct. This typographical error was corrected in Addendum 1 to API 650, 10th Edition.

650-I-28/03

Question: Should the bottom plates be for stainless tanks be $\frac{1}{4}$ in. thick?

Reply: No. The $\frac{3}{16}$ in. minimum bottom plate thickness for stainless steel is intentional and is not related to the joint efficiency.

1

APPENDIX E—SEISMIC DESIGN OF STORAGE TANKS

Part I—Provisions

E.1 Scope

This appendix provides minimum requirements for the design of welded steel storage tanks that may be subject to seismic ground motion. These requirements represent accepted practice for application to welded steel flat-bottom tanks supported at grade.

The fundamental performance goal for seismic design in this appendix is the protection of life and prevention of catastrophic collapse of the tank. Application of this Standard does not imply that damage to the tank and related components will not occur during seismic events.

This appendix is based on the allowable stress design (ASD) methods with the specific load combinations given herein. Application of load combinations from other design documents or codes is not recommended, and may require the design methods in this appendix be modified to produce practical, realistic solutions. The methods use an equivalent lateral force analysis that applies equivalent static lateral forces to a linear mathematical model of the tank based on a rigid wall, fixed based model.

The ground motion requirements in this appendix are derived from ASCE 7, which is based on a maximum considered earthquake ground motion defined as the motion due to an event with a 2% probability of exceedance within a 50-year period (a recurrence interval of approximately 2,500 years). Application of these provisions as written is deemed to meet the intent and requirements of ASCE 7. Accepted techniques for applying these provisions in regions or jurisdictions where the regulatory requirements differ from ASCE 7 are also included.

The pseudo-dynamic design procedures contained in this appendix are based on response spectra analysis methods and consider two response modes of the tank and its contents—impulsive and convective. Dynamic analysis is not required nor included within the scope of this appendix. The equivalent lateral seismic force and overturning moment applied to the shell as a result of the response of the masses to lateral ground motion are determined. Provisions are included to assure stability of the tank shell with respect to overturning and to resist buckling of the tank shell as a result of longitudinal compression.

The design procedures contained in this appendix are based on a 5% damped response spectra for the impulsive mode and 0.5% damped spectra for the convective mode supported at grade with adjustments for site-specific soil characteristics. Application to tanks supported on a framework elevated above grade is beyond the scope of this appendix. Seismic design of floating roofs is beyond the scope of this appendix.

Optional design procedures are included for the consideration of the increased damping and increase in natural period of vibration due to soil-structure interaction for mechanically-anchored tanks.

Tanks located in regions where S_1 is less than or equal to 0.04 and S_2 less than or equal to 0.15, or the peak ground acceleration for the ground motion defined by the regulatory requirements is less than or equal to 0.05g, need not be designed for seismic forces; however, in these regions, tanks in SUG III shall comply with the freeboard requirements of this appendix.

- Dynamic analysis methods incorporating fluid-structure and soil-structure interaction are permitted to be used in lieu of the procedures contained in this appendix with Purchaser approval and provided the design and construction details are as safe as otherwise provided in this appendix.

E.2 Definitions and Notations

E.2.1 DEFINITIONS

E.2.1.1 active fault: A fault for which there is an average historic slip rate of 1 mm (0.4 in.) per year or more and geologic evidence of seismic activity within Holocene times (past 11,000 years).

E.2.1.2 characteristic earthquake: An earthquake assessed for an active fault having a magnitude equal to the best-estimate of the maximum magnitude capable of occurring on the fault, but not less than the largest magnitude that has occurred historically on the fault.

E.2.1.3 maximum considered earthquake (MCE): The most severe earthquake ground motion considered in this appendix.

E.2.1.4 mechanically-anchored tank: Tanks that have anchor bolts, straps or other mechanical devices to anchor the tank to the foundation.

E.2.1.5 self-anchored tank: Tanks that use the inherent stability of the self-weight of the tank and the stored product to resist overturning forces.

E.2.1.6 site class: A classification assigned to a site based on the types of soils present and their engineering properties as defined in this appendix.

07 | E.2.2 NOTATIONS

	A	Lateral acceleration coefficient, %g
	A_c	Convective design response spectrum acceleration coefficient, %g
07 	A_f	Acceleration coefficient for sloshing wave height calculation, %g
	A_i	Impulsive design response spectrum acceleration coefficient, %g
	A_v	Vertical earthquake acceleration coefficient, %g
07 	C_d	Deflection amplification factor, $C_d = 2$
	C_i	Coefficient for determining impulsive period of tank system
	D	Nominal tank diameter, m (ft)
07 	d_c	Total thickness ($100 - d_s$) of cohesive soil layers in the top 30 m (100 ft)
	d_i	Thickness of any soil layer i (between 0 and 30 m [100 ft])
	d_s	Total thickness of cohesionless soil layers in the top 30 m (100 ft)
	E	Elastic Modulus of tank material, MPa (kPa)
	F_a	Acceleration-based site coefficient (at 0.2 sec period)
	F_c	Allowable longitudinal shell-membrane compression stress, MPa (kPa)
07 	F_{ty}	Minimum specified yield strength of shell course, MPa (lbf/in. ²)
	F_v	Velocity-based site coefficient (at 1.0 sec period)
	F_y	Minimum specified yield strength of bottom annulus, MPa (kPa)
	G	Specific gravity
	g	Acceleration due to gravity in consistent units, m/sec ² (ft/sec ²)
	G_e	Effective specific gravity including vertical seismic effects = $G(1 - 0.4A_v)$
	H	Maximum design product level, m (ft)
	H_S	Thickness of soil, m (ft)
	I	Importance factor coefficient set by seismic use group
	J	Anchorage ratio
	K	Coefficient to adjust the spectral acceleration from 5% – 0.5% damping = 1.5 unless otherwise specified
	L	Required minimum width of the bottom annulus measured from the inside of the shell m (ft)
	M_{rw}	Ringwall moment—Portion of the total overturning moment that acts at the base of the tank shell perimeter, Nm (ft-lb)
07 	M_s	Slab moment (used for slab and pile cap design), Nm (ft-lb)
	N	Standard penetration resistance, ASTM D 1536-84
	\bar{N}	Average field standard penetration test for the top 30 m (100 ft)
	n_A	Number of equally-spaced anchors around the tank circumference
	N_c	Convective hoop membrane force in tank shell, N/mm (lbf/in.)
	N_{ch}	Average standard penetration of cohesionless soil layers for the top 30 m (100 ft)
	N_h	Product hydrostatic membrane force, N/mm (lbf/in.)

N_i	Impulsive hoop membrane force in tank shell, N/mm (lbf/in.)
P_A'	Anchorage attachment design load, N (lbf)
P_{AB}	Anchor design load, N (lbf)
PI	Plasticity index, ASTM D 4318-93
Q	Scaling factor from the MCE to the design level spectral accelerations; equals $2/3$ for ASCE 7
R	Force reduction coefficient for strength level design methods
R_{wc}	Force reduction coefficient for the convective mode using allowable stress design methods
R_{wi}	Force reduction factor for the impulsive mode using allowable stress design methods
S_0	Mapped, maximum considered earthquake, 5% damped, spectral response acceleration parameter at a period of zero seconds (peak ground acceleration for a rigid structure), %g
S_1	Mapped, maximum considered earthquake, 5% damped, spectral response acceleration parameter at a period of one second, %g
S_a	The 5% damped, design spectral response acceleration parameter at any period based on mapped, probabilistic procedures, %g
S_a^*	The 5% damped, design spectral response acceleration parameter at any period based on site-specific procedures, %g
S_{a0}^*	The 5% damped, design spectral response acceleration parameter at zero period based on site-specific procedures, %g
S_{D1}	The design, 5% damped, spectral response acceleration parameter at one second based on the ASCE 7 methods, %g
S_{DS}	The design, 5% damped, spectral response acceleration parameter at short periods ($T = 0.2$ seconds) based on ASCE 7 methods, %g
S_p	Design level peak ground acceleration parameter for sites not addressed by ASCE methods
S_S	Mapped, maximum considered earthquake, 5% damped, spectral response acceleration parameter at short periods (0.2 sec), %g
s_u	Undrained shear strength, ASTM D 2166 or ASTM D 2850
\bar{s}_u	Average undrained shear strength in top 30 m (100 ft)
t	Thickness of the shell ring under consideration, mm (in.)
t_a	Thickness of the bottom plate under the shell extending at least the distance, L , from the inside of the shell, less corrosion allowance, mm (in.)
t_b	Thickness of tank bottom less corrosion allowance, mm (in.)
t_s	Thickness of bottom shell course less corrosion allowance, mm (in.)
t_u	Equivalent uniform thickness of tank shell, mm (in.)
T	Natural period of vibration of the tank and contents, seconds
T	Total weight of tank shell, roof, framing, knuckles, product, bottom, attachments, appurtenances, participating snow load, if specified, and appurtenances, N (lbf)
T_C	Natural period of the convective (sloshing) mode of behavior of the liquid, seconds
T_i	Natural period of vibration for impulsive mode of behavior, seconds
T_L	Regional-dependent transition period for longer period ground motion, seconds

T_0	$0.2 F_v S_I / F_a S_S$
T_S	$F_v S_I / F_a S_S$
V	Total design base shear, N (lbf)
V_c	Design base shear due to the convective component of the effective sloshing weight, N (lbf)
v_s	Average shear wave velocity at large strain levels for the soils beneath the foundation, m/s (ft/s)
\bar{v}_s	Average shear wave velocity in top one 30 m (100 ft), m/s (ft/s)
V_i	Design base shear due to impulsive component from effective weight of tank and contents, N (lbf)
w	Moisture content (in %), ASTM D 2216-92
w_a	Resisting force of tank contents per unit length of shell circumference that may be used to resist the shell overturning moment, N/m (lbf/ft)
w_{AB}	Calculated design uplift load on anchors per unit circumferential length, N/m (lbf/ft)
W_c	Effective convective (sloshing) portion of the liquid weight, N (lbf)
W_{eff}	Effective weight contributing to seismic response
W_f	Weight of the tank bottom, N (lbf)
W_{fd}	Total weight of tank foundation, N (lbf)
W_g	Weight of soil directly over tank foundation footing, N (lbf)
W_i	Effective impulsive portion of the liquid weight, N (lbf)
w_{int}	Calculated design uplift load due to product pressure per unit circumferential length, N/m (lbf/ft)
W_p	Total weight of the tank contents based on the design specific gravity of the product, N (lbf)
W_r	Total weight of fixed tank roof including framing, knuckles, any permanent attachments and 10% of the roof design snow load, N (lbf)
W_{rs}	Roof load acting on the tank shell including 10% of the roof design snow load, N (lbf)
w_{rs}	Roof load acting on the shell, including 10% of the specified snow load N/m (lbf/ft)
W_s	Total weight of tank shell and appurtenances, N (lbf)
w_t	Tank and roof weight acting at base of shell, N/m (lbf/ft)
X_c	Height from the bottom of the tank shell to the center of action of lateral seismic force related to the convective liquid force for ringwall moment, m (ft)
X_{cs}	Height from the bottom of the tank shell to the center of action of lateral seismic force related to the convective liquid force for the slab moment, m (ft)
X_i	Height from the bottom of the tank shell to the center of action of the lateral seismic force related to the impulsive liquid force for ringwall moment, m (ft)
X_{is}	Height from the bottom of the tank shell to the center of action of the lateral seismic force related to the impulsive liquid force for the slab moment, m (ft)
X_r	Height from the bottom of the tank shell to the roof and roof appurtenances center of gravity, m (ft)
X_s	Height from the bottom of the tank shell to the shell's center of gravity, m (ft)

Y	Distance from liquid surface to analysis point, (positive down), m (ft)
y_u	Estimated uplift displacement for self-anchored tank, mm (in.)
σ_c	Maximum longitudinal shell compression stress, MPa (kPa)
σ_h	Product hydrostatic hoop stress in the shell, Mpa (kPa)
σ_s	Hoop stress in the shell due to impulsive and convective forces of the stored liquid, MPa (kPa)
σ_T	Total combined hoop stress in the shell, MPa (kPa)
μ	Friction coefficient for tank sliding
ρ	Density of fluid, kg/m ³ (lb/ft ³)

E.3 Performance Basis

E.3.1 SEISMIC USE GROUP

- The Seismic Use Group (SUG) for the tank shall be specified by the Purchaser. If it is not specified, the SUG shall be assigned to be SUG I.

E.3.1.1 Seismic Use Group III

SUG III tanks are those providing necessary service to facilities that are essential for post-earthquake recovery and essential to the life and health of the public; or, tanks containing substantial quantities of hazardous substances that do not have adequate control to prevent public exposure.

E.3.1.2 Seismic Use Group II

SUG II tanks are those storing material that may pose a substantial public hazard and lack secondary controls to prevent public exposure, or those tanks providing direct service to major facilities.

E.3.1.3 Seismic Use Group I

SUG I tanks are those not assigned to SUGs III or II.

E.3.1.4 Multiple Use

Tanks serving multiple use facilities shall be assigned the classification of the use having the highest SUG.

E.4 Site Ground Motion

Spectral lateral accelerations to be used for design may be based on either “mapped” seismic parameters (zones or contours), “site-specific” procedures, or probabilistic methods as defined by the design response spectra method contained in this appendix. A method for regions outside the USA where ASCE 7 methods for defining the ground motion may not be applicable is also included.

A methodology for defining the design spectrum is given in the following sections.

E.4.1 MAPPED ASCE 7 METHOD

- For sites located in the USA, or where the ASCE 7 method is the regulatory requirement, the maximum considered earthquake ground motion shall be defined as the motion due to an event with a 2% probability of exceedance within a 50-year period. The following definitions apply:
 - S_S is the mapped, maximum considered earthquake, 5% damped, spectral response acceleration parameter at short periods (0.2 seconds).
 - S_1 is the mapped, maximum considered earthquake, 5% damped, spectral response acceleration parameter at a period of 1 second.

- S_0 is the mapped, maximum considered earthquake, 5% damped, spectral response acceleration parameter at zero seconds (usually referred to as the peak ground acceleration). Unless otherwise specified or determined, S_0 shall be defined as $0.4S_G$ when using the mapped methods.

E.4.2 SITE-SPECIFIC SPECTRAL RESPONSE ACCELERATIONS

The design method for a site-specific spectral response is based on the provisions of ASCE 7. Design using site-specific ground motions should be considered where any of the following apply:

- The tank is located within 10 km (6 miles) of a known active fault.
- The structure is designed using base isolation or energy dissipation systems, which is beyond the scope of this appendix.
- The performance requirements desired by the owner or regulatory body exceed the goal of this appendix.

Site-specific determination of the ground motion is required when the tank is located on Site Class F type soils.

- If design for an MCE site-specific ground motion is desired, or required, the site-specific study and response spectrum shall be provided by the Purchaser as defined this section.

However, in no case shall the ordinates of the site-specific MCE response spectrum defined be less than 80% of the ordinates of the mapped MCE response spectra defined in this appendix.

E.4.2.1 Site-Specific Study

A site-specific study shall account for the regional tectonic setting, geology, and seismicity. This includes the expected recurrence rates and maximum magnitudes of earthquakes on known faults and source zones, the characteristics of ground motion attenuation, near source effects, if any, on ground motions, and the effects of subsurface site conditions on ground motions. The study shall incorporate current scientific interpretations, including uncertainties, for models and parameter values for seismic sources and ground motions.

If there are known active faults identified, the maximum considered seismic spectral response acceleration at any period, S_a^* , shall be determined using both probabilistic and deterministic methods.

E.4.2.2 Probabilistic Site-Specific MCE Ground Motion

The probabilistic site-specific MCE ground motion shall be taken as that motion represented by a 5% damped acceleration response spectrum having a 2% probability of exceedance in a 50-year period.

E.4.2.3 Deterministic Site-Specific MCE Ground Motion

The deterministic site-specific MCE spectral response acceleration at each period shall be taken as 150% of the largest median 5% damped spectral response acceleration computed at that period for characteristic earthquakes individually acting on all known active faults within the region.

However, the ordinates of the deterministic site-specific MCE ground motion response spectrum shall not be taken lower than the corresponding ordinates of the response spectrum where the value of S_G is equal to $1.5F_a$ and the value of S_1 is equal to $0.6F_{vT}$.

• E.4.2.4 Site-Specific MCE Ground Motions

The 5% damped site-specific MCE spectral response acceleration at any period, S_a^* , shall be defined as the lesser of the probabilistic MCE ground motion spectral response accelerations determined in E.4.2.2 and the deterministic MCE ground motion spectral response accelerations defined in E.4.2.3.

The response spectrum values for 0.5% damping for the convective behavior shall be 1.5 times the 5% spectral values unless otherwise specified by the Purchaser.

The values for sites classified as F may not be less than 80% of the values for a Site Class E site.

E.4.3 SITES NOT DEFINED BY ASCE 7 METHODS

In regions outside the USA, where the regulatory requirements for determining design ground motion differ from the ASCE 7 methods prescribed in this appendix, the following methods may be utilized:

1. A response spectrum complying with the regulatory requirements may be used providing it is based on, or adjusted to, a basis of 5% and 0.5% damping as required in this appendix. The values of the design spectral acceleration coefficients, A_i and A_c , which include the effects of site amplification, importance factor and response modification may be determined directly. A_i shall be based on the calculated impulsive period of the tank (see E.4.5.1) using the 5% damped spectra, or the period may be assumed to be 0.2 seconds. A_c shall be based on the calculated convective period (see E.4.5.2) using the 0.5% spectra.
2. If no response spectra shape is prescribed and only the peak ground acceleration, S_p is defined, then the following substitutions shall apply:

$$S_s = 2.5 S_p \tag{E.4.3-1}$$

$$S_1 = 1.25 S_p \tag{E.4.3-2}$$

E.4.4 MODIFICATIONS FOR SITE SOIL CONDITIONS

The maximum considered earthquake spectral response accelerations for peak ground acceleration, shall be modified by the appropriate site coefficients, F_a and F_v , from Tables E-1 and E-2.

- Where the soil properties are not known in sufficient detail to determine the site class, Site Class D shall be assumed unless the authority having jurisdiction determines that Site Class E or F should apply at the site.

Table E-1—Value of F_a as a Function of Site Class

Site Class	Mapped Maximum Considered Earthquake Spectral Response Accelerations at Short Periods				
	$S_s \leq 0.25$	$S_s = 0.50$	$S_s = 0.75$	$S_s = 1.0$	$S_s \geq 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	a	a	a	a	a

^aSite-specific geotechnical investigation and dynamic site response analysis is required.

Table E-2—Value of F_v as a Function of Site Class

Site Class	Mapped Maximum Considered Earthquake Spectral Response Accelerations at 1 Sec Periods				
	$S_1 \leq 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \geq 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	a	a	a	a	a

^aSite-specific geotechnical investigation and dynamic site response analysis is required.

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SITE CLASS DEFINITIONS

The Site Classes are defined as follows:

- A Hard rock with measured shear wave velocity, $\bar{v}_s > 1500$ m/s (5,000 ft/sec)
- B Rock with 760 m/s $< \bar{v}_s \leq 1500$ m/s (2,500 ft/sec $< \bar{v}_s \leq 5,000$ ft/sec)
- C Very dense soil and soft rock with 360 m/s $< \bar{v}_s \leq 760$ m/s (1,200 ft/sec $< \bar{v}_s \leq 2,500$ ft/sec) or with either $\bar{N} > 50$ or $\bar{s}_u > 100$ kPa (2,000 psf)
- D Stiff soil with 180 m/s $\leq \bar{v}_s \leq 360$ m/s (600 ft/sec $\leq \bar{v}_s \leq 1,200$ ft/sec) or with either $15 \leq \bar{N} \leq 50$ or 50 kPa $\leq \bar{s}_u \leq 100$ kPa (1,000 psf $\leq \bar{s}_u \leq 2,000$ psf)
- E A soil profile with $\bar{v}_s < 180$ m/s (600 ft/sec) or with either $\bar{N} < 15$, $\bar{s}_u < 50$ kPa (1,000 psf), or any profile with more than 3 m (10 ft) of soft clay defined as soil with $PI > 20$, $w \geq 40\%$, and $\bar{s}_u < 25$ kPa (500 psf)
- F Soils requiring site-specific evaluations:
1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils. However, since tanks typically have an impulsive period of 0.5 secs or less, site-specific evaluations are not required but recommended to determine spectral accelerations for liquefiable soils. The Site Class may be determined as noted below, assuming liquefaction does not occur, and the corresponding values of F_a and F_v determined from Tables E-1 and E-2.
 2. Peats and/or highly organic clays ($H_G > 3$ m [10 ft] of peat and/or highly organic clay, where H = thickness of soil).
 3. Very high plasticity clays ($H_G > 8$ m [25 ft] with $PI > 75$).
 4. Very thick, soft/medium stiff clays ($H_G > 36$ m [120 ft])

The parameters used to define the Site Class are based on the upper 30 m (100 ft) of the site profile. Profiles containing distinctly different soil layers shall be subdivided into those layers designated by a number that ranges from 1 to n at the bottom where there are a total of n distinct layers in the upper 30 m (100 ft). The symbol i then refers to any one of the layers between 1 and n .

where

v_{si} = the shear wave velocity in m/s (ft/sec),

d_i = the *thickness* of any layer (between 0 and 30 m [100 ft]).

$$\bar{v} = \frac{\sum_{i=1}^n d_i}{\sum_{i=1}^n \frac{d_i}{v_{si}}} \quad (\text{E.4.4-1})$$

where

$$\sum_{i=1}^n d_i = 30 \text{ m (100 ft)},$$

N_i = the Standard Penetration Resistance determined in accordance with ASTM D 1586, as directly measured in the field without corrections, and shall not be taken greater than 100 blows/ft.

$$\bar{N} = \frac{\sum_{i=1}^n d_i}{\sum_{i=1}^n \frac{d_i}{N_i}} \quad (\text{E.4.4-2})$$

$$\bar{N}_{ch} = \frac{d_s}{\sum_{i=1}^m \bar{N}_i} \tag{E.4.4-3}$$

where $\sum_{i=1}^m d_i = d_s$.

Use only d_i and N_i for cohesionless soils.

d_s = the total thickness of cohesionless soil layers in the top 30 m (100 ft),

s_{ui} = the undrained shear strength in kPa (psf), determined in accordance with ASTM D 2166 or D 2850, and shall not be taken greater than 240 kPa (5,000 psf).

$$s_u = \frac{d_c}{\sum_{i=1}^k \frac{d_i}{s_{ui}}} \tag{E.4.4-4}$$

where $\sum_{i=1}^k d_i = d_c$.

d_c = the total thickness (100 – d_s) of cohesive soil layers in the top 30 m (100 ft),

PI = the plasticity index, determined in accordance with ASTM D 4318,

w = the moisture content in %, determined in accordance with ASTM D 2216.

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STEPS FOR CLASSIFYING A SITE:

- Step 1:** Check for the four categories of Site Class F requiring site-specific evaluation. If the site corresponds to any of these categories, classify the site as Site Class F and conduct a site-specific evaluation.
- Step 2:** Check for the existence of a total thickness of soft clay > 3 m (10 ft) where a soft clay layer is defined by: $s_u < 25$ kPa (500 psf) $w \geq 40\%$, and $PI > 20$. If these criteria are satisfied, classify the site as Site Class E.
- Step 3:** Categorize the site using one of the following three methods with \bar{v}_s , \bar{N} , and \bar{s}_u computed in all cases see Table E-3:
 - a. \bar{v}_s for the top 30 m (100 ft) (\bar{v}_s method).
 - b. \bar{N} for the top 30 m (100 ft) (\bar{N} method).
 - c. \bar{N} for cohesionless soil layers ($PI < 20$) in the top 30 m (100 ft) and average \bar{s}_u for cohesive soil layers ($PI > 20$) in the top 30 m (100 ft) (\bar{s}_u method).

Table E-3—Site Classification

Site Class	\bar{v}_s	\bar{N} or $\bar{N}ch$	Σ_u^a
E	< 180 m/s < 600 fps	< 15	< 50 kPa < 1,000 psf
D	180 m/s – 360 m/s (600 to 1,200 fps)	15 to 50	50 kPa – 100 kPa (1,000 psf – 2,000 psf)
C	360 m/s – 760 m/s (1,200 fps – 2,500 fps)	> 50	100 kPa (> 2,000 psf)
B	760 m/s – 1500 m/s (2,500 fps – 5,000 fps)		
A	> 1500 m/s (5,000 fps)		

Note: ^a If the \bar{s}_u method is used and the $\bar{N}ch$ and s_u criteria differ, select the category with the softer soils (for example, use Site Class E instead of D).

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Assignment of Site Class B shall be based on the shear wave velocity for rock. For competent rock with moderate fracturing and weathering, estimation of this shear wave velocity shall be permitted. For more highly fractured and weathered rock, the shear wave velocity shall be directly measured or the site shall be assigned to Site Class C.

Assignment of Site Class A shall be supported by either shear wave velocity measurements on site or shear wave velocity measurements on profiles of the same rock type in the same formation with an equal or greater degree of weathering and fracturing. Where hard rock conditions are known to be continuous to a depth of 30 m (100 ft), surficial shear wave velocity measurements may be extrapolated to assess \bar{v}_s .

Site Classes A and B shall not be used where there is more than 3 m (10 ft) of soil between the rock surface and the bottom of the tank foundation.

E.4.5 STRUCTURAL PERIOD OF VIBRATION

The pseudo-dynamic modal analysis method utilized in this appendix is based on the natural period of the structure and contents as defined in this section.

E.4.5.1 Impulsive Natural Period

The design methods in this appendix are independent of impulsive period of the tank. However, the impulsive period of the tank system may be estimated by Equation E.4.5.1-1.

In SI units:

$$T_i = \frac{1}{\sqrt{2000}} \frac{C_i H}{\sqrt{t_u}} \sqrt{E} \quad \text{Rho} = 9.35 \quad \text{(E.4.5.1-1a)}$$

In US Customary units:

$$T_i = \frac{1}{27.8} \frac{C_i H}{\sqrt{t_u}} \sqrt{E} \quad \text{Rho} = 9.35 \quad \text{(E.4.5.1-1b)}$$

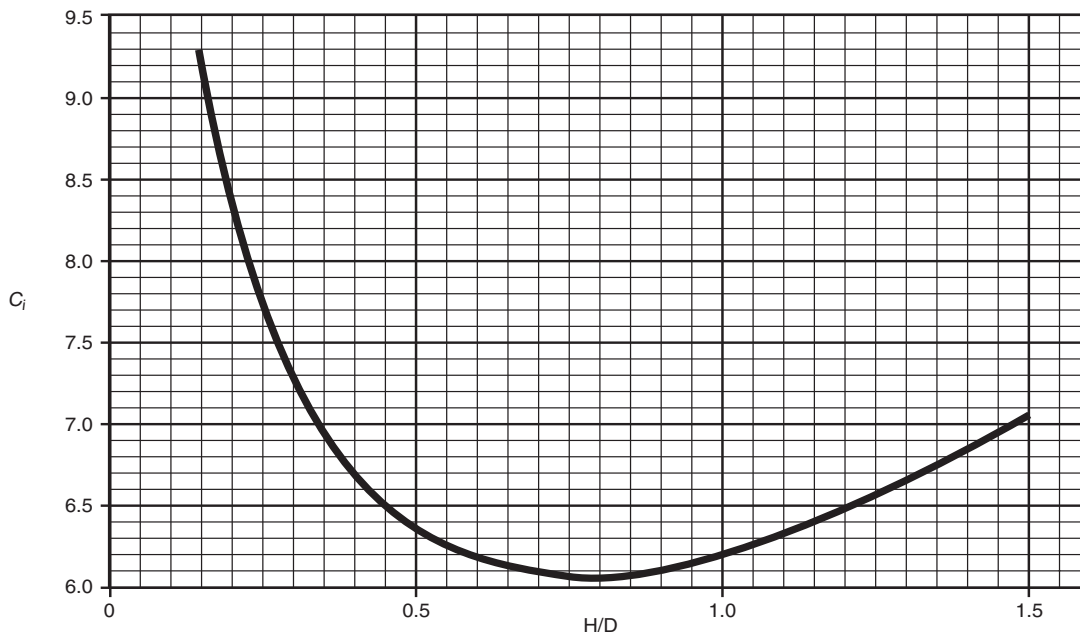


Figure E-1—Coefficient C_i

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E.4.5.2 Convective (Sloshing) Period

The first mode sloshing wave period, in seconds, shall be calculated by Equation E.4.5.2 where K_s is the sloshing period coefficient defined in Equation E.4.5.2-c:

In SI units:

$$T_c = 1.8K_s\sqrt{D} \quad (\text{E.4.5.2-a})$$

or, in US Customary units:

$$T_c = K_s\sqrt{D} \quad (\text{E.4.5.2-b})$$

$$K_s = \frac{0.578}{\sqrt{\tanh\left(\frac{3.68H}{D}\right)}} \quad (\text{E.4.5.2-c})$$

E.4.6 DESIGN SPECTRAL RESPONSE ACCELERATIONS

The design response spectrum for ground supported, flat-bottom tanks is defined by the following parameters:

• E.4.6.1 Spectral Acceleration Coefficients

When probabilistic or mapped design methods are utilized, the spectral acceleration parameters for the design response spectrum are given in Equations E.4.6.1-1 through E.4.6.1-5. Unless otherwise specified by the Purchaser, T_L shall be taken as the mapped value found in ASCE 7. For tanks falling in SUG I or SUG II, the mapped value of T_L shall be used to determine convective forces except that a value of T_L equal to 4 seconds shall be permitted to be used to determine the sloshing wave height. For tanks falling in SUG III, the mapped value of T_L shall be used to determine both convective forces and sloshing wave height except that the importance factor, I , shall be set equal to 1.0 in the determination of sloshing wave height. In regions outside the USA, where the regulatory requirements for determining design ground motion differ from the ASCE 7 methods prescribed in this appendix, T_L shall be taken as 4 seconds.

For sites where only the peak ground acceleration is defined, substitute S_P for S_0 in Equations E.4.6.1-1 through E.4.6.2-1. The scaling factor, Q , is defined as $^{2/3}$ for the ASCE 7 methods. Q may be taken equal to 1.0 unless otherwise defined in the regulatory requirements where ASCE 7 does not apply. Soil amplification coefficients, F_a and F_v ; the value of the importance factor, I , and the ASD response modification factors, R_{wi} and R_{wc} , shall be as defined by the local regulatory requirements. If these values are not defined by the regulations, the values in this appendix shall be used.

Impulsive spectral acceleration parameter, A_i :

$$A_i = S_{DS}\left(\frac{I}{R_{wi}}\right) = 2.5QF_aS_0\left(\frac{I}{R_{wi}}\right) \quad (\text{E.4.6.1-1})$$

However,

$$A_i \geq 0.007 \quad (\text{E.4.6.1-2})$$

and, for seismic design categories E and F only,:

$$A_i \geq 0.5S_1\left(\frac{I}{R_{wi}}\right) = 0.875S_P\left(\frac{I}{R_{wi}}\right) \quad (\text{E.4.6.1-3})$$

Convective spectral acceleration parameter, A_c :

$$\text{When, } T_C \leq T_L \quad A_c = KS_{D1}\left(\frac{1}{T_c}\right)\left(\frac{I}{R_{wc}}\right) = 2.5KQF_vS_0\left(\frac{T_s}{T_c}\right)\left(\frac{I}{R_{wc}}\right) \leq A_i \quad (\text{E.4.6.1-4})$$

$$\text{When, } T_C > T_L \quad A_c = KS_{D1}\left(\frac{T_L}{T_c^2}\right)\left(\frac{I}{R_{wc}}\right) = 2.5KQF_vS_0\left(\frac{T_sT_L}{T_c^2}\right)\left(\frac{I}{R_{wc}}\right) \leq A_i \quad (\text{E.4.6.1-5})$$

E.4.6.2 Site-Specific Response Spectra

07 | When site-specific design methods are specified, the seismic parameters shall be defined by Equations E.4.6.2-1 through E.4.6.2-3.

Impulsive spectral acceleration parameter:

$$A_i = 2.5Q\left(\frac{I}{R_{wi}}\right)S_{a0}^* \quad (\text{E.4.6.2-1})$$

Alternatively, A_i may be determined using either (1) the impulsive period of the tank system, or (2) assuming the impulsive period = 0.2 sec;

$$A_i = Q\left(\frac{I}{R_{wi}}\right)S_a^* \quad (\text{E.4.6.2-2})$$

07 | where, S_a^* is the ordinate of the 5% damped, site-specific MCE response spectra at the calculated impulsive period including site soil effects. See E.4.5.1.

Exception:

- Unless otherwise specified by the Purchaser, the value of the impulsive spectral acceleration, S_a^* , for flat-bottom tanks with $H/D \leq 0.8$ need not exceed 150%g when the tanks are:
 - self-anchored, or
 - mechanically-anchored tanks that are equipped with traditional anchor bolt and chairs at least 450 mm (18 in.) high and are not otherwise prevented from sliding laterally at least 25 mm (1 in.).

Convective spectral acceleration:

$$A_c = QK\left(\frac{I}{R_{wc}}\right)S_a^* \quad (\text{E.4.6.2-3})$$

07 | where, S_a^* is the ordinate of the 5% damped, site-specific MCE response spectra at the calculated convective period including site soil effects (see E.4.5.2).

Alternatively, the ordinate of a site-specific spectrum based on the procedures of E.4.2 for 0.5% damping may be used to determine the value S_a^* with K set equal to 1.0.

E.5 Seismic Design Factors

E.5.1 DESIGN FORCES

The equivalent lateral seismic design force shall be determined by the general relationship

$$F = AW_{\text{eff}} \quad (\text{E.5.1-1})$$

where

A = lateral acceleration coefficient, %g,

W_{eff} = effective weight.

E.5.1.1 Response Modification Factor

The response modification factor for ground supported, liquid storage tanks designed and detailed to these provisions shall be less than or equal to the values shown in Table E-4.

Table E-4—Response Modification Factors for ASD Methods

Anchorage system	R_{wi} (impulsive)	R_{wc} (convective)
Self-anchored	3.5	2
Mechanically-anchored	4	2

E.5.1.2 Importance Factor

- The importance factor (I) is defined by the SUG and shall be specified by the Purchaser. See E.3 and Table E-5.

Table E-5—Importance Factor (I) and Seismic Use Group Classification

Seismic Use Group	I
I	1.0
II	1.25
III	1.5

E.6 Design

E.6.1 DESIGN LOADS

Ground-supported, flat-bottom tanks, storing liquids shall be designed to resist the seismic forces calculated by considering the effective mass and dynamic liquid pressures in determining the equivalent lateral forces and lateral force distribution. This is the default method for this appendix. The equivalent lateral force base shear shall be determined as defined in the following sections. The seismic base shear shall be defined as the square root of the sum of the squares (SRSS) combination of the impulsive and convective components unless the applicable regulations require direct sum. For the purposes of this appendix, an alternate method using the direct sum of the effects in one direction combined with 40% of the effect in the orthogonal direction is deemed to be equivalent to the SRSS summation.

$$V = \sqrt{V_i^2 + V_c^2} \quad (\text{E.6.1-1})$$

where

$$V_i = A_i(W_s + W_r + W_f + W_i) \quad (\text{E.6.1-2})$$

$$V_c = A_c W_c \quad (\text{E.6.1-3})$$

E.6.1.1 Effective Weight of Product

The effective weights W_i and W_c shall be determined by multiplying the total product weight, W_p , by the ratios W_i/W_p and W_c/W_p , respectively, Equations E.6.1.1-1 through E.6.1.1-3.

When D/H is greater than or equal to 1.333, the effective impulsive weight is defined in Equation E.6.1.1-1:

$$W_i = \frac{\tanh\left(0.866\frac{D}{H}\right)}{0.866\frac{D}{H}} W_p \quad (\text{E.6.1.1-1})$$

When D/H is less than 1.333, the effective impulsive weight is defined in Equation E.6.1.1-2:

$$W_i = \left[1.0 - 0.218\frac{D}{H}\right] W_p \quad (\text{E.6.1.1-2})$$

The effective convective weight is defined in Equation E.6.1.1-3:

$$W_c = 0.230 \frac{D}{H} \tanh\left(\frac{3.67H}{D}\right) \quad (\text{E.6.1.1-3})$$

E.6.1.2 Center of Action for Effective Lateral Forces

07 | The moment arm from the base of the tank to the center of action for the equivalent lateral forces from the liquid is defined by Equations E.6.1.2.1-1 through E.6.1.2.2-3.

The center of action for the impulsive lateral forces for the tank shell, roof and appurtenances is assumed to act through the center of gravity of the component.

E.6.1.2.1 Center of Action for Ringwall Overturning Moment

The ringwall moment, M_{rw} , is the portion of the total overturning moment that acts at the base of the tank shell perimeter. This moment is used to determine loads on a ringwall foundation, the tank anchorage forces, and to check the longitudinal shell compression.

The heights from the bottom of the tank shell to the center of action of the lateral seismic forces applied to W_i and W_c , X_i and X_c , may be determined by multiplying H by the ratios X_i/H and X_c/H , respectively, obtained for the ratio D/H by using Equations E.6.1.2.1-1 through E.6.1.2.1-3.

When D/H is greater than or equal to 1.3333, the height X_i is determined by Equation E.6.1.2.1-1:

$$X_i = 0.375H \quad (\text{E.6.1.2.1-1})$$

When D/H is less than 1.3333, the height X_i is determined by Equation E.6.1.2.1-2:

$$X_i = \left[0.5 - 0.094 \frac{D}{H}\right]H \quad (\text{E.6.1.2.1-2})$$

The height X_c is determined by Equation E.6.1.2.1-3:

07 |

$$X_c = \left[1.0 - \frac{\cosh\left(\frac{3.67H}{D}\right) - 1}{\frac{3.67H}{D} \sinh\left(\frac{3.67H}{D}\right)}\right]H \quad (\text{E.6.1.2.1-3})$$

E.6.1.2.2 Center of Action for Slab Overturning Moment

The “slab” moment, M_s , is the total overturning moment acting across the entire tank base cross-section. This overturning moment is used to design slab and pile cap foundations.

When D/H is greater than or equal to 1.333, the height X_{is} is determined by Equation E.6.1.2.2-1:

$$X_{is} = 0.375 \left[1.0 + 1.333 \left(\frac{0.866 \frac{D}{H}}{\tanh\left(0.866 \frac{D}{H}\right)} - 1.0\right)\right]H \quad (\text{E.6.1.2.2-1})$$

When D/H is less than 1.333, the height X_{is} is determined by Equation E.6.1.2.2-2:

07 |

$$X_{is} = \left[0.500 + 0.060 \frac{D}{H}\right]H \quad (\text{E.6.1.2.2-2})$$

The height, X_{cs} , is determined by Equation E.6.1.2.2-3:

$$X_{cs} = \left[1.0 - \frac{\cosh\left(\frac{3.67H}{D}\right) - 1.937}{\frac{3.67H}{D} \sinh\left(\frac{3.67H}{D}\right)} \right] H \quad (\text{E.6.1.2.2-3})$$

E.6.1.3 Vertical Seismic Effects

- When specified (see Line 12 in the Data Sheet), vertical acceleration effects shall be considered as acting in both upward and downward directions and combined with lateral acceleration effects by the SRSS method unless a direct sum combination is required by the applicable regulations. Vertical acceleration effects for hydrodynamic hoop stresses shall be combined as shown in E.6.1.4. Vertical acceleration effects need not be combined concurrently for determining loads, forces, and resistance to overturning in the tank shell.
- The maximum vertical seismic acceleration parameter shall be taken as $0.14S_{DS}$ or greater for the ASCE 7 method unless otherwise specified by the Purchaser. Alternatively, the Purchaser may specify the vertical ground motion acceleration parameter, A_v . The total vertical seismic force shall be:

$$F_v = \pm A_v W_{\text{eff}} \quad (\text{E.6.1.3-1})$$

Vertical seismic effects shall be considered in the following when specified:

- Shell hoop tensile stresses (see E.6.1.4).
- Shell-membrane compression (see E.6.2.2).
- Anchorage design (see E.6.2.1).
- Fixed roof components (see E.7.5).
- Sliding (see E.7.6).
- Foundation design (see E.6.2.3).
- In regions outside the USA where the regulatory requirements differ from the methods prescribed in this appendix, the vertical acceleration parameter and combination with lateral effects may be applied as defined by the governing regulatory requirements.

E.6.1.4 Dynamic Liquid Hoop Forces

Dynamic hoop tensile stresses due to the seismic motion of the liquid shall be determined by the following formulas:

For $D/H \geq 1.333$:

In SI units:

$$N_i = 21.4A_iGDH \left[\frac{Y}{H} - 0.5 \left(\frac{Y}{H} \right)^2 \right] \tanh \left(0.866 \frac{D}{H} \right) \quad (\text{E.6.1.4-1a})$$

or, in US Customary units:

$$N_i = 18A_iGDH \left[\frac{Y}{H} - 0.5 \left(\frac{Y}{H} \right)^2 \right] \tanh \left(0.866 \frac{D}{H} \right) \quad (\text{E.6.1.4-1b})$$

For $D/H < 1.33$ and $Y < 0.75D$:

In SI units:

$$N_i = 13.16A_iGD^2 \left[\frac{Y}{0.75D} - 0.5 \left(\frac{Y}{0.75D} \right)^2 \right] \quad (\text{E.6.1.4-2a})$$

or, in US Customary units:

$$N_i = 11A_iGD^2 \left[\frac{Y}{0.75D} - 0.5 \left(\frac{Y}{0.75D} \right)^2 \right] \quad (\text{E.6.1.4-2b})$$

For $D/H < 1.333$ and $Y \geq 0.75D$:

In SI units:

$$N_i = 6.6A_iGD^2 \quad (\text{E.6.1.4-3a})$$

or, in US Customary units:

$$N_i = 5.54A_iGD^2 \quad (\text{E.6.1.4-3b})$$

For all proportions of D/H :

In SI units:

$$N_c = \frac{33.1A_cC_cSGD^2 \cosh \left[\frac{3.68(H-Y)}{D} \right]}{\cosh \left[\frac{3.68H}{D} \right]} \quad (\text{E.6.1.4-4a})$$

07 | or, in US Customary units:

$$N_c = \frac{3.9A_cC_cSGD^2 \cosh \left[\frac{3.68(H-Y)}{D} \right]}{\cosh \left[\frac{3.68H}{D} \right]} \quad (\text{E.6.1.4-4b})$$

07 | When the Purchaser specifies that vertical acceleration need not be considered (i.e., $A_v = 0$), the combined hoop stress shall be defined by Equation E.6.1.4-5. The dynamic hoop tensile stress shall be directly combined with the product hydrostatic design stress in determining the total stress.

$$\sigma_T = \sigma_h \pm \sigma_s = \frac{N_h \pm \sqrt{N_i^2 + N_c^2}}{t} \quad (\text{E.6.1.4-5})$$

07 | When vertical acceleration is specified.

$$\sigma_T = \sigma_h \pm \sigma_s = \frac{N_h \pm \sqrt{N_i^2 + N_c^2 + (A_v N_h)^2}}{t} \quad (\text{E.6.1.4-6})$$

E.6.1.5 Overturning Moment

- The seismic overturning moment at the base of the tank shell shall be the SRSS summation of the impulsive and convective components multiplied by the respective moment arms to the center of action of the forces unless otherwise specified.

Ringwall Moment, M_{rw} :

$$M_{rw} = \sqrt{[A_i(W_iX_i + W_sX_s + W_rX_r)]^2 + [A_c(W_cX_c)]^2} \quad (\text{E.6.1.5-1})$$

Slab Moment, M_s :

$$M_s = \sqrt{[A_i(W_iX_{is} + W_sX_s + W_rX_r)]^2 + [A_c(W_cX_{cs})]^2} \quad (\text{E.6.1.5-2})$$

Unless a more rigorous determination is used, the overturning moment at the bottom of each shell ring shall be defined by linear approximation using the following:

1. If the tank is equipped with a fixed roof, the impulsive shear and overturning moment is applied at the top of the shell.
2. The impulsive shear and overturning moment for each shell course is included based on the weight and centroid of each course.
3. The overturning moment due to the liquid is approximated by a linear variation that is equal to the ringwall moment, M_{rw} at the base of the shell to zero at the maximum liquid level.

E.6.1.6 Soil-Structure Interaction

- If specified by the Purchaser, the effects of soil-structure interaction on the effective damping and period of vibration may be considered for tanks in accordance with ASCE 7 with the following limitations:
 - Tanks shall be equipped with a reinforced concrete ringwall, mat or similar type foundation supported on grade. Soil structure interaction effects for tanks supported on granular berm or pile type foundation are outside the scope of this appendix.
 - The tanks shall be mechanically anchored to the foundation.
 - The value of the base shear and overturning moments for the impulsive mode including the effects of soil-structure interaction shall not be less than 80% of the values determined without consideration of soil-structure interaction.
 - The effective damping factor for the structure-foundation system shall not exceed 20%.

E.6.2 RESISTANCE TO DESIGN LOADS

The allowable stress design (ASD) method is utilized in this appendix. Allowable stresses in structural elements applicable to normal operating conditions may be increased by 33% when the effects of the design earthquake are included unless otherwise specified in this appendix.

E.6.2.1 Anchorage

Resistance to the design overturning (ringwall) moment at the base of the shell may be provided by:

- The weight of the tank shell, weight of roof reaction on shell W_{rs} , and by the weight of a portion of the tank contents adjacent to the shell for unanchored tanks.
- Mechanical anchorage devices.

E.6.2.1.1 Self-Anchored

For self-anchored tanks, a portion of the contents may be used to resist overturning. The anchorage provided is dependent on the assumed width of a bottom annulus uplifted by the overturning moment. The resisting annulus may be a portion of the tank bottom (i.e., $t_a = t_b$) or a separate butt-welded annular ring (i.e., $t_a > t_b$). The resisting force of the annulus that lifts off the foundation shall be determined by Equation E.6.2.1.1-1.

In SI units:

$$w_a = 99t_a\sqrt{F_yHG_e} \leq 1.96 HDG_c \quad \text{(E.6.2.1.1-1a)} \quad | \quad 07$$

or, in US Customary units:

$$w_a = 7.9t_a\sqrt{F_yHG_e} \leq 1.28 HDG_c \quad \text{(E.6.2.1.1-1b)} \quad | \quad 07$$

Equation E.6.2.1.1-1 for w_a applies whether or not a thickened bottom annulus is used.

The tank is self-anchored providing the following conditions are met:

1. The resisting force is adequate for tank stability (i.e., the anchorage ratio, $J \leq 1.54$).
2. The maximum width of annulus for determining the resisting force is 3.5% of the tank diameter.
3. The shell compression satisfies E.6.2.2.
4. The required annular plate thickness does not exceed the thickness of the bottom shell course.
5. Piping flexibility requirements are satisfied.

E.6.2.1.1.1 Anchorage Ratio, J

$$J = \frac{M_{rw}}{D^2(w_t(1 - 0.4A_v) + w_a)} \quad (\text{E.6.2.1.1.1-1})$$

where

$$w_t = \left[\frac{W_s}{\pi D} + w_{rs} \right] \quad (\text{E.6.2.1.1.1-2})$$

Table E-6—Anchorage Ratio Criteria

Anchorage Ratio J	Criteria
$J \leq 0.785$	No calculated uplift under the design seismic overturning moment. The tank is self-anchored.
$0.785 < J \leq 1.54$	Tank is uplifting, but the tank is stable for the design load providing the shell compression requirements are satisfied. Tank is self-anchored.
$J > 1.54$	Tank is not stable and cannot be self-anchored for the design load. Modify the annular plate if $L < 0.035D$ is not controlling or add mechanical anchorage.

E.6.2.1.1.2 Annular Plate Requirements

The thickness of the tank bottom plate provided under the shell may be greater than or equal to the thickness of the general tank floor plate (i.e., $t_a \geq t_b$) with the following restrictions.

Note: In thickening the bottom annulus, the intent is not to force a thickening of the lowest shell course, thereby inducing an abrupt thickness change in the shell, but rather to impose a limit on the bottom annulus thickness based on the shell design.

1. The thickness, t_a , used to calculate w_a in Equation E.6.2.1.1-1b shall not exceed the first shell course thickness, t_s , less the shell corrosion allowance.
2. Nor shall the thickness, t_a , used in Equation E.6.2.1.1-1b exceed the actual thickness of the plate under the shell less the corrosion allowance for tank bottom.
3. When the bottom plate under the shell is thicker than the remainder of the tank bottom (i.e., $t_a > t_b$) the minimum projection of the supplied thicker annular plate inside the tank wall, L_s , shall be equal to or greater than L :

In SI units:

$$L = 0.01723t_a\sqrt{F_y/HG_e} \leq 0.035D \quad (\text{E.6.2.1.1.2-1a})$$

or, in US Customary units:

$$L = 0.216t_a\sqrt{F_y/HG_e} \leq 0.035D \quad (\text{E.6.2.1.1.2-1b})$$

E.6.2.1.2 Mechanically-Anchored

- If the tank configuration is such that the self-anchored requirements can not be met, the tank must be anchored with mechanical devices such as anchor bolts or straps.

When tanks are anchored, the resisting weight of the product shall not be used to reduce the calculated uplift load on the anchors. The anchors shall be sized to provide for at least the following minimum anchorage resistance:

$$w_{AB} = \left(\frac{1.273M_{rw}}{D^2} - w_t(1 - 0.4A_v) \right) \quad (\text{E.6.2.1.2-1})$$

plus 0.4 times the uplift, in N/m (lbf/ft²) of shell circumference, due to design internal pressure. See Appendix R for load combinations. If the ratio of operating pressure to design pressure exceeds 0.4, the Purchaser should consider specifying a higher factor on design. Wind loading need not be considered in combination with seismic loading.

The anchor seismic design load, P_{AB} , is defined in Equation E.6.2.1.2-2:

$$P_{AB} = w_{AB} \left(\frac{\pi D}{n_A} \right) \quad (\text{E.6.2.1.2-2})$$

where, n_A is the number of equally-spaced anchors around the tank circumference. P_{AB} shall be increased to account for unequal spacing.

When mechanical anchorage is required, the anchor embedment or attachment to the foundation, the anchor attachment assembly and the attachment to the shell shall be designed for P_A . The anchor attachment design load, P_A , shall be the lesser of the load equal to the minimum specified yield strength multiplied by the as-built cross-sectional area of the anchor or three times P_{AB} .

The maximum allowable stress for the anchorage parts shall not exceed the following values for anchors designed for the seismic loading alone or in combination with other load cases:

- An allowable tensile stress for anchor bolts and straps equal to 80% of the published minimum yield stress.
- For other parts, 133% of the allowable stress in accordance with 5.10.3.
- The maximum allowable design stress in the shell at the anchor attachment shall be limited to 170 MPa (25,000 kPa) with no increase for seismic loading. These stresses can be used in conjunction with other loads for seismic loading when the combined loading governs.

E.6.2.2 Maximum Longitudinal Shell-Membrane Compression Stress

E.6.2.2.1 Shell Compression in Self-Anchored Tanks

The maximum longitudinal shell compression stress at the bottom of the shell when there is no calculated uplift, $J < 0.785$, shall be determined by the formula

In SI units:

$$\sigma_c = \left(w_i(1 + 0.4A_v) + \frac{1.273M_{rw}}{D^2} \right) \frac{1}{1000t_s} \quad (\text{E.6.2.2.1-1a})$$

or, in US Customary units:

$$\sigma_c = \left(w_i(1 + 0.4A_v) + \frac{1.273M_{rw}}{D^2} \right) \frac{1}{12t_s} \quad (\text{E.6.2.2.1-1b})$$

The maximum longitudinal shell compression stress at the bottom of the shell when there is calculated uplift, $J > 0.785$, shall be determined by the formula:

In SI units:

$$\sigma_c = \left(\frac{w_i(1 + 0.4A_v) + w_a}{0.607 - 0.18667[J]^{2.3}} - w_a \right) \frac{1}{1000t_s} \quad (\text{E.6.2.2.1-2a})$$

or, in US Customary units:

$$\sigma_c = \left(\frac{w_i(1 + 0.4A_v) + w_a}{0.607 - 0.18667[J]^{2.3}} - w_a \right) \frac{1}{12t_s} \quad (\text{E.6.2.2.1-2b})$$

E.6.2.2.2 Shell Compression in Mechanically-Anchored Tanks

The maximum longitudinal shell compression stress at the bottom of the shell for mechanically-anchored tanks shall be determined by the formula

In SI units:

$$\sigma_c = \left(w_t(1 + 0.4A_v) + \frac{1.273M_{rw}}{D^2} \right) \frac{1}{1000t_s} \quad (\text{E.6.2.2.2-1a})$$

or, in US Customary units:

$$\sigma_c = \left(w_t(1 + 0.4A_v) + \frac{1.273M_{rw}}{D^2} \right) \frac{1}{12t_s} \quad (\text{E.6.2.2.2-1b})$$

E.6.2.2.3 Allowable Longitudinal Shell-Membrane Compression Stress in Tank Shell

The maximum longitudinal shell compression stress s_c must be less than the seismic allowable stress F_C , which is determined by the following formulas and includes the 33% increase for ASD. These formulas for F_C consider the effect of internal pressure due to the liquid contents.

When GHD^2/t^2 is greater than or equal to 44 (SI units) (10^6 US Customary units),

In SI units:

$$F_C = 83 t_s/D \quad (\text{E.6.2.2.3-1a})$$

or, in US Customary units:

$$07 \quad F_C = 10^6 t_s/D \quad (\text{E.6.2.2.3-1b})$$

In SI units:

When GHD^2/t^2 is less than 44:

$$07 \quad F_C = 8t_s/(2.5D) + 7.5\sqrt{GH} < 0.5F_{ty} \quad (\text{E.6.2.2.3-2a})$$

or, in US Customary units:

When GHD^2/t^2 is less than 1×10^6 :

$$07 \quad F_C = 10^6 t_s/(2.5D) + 600\sqrt{GH} < 0.5F_{ty} \quad (\text{E.6.2.2.3-2b})$$

If the thickness of the bottom shell course calculated to resist the seismic overturning moment is greater than the thickness required for hydrostatic pressure, both excluding any corrosion allowance, then the calculated thickness of each upper shell course for hydrostatic pressure shall be increased in the same proportion, unless a special analysis is made to determine the seismic overturning moment and corresponding stresses at the bottom of each upper shell course (see E.6.1.5).

E.6.2.3 Foundation

Foundations and footings for mechanically-anchored flat-bottom tanks shall be proportioned to resist peak anchor uplift and overturning bearing pressure. Product and soil load directly over the ringwall and footing may be used to resist the maximum anchor uplift on the foundation, provided the ringwall and footing are designed to carry this eccentric loading.

Product load shall not be used to reduce the anchor load.

When vertical seismic accelerations are applicable, the product load directly over the ringwall and footing:

1. When used to resist the maximum anchor uplift on the foundation, the product pressure shall be multiplied by a factor of $(1 - 0.4A_v)$ and the foundation ringwall and footing shall be designed to resist the eccentric loads with or without the vertical seismic accelerations.
2. When used to evaluate the bearing (downward) load, the product pressure over the ringwall shall be multiplied by a factor of $(1 + 0.4A_v)$ and the foundation ringwall and footing shall be designed to resist the eccentric loads with or without the vertical seismic accelerations.

The overturning stability ratio for mechanically-anchored tank system excluding vertical seismic effects shall be 2.0 or greater as defined in Equation E.6.2.3-1.

$$\frac{0.5D[W_p + W_f + W_T + W_{fd} + W_g]}{M_s} \geq 2.0 \quad (\text{E.6.2.3-1})$$

Ringwalls for self-anchored flat-bottom tanks shall be proportioned to resist overturning bearing pressure based on the maximum longitudinal shell compression force at the base of the shell in Equation E.6.2.3-2. Slabs and pile caps for self-anchored tanks shall be designed for the peak loads determined in E.6.2.2.1.

$$P_f = \left(w_t(1 + 0.4A_v) + \frac{1.273M_{rw}}{D^2} \right) \quad (\text{E.6.2.3-2})$$

E.6.2.4 Hoop Stresses

The maximum allowable hoop tension membrane stress for the combination of hydrostatic product and dynamic membrane hoop effects shall be the lesser of:

- The basic allowable membrane in this Standard for the shell plate material increased by 33%; or,
- $0.9F_y$ times the joint efficiency where F_y is the lesser of the published minimum yield strength of the shell material or weld material.

E.7 Detailing Requirements

E.7.1 ANCHORAGE

Tanks at grade are permitted to be designed without anchorage when they meet the requirements for self-anchored tanks in this appendix.

The following special detailing requirements shall apply to steel tank mechanical anchors in seismic regions where $S_{DS} > 0.05g$.

E.7.1.1 Self-Anchored

For tanks in SUG III and located where $S_{DS} = 0.5g$ or greater, butt-welded annular plates shall be required. Annular plates exceeding 10 mm ($3/8$ in.) thickness shall be butt-welded. The weld of the shell to the bottom annular plate shall be checked for the design uplift load.

E.7.1.2 Mechanically-Anchored

When mechanical-anchorage is required, at least six anchors shall be provided. The spacing between anchors shall not exceed 3 m (10 ft).

When anchor bolts are used, they shall have a minimum diameter of 25 mm (1 in.), excluding any corrosion allowance. Carbon steel anchor straps shall be 6 mm ($1/4$ in.) minimum thickness and have a minimum corrosion allowance of 1.5 mm ($1/16$ in.) on each surface for a distance at least 75 mm (3 in.) but not more than 300 mm (12 in.) above the surface of the concrete.

Hooked anchor bolts (L- or J-shaped embedded bolts) or other anchorage systems based solely on bond or mechanical friction shall not be used when seismic design is required by this appendix. Post-installed anchors may be used provided that testing validates their ability to develop yield load in the anchor under cyclic loads in cracked concrete and meet the requirements of ACI 355.

E.7.2 FREEBOARD

- Slashing of the liquid within the tank or vessel shall be considered in determining the freeboard required above the top capacity liquid level. A minimum freeboard shall be provided per Table E-7. See E.4.6.1. Purchaser shall specify whether freeboard is desired for SUG I tanks. Freeboard is required for SUG II and SUG III tanks. The height of the slashing wave above the product design height can be estimated by:

$$\delta_s = 0.5DA_f \text{ (see Note c in Table E-7)} \tag{E.7.2-1}$$

For SUG I and II,

$$\text{When, } T_C \leq 4 \tag{E.7.2-2} \quad A_f = KS_{D1}I\left(\frac{1}{T_C}\right) = 2.5KQF_vS_0I\left(\frac{T_S}{T_C}\right)$$

$$\text{When, } T_C > 4 \tag{E.7.2-3} \quad A_f = KS_{D1}I\left(\frac{4}{T_C^2}\right) = 2.5KQF_vS_0I\left(\frac{4T_S}{T_C^2}\right)$$

For SUG III,

$$\text{When, } T_C \leq T_L \tag{E.7.2-4} \quad A_f = KS_{D1}\left(\frac{1}{T_C}\right) = 2.5KQF_vS_0\left(\frac{T_S}{T_C}\right)$$

$$\text{When, } T_C > T_L \tag{E.7.2-5} \quad A_f = KS_{D1}\left(\frac{T_L}{T_C^2}\right) = 2.5KQF_vS_0\left(\frac{T_S T_L}{T_C^2}\right)$$

Table E-7—Minimum Required Freeboard

Value of S_{DS}	SUG I	SUG II	SUG III
$S_{DS} < 0.33g$	$0.7\delta_s (a)$	$0.7\delta_s (a)$	$\delta_s (c)$
$S_{DS} \geq 0.33g$	$0.7\delta_s (a)$	$0.7\delta_s (b)$	$\delta_s (c)$

a. A freeboard of $0.7\delta_s$ is recommended for economic considerations but not required.
 b. A freeboard equal to $0.7\delta_s$ is required unless one of the following alternatives are provided:
 1. Secondary containment is provided to control the product spill.
 2. The roof and tank shell are designed to contain the slashing liquid.
 c. Freeboard equal to the calculated wave height, δ_s , is required unless one of the following alternatives are provided:
 1. Secondary containment is provided to control the product spill.
 2. The roof and tank shell are designed to contain the slashing liquid.

E.7.3 PIPING FLEXIBILITY

Piping systems connected to tanks shall consider the potential movement of the connection points during earthquakes and provide sufficient flexibility to avoid release of the product by failure of the piping system. The piping system and supports shall be designed so as to not impart significant mechanical loading on the attachment to the tank shell. Local loads at piping connections shall be considered in the design of the tank shell. Mechanical devices which add flexibility such as bellows, expansion joints, and other flexible apparatus may be used when they are designed for seismic loads and displacements.

- Unless otherwise calculated, piping systems shall provide for the minimum displacements in Table E-8 at working stress levels (with the 33% increase for seismic loads) in the piping, supports and tank connection. The piping system and tank connection shall also be designed to tolerate $1.4C_d$ times the working stress displacements given in Table E-8 without rupture, although permanent deformations and inelastic behavior in the piping supports and tank shell is permitted. For attachment points located above the support or foundation elevation, the displacements in Table E-8 shall be increased to account for drift of the tank or vessel.

Table E-8—Design Displacements for Piping Attachments

Condition	ASD Design Displacement mm (in.)
Mechanically-anchored tanks	
Upward vertical displacement relative to support or foundation:	25 (1)
Downward vertical displacement relative to support or foundation:	13 (0.5)
Range of horizontal displacement (radial and tangential) relative to support or foundation:	13 (0.5)
Self-anchored tanks	
Upward vertical displacement relative to support or foundation:	
Anchorage ratio less than or equal to 0.785:	25 (1)
Anchorage ratio greater than 0.785:	100 (4)
Downward vertical displacement relative to support or foundation:	
For tanks with a ringwall/mat foundation:	13 (0.5)
For tanks with a berm foundation:	25 (1)
Range of horizontal displacement (radial and tangential) relative to support or foundation	50 (2)

The values given in Table E-8 do not include the influence of relative movements of the foundation and piping anchorage points due to foundation movements (such as settlement or seismic displacements). The effects of foundation movements shall be included in the design of the piping system design, including the determination of the mechanical loading on the tank or vessel consideration of the total displacement capacity of the mechanical devices intended to add flexibility.

When $S_{DS} < 0.1$, the values in Table E-7 may be reduced to 70% of the values shown.

E.7.3.1 Method for Estimating Tank Uplift

The maximum uplift at the base of the tank shell for a self-anchored tank constructed to the criteria for annular plates (see E.6.2.1) may be approximated by Equation E.7.3.1-1:

In SI units:

$$y_u = \frac{12.10F_y L^2}{t_b} \quad (\text{E.7.3.1-1a})$$

Or, in US Customary units:

$$y_u = \frac{F_y L^2}{83300t_b} \quad (\text{E.7.3.1-1b})$$

where

t_b = calculated annular ring t holddown.

E.7.4 CONNECTIONS

Connections and attachments for anchorage and other lateral force resisting components shall be designed to develop the strength of the anchor (e.g., minimum published yield strength, F_y in direct tension, plastic bending moment), or 4 times the calculated element design load.

Penetrations, manholes, and openings in shell components shall be designed to maintain the strength and stability of the shell to carry tensile and compressive membrane shell forces.

The bottom connection on an unanchored flat-bottom tank shall be located inside the shell a sufficient distance to minimize damage by uplift. As a minimum, the distance measured to the edge of the connection reinforcement shall be the width of the calculated unanchored bottom hold-down plus 300 mm (12 in.)

E.7.5 INTERNAL COMPONENTS

The attachments of internal equipment and accessories which are attached to the primary liquid- or pressure-retaining shell or bottom, or provide structural support for major components shall be designed for the lateral loads due to the sloshing liquid in addition to the inertial forces.

- Seismic design of roof framing and columns shall be made if specified by the Purchaser. The Purchaser shall specify live loads and amount of vertical acceleration to be used in seismic design of the roof members. Columns shall be designed for lateral liquid inertia loads and acceleration as specified by the Purchaser. Seismic beam-column design shall be based upon the primary member allowable stresses set forth in AISC (ASD), increased by one-third for seismic loading. Internal columns shall be guided or supported to resist lateral loads (remain stable) even if the roof components are not specified to be designed for the seismic loads, including tanks that need not be designed for seismic ground motion in this appendix (see E.1).

E.7.6 SLIDING RESISTANCE

The transfer of the total lateral shear force between the tank and the subgrade shall be considered.

For self-anchored flat-bottom steel tanks, the overall horizontal seismic shear force shall be resisted by friction between the tank bottom and the foundation or subgrade. Self-anchored storage tanks shall be proportioned such that the calculated seismic base shear, V_s , does not exceed V_s :

The friction coefficient, m , shall not exceed 0.4. Lower values of the friction coefficient should be used if the interface of the bottom to supporting foundation does not justify the friction value above (e.g., leak detection membrane beneath the bottom with a lower friction factor, smooth bottoms, etc.).

$$V_s = \mu(W_s + W_r + W_f + W_p)(1.0 - 0.4A_v) \quad (\text{E.7.6-1})$$

No additional lateral anchorage is required for mechanically-anchored steel tanks designed in accordance with this appendix even though small movements of approximately 25 mm (1 in.) are possible.

The lateral shear transfer behavior for special tank configurations (e.g., shovel bottoms, highly crowned tank bottoms, tanks on grillage) can be unique and are beyond the scope of this appendix.

E.7.7 LOCAL SHEAR TRANSFER

Local transfer of the shear from the roof to the shell and the shell of the tank into the base shall be considered. For cylindrical tanks, the peak local tangential shear per unit length shall be calculated by:

$$V_{\max} = \frac{2V}{\pi D} \quad (\text{E.7.7-1})$$

Tangential shear in flat-bottom steel tanks shall be transferred through the welded connection to the steel bottom. The shear stress in the weld shall not exceed 80% of the weld or base metal yield stress. This transfer mechanism is deemed acceptable for steel tanks designed in accordance with the provisions and $S_{DS} < 1.0g$.

E.7.8 CONNECTIONS WITH ADJACENT STRUCTURES

Equipment, piping, and walkways or other appurtenances attached to the tank or adjacent structures shall be designed to accommodate the elastic displacements of the tank imposed by design seismic forces amplified by a factor of 3.0 plus the amplified displacement of the other structure.

E.7.9 SHELL SUPPORT

Self-anchored tanks resting on concrete ringwalls or slabs shall have a uniformly supported annulus under the shell. The foundation must be supplied to the tolerances required in 7.5.5 in to provide the required uniform support for Items b, c, and d below. Uniform support shall be provided by one of the following methods:

- Shimming and grouting the annulus,
- Using fiberboard or other suitable padding
- Using double butt-welded bottom or annular plates resting directly on the foundation, Annular plates or bottom plates under the shell may utilize back-up bars welds if the foundation is notched to prevent the back-up bar from bearing on the foundation.
- 07 Using closely spaced shims (without structural grout) provided that the localized bearing loads are considered in the tank wall and foundation to prevent local crippling and spalling.

Mechanically-anchored tanks shall be shimmed and grouted.

APPENDIX F—DESIGN OF TANKS FOR SMALL INTERNAL PRESSURES

F.1 Scope

F.1.1 The maximum internal pressure for closed-top API Std 650 tanks may be increased to the maximum internal pressure permitted when the additional requirements of this appendix are met. This appendix applies to the storage of nonrefrigerated liquids (see also API Std 620, Appendices Q and R). For maximum design temperatures above 93°C (200°F), see Appendix M.

F.1.2 When the internal pressure multiplied by the cross-sectional area of the nominal tank diameter does not exceed the nominal weight of the metal in the shell, roof, and any framing supported by the shell or roof, see the design requirements in F.3 through F.6. Overturning stability with respect to seismic conditions shall be determined independently of internal pressure uplift. Seismic design shall meet the requirements of Appendix E.

F.1.3 Internal pressures that exceed the weight of the shell, roof, and framing but do not exceed 18 kPa (2½ lbf/in.²) gauge when the shell is anchored to a counterbalancing weight, such as a concrete ringwall, are covered in F.7.

F.1.4 Tanks designed according to this appendix shall comply with all the applicable rules of this Standard unless the rules are superseded by the requirements of F.7.

F.1.5 The tank nameplate (see Figure 10-1) shall indicate whether the tank has been designed in accordance with F.1.2 or F.1.3.

F.1.6 Figure F-1 is provided to aid in the determination of the applicability of various sections of this appendix.

F.2 Venting (Deleted)

F.3 Roof Details

The details of the roof-to-shell junction shall be in accordance with Figure F-2, in which the participating area resisting the compressive force is shaded with diagonal lines.

F.4 Maximum Design Pressure and Test Procedure

F.4.1 The design pressure, P , for a tank that has been constructed or that has had its design details established may be calculated from the following equation (subject to the limitations of P_{\max} in F.4.2):

In SI units:

$$P = \frac{(1.1)(A)(\tan\theta)}{D^2} + 0.08t_h$$

where

P = internal design pressure (kPa),

A = area resisting the compressive force, as illustrated in Figure F-1 (mm²),

θ = angle between the roof and a horizontal plane at the roof-to-shell junction (degrees),

$\tan \theta$ = slope of the roof, expressed as a decimal quantity,

D = tank diameter (m),

t_h = nominal roof thickness (mm).

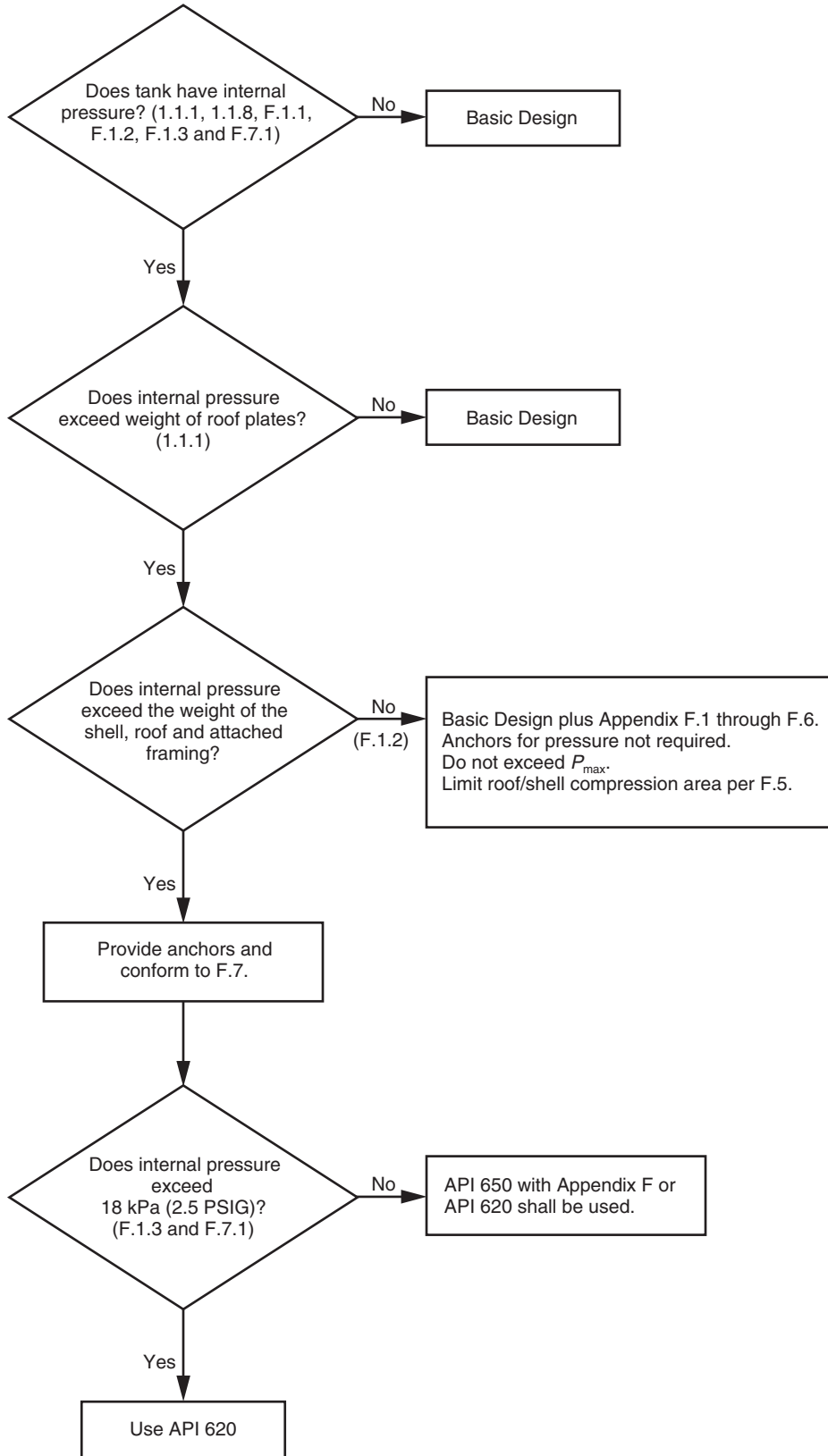
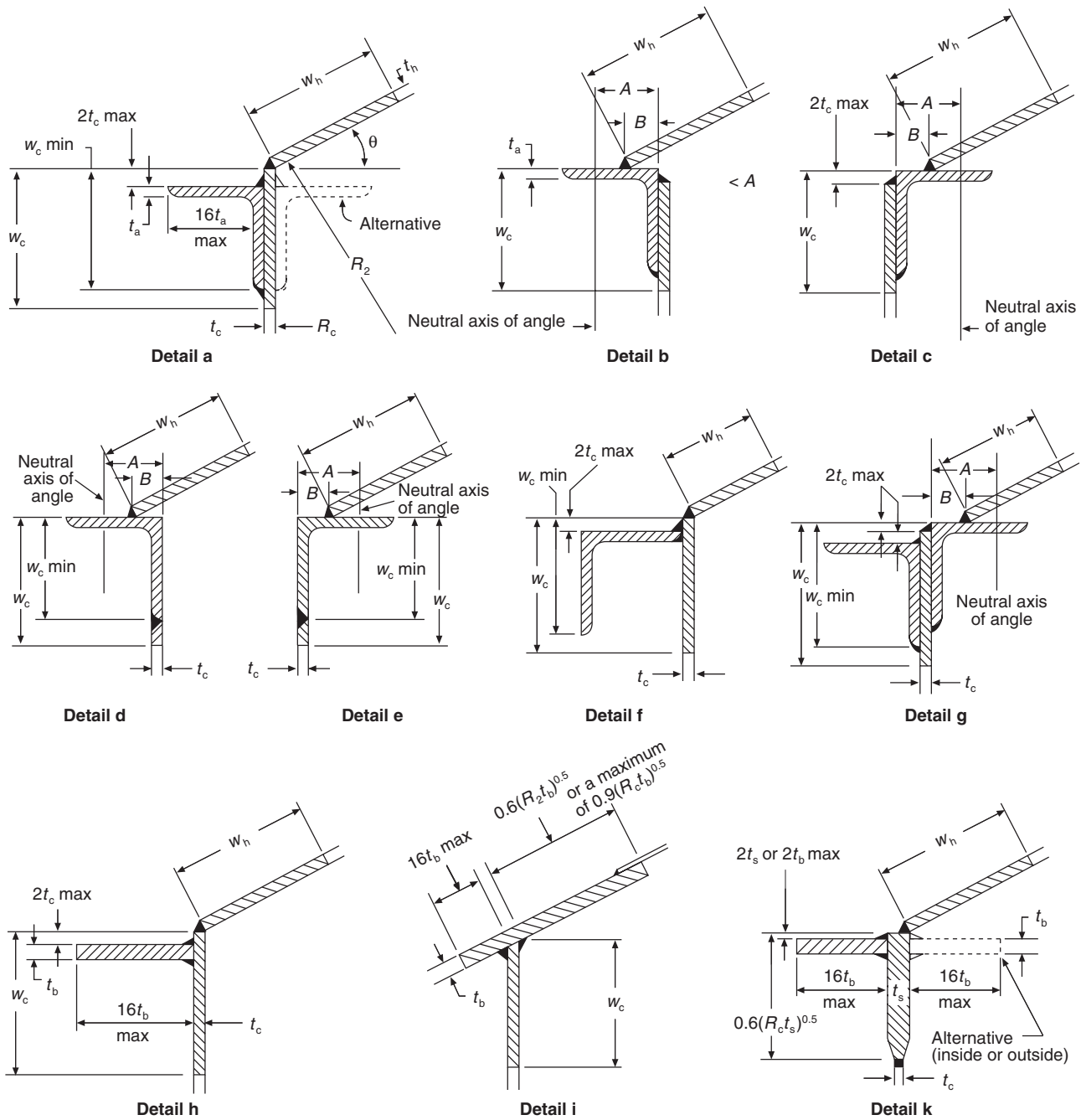


Figure F-1—Appendix F Decision Tree



t_a = thickness of angle leg,
 t_b = thickness of bar,
 t_c = thickness of shell plate,
 t_h = thickness of roof plate,
 t_s = thickness of thickened plate in shell,
 w_c = maximum width of participating shell,
 $= 0.6 (R_c t_s)^{0.5}$, where $t = t_c$ or t_s as applicable,

w_h = maximum width of participating roof,
 $= 0.3 (R_2 t_h)^{0.5}$ 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,
 $= R_c / (\sin \theta)$.

- Notes:
1. All dimensions and thicknesses are in mm (in.).
 2. Dimension B in details b, c, d, and e is: $0 \leq B \leq A$.

Figure F-2—Permissible Details of Compression Rings

In US Customary units:

$$P = \frac{(30,800)(A)(\tan\theta)}{D^2} + 8t_h$$

where

- P = internal design pressure (in. of water),
- A = area resisting the compressive force, as illustrated in Figure F-2 (in.²),
- θ = angle between the roof and a horizontal plane at the roof-to-shell junction (degrees),
- $\tan \theta$ = slope of the roof, expressed as a decimal quantity,
- D = tank diameter (ft),
- t_h = nominal roof thickness (in.).

F.4.2 The maximum design pressure, limited by uplift at the base of the shell, shall not exceed the value calculated from the following equation unless further limited by F.4.3:

In SI units:

$$P_{\max} = \frac{0.00127D_{LS}}{D^2} + 0.08t_h - \frac{0.00425M}{D^3}$$

where

- P_{\max} = maximum design internal pressure (kPa),
- D_{LS} = total weight of the shell and any framing (but not roof plates) supported by the shell and roof (N),
- M = wind moment (N-m).

In US Customary units:

$$P_{\max} = \frac{0.245D_{LS}}{D^2} + 8t_h - \frac{0.817M}{D^3}$$

where

- P_{\max} = maximum design internal pressure (in. of water),
- D_{LS} = total weight of the shell and any framing (but not roof plates) supported by the shell and roof (lbf),
- M = wind moment (ft-lbf).

F.4.3 As top angle size and roof slope decrease and tank diameter increases, the design pressure permitted by F.4.1 and F.4.2 approaches the failure pressure of F.6 for the roof-to-shell junction. In order to provide a safe margin between the maximum operating pressure and the calculated failure pressure, a suggested further limitation on the maximum design pressure for tanks with a weak roof-to-shell attachment (frangible joint) is:

$$P_{\max} \leq 0.8P_f$$

F.4.4 When the entire tank is completed, it shall be filled with water to the top angle or the design liquid level, and the design internal air pressure shall be applied to the enclosed space above the water level and held for 15 minutes. The air pressure shall then be reduced to one-half the design pressure, and all welded joints above the liquid level shall be checked for leaks by means of a soap film, linseed oil, or another suitable material. Tank vents shall be tested during or after this test.

F.5 Required Compression Area at the Roof-to-Shell Junction

- **F.5.1** Where the maximum design pressure has already been established (not higher than that permitted by F.4.2 or F.4.3), the total required compression area at the roof-to-shell junction calculated from the following equation:

In SI units:

$$A = \frac{D^2(P_i - 0.08t_h)}{1.1(\tan\theta)}$$

where

A = total required compression area at the roof-to-shell junction (mm²),

P_i = design internal pressure (kPa).

In US Customary units:

$$A = \frac{D^2(P_i - 8t_h)}{30,800(\tan\theta)}$$

where

A = total required compression area at the roof-to-shell junction (in.²),

P_i = design internal pressure (in. of water),

A is based on the nominal material thickness less any corrosion allowance.

F.5.2 For self-supporting roofs, the compression area shall not be less than the cross-sectional area calculated in 5.10.5 and 5.10.6.

F.6 Calculated Failure Pressure

In tanks that meet the criteria of 5.10.2.6, failure can be expected to occur when the stress in the compression ring area reaches the yield point. On this basis, an approximate formula for the pressure at which failure of the top compression ring is expected to occur can be expressed in terms of the design pressure permitted by F.4.1, as follows:

In SI units:

$$P_f = 1.6P - 0.047t_h$$

where

P_f = calculated failure pressure (kPa).

In US Customary units:

$$P_f = 1.6P - 4.8t_h$$

where

P_f = calculated failure pressure (in. of water).

Note: This formula is based on failure occurring at a yield stress of 220 MPa (32,000 lbf/in.²). Experience with actual failures indicates that buckling of the roof-to-shell junction is localized and probably occurs when the yield point of the material is exceeded in the compression ring area.

F.7 Anchored Tanks with Design Pressures up to 18 kPa (2¹/₂ lbf/in.²) Gauge

F.7.1 In calculating shell thickness for Appendix F tanks that are to be anchored to resist uplift due to internal pressure, and when selecting shell manhole thicknesses in Table 5-3 and flush-type cleanout fitting thicknesses in Table 5-10, H shall be increased by the quantity $P/(9.8G)$ [$P/(12G)$],—where H is the design liquid height, in m (ft), P is the design pressure kPa (in. of water), and G is the design specific gravity.

F.7.2 The required compression area at the roof-to-shell junction of a supported cone roof shall be calculated as in F.5.1, and the participating compression area at the junction shall be determined by Figure F-2. For dome roofs and self-supporting cone roofs, the required area and the participating compression area shall be in accordance with 5.12.4 of API Std 620, except the allowable compressive stress shall be increased to 140 MPa (20,000 lbf/in.²).

Note: When radial lap joints are included in the compression ring region, see API Std 620, Section 5.12.2, Note 18, for an important design issue.

F.7.3 The design and welding of roofs and the design, reinforcement, and welding of roof manholes and nozzles shall be in accordance with API Std 620. The thickness of a self-supporting roof shall not be less than that specified in 5.10.5 or 5.10.6, as applicable. As an alternative to designing the roof manhole per API Std 620, an API Std 650 shell manhole may be used as a roof manhole provided it meets all the requirements for API Std 650 shell manholes, except that it need not meet the toughness requirements in 4.2.9.

- **F.7.4** The design of the anchorage and its attachment to the tank shall be a matter of agreement between the Manufacturer and the Purchaser and shall meet the requirements of 5.12.

F.7.5 The counterbalancing weight, in addition to the requirements in 5.12, shall be designed so that the resistance to uplift at the bottom of the shell will be the greatest of the following:

- a. The uplift produced by 1.5 times the design pressure of the empty tank (minus any specified corrosion allowance) plus the uplift from the design wind velocity on the tank.
- b. The uplift produced by 1.25 times the test pressure applied to the empty tank (with the as-built thicknesses).
- c. The uplift produced by 1.5 times the calculated failure pressure (P_f in F.6) applied to the tank filled with the design liquid. The effective weight of the liquid shall be limited to the inside projection of the ringwall (Appendix B type) from the tank shell. Friction between the soil and the ringwall may be included as resistance. When a footing is included in the ringwall design, the effective weight of the soil may be included.

F.7.6 After the tank is filled with water, the shell and the anchorage shall be visually inspected for tightness. Air pressure of 1.25 times the design pressure shall be applied to the tank filled with water to the design liquid height. The air pressure shall be reduced to the design pressure, and the tank shall be checked for tightness. In addition, all seams above the water level shall be tested using a soap film or another material suitable for the detection of leaks. After the test water has been emptied from the tank (and the tank is at atmospheric pressure), the anchorage shall be checked for tightness. The design air pressure shall then be applied to the tank for a final check of the anchorage.

APPENDIX G—STRUCTURALLY-SUPPORTED ALUMINUM DOME ROOFS

G.1 General

G.1.1 PURPOSE

This appendix establishes minimum criteria for the design, fabrication, and erection of structurally-supported aluminum dome roofs. When this appendix is applicable, the requirements of 5.10 and the paragraphs in Appendix F that deal with roof design are superseded. All other requirements of API Std 650 shall apply, except that the maximum design temperature shall not exceed 90°C (200°F).

G.1.2 DEFINITION

A structurally-supported aluminum dome roof is a fully triangulated aluminum space truss with the struts joined at points arrayed on the surface of a sphere. Aluminum closure panels are firmly attached to the frame members. The roof is attached to and supported by the tank at mounting points equally spaced around the perimeter of the tank.

G.1.3 GENERAL APPLICATION

G.1.3.1 New Tanks

When this appendix is specified for a new tank, the tank shall be designed to support the aluminum dome roof. The roof manufacturer shall supply the magnitude and direction of all the forces acting on the tank as a result of the roof loads, together with details of the roof-to-shell attachment. The tank shall be designed as an open-top tank, and its wind girder shall meet the requirements of 5.9. The top of the tank shell shall be structurally suitable for attachment of the dome roof structure.

• G.1.3.2 Existing Tanks

When this appendix is specified for an aluminum dome roof to be added to an existing tank (with or without an existing roof), the roof manufacturer shall verify that the tank has sufficient strength to support a new roof. Information on the existing tank shall be provided by the Purchaser. The Purchaser shall specify the existing or new appurtenances to be accommodated by the roof manufacturer. The roof manufacturer shall supply the values of the forces acting on the tank as a result of the roof loads. The Purchaser shall verify the adequacy of the foundations. Unless otherwise specified, any reinforcement required to enable the tank to support the roof shall be the responsibility of the Purchaser. The design and erection of the roof shall accommodate the actual tank shape. The existing tank shall be equipped with a wind girder that meets the requirements of 5.9 for an open-top tank.

• G.1.3.3 Existing Tank Data Sheet

When an aluminum dome is ordered for an existing tank, a data sheet shall be completed by the Purchaser (see Figure G-1).

G.1.4 SPECIAL FEATURES

• G.1.4.1 Self-Supporting Structure

The aluminum dome roof shall be supported only from the rim of the tank; primary horizontal thrust shall be contained by an integral tension ring. The design of the connection between the roof and the tank rim shall allow for thermal expansion. A minimum temperature range of $\pm 70^{\circ}\text{C}$ (120°F) shall be used for design unless a wider range is specified by the Purchaser.

• G.1.4.2 Finish

Unless otherwise specified, the aluminum dome roof materials shall have a mill finish.

G.1.4.3 Maintenance and Inspection

The roof manufacturer shall provide a maintenance and inspection manual for roof items that may require maintenance, periodic inspection, or both.

DATA SHEET FOR A STRUCTURALLY-SUPPORTED ALUMINUM DOME ADDED TO AN EXISTING TANK

JOB NO. _____ ITEM NO. _____
 PURCHASE ORDER NO. _____
 REQUISITION NO. _____
 INQUIRY NO. _____
 PAGE 1 OF 1 BY _____

(INFORMATION TO BE COMPLETED BY THE PURCHASER)

1. PURCHASER/AGENT _____
 ADDRESS _____
 CITY _____ STATE _____ ZIP _____
 PHONE _____ FAX _____
2. USER _____
3. ERECTION SITE: NAME OF PLANT _____
 LOCATION _____
4. TANK NO. _____
5. PUMPING RATES: IN _____ m³/h (bbl/h) OUT _____ m³/h (bbl/h)
6. MAXIMUM DESIGN TEMPERATURE _____ (NOT TO EXCEED 90°C [200°F])
7. DESIGN PRESSURE: ATMOSPHERIC OR _____ kPa (in.) OF WATER (INDICATE WHETHER POSITIVE OR NEGATIVE)
8. ROOF LOADS: UNIFORM LIVE _____ kPa (lb/ft²)
 SPECIAL (PROVIDE SKETCH) _____ kPa (lb/ft²)
9. EARTHQUAKE DESIGN: YES NO
 SEISMIC ZONE _____
 ZONE FACTOR (SEE TABLE E-2) _____
 IMPORTANT FACTOR _____
 SNOW LOAD, IF ANY, TO BE COMBINED WITH SEISMIC _____ kPa (lb/ft²)
10. WIND LOAD: VELOCITY _____ Km/h (mph)
11. MAXIMUM HEIGHT FROM TOP OF SHELL TO TOP OF DOME _____ m (ft)

12. TANK SHELL THICKNESS (ACTUAL)

COURSE NUMBER	MINIMUM THICKNESS	TYPICAL THICKNESS	PLATE WIDTH
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

13. ACTUAL TANK STIFFENER DETAILS, POSITION AND DIMENSIONS (PROVIDE SKETCH)
14. GASES EXPECTED IN THE VAPOR SPACE _____
15. REQUIRED FREEBOARD ABOVE TOP OF TANK _____ mm (in.)
16. ACTUAL MINIMUM TANK DIAMETER AT THE TOP OF THE TANK _____ m (ft)
 ACTUAL MAXIMUM TANK DIAMETER AT THE TOP OF THE TANK _____ m (ft)
17. ELEVATION OF TOP OF TANK: MAXIMUM _____ MINIMUM _____
18. LIST ALL APPURTENANCES, OTHER THAN THOSE TO BE REMOVED BY THE PURCHASER, AND INDICATE ACTION REQUIRED OF CONTRACTOR

APPURTENANCE	CONTRACTOR ACTION	
	REMOVE	ACCOMMODATE
_____	<input type="radio"/>	<input type="radio"/>
_____	<input type="radio"/>	<input type="radio"/>
_____	<input type="radio"/>	<input type="radio"/>
_____	<input type="radio"/>	<input type="radio"/>
_____	<input type="radio"/>	<input type="radio"/>
_____	<input type="radio"/>	<input type="radio"/>
_____	<input type="radio"/>	<input type="radio"/>
_____	<input type="radio"/>	<input type="radio"/>

Figure G-1—Data Sheet for a Structurally-Supported Aluminum Dome Added to an Existing Tank

- **G.1.4.4 Jurisdictional Requirements**

The Purchaser is required to provide all applicable jurisdictional requirements that apply to the aluminum dome roof (see 1.3).

G.2 Materials

- **G.2.1 GENERAL**

Materials furnished to meet the requirements of this appendix shall be new. A complete material specification shall be submitted by the roof manufacturer for approval by the Purchaser. The materials shall be compatible with the product specified to be stored in the tank and the surrounding environment. No aluminum alloy with a magnesium content greater than 3% shall be used when the maximum design temperature exceeds 65°C (150°F). Properties and tolerances of aluminum alloys shall conform to *Aluminum Standards and Data*, as published by the Aluminum Association (Washington, D.C.).

G.2.2 STRUCTURAL FRAME

Structural frame members shall be fabricated from 6061-T6 or a recognized alloy with properties established by the Aluminum Association, Inc.

G.2.3 ROOF PANELS

Roof panels shall be fabricated from Series 3000 or 5000 aluminum with a minimum nominal thickness of 1.20 mm (0.050 in.).

- **G.2.4 BOLTS AND FASTENERS**

Fasteners shall be of 7075-T73 aluminum, 2024-T4 aluminum, austenitic stainless steel, or other materials as agreed to by the Purchaser. Only stainless steel fasteners shall be used to attach aluminum to steel.

G.2.5 SEALANT AND GASKET MATERIAL

G.2.5.1 Sealants shall be silicone or urea urethane compounds that conform to Federal Spec TT-S-00230C unless another material is required for compatibility with stored materials. Sealants shall remain flexible over a temperature range of -60°C to +150°C (-80°F to +300°F) without tearing, cracking, or becoming brittle. Elongation, tensile strength, hardness, and adhesion shall not change significantly with aging or exposure to ozone, ultraviolet light, or vapors from the product stored in the tank.

G.2.5.2 Preformed gasket material shall be Neoprene, silicone, Buna-N, urea urethane, or EPDM elastomer meeting ASTM C 509 or Federal Spec ZZ-R-765C unless another material is required for compatibility with stored materials.

G.2.6 SKYLIGHT PANELS

Skylight panels shall be clear acrylic or polycarbonate with a minimum nominal thickness of 6 mm (0.25 in.).

G.3 Allowable Stresses

G.3.1 ALUMINUM STRUCTURAL MEMBERS

Aluminum structural members and connections shall be designed in accordance with the *Aluminum Design Manual*, as published by the Aluminum Association, Inc. (Washington, D.C.), except as modified by this appendix.

G.3.2 ALUMINUM PANELS

Aluminum panels shall be designed in accordance with *Specifications for Aluminum Sheet Metal Work in Building Construction*, as published by the Aluminum Association, Inc. (Washington, D.C.) and this appendix. Attachment fasteners shall not penetrate both the panel and the flange of the structural member.

G.3.3 BOLTS AND FASTENERS

G.3.3.1 The maximum stress in bolts and fasteners for any design condition shall not exceed the allowable stress given in Table G-1.

G.3.3.2 The hole diameter for a fastener shall not exceed the diameter of the fastener plus 1.5 mm ($1/16$ in.).

Table G-1—Bolts and Fasteners

Materials	Allowable Tensile Stress ^{a,b}		Allowable Shear Stress ^{a,b,c}	
	(MPa)	(ksi)	(MPa)	(ksi)
Austenitic stainless steel ^d	172	25.0	124	18.0
Austenitic stainless steel ^e	234	34.0	172	25.0
2024-T4 aluminum	182	26.0	109	16.0
7075-T73 aluminum	201	28.0	120	17.0

^aThe root-of-thread area shall be used to calculate the strength of threaded parts.

^bFor seismic loads, these values may be increased by one-third.

^cIf the thread area is completely out of the shear area, the cross-sectional area of the shank may be used to determine the allowable shear load.

^dFor bolts with a minimum tensile strength of 620 MPa (90 ksi).

^eFor bolts with a minimum tensile strength of 860 MPa (125 ksi).

^fFor fasteners not shown, design shall be in accordance with the *Aluminum Design Manual*, as published by the Aluminum Association, Inc. (Washington, D.C.).

G.4 Design

G.4.1 DESIGN PRINCIPLES

G.4.1.1 The roof framing system shall be designed as a three-dimensional space frame or truss with membrane covering (roof panels) providing loads along the length of the individual members. The design must consider the increased compression induced in the framing members due to the tension in the roof panels.

G.4.1.2 The actual stresses in the framing members and panels under all design load conditions shall be less than or equal to the allowable stresses per the *Aluminum Design Manual*, as published by the Aluminum Association, Inc. (Washington, D.C.).

G.4.1.3 Local and general buckling of the dome roof must be considered with a minimum factor of safety of 1.65 applied to the buckling equation or method. General buckling of the dome roof shall be considered either by using non-linear finite element analysis or the following equation:

In SI units:

$$W_a = \frac{108.1 \times 10^6 \sqrt{I_x A_g}}{(SF)L R^2} \quad (\text{G.4.1.3-1a})$$

where

W_a = allowable total downward load in kPa,

I_x = moment of inertia of frame members against bending in a plane normal to the dome surface in cm⁴,

A_g = cross-sectional area of beam in cm²,

R = spherical radius of the dome in cm,

L = average dome beam length in cm,

SF = safety factor (1.65).

In US Customary units:

$$W_a = \frac{2258 \times 10^6 \sqrt{I_x A_g}}{(SF)L R^2} \quad (\text{G4.1.3-1b})$$

where

W_a = allowable total downward load (lbf/ft²),

I_x = moment of inertia of frame members against bending in a plane normal to the dome surface (in.⁴),

A_g = cross-sectional area of beam (in.²),

R = spherical radius of the dome (in.),

L = average dome beam length (in.),

SF = safety factor (1.65).

G.4.1.4 The minimum net tension ring area (exclusive of bolt holes and member top flange protrusions) shall be determined per the following formula:

In SI units:

$$A_n = \frac{5.27D^2}{\eta \tan \theta \sin\left(\frac{180}{\eta}\right) F_t} \quad (\text{G4.1.4-1a})$$

where

A_n = net area of tension beam, in cm²,

D = nominal tank diameter, in m,

η = number of dome supports,

θ = $1/2$ the central angle of the dome or roof slope at the tank shell,

F_t = allowable stress of the tension ring, in kPa.

In US Customary units:

$$A_n = \frac{11D^2}{\eta \tan \theta \sin\left(\frac{180}{\eta}\right) F_t} \quad (\text{G4.1.4-1b})$$

where

A_n = net area of tension beam (in.²),

D = nominal tank diameter (ft),

η = number of dome supports,

θ = $1/2$ the central angle of the dome or roof slope at the tank shell,

F_t = allowable stress of the tension ring (lbf/in.²).

In cases where the total dead load plus live load is greater than 1.34 kPa (28 lb/ft²), the above formula shall be multiplied by the factor $W/1.34$ (or 28), where W = the total dead load plus live load for the dome.

Note: This formula does not include factors for bending stresses due to loads from the panel attached to the beam. These stresses must also be considered in the tension ring design, as per G.3.1.

G.4.2 DESIGN LOADS

Dome roofs shall be designed for the loads in 5.2.1, G.4.2, and G.4.3; and for the load combinations (a), (b), (c), (e), and (f) of Appendix R.

G.4.2.1 Unbalanced Load

The design shall consider one-half of the uniform downward load required applied to one-half of the dome with only the dead load on the other half.

G.4.2.2 Wind Load

G.4.2.2.1 For dome structural design, the minimum wind load shall be the load resulting from a design wind speed of 190 km/h (120 mph) which imposes a velocity pressure of 1.48 kPa (31 lbf/ft²). The following pressure coefficients shall be used:

- a. Windward quarter = -0.9
- b. Center half = -0.7
- c. Leeward quarter = -0.5

For domes designed for 3-sec gust wind speeds other than 190 km/h (120 mph), the wind load shall be multiplied by the following:

In SI units:

$$(V/190)^2 \quad \text{(G.4.2.2-1a)}$$

In US Customary units:

$$(V/120)^2 \quad \text{(G.4.2.2-1b)}$$

where

V = wind speed (3-sec gust) in km/h (mph).

Note: The velocity pressure of 1.48 kPa (31 lbf/ft²) is based on ASCE 7-98, Category II, Exposure C, with an Importance Factor of 1.0.

G.4.2.2.2 See 5.11 for tank overturning stability.

G.4.2.3 Seismic Load

If the tank is designed for seismic loads, the roof shall be designed for a horizontal seismic force determined as follows:

$$F = 0.6 ZIW_r \quad \text{(G.4.2.3-1)}$$

where

F = horizontal seismic force.

Z , I , and W_r are as defined in Appendix E. The force shall be uniformly applied over the surface of the roof.

G.4.2.4 Panel Loads

G.4.2.4.1 Roof panels shall be of one-piece aluminum sheet (except for skylights as allowed by G.8.4) and shall be designed to support a uniform load of 3 kPa (60 lbf/ft²) over the full area of the panel without sustaining permanent distortion.

G.4.2.4.2 The roof shall be designed to support two concentrated loads 1100 N (250 lbf), each distributed over two separate 0.1 m² (1 ft²) areas of any panel.

G.4.2.4.3 The loads specified in G.4.2.4.1 and G.4.2.4.2 shall not be considered to act simultaneously or in combination with any other loads.

● G.4.3 INTERNAL PRESSURE

Unless otherwise specified by the Purchaser, the internal design pressure shall not exceed the weight of the roof. In no case shall the maximum design pressure exceed 2.2 kPa (9 in.) water column. When the design pressure, P_{\max} , for a tank with an aluminum dome roof is being calculated, the weight of the roof, including structure, shall be added to the weight of the shell in the W term in F.4.2, and t_h shall be taken as zero.

G.5 Roof Attachment

G.5.1 LOAD TRANSFER

Structural supports for the roof shall be bolted or welded to the tank. To preclude overloading of the shell, the number of attachment points shall be determined by the roof manufacturer in consultation with the tank Manufacturer. The attachment detail shall be suitable to transfer all roof loads to the tank shell and keep local stresses within allowable limits.

G.5.2 ROOF SUPPORTS

The roof attachment points may incorporate a slide bearing with low-friction bearing pads to minimize the horizontal radial forces transferred to the tank. As an alternative, the roof may be attached directly to the tank, and the top of the tank analyzed and designed to sustain the horizontal thrust transferred from the roof, including that from differential thermal expansion and contraction.

● G.5.3 SEPARATION OF CARBON STEEL AND ALUMINUM

Unless another method is specified by the Purchaser, aluminum shall be isolated from carbon steel by an austenitic stainless steel spacer or an elastomeric isolator bearing pad.

G.5.4 ELECTRICAL GROUNDING

The aluminum dome roof shall be electrically interconnected with and bonded to the steel tank shell or rim. As a minimum, stainless steel cable conductors 3 mm ($1/8$ in.) in diameter shall be installed at every third support point. The choice of cable shall take into account strength, corrosion resistance, conductivity, joint reliability, flexibility, and service life.

G.6 Physical Characteristics

G.6.1 SIZES

An aluminum dome roof may be used on any size tank erected in accordance with this Standard.

● G.6.2 DOME RADIUS

The maximum dome radius shall be 1.2 times the diameter of the tank. The minimum dome radius shall be 0.7 times the diameter of the tank unless otherwise specified by the Purchaser.

● G.7 Platforms, Walkways, and Handrails

Platforms, walkways, and handrails shall conform to 3.8.10 except that the maximum concentrated load on walkways or stairways supported by the roof structure shall be 4450 N (1000 lbf). When walkways are specified to go across the exterior of the roof (to the apex, for example), stairways shall be provided on portions of walkways whose slope is greater than 20 degrees. Walkways and stairways may be curved or straight segments.

G.8 Appurtenances

G.8.1 ROOF HATCHES

If roof hatches are required, each hatch shall be furnished with a curb 100 mm (4 in.) or higher and a positive latching device to hold the hatch in the open position. The minimum size of opening shall not be less than 600 mm (24 in.). The axis of the opening may be perpendicular to the slope of the roof, but the minimum clearance projected on a horizontal plane shall be 500 mm (20 in.).

G.8.2 ROOF NOZZLES AND GAUGE HATCHES

Roof nozzles and gauge hatches shall be flanged at the base and bolted to the roof panels with an aluminum reinforcing plate on the underside of the panels. The axis of a nozzle or gauge hatch shall be vertical. If the nozzle is used for venting purposes, it shall not project below the underside of the roof panel. Aluminum or stainless steel flanges may be bolted directly to the roof panel, with the joint caulked with sealant. Steel flanges shall be separated from the aluminum panel by a gasket (see Figure G-2 for a typical nozzle detail).

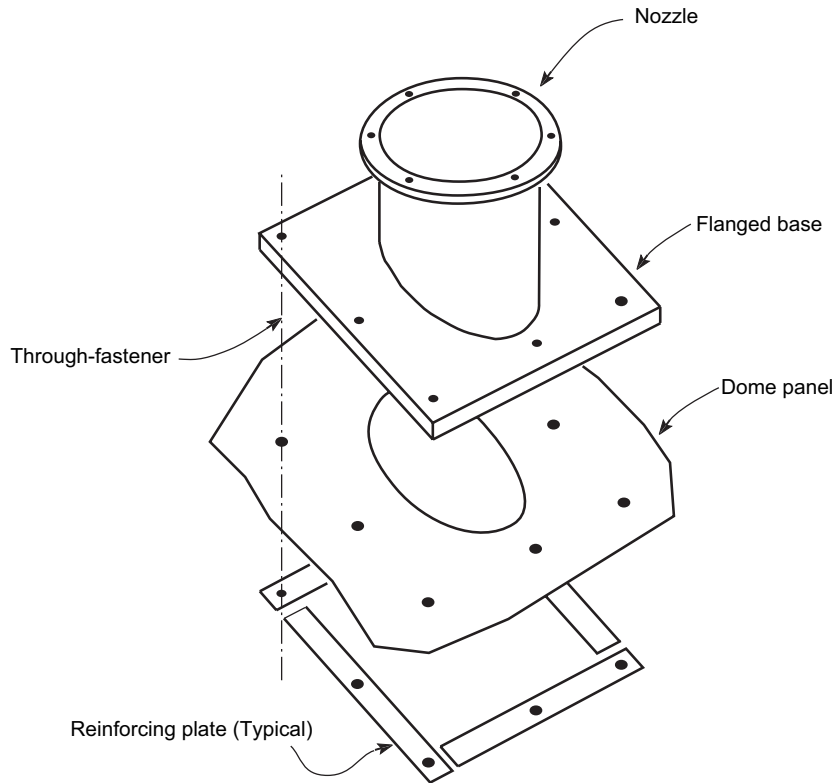


Figure G-2—Typical Roof Nozzle

07 | G.8.3 SKYLIGHTS

G.8.3.1 If skylights are specified by the Purchaser, each skylight shall be furnished with a curb 100 mm (4 in.) or higher and shall be designed for the live and wind loads specified in G.4.2.5. The Purchaser shall specify the total skylight area to be provided.

G.8.3.2 When skylights are specified for tanks without floating roofs or for floating roof tanks which are sealed and gas-blanketed (not provided with circulation venting per H.5.2.2.1 and H.5.2.2.2), the Purchaser shall consider skylight material compatibility with exposure to elevated concentrations of the stored product.

• G.9 Sealing at the Shell

The roof need not be sealed to the tank shell unless specified by the Purchaser or required to contain internal pressure. The bottom of the flashing shall extend at least 50 mm (2 in.) below the top of the tank. Corrosion-resistant coarse-mesh screen (13 mm [$1/2$ in.] openings) shall be provided to prevent the entrance of birds.

G.10 Testing

G.10.1 LEAK TESTING

- **G.10.1.1** After completion, the roof seams shall be leak tested by spraying the outside of the seams with water from a hose with a minimum static head pressure 350 kPa (50 lbf/in.²) gauge at the nozzle. Because of possible corrosive effects, consideration shall be given to the quality of the water used and the duration of the test. Potable water shall be used unless otherwise specified. The water shall not be sprayed directly on roof vents. Any water on the inside of the roof shall constitute evidence of leakage.
- **G.10.1.2** Where gas-tight roofs are required, leak testing may be accomplished in accordance with F.4.4 or F.7.6 or by another means acceptable to the roof manufacturer and the Purchaser.
- **G.10.1.3** Any leaks discovered during testing shall be sealed, and the roof shall be retested until all leaks are sealed.

G.11 Fabrication and Erection

G.11.1 GENERAL

The dome contractor shall perform the work described in this appendix using qualified supervisors who are skilled and experienced in the fabrication and erection of aluminum structures.

G.11.2 FABRICATION

All roof parts shall be prefabricated for field assembly. Fabrication procedures shall be in accordance with Section 6 of the *Aluminum Design Manual*. All structural shapes used to make the roof shall be punched or drilled before any shop coating is applied.

- **G.11.3 WELDING**

The design and fabrication of welded aluminum parts shall be in accordance with the *Aluminum Design Manual: Specifications for Aluminum Structures* and AWS D1.2. All aluminum structural welds and components joined by welding shall be visually inspected and tested by dye-penetrant examination in accordance with Section 5, Part D, of AWS D1.2. All structural welding of aluminum shall be performed before the dome is erected in the field. A full set of satisfactory examination records shall be delivered to the owner before field erection.

G.11.4 SHIPPING AND HANDLING

Materials shall be handled, shipped, and stored in a manner that does not damage the surface of aluminum or the surface coating of steel.

G.11.5 ERECTION

The erection supervisor shall be experienced in the construction of aluminum dome roofs and shall follow the Manufacturer's instructions and drawings furnished for that purpose.

G.11.6 WORKMANSHIP

To minimize internal stresses on the structure when fasteners are tightened, the roof shall be installed on supports that are in good horizontal alignment. The components of the structure shall be erected with precise fit and alignment. Field cutting and trimming, relocation of holes, or the application of force to the parts to achieve fit-up is not acceptable.

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APPENDIX H—INTERNAL FLOATING ROOFS

H.1 Scope

- **H.1.1** This appendix provides minimum requirements that apply to a tank with an internal floating roof and a fixed roof at the top of the tank shell, and to the tank appurtenances. This appendix is intended to limit only those factors that affect the safety and durability of the installation and that are considered to be consistent with the quality and safety requirements of this Standard. Types of internal floating roofs (listed under H.2) and materials (listed under H.3) are provided as a basic guide and shall not be considered to restrict the Purchaser option of employing other commonly accepted or alternative designs, as long as all design loading is documented to meet the minimum requirements herein, and all other criteria are met (except alternative materials and thicknesses as permitted by H.3.1). The requirements apply to the internal floating roof of a new tank and may be applied to an existing fixed-roof tank. Section 5.10 of this Standard is applicable, except as modified in this appendix.
- **H.1.2** The Purchaser is required to provide all applicable jurisdictional requirements that apply to internal floating roofs (see 1.3).
- **H.1.3** See Appendix W for bid requirements pertaining to internal floating roofs.

H.2 Types of Internal Floating Roofs

H.2.1 The internal floating roof type shall be selected by the Purchaser after consideration of both proposed and future product service, operating conditions, maintenance requirements, regulatory compliance, service life expectancy, ambient temperature, maximum design temperature, product vapor pressure, corrosion conditions and other compatibility factors. Other operating conditions requiring consideration include (but are not limited to) anticipated pumping rates, roof landing cycles, and the potential for turbulence resulting from upsets, such as vapor slugs injected into the tank. Safety and risk factors associated with the roof types shall also be evaluated²¹. The type of roof, which shall be designated by the Purchaser on the Data Sheet, Line 30, shall be one of the types described in H.2.2.

H.2.2 The following types of internal floating roofs are described in this appendix:

- a. Metallic pan internal floating roofs^{22,23,24} have a peripheral rim above the liquid for buoyancy. These roofs are in full contact with the liquid surface and are typically constructed of steel.
- b. Metallic open-top bulk-headed internal floating roofs^{23,24} have peripheral open-top bulk-headed compartments for buoyancy. Distributed open-top bulk-headed compartments shall be used as required. These roofs are in full contact with the liquid surface and are typically constructed of steel.
- c. Metallic pontoon internal floating roofs have peripheral closed-top bulk-headed compartments for buoyancy. Distributed closed-top bulk-headed compartments shall be used as required. These roofs are in full contact with the liquid surface and are typically constructed of steel.
- d. Metallic double-deck internal floating roofs have continuous closed top and bottom decks, which contain bulk-headed compartments for buoyancy. These roofs are in full contact with the liquid surface and are typically constructed of steel.
- e. Metallic internal floating roofs on floats have their deck above the liquid, supported by closed pontoon compartments for buoyancy. These roof decks are not in full contact with the liquid surface and are typically constructed of aluminum alloys or stainless steel.

²¹Internal floating roof tanks generally have reduced fire risk, and the use of fixed fire suppression systems is often not mandatory. Various internal floating roof materials will have unique flammability characteristics, melting points and weights (perhaps with reduced buoyancy being required). If fire suppression systems are used, certain roof types need to be evaluated for full surface protection. NFPA 11 *Standard for Low-Expansion Foam* can provide guidance for this evaluation.

²²The Purchaser is cautioned that this design does not have multiple flotation compartments necessary to meet the requirements of H.4.2.1.3.

²³These designs contain no closed buoyancy compartments, and are subject to flooding during sloshing or during application of fire-fighting foam/water solution. Also, without bracing of the rim being provided by the pontoon top plate, design to resist buckling of the rim must be evaluated.

²⁴If the floating roof is a) a metallic pan roof with or without bulkheads, or b) a non-metallic roof with or without closed buoyancy compartments, then the tank is considered a fixed-roof tank (i.e., having no internal floating roof) for the requirements of NFPA 30. See NFPA 30 for spacing restrictions on floating roof tanks.

- 07 f. Metallic sandwich-panel/composite internal floating roofs have metallic or composite material panel modules for buoyancy compartments. Panel modules may include a honeycomb or closed cell foam core; however, cell walls within the panel module are not considered “compartments” for purposes of inspection and design buoyancy requirements (see H.4.1.7 and H.4.2.1)²⁵. These roofs are in full contact with the liquid surface and are typically constructed of aluminum alloys or Purchaser approved composite materials.²⁴
- g. Hybrid internal floating roofs shall, upon agreement between the Purchaser and the manufacturer, be a design combination of roof types described in H.2.2.b and H.2.2.c, having bulkhead compartments with closed-top perimeter pontoon and open-top center compartments for buoyancy. These roofs are in full contact with the liquid surface and are typically constructed of steel.
- 07 h. Other roof materials or designs if specified and described in detail by the Purchaser on the Data Sheet.

• H.3 Material

H.3.1 SELECTION

Internal floating roof materials shall be selected by the Purchaser after consideration of items listed under H.2.1. The manufacturer shall submit a complete material specification in his proposal. The choice of materials should be governed by compatibility with the specified liquid. Material produced to specifications other than those listed in this appendix (alternative materials) may be used. Material shall be certified to meet all the requirements of a material specification listed in this appendix, and approved by the Purchaser or shall comply with requirements as specified by the Purchaser. When specified by the Purchaser, a corrosion allowance shall be added to the minimum nominal thickness indicated below. The “nominal thickness” is the purchased thickness with allowance for the permissible mill tolerance.

H.3.2 STEEL

Steel shall conform to the requirements of Section 4 of this Standard. Steel in contact with vapor or liquid shall be 5 mm ($3/16$ in.) minimum nominal thickness. Other steel shall be 2.5 mm (0.094 in.) minimum nominal thickness.

H.3.3 ALUMINUM

Aluminum shall conform to the requirements of Section 2 of ASME B96.1. Aluminum skin shall be 0.51 mm (0.020 in.) minimum nominal thickness. Aluminum floats shall be 1.3 mm (0.050 in.) minimum nominal thickness. For a sandwich panel flotation unit, core material shall be at least 25 mm (1.0 in.) thick, and metallic skin (except carbon steel) shall be 0.41 mm (0.016 in.) minimum nominal thickness.

H.3.4 STAINLESS STEEL

Stainless steel shall conform to the requirements of ASTM A 240/A 240M (austenitic type only). Stainless steel skin shall be 0.46 mm (0.018 in.) minimum nominal thickness. Stainless steel floats shall be 1.2 mm (0.048 in.) minimum nominal thickness.

H.4 Requirements for All Types

H.4.1 GENERAL

H.4.1.1 An internal floating roof and its accessories shall be designed and constructed to allow the roof to operate throughout its normal travel without manual attention and without damage to any part of the fixed roof, the internal floating roof, internal floating roof seals (except for normal wear), the tank, or their appurtenances. The internal floating roof and seals shall be designed to operate in a tank constructed within the dimensional limits defined in 7.5 of this Standard.

H.4.1.2 The internal floating roof shall be designed and built to float and rest in a uniform horizontal plane (no drainage slope required).

H.4.1.3 All seams in the internal floating roof that are exposed to product vapor or liquid shall be vapor-tight in accordance with H.4.3.1.

²⁵A single inspection opening per panel module is permitted, regardless of core material; however, core materials producing enclosed spaces within a module may result in undetectable combustible gas in areas isolated from the inspection opening. Design buoyancy shall be based on the loss of any two full panel modules (not cells within modules).

H.4.1.4 A vapor-tight rim (or skirt), extending at least 150 mm (6 in.) above the liquid at the design flotation level, shall be provided around both the internal floating roof periphery and around all internal floating roof penetrations (columns, ladders, stilling wells, manways, open deck drains and other roof openings).

H.4.1.5 The non-contact type (see H.2.2e) internal floating roof shall have a vapor-tight rim (or skirt), extending at least 100 mm (4 in.) into the liquid at the design flotation level, around both the internal floating roof periphery and around all internal floating roof penetrations (columns, ladders, stilling wells, manways, open deck drains and other roof openings), with the exception of penetrations for pressure-vacuum (bleeder) vents (per H.5.2.1).

- **H.4.1.6** All conductive parts of the internal floating roof shall be electrically interconnected and bonded to the outer tank structure. This shall be accomplished by electric bonding shunts in the seal area (a minimum of four, uniformly distributed) or flexible multi-strand cables from the external tank roof to the internal floating roof (a minimum of two, uniformly distributed). The choice of bonding devices shall be specified by the Purchaser on the Data Sheet, Line 32, considering strength, corrosion resistance, joint reliability, flexibility, and service life. All movable cover accessories (hatches, manholes, pressure relief devices, and other openings) on the internal floating roof shall be electrically bonded to the internal floating roof to prevent static electricity sparking when they are opened.
- **H.4.1.7** Each closed flotation compartment shall be capable of being field-inspected for the presence of combustible gas. Inspection openings shall be located above the liquid level and closed compartments shall be capable of being resealed in the field after periodic inspection (to prevent liquid or vapor entry). Closed-top compartments (types H.2.2c, d, and g) shall be accessible from the top of the internal floating roof and provided with a secured and gasketed manhole for visual internal inspection and the manhole cover shall be provided with a suitable vent. The top edge of the manhole shall extend a minimum of 25 mm (1 in.) above the top of the pontoon rim/skirt. With agreement by the Purchaser, type H.2.2c, d, and g floating roofs 6 m (20 ft) in diameter or less may be provided with an inspection port in place of a manhole. The inspection ports must meet the sealing, securing and extension requirements listed here for manholes in internal floating roof closed compartments.
- **H.4.1.8** All closed flotation compartments shall be seal welded to prevent liquid or vapor entry, unless otherwise specified by the Purchaser. For pontoon, double-deck and hybrid internal floating roofs (types H.2.2c, d, and g), each bulkhead in a closed flotation compartment shall also be provided with a continuous seal weld all around so that the bulkhead is liquid and vapor-tight.
- **H.4.1.9** For metallic/composite sandwich-panel roofs (type H.2.2f), if the use of adhesives is allowed by the Purchaser (per H.4.3.4) to seal the flotation panels (in lieu of welding), all exposed adhesives shall be compatible with the product service and flotation test water (Purchaser shall consider future product service, the hydrostatic test condition, and design condition changes to specify adhesive compatibility.)
- **H.4.1.10** When specified by the Purchaser for deck surfaces above the liquid level, deck drains shall be provided to return any spillage or condensate to the product. Such drains shall close automatically or extend at least 100 mm (4 in.) into the product to minimize vapor loss.
- **H.4.1.11** Internal floating roofs classified as full-contact types (see H.2.2) shall be designed to minimize trapped vapor space beneath the internal floating roof.

H.4.2 INTERNAL FLOATING ROOF DESIGN

H.4.2.1 Buoyancy Requirements

- **H.4.2.1.1** All internal floating roof design calculations shall be based on the lower of the product specific gravity or 0.7 (to allow for operation in a range of hydrocarbon service), regardless of any higher specific gravity that might be specified by the Purchaser.
- **H.4.2.1.2** All internal floating roofs shall include buoyancy required to support at least twice its dead weight (including the weight of the flotation compartments, seal and all other floating roof and attached components), plus additional buoyancy to offset the calculated friction exerted by peripheral and penetration seals during filling.
- **H.4.2.1.3** All internal floating roofs with multiple flotation compartments shall be capable of floating without additional damage after any two compartments are punctured and flooded. Designs which employ an open center deck in contact with the liquid (types H.2.2b, c, and g) shall be capable of floating without additional damage after any two compartments and the center deck are punctured and flooded. With agreement by the Purchaser, any floating roof 6 m (20 ft) in diameter or less with multiple flota-

tion compartments may be designed to be capable of floating without additional damage after any one compartment is punctured and flooded.

• H.4.2.2 Design Loads

H.4.2.2.1 The internal floating roof shall be designed to meet the requirements of H.4.2.1.3 and to safely support at least two men (2.2 kN [500 lbf] over 0.1 m² [1 ft²]) walking anywhere on the roof while it is floating or resting on its supports without damaging the floating roof and without allowing product on the roof. If specified by the Purchaser, the concentrated load design criteria may be modified for roofs less than 9 m (30 ft) diameter (where internal floating roofs may become unstable), to account for access needs, and expected concentrated live loads.

H.4.2.2.2 Internal floating roof supports and deck structural attachments (such as reinforcing pads and pontoon end gussets) shall be designed to support the full dead load of the internal floating roof (including all components, such as seals and accessories) plus a uniform live load of 0.6 kPa (12.5 lbf/ft²) over the internal floating roof deck surface while the internal floating roof is resting on its supports. This uniform live load may be reduced to 0.24 kPa (5 lbf/ft²) if the floating roof is equipped with operable drains or other means of automatically preventing an accumulation of liquid. Consideration shall also be made for non-uniform support settlement/load distribution, based on anticipated conditions specified by the Purchaser.

H.4.2.3 Other Design Requirements

H.4.2.3.1 Aluminum load carrying members, assemblies and connections shall comply with the design requirements of the latest edition of the Aluminum Design Manual.

- **H.4.2.3.2** Steel structural components shall be proportioned so that the maximum stresses shall not exceed the limitations specified in the latest edition of the *Manual of Steel Construction, Allowable Stress Design*, as published by the American Institute of Steel Construction (Chicago, IL). For other steel components, the allowable stress and stability requirements shall be jointly established by the Purchaser and the manufacturer, as part of the inquiry. Alternatively, a proof test (simulating the conditions of H.4.2) may be performed on the roof or on one of similar design.

H.4.3 JOINT DESIGN

H.4.3.1 All seams in the floating roof exposed directly to product vapor or liquid shall be welded, bolted, screwed, riveted, clamped, or sealed and checked for vapor-tightness per H.6.2.

H.4.3.2 Welded joints between stainless steel members and welded joints between carbon steel members shall conform to 5.1 of this Standard. Welded joints between aluminum members shall conform to 3.1 of ASME B96.1.

H.4.3.2.1 Single-welded butt joints without backing are acceptable for flotation units where one side is inaccessible.

H.4.3.2.2 The thickness of fillet welds on material less than 5 mm (³/₁₆ in.) thick shall not be less than that of the thinner member of the joint.

- **H.4.3.3** Bolted, threaded, and riveted joints are acceptable when mutually agreed upon by the Purchaser and the manufacturer.

H.4.3.3.1 Only austenitic type stainless steel hardware shall be used to join aluminum and/or stainless steel components to each other or to carbon steel. Where acceptable to the Purchaser and the manufacturer, aluminum hardware may be used to join aluminum components. Aluminum shall be isolated from carbon steel by an austenitic stainless steel spacer, an elastomeric pad, or equivalent protection. The use of plated fasteners shall be permitted only when connecting steel components, if specified by the Purchaser.

- **H.4.3.4** Use of any joint sealing compound, insulating material, polymer, elastomer or adhesive must be pre-approved by the Purchaser. The joining procedure along with test results demonstrating the properties required by this paragraph shall be described completely. Where such joints are permitted, any joint sealing compound, insulating material, elastomeric or adhesive shall be compatible with the product stored, specified service conditions, and with materials joined. Resulting joints shall be equivalent in serviceability (with the basic floating roof components), of a size and strength that will accept the roof design loads without failure or leakage, and shall have an expected life equal to the service life of the roof. Any non-metallic component shall be selected and fabricated to preclude absorption (under design conditions specified and permitted by this Standard) of hydrocarbons, hydro-test water and specified product to be stored.

- **H.4.3.5** If specified by the Purchaser, all steel plate seams exposed to the product liquid or vapor shall be seal welded (for corrosive service conditions).

H.4.4 PERIPHERAL SEALS

- In addition to the required floating roof primary peripheral seal, secondary-peripheral seals shall be provided if specified on the Data Sheet, Line 31. Floating roof primary and secondary peripheral seal types and configurations shall be provided as specified on the Data Sheet, Line 31.

H.4.4.1 A peripheral seal (also referred to as “rim seal”) that spans the annular space between the internal floating roof deck and the shell shall be provided. When an internal floating roof has two such devices, one mounted above the other, the lower is the primary peripheral seal and the upper is the secondary peripheral seal. When there is only one such device, it is a primary peripheral seal, regardless of its mounting position.

- **H.4.4.2** The peripheral seal type and material shall be selected by the Purchaser after consideration of both proposed and future product service, tank shell construction/condition, maintenance requirements, regulatory compliance, service life expectancy, ambient temperature, design metal temperature, maximum design temperature, permeability, abrasion resistance, discoloration, aging, embrittlement, flammability, and other compatibility factors. The various seal types (listed H.4.4.4) will have variable life expectancy and service limitations.

The following non-mandatory table provides guidance on frequently used materials for selected products. Each material must be evaluated for the specific product and temperature.

Fluid Stored	Seal Material
Crude oil	Fluoropolymers, urethane, nitrile
Refined products	Fluoropolymers, urethane, urethane laminate, fluoroelastomers, or Buna-N-Vinyl
Gasoline/MTBE blend	Fluoropolymers or nitrile

H.4.4.3 All peripheral seals and their attachment to the floating roof shall be designed to accommodate ± 100 mm (± 4 in.) of local deviation between the floating roof and the shell.

H.4.4.4 Types of Primary Seals

a. **Liquid-mounted rim seal:** Means a resilient foam-filled or liquid-filled primary rim seal mounted in a position resulting in the bottom of the seal being normally in contact with the stored liquid surface. This seal may be a flexible foam (such as polyurethane foam in accordance with ASTM D 3453) or liquid contained in a coated fabric envelope. Circumferential joints on liquid-mounted peripheral seals shall be liquid-tight and shall overlap at least 75 mm (3 in.). The material and thickness of the envelope fabric shall be determined after the factors given in H.4.4.2 are considered.

b. **Vapor-mounted rim seal:** Means a peripheral seal positioned such that it does not normally contact the surface of the stored liquid. Vapor-mounted peripheral seals may include, but are not limited to, resilient-filled seals (similar in design to liquid-mounted rim seals per H.4.4.4a), and flexible-wiper seals. Flexible-wiper seal means a rim seal utilizing a blade or tip of a flexible material (such as extruded rubber or synthetic rubber) with or without a reinforcing cloth or mesh.

c. **Mechanical shoe (metallic shoe):** Means a peripheral seal that utilizes a light-gauge metallic band as the sliding contact with the shell and a fabric seal to close the annular space between the metallic band and the rim of the floating roof deck. The band is typically formed as a series of sheets (shoes) that are overlapped or joined together to form a ring and held against the shell by a series of mechanical devices.

Galvanized shoes shall conform to ASTM A 924 and shall have a minimum nominal thickness of 1.5 mm (16 gauge) and a G90 coating. Stainless steel shoes shall conform to H.3.3, and shall have a minimum nominal thickness of 1.2 mm (18 gauge). For internal floating roofs the primary shoes shall extend at least 150 mm (6 in.) above and at least 100 mm (4 in.) into the liquid at the design flotation level. If necessary, bottom shell course accessories (e.g., side mixers) and other assemblies shall be modified or relocated to eliminate interference between lower portions of metallic seal assemblies.

- Unless specified otherwise by the Purchaser, the seal shoe and compression mechanism shall be installed before hydrostatic testing. It may be necessary to remove the seal shoe after the hydro-test to accommodate cleaning, application of interior coat-

ings, or any situation where the installed shoe might interfere with the process. The fabric seal may be installed after the hydrostatic testing.

H.4.4.5 The specific requirements for all floating roof peripheral seals are:

1. All fasteners and washers for installation of seal joints, including fabric seal joints, shall be austenitic stainless steel. (See restrictions on contact between galvanizing and stainless steel in S.2.1.3.)
2. The seals shall be designed for a temperature range extending from design metal temperature less 8°C (15°F) to the maximum operating temperature.
3. Lengths of seal sections shall be as long as practical. No holes or openings shall be permitted in the completed seal. The seal material may be fabricated in sections resulting in seams, but any such seam shall be joined or otherwise held tightly together along the entire seam. For peripheral seals that use a fabric material to effect the seal, the requirement in the preceding sentence applies only to the fabric and not to any support devices. An adequate but minimum number of expansion joints shall be provided.
4. Provisions shall be made to prevent damage to the seal due to any overflow openings in the shell.
5. Rough spots on the shell that could damage the seal assembly shall be ground smooth. See H.6.1.
6. All metallic components shall be electrically bonded. See H.4.1.6 or C.3.1.6 for electrical bonding requirements.

H.4.4.6 If wax scrapers are specified on the Data Sheet, Line 31, they shall be located such that the scraping action occurs below the liquid surface. Design of wax scrapers shall not interfere with bottom shell course accessories.

H.4.5 ROOF PENETRATIONS

Columns, ladders, and other rigid vertical appurtenances that penetrate the deck shall be provided with a seal that will permit a local deviation of ± 125 mm (± 5 in.). Appurtenances shall be plumb within a tolerance of ± 75 mm (± 3 in.).

H.4.6 ROOF SUPPORTS

- **H.4.6.1** The floating roof shall be provided with adjustable supports, unless the Purchaser specifies fixed supports.
- **H.4.6.2** Unless specified otherwise, the height of the floating roof shall be adjustable to two positions with the tank in service. The design of the supports shall prevent damage to the fixed roof and floating roof when the tank is in an overflow condition.
- **H.4.6.3** The Purchaser shall specify clearance requirements to establish the low (operating) and high (maintenance) levels of the roof supports. The low roof position shall be the lowest permitted by the internal components of the tank including shell nozzles with internal projections. If specified, a single position support height shall be based on the Purchaser-specified clearance dimension. The Purchaser shall provide data to enable the manufacturer to ensure that all tank appurtenances (such as mixers, interior piping, and fill nozzles) are cleared by the roof in its lowest position. In addition to fitting elevations, such data shall include minimum mixer operation level and low level alarm settings (if applicable). If not specified otherwise by the Purchaser, the following apply:

H.4.6.3.1 The high roof position shall provide a 2-m (78-in.) minimum clearance throughout the bottom, between the roof and the tank bottom.

H.4.6.3.2 Where propeller-type mixers are used, the support legs shall provide a minimum clearance of 75 mm (3 in.) from the underside of the internal floating roof (or roof notch) to the tip of the mixer propeller.

H.4.6.4 Support attachments in the deck area shall be designed to prevent failure at the point of attachment. On the bottom of the steel welded deck plates (used on types H.2.2a, b, c, d, and g), where flexure is anticipated adjacent to supports or other relatively rigid members, full-fillet welds not less than 50 mm (2 in.) long on 250 mm (10 in.) centers shall be used on any plate laps that occur within 300 mm (12 in.) of any such support or member.

- **H.4.6.5** Supports shall be fabricated from pipe, unless cable or another type is specified on the Data Sheet, Line 34 and approved by the Purchaser. Supports fabricated from pipe shall be notched or otherwise constructed at the bottom to provide complete liquid drainage. Cable supports shall be adjustable externally and shall not have an open penetration at the floating roof surface. Fixed roofs shall be designed or verified suitable for cable support loads, when used, per agreement between the Purchaser and tank/roof Manufacturers.

- **H.4.6.6** Steel pads or other means shall be used to distribute the loads on the bottom of the tank and provide a wear surface. With the Purchaser's approval, pads may be omitted if the tank bottom will support the live load plus the dead load of the floating roof. If pads are used, they shall be continuously welded to the tank bottom.
- **H.4.6.7** Aluminum supports shall be isolated from carbon steel by an austenitic stainless steel spacer, an elastomeric bearing pad, or equivalent protection, unless specified otherwise by the Purchaser.
- **H.4.6.8** Special protective measures (corrosion allowance, material selection, coatings) are to be evaluated for supports that interface with stratified product bottoms, which may include corrosive contaminant combinations not found in the normal product. The Purchaser shall specify if any protective measures are required.
- **H.4.6.9** For tanks with internal coatings, the Purchaser shall specify on Line 23 of the Data Sheet any special requirements for minimizing corrosion where the leg contacts the tank bottom, such as a flat plate or bull nose on the leg base, a thicker base plate, or other means.

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H.5 Openings and Appurtenances

H.5.1 LADDER

- **H.5.1.1** The tank interior is considered a confined space environment with restricted access (see API RP 2026). If specified by the Purchaser, the tank shall be supplied with a ladder for internal floating roof deck access. If a ladder is not supplied and the floating roof is not steel, a ladder landing pad shall be provided on the floating roof.
- **H.5.1.2** The ladder shall be designed to allow for the full travel of the internal floating roof, regardless of any settling of the roof supports.
- **H.5.1.3** The ladder shall be installed within a fixed-roof manhole, per H.5.5.1.
- **H.5.1.4** If a level-gauge stilling well is provided, the well may form one or both legs of the ladder, as specified by the Purchaser.
- **H.5.1.5** The ladder shall not be attached to the tank bottom unless provision is made for vertical movement at the upper connection.

H.5.2 VENTS

- **H.5.2.1 Internal Floating Roof Pressure-Vacuum (Bleeder) Vents**

Vents suitable to prevent overstressing of the roof deck or seal membrane shall be provided on the floating roof. These vents shall be adequate to evacuate air and gases from underneath the roof such that the internal floating roof is not lifted from resting on its supports during filling operations, until floating on the stored liquid. The vents shall also be adequate to release any vacuum generated underneath the roof after it settles on its supports during emptying operations. The Purchaser shall specify filling and emptying rates so that the manufacturer can size the vents. Leg- or float-activated vents are required unless the Purchaser specifies otherwise, such as pressure vacuum vents, and the associated design conditions (see Line 33 of the Data Sheet). Leg activated vents shall be adjustable as required per H.4.6. Leg-activated vents shall be designed to open automatically when the roof lowers to 150 mm (6 in.) above its lowest operating position and to close automatically when the roof raises more than 150 mm (6 in.) above its lowest position. Float-activated vents shall be designed to remain closed while the roof is floating.

H.5.2.2 Tank Circulation Vents

- **H.5.2.2.1** Peripheral circulation vents shall be located on the tank roof (unless otherwise specified by the Purchaser) and meet the requirements of H.5.3.3, so that they are above the seal of the internal floating roof when the tank is full. The maximum spacing between vents shall be 10 m (32 ft), based on an arc measured at the tank shell, but there shall not be fewer than four equally-spaced vents. The venting shall be distributed such that the sum of the open areas of the vents located within any 10 m (32 ft) interval is at least 0.2 m² (2.0 ft²). The total net open area of these vents shall be greater than or equal to 0.06 m²/m (0.2 ft²/ft) of tank diameter. These vents shall be covered with a corrosion-resistant coarse-mesh screen (13 mm [¹/₂ in.] openings, unless specified otherwise by the Purchaser) and shall be provided with weather shields (the closed area of the screen must be deducted to determine the net open vent area).

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H.5.2.2.2 A center circulation vent with a minimum net open area of 30,000 mm² (50 in.²) shall be provided at the center of the fixed roof or at the highest elevation possible on the fixed roof. It shall have a weather cover and shall be provided with a corrosion-resistant coarse-mesh screen (the closed area of the screen must be deducted to determine the net open vent area).

07 **H.5.2.2.3** If circulation vents (per H.5.2.2.1 and H.5.2.2.2) are not installed, gas blanketing or another acceptable method to prevent the development of a combustible gas mixture within the tank is required. Additionally, the tank shall be protected by pressure-vacuum vents in accordance with 5.8.5, based on information provided by the Purchaser.

H.5.3 LIQUID-LEVEL INDICATION, OVERFILL PROTECTION, AND OVERFLOW SLOTS

- **H.5.3.1** The Purchaser shall provide appropriate alarm devices to indicate a rise of the liquid in the tank to a level above the normal and overflow protection levels (see NFPA 30 and API RP 2350). Overflow slots shall not be used as a primary means of detecting an overflow incident.
- **H.5.3.2** The internal floating roof manufacturer shall provide information defining the internal floating roof and seal dimensional profile for the Purchasers' determination of the maximum normal operating and overflow protection liquid levels (considering tank fixed-roof support, overflow slots or any other top of shell obstructions). The floating roof manufacturer shall provide the design flotation level (liquid surface elevation) of the internal floating roof at which the pressure/vacuum relief vents will begin to open (to facilitate the Purchasers' determination of minimum operating levels).
- **H.5.3.3** The use of emergency overflow slots shall only be permitted if specified by the Purchaser. When emergency overflow slots are used, they shall be sized to discharge at the pump-in rates for the tank. The greater of the product specific gravity or 1.0 shall be used to determine the overflow slot position so that accidental overfilling will not damage the tank or roof or interrupt the continuous operation of the floating roof. Overflow discharge rates shall be determined by using the net open area (less screen) and using a product level (for determining head pressure) not exceeding the top of the overflow opening. The overflow slots shall be covered with a corrosion-resistant coarse-mesh screen (13 mm [¹/₂ in.] openings) and shall be provided with weather shields (the closed area of the screen must be deducted to determine the net open area). The open area of emergency overflow slots may contribute to the peripheral venting requirement of H.5.2.2.1 provided that at least 50% of the circulation-vent area remains unobstructed during emergency overflow conditions. The floating-roof seal shall not interfere with the operation of the emergency overflow openings. Overflow slots shall not be placed over the stairway or nozzles unless restricted by tank diameter/height or unless overflow piping, collection headers, or troughs are specified by the Purchaser to divert flow.

H.5.4 ANTI-ROTATION AND CENTERING DEVICES

The internal floating roof shall be centered and restrained from rotating. A guide pole with rollers, two or more seal centering cables or other suitable device(s) shall be provided as required for this purpose. The internal floating roof shall not depend solely on the peripheral seals or vertical penetration wells to maintain the centered position or to resist rotation. Any device used for either purpose shall not interfere with the ability of the internal floating roof to travel within the full operating elevations in accordance with H.4.1.1.

H.5.5 MANHOLES AND INSPECTION HATCHES

H.5.5.1 Fixed-Roof Manholes

07 At least one fixed-roof manhole complying with this Standard, with a nominal opening of 600 mm (24 in.) or larger, shall be provided in the fixed roof for maintenance ventilation purposes. If used for access to the tank interior, the minimum clear opening shall be 750 mm (30 in.).

H.5.5.2 Floating-Roof Manholes

At least one internal floating roof deck manhole shall be provided for access to and ventilation of the tank when the floating roof is on its supports and the tank is empty. The manhole shall have a nominal opening of 600 mm (24 in.) or larger and shall be provided with a bolted or secured and gasketed manhole cover. The manhole neck dimensions shall meet the requirements of H.4.1.4 and H.4.1.5.

● H.5.5.3 Inspection Hatches

When specified by the Purchaser, inspection hatches shall be located on the fixed roof to permit visual inspection of the seal region. The maximum spacing between inspection hatches shall be 23 m (75 ft), but there shall not be fewer than four equally-spaced hatches. Designs that combine inspection hatches with tank-shell circulation vents (located on the tank roof) are acceptable.

● H.5.6 INLET DIFFUSER

Purchaser shall specify the need for an inlet diffuser sized to reduce the inlet velocity to less than 1 m (3 ft) per second during initial fill per API RP 2003. Purchaser shall provide pumping rates and any blending, pigging and recirculation data along with the inlet diameter, for manufacturer's determination of the diffuser design and size.

● H.5.7 GAUGING AND SAMPLING DEVICES

When specified by the Purchaser, the fixed roof and the internal floating roof shall be provided with and/or accommodate gauging and sampling devices. Sampling devices on the deck of the floating roof shall be installed beneath the fixed-roof hatch (as specified for this purpose) and, unless designed as a gauge pole (extending up to the fixed roof), shall have a funneled (tapered) cover to facilitate use from the roof of the tank. All such devices on the floating roof shall be installed within the plumbness tolerance of H.4.5. See C.3.14 for additional requirements applicable to gauge wells and poles.

● H.5.8 CORROSION GAUGE

When specified by the Purchaser, a corrosion gauge for the internal floating roof shall be provided adjacent to the ladder to indicate the general corrosion rate.

● H.5.9 FOAM DAMS

A foam dam, if specified on the Data Sheet, Line 32, shall be fabricated and installed in compliance with NFPA 11.

H.6 Fabrication, Erection, Welding, Inspection, and Testing

● **H.6.1** The applicable fabrication, erection, welding, inspection, and testing requirements of this Standard shall be met. Upon the start of internal floating roof installation, or concurrent with assembly within a tank under construction, the tank (interior shell and vertical components) shall be inspected by the floating roof erector, unless otherwise specified. The purpose of this inspection shall be to confirm plumbness of all interior components, along with roundness and the condition of the shell (for the presence of damage, projections, or obstructions) to verify that the floating roof and seals will operate properly. Any defects, projections, obstructions or tank tolerance limits (exceeding those defined in 7.5 of this Standard), which would inhibit proper internal floating roof and seal operation, that are identified by the internal floating roof erector shall be reported to the Purchaser.

● **H.6.2** Deck seams and other joints that are required to be or vapor-tight per H.4.1.3 shall be tested for leaks by the shop or field joint assembler. Joint testing shall be performed by means of penetrating oil or another method consistent with those described in this Standard for testing cone-roof and/or tank-bottom seams, or by any other method mutually agreed upon by the Purchaser and the roof manufacturer.

H.6.3 The floating roof manufacturer shall supply all floating roof closures required for testing per H.4.1.3, H.4.1.7, H.4.3.1, and H.6.2. Rivets, self-tapping screws, and removable sections are not acceptable for test plugs.

● **H.6.4** Any flotation compartment that is completely shop-fabricated or assembled in such a manner as to permit leak testing at the fabricating shop shall be leak tested at the shop as well as retested in the field by the floating roof erector for all accessible seams. In the field assembly yard or in the erected position, the erector shall spot leak test 10% of the flotation compartments, whether shop- or field-fabricated. The Purchaser may select the specific compartments to test and the test location, based on his visual inspections for indications of damage or potential leaks (see the Data Sheet, Line 34). Any leaking compartments shall be repaired and re-tested by the roof manufacturer. If the testing finds any leaks in compartments tested, except for those damaged by shipping, then 100% of the roof compartments shall be leak tested. Unless prohibited by safety concerns, leak testing shall be at an internal pressure of 20 kPa – 55 kPa (3 lbf/in.² – 8 lbf/in.²) gauge using a soap solution or commercial leak detection solution.

● Note: Special contract terms may be required to cover the costs of the field testing.

H.6.5 Upon assembly and prior to a flotation test, the erector shall inspect to verify that the peripheral seal produces an acceptable fit against the tank shell.

• **H.6.6 INITIAL FLOTATION**

A flotation test and initial fill inspection shall be conducted by the Purchaser. This test may be performed or witnessed by the erector, as subject to agreement with the Purchaser. The party performing the flotation test shall make water connections and supply all tank closures required for testing and remove all water connections and temporary closures (including gaskets, fasteners, test blanks, etc.) after completion of the test, unless otherwise specified by the Purchaser.

- 07 • **H.6.6.1** Internal floating roofs in accordance with types H.2.2a, b, c, d, and g. shall be given a flotation test on water. Internal floating roofs in accordance with types H.2.2e and H.2.2f shall be given a flotation test on water or product at the option of the Purchaser. During this test, the roof and all accessible compartments shall be checked to confirm that they are free from leaks. The appearance of a damp spot on the upper side of the part in contact with the liquid shall be considered evidence of leakage.

H.6.6.2 During initial fill the internal floating roof should be checked to confirm that it travels freely to its full height. The peripheral seal shall be checked for proper operation throughout the entire travel of the internal floating roof. During the first event of lowering the level from full height, particular attention shall be given for tanks that contain a floating suction to insure proper operation.

H.6.6.3 Because of possible corrosive effects, consideration shall be given to the quality of water used and the duration of the test. Potable water is recommended. For aluminum or stainless steel floating roofs, S.4.10 shall be followed.

H.6.6.4 The high flotation level shall be evaluated for clearance and the floating suction (if existing) shall be compensated for the excess buoyancy that will be encountered during hydrostatic testing of the floating roof system.

APPENDIX I—UNDERTANK LEAK DETECTION AND SUBGRADE PROTECTION

I.1 Scope and Background

I.1.1 This appendix provides acceptable construction details for the detection of product leaks through the bottoms of above-ground storage tanks, and provides guidelines for tanks supported by grillage.

Note: API supports a general position of installation of a Release Prevention Barrier (RPB) under new tanks during initial construction. An RPB includes steel bottoms, synthetic materials, clay liners, and all other barriers or combination of barriers placed in the bottom of or under an aboveground storage tank, which have the following functions: (a) preventing the escape of contaminated material, and (b) containing or channeling released material for leak detection.

- **I.1.2** Several acceptable construction details are provided for detection of leaks through the tank bottom and details for tanks supported by grillage (see Figures I-1 through I-11). Alternative details or methods may be used if agreed upon by the tank owner and Manufacturer, provided the details or methods satisfy the requirements of I.2.
- **I.1.3** The tank owner shall determine whether the undertank area is to be constructed for leak detection. If leak detection is required, the owner shall specify the method or methods to be employed.

I.1.4 The bottoms of aboveground storage tanks may leak as a result of product side corrosion, soil side corrosion, or a combination of both. The extent of product side corrosion can be detected using standard inspection techniques during an internal inspection, but determining the nature and extent of soil side corrosion is more difficult. Therefore, in certain services and tank locations, it may be desirable to provide for undertank monitoring of leakage through the tank bottom plates.

I.1.5 For additional information on the use of internal coatings to prevent internal bottom corrosion, see API RP 652. Similarly, see API RP 651 for guidelines and requirements relating to preventing corrosion from the soil side of the bottom plate.

I.1.6 When the appropriate tank foundation design is being selected, it is important to consider the environmental and safety regulatory implications of leakage of tank contents into the containment space below the tank bottom. Specifically, the contamination of permeable material such as sand used as a floor support may constitute the generation of a hazardous waste. The treatment or disposal costs of such contaminated material must be determined.

I.1.7 The requirements for secondary containment as it relates to diked areas and impoundments are not within the scope of this appendix.

I.2 Performance Requirements

The following general requirements shall be satisfied for all leak detection systems:

- a. Leaks through the tank bottom shall be detectable by observation at the tank perimeter. If a leak is detected, it shall be collected.
- b. The use of electronic sensors for the detection of vapors and liquids is acceptable; however, the requirements of Item a above shall be satisfied. Any such sensor shall be fail-safe or have provision for calibration.

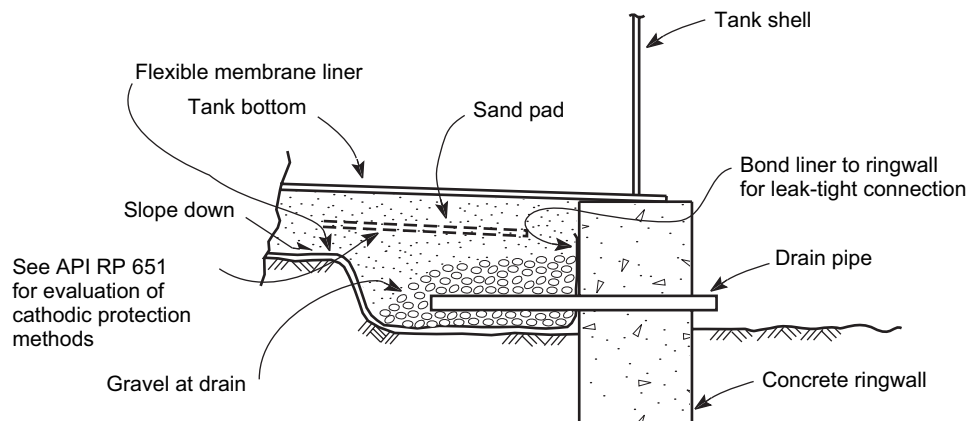


Figure I-1—Concrete Ringwall with Undertank Leak Detection at the Tank Perimeter (Typical Arrangement)

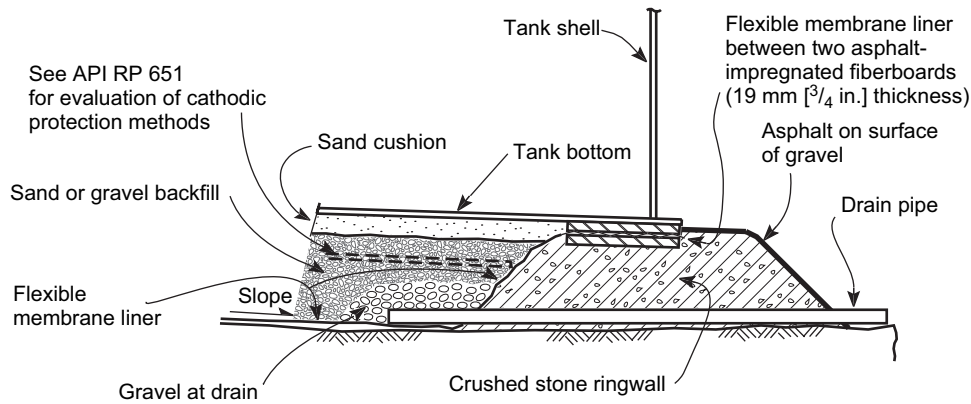


Figure I-2—Crushed Stone Ringwall with Undertank Leak Detection at the Tank Perimeter (Typical Arrangement)

- c. The materials of construction shall be chemically resistant to the range of products to be stored at the temperature range expected in service. Other physical properties shall be specified by the tank owner.
- d. The permeability of the leak detection barrier shall not exceed 1×10^{-7} cm (4×10^{-5} mils) per second.
- e. The material in contact with the subgrade shall be suitable for below-grade service or be protected against degradation.
- f. The leak barrier shall be of one-piece construction, or the joints shall satisfy the leak tightness, permeability, and chemical resistance requirements for the base leak-barrier material. The Manufacturer and a complete description of the leak barrier material shall be identified to the tank owner.
- g. The installation of sumps and pipes below the tank bottom is acceptable; however, the required leak detection and leak tightness shall be maintained. See Figures I-8 and I-9 for typical details.

I.3 Cathodic Protection

Cathodic protection systems may be installed in conjunction with undertank leak detection systems. See API RP 651 for guidelines on the use of cathodic protection methods.

I.4 Double Steel Bottom Construction

I.4.1 If a double steel bottom is used, the details of construction shall provide for the proper support of the primary bottom and shell for all operating conditions. The design shall be evaluated to verify that the primary bottom and shell are not overstressed. The evaluation shall consider all anticipated operating conditions such as design metal temperature, maximum design temperature, fill height, hydrostatic testing, seismic conditions, and tank settlement. The evaluation is not required if the primary bottom is uniformly supported on both sides of the shell and is not structurally attached to the secondary bottom or primary bottom support.

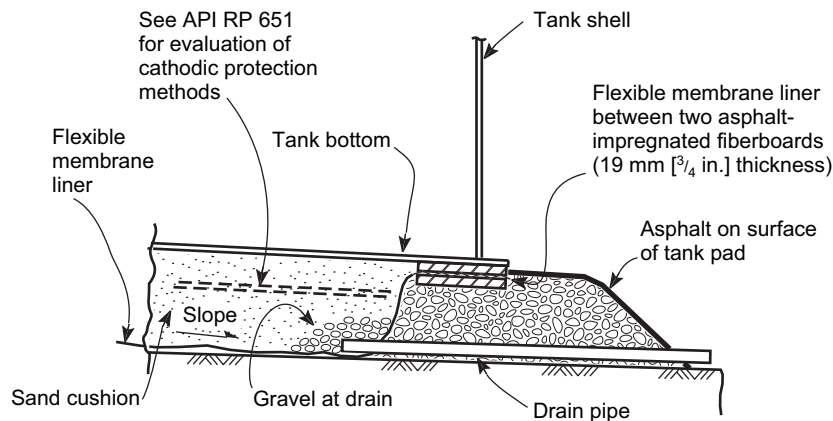


Figure I-3—Earthen Foundation with Undertank Leak Detection at the Tank Perimeter (Typical Arrangement)

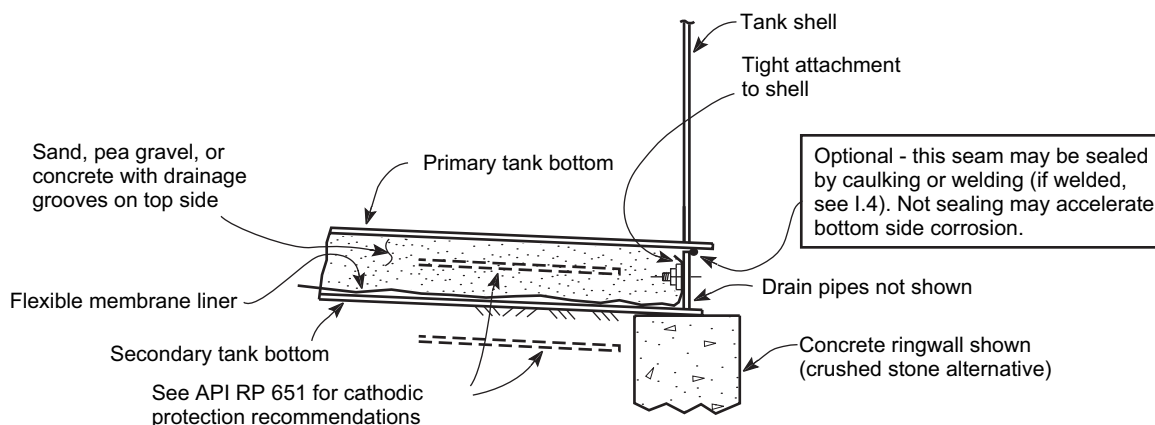


Figure I-4—Double Steel Bottom with Leak Detection at the Tank Perimeter (Typical Arrangement)

I.4.2 For double steel bottom systems that use steel members (such as grating, structural shapes, or wire mesh) to separate the bottoms, ingress of water between the bottoms will result in local accelerated corrosion rates. If the perimeter of the bottoms is not sealed, corrosion protection of the tank bottoms shall be provided.

I.5 Material Requirements and Construction Details

I.5.1 The minimum thickness of flexible-membrane leak barriers shall be 800 millimicrons (30 mils) for fiber-reinforced membranes and 1000 millimicrons (40 mils) for unreinforced membranes. If clay liners are used, they shall be thick enough to meet the permeability requirements of I.2, Item d.

I.5.2 The leak barrier shall be protected as required to prevent damage during construction. If the foundation fill or tank pad material is likely to cause a puncture in the leak barrier, a layer of sand or fine gravel or a geotextile material shall be used as a protective cushion.

I.5.3 For a flexible-membrane liner installed over a steel bottom, all nicks, burrs, and sharp edges shall be removed or a layer of fine sand, gravel, or geotextile material shall be used to protect the liner.

I.5.4 The flexible leak barrier shall be covered by at least 100 mm (4 in.) of sand, except as otherwise shown in Figures I-1 through I-10. This dimension may have to be increased if cathodic protection is to be provided in the space between the tank bottom and the leak barrier.

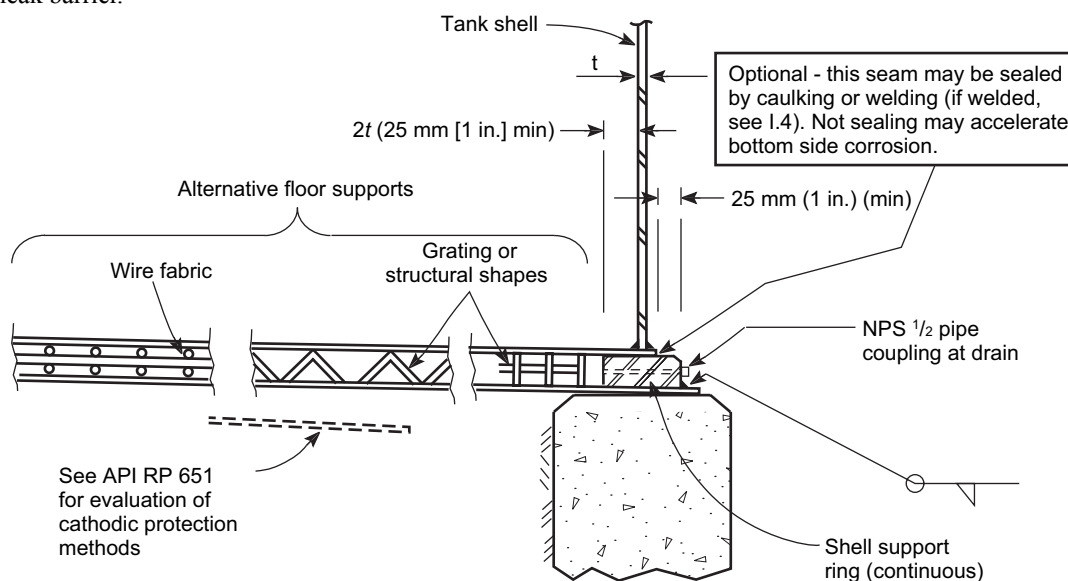


Figure I-5—Double Steel Bottom with Leak Detection at the Tank Perimeter (Typical Arrangement)

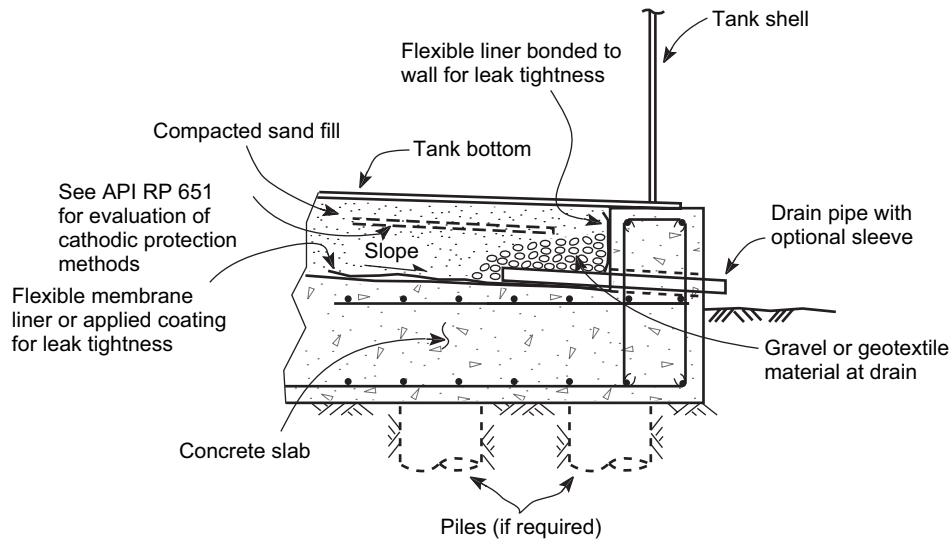


Figure I-6—Reinforced Concrete Slab with Leak Detection at the Perimeter (Typical Arrangement)

- I.5.5** If drain pipes are used around the tank perimeter, they shall be at least NPS 1 in diameter and have a minimum wall thickness of Schedule 40. The pipes may be perforated in the undertank area to improve their leak detection function. The inner ends and perforations of the drain pipes shall be protected from clogging by the use of gravel, screening, geotextiles, or another method approved by the tank owner. The drain pipes shall exit through the foundation and shall be visible to indicate any leakage. If specified by the owner, the undertank drains shall be fitted with a valve or piped to a leak detection well as shown in Figure I-10. The maximum spacing of drain pipes shall be 15 m (50 ft), with a minimum of four drain pipes per tank; however, two drain pipes may be used for tanks 6 m (20 ft) or less in diameter.

I.5.6 The need for pipe sleeves, expansion joints, or both in conjunction with drain pipes shall be evaluated.

I.5.7 The outlet of the drain pipes and collection sumps, if used, shall be protected from the ingress of water from external sources.

I.5.8 Leak detection systems that use sumps in the liner below the tank bottom shall have a drain line that extends from the sump to the tank perimeter. Consideration shall be given to installation of supplemental perimeter drains.

I.6 Testing and Inspection

I.6.1 The leak barrier, all leak-barrier penetrations, attachments of the leak barrier to the foundation ringwall, and other appurtenances shall be visually inspected for proper construction in accordance with applicable specifications.

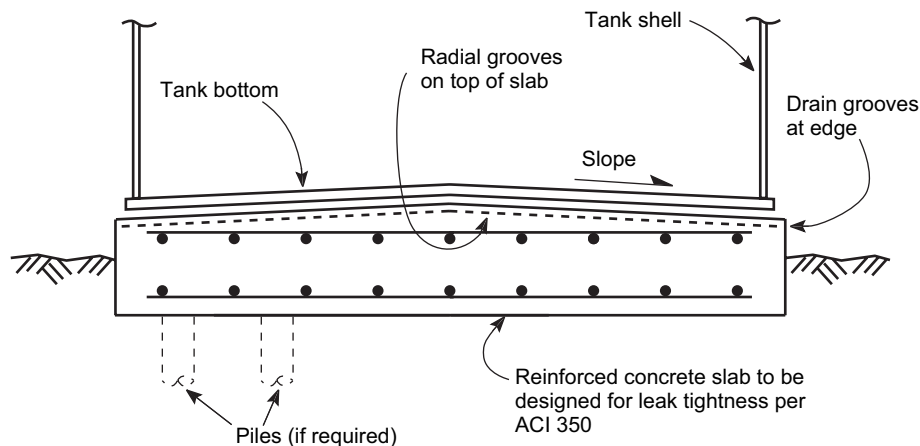


Figure I-7—Reinforced Concrete Slab with Radial Grooves for Leak Detection (Typical Arrangement)

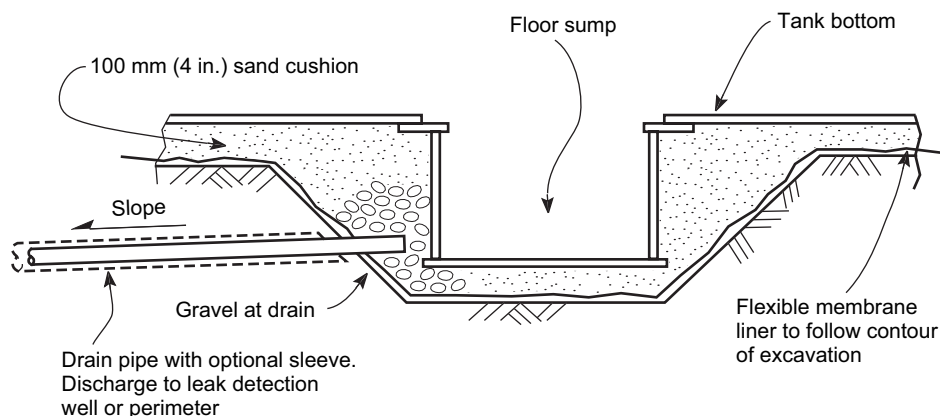


Figure I-8—Typical Drawoff Sump

- **I.6.2** The shop and field seams of flexible-membrane liners shall pass a vacuum-box test. All leaks shall be repaired and retested. Alternative testing methods may be used with the tank owner's approval.
- **I.6.3** Proof testing of samples of the flexible-membrane liner seam shall be performed to verify the seam strength and flexibility and the adequacy of the bonding. The procedure (including testing methods) used to bond or weld the liner seams shall be submitted to the owner for review and shall specify all critical parameters, such as temperature, speed, surface preparation, and curing time, required to achieve liquid-tight seams. The required strength and flexibility of the liner seams shall be agreed upon by the tank owner and Manufacturer. The seam samples shall be produced at the beginning of each shift for each operator and welding machine.
- **I.6.4** All liner penetrations, attachments of the liner to the foundation ringwall, and other appurtenances shall be demonstrated to be leak tight. This may be demonstrated by a mock-up test, prior experience, or other methods acceptable to the owner.

I.7 Tanks Supported by Grillage

- **I.7.1** Tanks designed and constructed in accordance with API Std 650 that have a maximum nominal shell thickness of 13 mm ($1/2$ in.), including any customer specified corrosion allowance, and maximum design temperature not exceeding 93°C (200°F) may be supported by steel or concrete grillage. By agreement between the Purchaser and the Manufacturer, these rules may be applied to tanks with shell thickness greater than 13 mm ($1/2$ in.). These rules apply to single steel butt-welded bottoms supported by grillage members.
- **I.7.2** The thickness and design metal temperature of the bottom plate shall be in accordance with Figure 4-1.
- **I.7.3** The maximum spacing between adjacent or radial grillage members and the bottom plate thickness shall satisfy the requirements of I.7.3.1 and I.7.3.2.

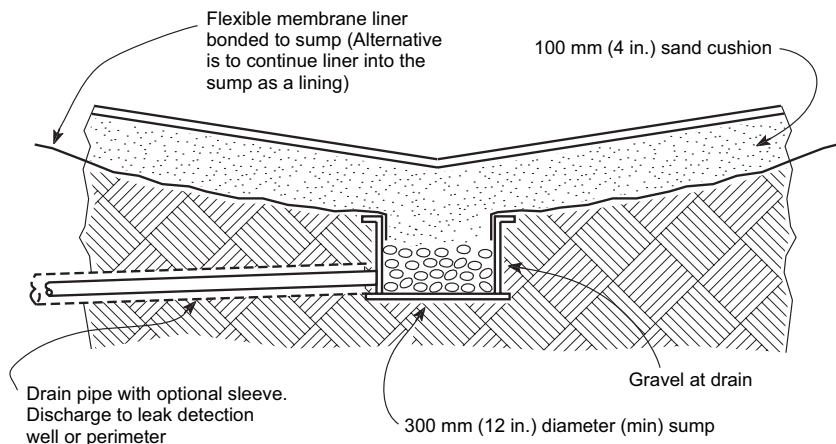
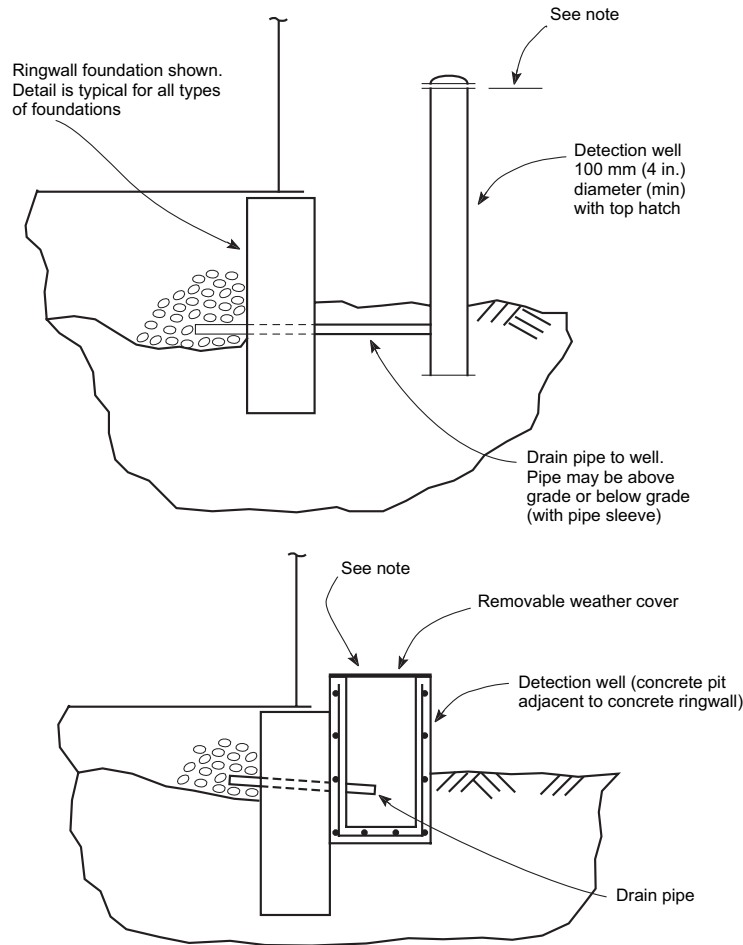


Figure I-9—Center Sump for Downward-Sloped Bottom



Note: Top of well shall be above maximum high water level within dike.

Figure I-10—Typical Leak Detection Wells

I.7.3.1 The maximum spacing between adjacent or radial grillage members shall not exceed:

$$b = \left[\frac{1.5F_y(t_g - CA)^2}{p} \right]^{0.5} \quad (\text{I.7.3.1-1})$$

I.7.3.2 The required minimum thickness of the bottom plate supported on grillage shall be determined by the following equation:

$$t_g = \left[\frac{b^2(p)}{1.5F_y} \right]^{0.5} + CA \quad (\text{I.7.3.2-1})$$

where

b = maximum allowable spacing (center-to-center) between adjacent or radial grillage members, in mm (in.),

F_y = specified minimum yield strength of bottom plate material, in MPa (psi),

t_g = nominal thickness (including any corrosion allowance) of the bottom plate supported on grillage, in mm (in.),

• CA = corrosion allowance to be added to the bottom plate, in mm (in.). The Purchaser shall specify the corrosion allowance,

p = uniform pressure (including the weight of the bottom plate) acting on the bottom resulting from the greater of the weight of the product plus any internal pressure, or the weight of the hydrostatic test water, in MPa (psi).

1.7.3.3 The maximum calculated deflection of the bottom plate at mid-span shall not exceed $(t_g - CA) / 2$:

$$d = \frac{0.0284pb^4}{E_s(t_g - CA)^3} \leq (t_g - CA) / 2 \quad (\text{I.7.3.3-1})$$

where

d = maximum calculated deflection of the bottom plate at mid-span, in mm (in.),

E_s = modulus of elasticity of the bottom plate material, in MPa (psi).

1.7.4 The bottom plates shall be jointed together by butt-welds having complete penetration and complete fusion. Joints shall be visually inspected prior to welding to ensure the weld gap and fit-up will allow complete penetration. Each weld pass shall be visually inspected. The alignment and spacing of grillage members shall be such that the joints between bottom plates are located approximately above the center of the grillage members to the greatest extent practical. Grillage members shall be arranged to minimize the length of unsupported tank shell spanning between grillage members.

1.7.5 Grillage members shall be symmetrical about their vertical centerline. Steel grillage members shall be designed to prevent web crippling and web buckling as specified in Chapter K of the AISC *Manual of Steel Construction, Allowable Stress Design*. Concrete grillage members may also be used.

- **1.7.6** The Purchaser shall specify the corrosion allowance to be added to steel grillage members. If a corrosion allowance is required, the manner of application (added to webs only, added to webs and flanges, added to one surface, added to all surfaces, and so forth) shall also be specified.

1.7.7 For tanks designed to withstand wind or seismic loads, provisions shall be made to prevent sliding, distortion, and overturning of the grillage members. Lateral bracing between the top and bottom flanges of adjacent steel grillage members may be required to prevent distortion and overturning. The lateral bracing and connections shall be designed to transfer the specified lateral loads. If friction forces between the grillage members and the foundation are not adequate to transfer the specified later load, the grillage members shall be anchored to the foundation.

1.7.8 The tank shall be anchored to resist uplift forces (in excess of the corroded dead load) due to pressure and wind or seismic overturning. Anchors shall be located near the intersection of the tank shell and a grillage member, or near an additional stiffening member.

1.7.9 The tank shell shall be designed to prevent local buckling at the grillage members and consideration shall be given to shell distortion when the spacing of the grillage members is determined.

1.7.10 The bottom plate and grillage members directly beneath roof support columns and other items supported by the bottom shall be designed for the loads imposed. Additional support members are to be furnished if required to adequately support the bottom.

1.7.11 If flush-type cleanouts or flush-type shell connections are furnished, additional support members shall be provided to adequately support the bottom-reinforcing and bottom-transition plates. As a minimum, the additional support members shall consist of a circumferential member (minimum length and location according to Method A of Figure 5-12) and radial support members. The radial support members shall extend from the circumferential member to the inner edge of the bottom reinforcing (for flush-type cleanouts) or bottom-transition plate (for flush-type shell connections). The circumferential spacing of the radial support members shall not exceed 300 mm (12 in.).

1.7.12 For tanks located in a corrosive environment, and where atmospheric corrosion due to wet/dry cycles may occur, consideration shall be given to protecting the soil side of the bottom plates, grillage members, and in particular, the contact surface between the bottom plates and grillage members by utilizing protective coatings or by adding a corrosion allowance to these members.

I.8 Typical Installations

Although it is not the intent of this appendix to provide detailed designs for the construction of undertank leak detection systems and tanks supported by grillage, Figures I-1 through I-11 illustrate the general use and application of the recommendations presented in this appendix.

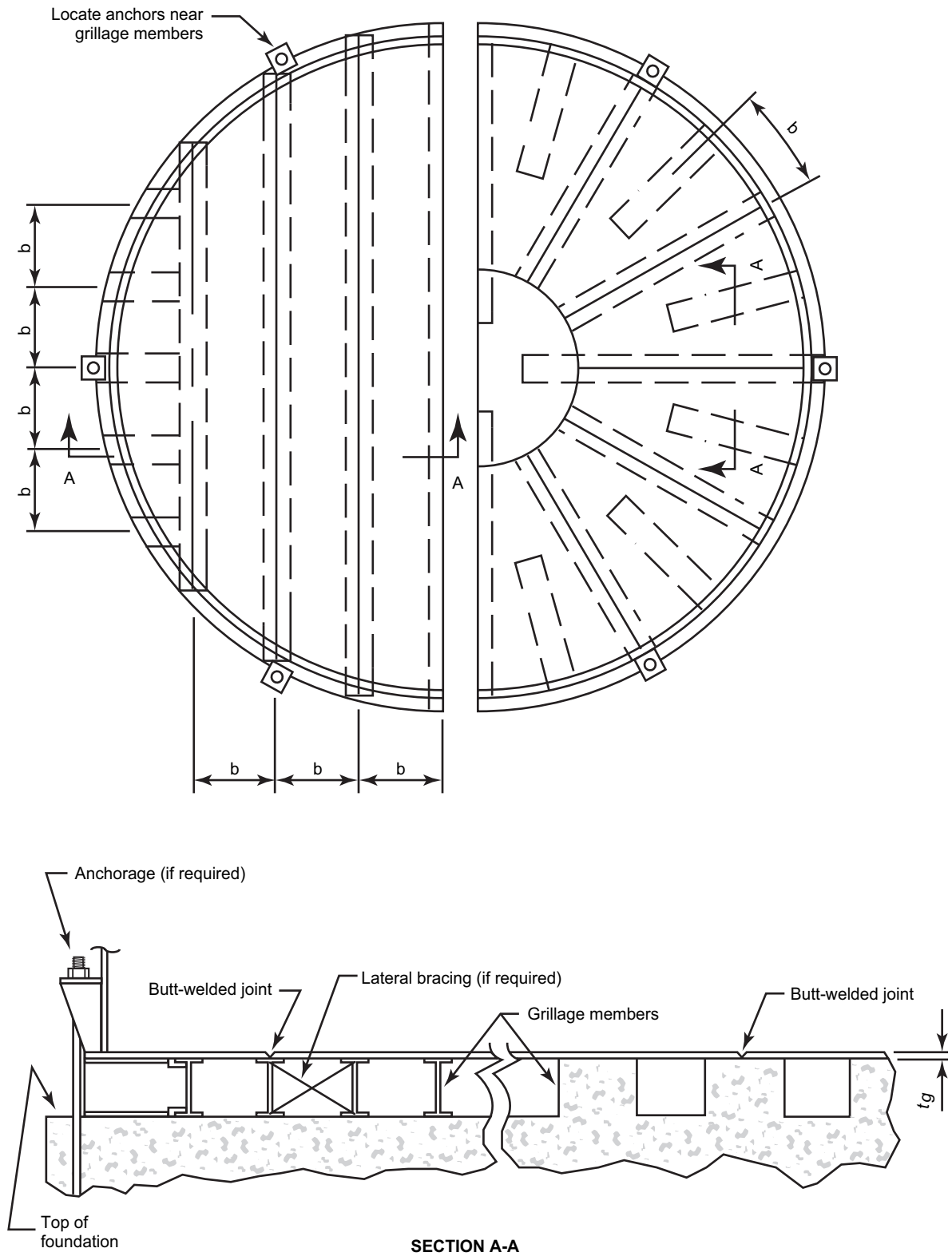


Figure I-11—Tanks Supported by Grillage Members (General Arrangement)

APPENDIX J—SHOP-ASSEMBLED STORAGE TANKS

J.1 Scope

J.1.1 This appendix provides requirements for the design and fabrication of vertical storage tanks in sizes that permit complete shop assembly and delivery to the installation site in one piece. Storage tanks designed according to this appendix shall not exceed 6 m (20 ft) in diameter.

- **J.1.2** The application of this appendix to the design and fabrication of shop-assembled storage tanks shall be mutually agreed upon by the Purchaser and the Manufacturer.

J.2 Materials

The material requirements of Section 4 of this Standard are applicable.

J.3 Design

J.3.1 JOINTS

J.3.1.1 Joints shall be designed as specified in 5.1; however, lap-welded joints in bottoms are not permissible. In addition, the modifications given in J.3.1.2 through J.3.1.5 are applicable.

J.3.1.2 All shell joints shall be butt-welded so that full penetration is produced without the use of back-up bars.

J.3.1.3 Shell plates shall be sized to limit the number of plates to the smallest practical number consistent with sound economic practice. Each course should preferably be constructed of one plate.

J.3.1.4 Top angles are not required for flanged-roof tanks.

J.3.1.5 Joints in bottom plates shall be butt-welded. The welding shall produce complete penetration of the parent metal.

J.3.2 BOTTOMS

J.3.2.1 All bottom plates shall have a minimum nominal thickness of 6 mm ($1/4$ in.) (49.8 kg/m² [10.2 lbf/ft²], see 2.2.1.2 and 3.4.1).

J.3.2.2 Bottoms shall be constructed of a minimum number of pieces; wherever feasible they shall be constructed of one piece.

J.3.2.3 Bottoms may be flat or flat flanged. A flat-bottom shall project at least 25 mm (1 in.) beyond the outside diameter of the weld attaching the bottom to the shell plate. A flat-flanged bottom shall have an inside corner radius that is not less than three times the bottom thickness and a straight flange that is a minimum of 19 mm ($3/4$ in.).

J.3.2.4 For flat bottoms, the attachment between the bottom edges of the lowest course shell plate and the bottom plate shall be a continuous fillet weld laid on each side of the shell plate. Each fillet weld shall be sized in accordance with 5.1.5.7. A flat-flanged bottom shall be attached to the shell by full-penetration butt-welds.

J.3.3 SHELLS

Shell plates shall be designed in accordance with the formula given in A.4.1, but the nominal thickness of shell plates shall not be less than the following:

- a. For tanks with a diameter less than or equal to 3.2 m (10.5 ft) – 5 mm ($3/16$ in.).
- b. For tanks with a diameter greater than 3.2 m (10.5 ft) – 6 mm ($1/4$ in.).

J.3.4 WIND GIRDERS FOR OPEN-TOP TANKS

Open-top tanks shall be provided with wind girders as specified in 5.9.

J.3.5 ROOFS

J.3.5.1 General

Roofs for tanks constructed in accordance with this appendix shall be of the self-supporting type and shall conform to either J.3.5.2 or J.3.5.3.

J.3.5.2 Cone Roofs

Self-supporting cone roofs shall be designed as specified in 5.10.5, except they may be provided with a flange that will permit butt-welded attachment to the shell (see J.3.1.4). Flanges shall be formed with a minimum inside corner radius of three times the roof thickness or 19 mm ($3/4$ in.), whichever is larger.

J.3.5.3 Dome and Umbrella Roofs

Self-supporting dome and umbrella roofs shall be designed as specified in 5.10.6, except they may be flanged as described in J.3.5.2. For dome roofs that are flanged, the radius of curvature shall not be limited to the maximum requirements given in 5.10.6; instead, the curvature shall be limited by the depth of the roof, including the crown and knuckle depth, as listed in Table J-1.

Table J-1—Maximum Roof Depths for Shop-Assembled Dome-Roof Tanks

Diameter		Depth	
m	ft	mm	in.
≤ 1.8	6	50	2
≤ 2.4	8	90	3 $1/2$
≤ 3.0	10	140	5 $1/2$
≤ 3.7	12	200	8
≤ 4.3	14	275	11
≤ 4.9	16	375	15
≤ 6.0	20	500	20

J.3.5.4 Top Angles

When top angles are required, they shall be attached as specified in 5.10.7.

J.3.6 TANK CONNECTIONS AND APPURTENANCES

J.3.6.1 Manholes, nozzles, and other connections in the shell shall be constructed and attached as specified in 5.7, but it is unlikely that reinforcing plates will be required for manholes and nozzles in the tank shell. The need for reinforcement shall be checked according to the procedure given in 5.7.2. Since the minimum shell-plate thicknesses given in J.3.3 will normally exceed the calculated thickness, the excess material in the shell should satisfy the reinforcement requirements in nearly all cases.

- **J.3.6.2** The roofs of tanks constructed in accordance with this appendix will be inherently strong because of the limitations in diameter required for shipping clearances. Thus, reinforcement of roof manholes and nozzles is not required unless specifically requested by the Purchaser or unless roof loads exceed 1.2 kPa (25 lbf/ft²), in which case the amount and type of reinforcement shall be agreed upon by the Purchaser and the Manufacturer.

J.3.7 CORROSION ALLOWANCE

- **J.3.7.1** If the Purchaser requires that a corrosion allowance be provided, the allowance and the areas to which the allowance is to be added shall be specified. If a corrosion allowance is specified without an indication of the area to which it is to be added, the Manufacturer shall assume that it is to be added only to the calculated shell-plate thickness.
- **J.3.7.2** When a corrosion allowance is specified for the roof and bottom plates, it shall be added to the minimum nominal thicknesses.

J.3.8 LIFTING LUGS

J.3.8.1 Lugs or clips for use in loading and unloading tanks and for use in placing tanks on foundations shall be provided on all tanks constructed in accordance with this appendix.

- **J.3.8.2** There shall be a minimum of two lugs on each tank. The location of the lugs shall be agreed upon by the Purchaser and the Manufacturer. The lugs shall preferably be located at the top of the tank, in pairs, 180 degrees apart.

J.3.8.3 Lugs and their attachment welds shall be designed to carry their share of the applied load (twice the empty weight of the tank) distributed in a reasonable manner and based on a safety factor of 4.

J.3.8.4 Lugs capable of carrying the load described in J.3.8.3 shall be designed and attached in a manner that will not damage the tank.

J.3.9 ANCHORING

Because of the proportions of shop-assembled storage tanks, overturning as a result of wind loading must be considered. If necessary, adequate provisions for anchoring shall be provided.

J.4 Fabrication and Construction

J.4.1 GENERAL

J.4.1.1 Fabrication and construction shall be in accordance with the applicable provisions of Sections 6 and 7 of this Standard. Erection shall be interpreted as assembly, and it shall be understood that the entire vessel is constructed in the shop and not at the field site.

J.4.1.2 Sections 7.2.2 and 7.2.5 of this Standard are not applicable to the bottoms and roofs of shop-assembled tanks.

J.4.2 TESTING, REPAIRS, AND INSPECTION

J.4.2.1 General

For testing of, repairs to, and inspection of shop-assembled tanks, the requirements of J.4.2.2 through J.4.2.4 replace those of 5.3.2 through 5.3.6.

• **J.4.2.2 Testing**

Unless otherwise specified by the Purchaser, as an alternative to the requirements of 7.3.2 through 7.3.7, a tank may be shop tested for leaks by the following method:

- a. The tank bottom shall be braced by securely attaching an external stiffening member as required to prevent permanent deformation during the test.
- b. All openings shall be closed with plugs or covers as needed. Bolts and gaskets of the size and type required for final installation shall be used during the test.
- c. An internal air pressure of 14 kPa – 21 kPa (2 lbf/in.² – 3 lbf/in.²) gauge shall be applied to the tank. For tanks with a diameter of 3.7 m (12 ft) or less, a maximum pressure of 35 kPa (5 lbf/in.²) gauge shall be used.
- d. Soap film, linseed oil, or another material suitable for the detection of leaks shall be applied to all shell, bottom, roof, and attachment welds, and the tank shall be carefully examined for leaks.
- e. After the air pressure is released, the external stiffening member shall be removed, and any weld scars shall be repaired.

J.4.2.3 Repairs

All weld defects found by the leak test or by radiographic examination shall be repaired as specified in Section 8.

J.4.2.4 Inspection

The Purchaser's inspector shall have free entry to the Manufacturer's shop at all times. The Manufacturer shall afford the Purchaser's inspector reasonable facilities to assure the inspector that the work is being performed in accordance with the requirements of this Standard. All material and workmanship shall be subject to the replacement requirements of 6.2.3.

J.5 Inspection of Shell Joints

The methods of inspecting shell joints described in Section 8 apply to shop-assembled tanks, but spot radiography may be omitted when a joint efficiency of 0.70 is used (see A.3.4).

J.6 Welding Procedure and Welder Qualifications

The requirements for qualification of welding procedures and welders given in Section 9 apply to shop-assembled tanks.

J.7 Marking

Shop-assembled tanks shall be marked in accordance with Section 10, except that 10.1.4 and 10.2 are not applicable. The nameplate (see Figure 10-1) shall indicate that the tank has been designed in accordance with this appendix.

APPENDIX K—SAMPLE APPLICATION OF THE VARIABLE-DESIGN-POINT METHOD TO DETERMINE SHELL-PLATE THICKNESS

K.1 Data

<input type="checkbox"/>	Design condition	<input checked="" type="checkbox"/>	Test condition	
	Specific gravity of liquid, G :			1.0
	Corrosion allowance:			0.0 mm (0.0 in.)
	Tank diameter, D :			85.0 m (280 ft)
	Design Liquid Level (also total height of tank for the examples in this appendix), H :			19.2 m (64 ft)
	Number of courses:			8.0
	Allowable stress for design, S_d :			—
	Allowable stress for testing, S_t :			208 MPa (30,000 lbf/in. ²)
	Height of bottom course, h_1 :			2,400 mm (96 in.)
	Nominal tank radius, r :			42,500 mm (1,680 in.)

(See 5.6.4 for definition of nomenclature.)

K.2 Calculations

K.2.1 FIRST COURSE (t_1)

For the test condition, t_1 is equal to t_{1t} but not greater than t_{pt} .

In SI units:

$$\begin{aligned}
 t_{pt} &= \frac{4.9D(H-0.3)}{S_t} = \frac{(4.9)(85)(19.2-0.3)}{208} = 37.85 \\
 t_{1t} &= \left[1.06 - \frac{0.0696D}{H} \sqrt{\frac{H}{S_t}} \right] \left[\frac{(4.9HD)}{S_t} \right] \\
 &= \left[1.06 - \frac{0.0696(85)}{19.2} \sqrt{\frac{19.2}{208}} \right] \left[\frac{4.9(19.2)(85)}{208} \right] \\
 &= [1.06 - (0.3081)(0.3038)][38.45] \\
 &= [1.06 - 0.0936][38.45] \\
 &= [0.9664][38.45] \\
 &= 37.15 \text{ mm} = t_1
 \end{aligned}$$

In US Customary units:

$$\begin{aligned}
 t_{pt} &= \frac{2.6D(H-1)}{S_t} = \frac{2.6(280)(64-1)}{30,000} = 1.529 \\
 t_{1t} &= \left[1.06 - \frac{(0.463D)}{H} \sqrt{\frac{H}{S_t}} \right] \left[\frac{(2.6HD)}{S_t} \right] \\
 &= \left[1.06 - \frac{0.463(280)}{64} \sqrt{\frac{64}{30,000}} \right] \left[\frac{2.6(64)(280)}{30,000} \right] \\
 &= [1.06 - (2.026)(0.0462)][1.553] \\
 &= [1.06 - 0.0936][1.553] \\
 &= [0.9664][1.553] \\
 &= 1.501 \text{ in.} = t_1
 \end{aligned}$$

K.2.2 SECOND COURSE (t_2)

In SI units:

$$\frac{h_1}{(rt_1)^{0.5}} = \frac{2400}{[(42,500)(37.2)]^{0.5}} = 1.909$$

$$\text{If } \frac{h_1}{(rt_1)^{0.5}} \leq 1.375, t_2 = t_1; \quad \text{if } \frac{h_1}{(rt_1)^{0.5}} \geq 2.625, t_2 = t_{2a}$$

$$\text{If } 1.375 < \frac{h_1}{(rt_1)^{0.5}} < 2.625$$

$$\begin{aligned} t_2 &= t_{2a} + (t_1 - t_{2a}) \left[2.1 - \frac{h_1}{1.25(rt_1)^{0.5}} \right] \\ &= 31.28 + (5.87) \left[2.1 - \frac{2400}{1.25[(42,500)(37.16)]^{0.5}} \right] \\ &= 31.28 + (5.87)[2.1 - 1.528] \\ &= 31.28 + (5.87)[0.572] \\ &= 31.28 + 3.36 \\ &= 34.64 \text{ mm} \end{aligned}$$

In US Customary units:

$$\frac{h_1}{(rt_1)^{0.5}} = \frac{96}{[(1680)(1.501)]^{0.5}} = \frac{96}{50.216} = 1.912$$

$$\text{If } \frac{h_1}{(rt_1)^{0.5}} \leq 1.375, t_2 = t_1; \quad \text{if } \frac{h_1}{(rt_1)^{0.5}} \geq 2.625, t_2 = t_{2a}$$

$$\text{If } 1.375 < \frac{h_1}{(rt_1)^{0.5}} < 2.625$$

$$\begin{aligned} t_2 &= t_{2a} + (t_1 - t_{2a}) \left[2.1 - \frac{h_1}{1.25(rt_1)^{0.5}} \right] \\ &= 1.263 + (0.238) \left[2.1 - \frac{96}{1.25[(1680)(1.501)]^{0.5}} \right] \\ &= 1.263 + (0.238)[2.1 - 1.529] \\ &= 1.263 + (0.238)[0.571] \\ &= 1.263 + 0.136 \\ &= 1.399 \text{ in.} \end{aligned}$$

K.2.3 UPPER COURSES**K.2.3.1 Course 2**

Note: $H = 16.8$ m (56 ft).

K.2.3.1.1 First Trial

In SI units:

$$t_{tx} = \frac{4.9D(H-0.3)}{S_t} = \frac{4.9(85)(16.8-0.3)}{208}$$

$$= 33.04 \text{ mm} = t_u$$

$$t_L = 37.15 \text{ mm}$$

$$K = \frac{t_L}{t_u} = \frac{37.15}{33.04} = 1.124$$

$$K^{0.5} = 1.060$$

$$C = \frac{K^{0.5}(K-1)}{1+K^{1.5}} = \frac{(1.06)(0.124)}{1+1.192} = 0.060$$

$$(rt_u)^{0.5} = [(42,500)(33.04)]^{0.5} = 1185.0$$

$$x_1 = 0.61(rt_u)^{0.5} + 320CH$$

$$= 0.61(1185) + 320(0.060)(16.8) = 1045.4$$

$$x_2 = 1000CH = 1000(0.060)(16.8) = 1008$$

$$x_3 = 1.22(rt_u)^{0.5} = 1.22(1185) = 1445.7$$

$$x = \min(x_1, x_2, x_3) = 1008$$

$$x/1000 = 1.008$$

$$t_{tx} = \frac{4.9D(H-x)}{S_t} = \frac{4.9(85)(16.8-1.008)}{208} = 31.62 \text{ mm}$$

In US Customary units:

$$t_{tx} = \frac{2.6D(H-1)}{S_t} = \frac{2.6(280)(55)}{30,000}$$

$$= 1.335 \text{ in.} = t_u$$

$$t_L = 1.501 \text{ in.}$$

$$K = \frac{t_L}{t_u} = \frac{1.501}{1.335} = 1.124$$

$$K^{0.5} = 1.060$$

$$C = \frac{K^{0.5}(K-1)}{1+K^{1.5}} = \frac{(1.06)(0.124)}{1+1.191} = 0.060$$

$$(rt_u)^{0.5} = [(1680)(1.335)]^{0.5} = 47.358$$

$$x_1 = 0.61(rt_u)^{0.5} + 3.84CH$$

$$= 0.61(47.358) + 3.84(0.060)(56) = 28.89 + 12.90 = 41.79$$

$$x_2 = 12CH = 12(0.060)(56) = 40.32$$

$$x_3 = 1.22(rt_u)^{0.5} = 1.22(47.358) = 57.78$$

$$x = \min(x_1, x_2, x_3) = 40.32$$

$$x/12 = 3.36$$

$$t_{tx} = \frac{2.6D(H-x/12)}{S_t} = \frac{2.6(280)(56-3.36)}{30,000} = 1.277 \text{ in.}$$

With this value of t_{tx} , start the second trial.

K.2.3.1.2 Second Trial

In SI units:

$$t_u = t_{tx} \text{ from first trial} = 31.62 \text{ mm}$$

$$t_L = 37.15 \text{ mm}$$

$$K = \frac{t_L}{t_u} = \frac{37.15}{31.62} = 1.175$$

$$K^{0.5} = 1.084$$

$$C = \frac{K^{0.5}(K-1)}{1+K^{1.5}} = \frac{(1.084)(0.175)}{1+1.175^{1.5}} = 0.0834$$

$$(rt_u)^{0.5} = [(42,500)(31.62)]^{0.5} = 1159.2$$

$$\begin{aligned} x_1 &= 0.61(rt_u)^{0.5} + 320CH \\ &= 0.61(1159.2) + 320(0.0834)(16.8) = 1155.5 \end{aligned}$$

$$x_2 = 1000CH = 1000(0.0834)(16.8) = 1401.1$$

$$x_3 = 1.22(rt_u)^{0.5} = 1.22(1159.2) = 1414.2$$

$$x = \min(x_1, x_2, x_3) = 1155.5$$

$$x/1000 = 1.155$$

$$t_{tx} = \frac{4.9D(H-x/1000)}{S_t} = \frac{4.9(85)(16.8-1.155)}{208} = 31.33 \text{ mm}$$

In US Customary units:

$$t_u = t_{tx} \text{ from first trial} = 1.277 \text{ in.}$$

$$t_L = 1.501 \text{ in.}$$

$$K = \frac{t_L}{t_u} = \frac{1.501}{1.277} = 1.175$$

$$K^{0.5} = 1.084$$

$$C = \frac{K^{0.5}(K-1)}{1+K^{1.5}} = \frac{(1.084)(0.175)}{1+1.175^{1.5}} = 0.0834$$

$$(rt_u)^{0.5} = [(1680)(1.277)]^{0.5} = 46.32$$

$$\begin{aligned} x_1 &= 0.61(rt_u)^{0.5} + 3.84CH \\ &= 0.61(46.32) + 3.84(0.0834)(56) = 28.25 + 17.93 = 46.19 \end{aligned}$$

$$x_2 = 12CH = 12(0.0834)(56) = 56.04$$

$$x_3 = 1.22(rt_u)^{0.5} = 1.22(46.32) = 56.51$$

$$x = \min(x_1, x_2, x_3) = 46.19$$

$$x/12 = 3.80$$

$$t_{tx} = \frac{2.6D(H-x/12)}{S_t} = \frac{2.6(280)(56-3.80)}{30,000} = 1.267 \text{ in.}$$

With this value of t_{tx} , start the third trial.

K.2.3.1.3 Third Trial

In SI units:

$$t_u = t_{tx} \text{ from second trial} = 31.33 \text{ mm}$$

$$t_L = 37.15 \text{ mm}$$

$$K = \frac{t_L}{t_u} = \frac{37.15}{31.33} = 1.186$$

$$K^{0.5} = 1.089$$

$$C = \frac{K^{0.5}(K-1)}{1+K^{1.5}} = \frac{(1.089)(0.186)}{1+1.186^{1.5}} = 0.088$$

$$(rt_u)^{0.5} = [(42,500)(31.33)]^{0.5} = 1153.9$$

$$\begin{aligned} x_1 &= 0.61(rt_u)^{0.5} + 320CH \\ &= 0.61(1153.9) + 320(0.088)(16.8) = 1177.0 \end{aligned}$$

$$x_2 = 1000CH = 1000(0.088)(16.8) = 1478.4$$

$$x_3 = 1.22(rt_u)^{0.5} = 1.22(1153.9) = 1407.8$$

$$x = \min(x_1, x_2, x_3) = 1177$$

$$x/1000 = 1.177$$

$$t_{tx} = \frac{4.9D(H-x/1000)}{S_t} = \frac{4.9(85)(16.8-1.177)}{208} = 31.28 \text{ mm} = t_{2a}$$

In US Customary units:

$$t_u = t_{tx} \text{ from first trial} = 1.267 \text{ in.}$$

$$t_L = 1.501 \text{ in.}$$

$$K = \frac{t_L}{t_u} = \frac{1.501}{1.267} = 1.185$$

$$K^{0.5} = 1.089$$

$$C = \frac{K^{0.5}(K-1)}{1+K^{1.5}} = \frac{(1.089)(0.185)}{1+1.290} = 0.088$$

$$(rt_u)^{0.5} = [(1680)(1.266)]^{0.5} = 46.12$$

$$\begin{aligned} x_1 &= 0.61(rt_u)^{0.5} + 3.84CH \\ &= 0.61(46.12) + 3.84(0.088)(56) = 28.13 + 18.92 = 47.05 \end{aligned}$$

$$x_2 = 12CH = 59.14$$

$$x_3 = 1.22(rt_u)^{0.5} = 1.22(46.12) = 56.27$$

$$x = \min(x_1, x_2, x_3) = 47.05$$

$$x/12 = 3.92$$

$$t_{tx} = \frac{2.6D(H-x/12)}{S_t} = \frac{2.6(280)(56-3.92)}{30,000} = 1.263 \text{ in.} = t_{2a}$$

Use this value to calculate t_2 .

K.2.3.2 Course 3

Note: $H = 14.4$ m (48 ft).

K.2.3.2.1 First Trial

In SI units:

$$t_{tx} = \frac{4.9D(H-0.3)}{S_t} = \frac{4.9(85)(14.4-0.3)}{208}$$

$$= 28.23 \text{ mm} = t_u$$

$$t_L = 34.64 \text{ mm}$$

$$K = \frac{t_L}{t_u} = \frac{34.64}{28.23} = 1.227$$

$$K^{0.5} = 1.108$$

$$C = \frac{K^{0.5}(K-1)}{1+K^{0.5}} = \frac{(1.108)(0.227)}{1+1.227^{1.5}} = 0.107$$

$$(rt_u)^{0.5} = [(42,500)(28.23)]^{0.5} = 1095$$

$$x_1 = 0.61(rt_u)^{0.5} + 320CH$$

$$= 0.61(1095) + 320(0.107)(14.4) = 1161$$

$$x_2 = 1000CH = 1000(0.107)(14.4) = 1541$$

$$x_3 = 1.22(rt_u)^{0.5} = 1.22(1095) = 1336$$

$$x = \min(x_1, x_2, x_3) = 1161$$

$$x/1000 = 1.161$$

$$t_{tx} = \frac{4.9D(H-x/1000)}{S_t} = \frac{4.9(85)(14.4-1.161)}{208} = 26.51 \text{ mm}$$

In US Customary units:

$$t_{tx} = \frac{2.6D(H-1)}{S_t} = \frac{2.6(280)(47)}{30,000}$$

$$= 1.141 \text{ in.} = t_u$$

$$t_L = 1.399 \text{ in.}$$

$$K = \frac{t_L}{t_u} = \frac{1.399}{1.141} = 1.226$$

$$K^{0.5} = 1.107$$

$$C = \frac{K^{0.5}(K-1)}{1+K^{0.5}} = \frac{(1.107)(0.266)}{1+1.357} = 0.106$$

$$(rt_u)^{0.5} = [(1680)(1.141)]^{0.5} = 43.78$$

$$x_1 = 0.61(rt_u)^{0.5} + 3.84CH$$

$$= 0.61(43.78) + 3.84(0.106)(48) = 26.71 + 19.54 = 46.25$$

$$x_2 = 12CH = 12(0.106)(48) = 61.06$$

$$x_3 = 1.22(rt_u)^{0.5} = 1.22(43.78) = 53.41$$

$$x = \min(x_1, x_2, x_3) = 46.25$$

$$x/12 = 3.85$$

$$t_{tx} = \frac{2.6D(H-x/12)}{S_t} = \frac{2.6(280)(48-3.85)}{30,000} = 1.071 \text{ in.}$$

With this value of t_{tx} , start the second trial.

K.2.3.2.2 Second Trial

In SI units:

$$t_u = t_{tx} \text{ from the first trial} = 26.51 \text{ mm}$$

$$t_L = 34.64 \text{ mm}$$

$$K = \frac{t_L}{t_u} = \frac{34.64}{26.51} = 1.307$$

$$K^{0.5} = 1.143$$

$$C = \frac{K^{0.5}(K-1)}{1+K^{1.5}} = \frac{(1.143)(0.307)}{1+1.307^{1.5}} = 0.141$$

$$(rt_u)^{0.5} = [(42,500)(26.51)]^{0.5} = 1061$$

$$\begin{aligned} x_1 &= 0.61(rt_u)^{0.5} + 320CH \\ &= 0.61(1061) + 320(0.141)(14.4) = 1297 \end{aligned}$$

$$x_2 = 1000CH = 1000(0.141)(14.4) = 2030$$

$$x_3 = 1.22(rt_u)^{0.5} = 1.22(1061) = 1294$$

$$x = \min(x_1, x_2, x_3) = 1294$$

$$x/1000 = 1.294$$

$$t_{tx} = \frac{4.9D(H-x/1000)}{S_t} = \frac{4.9(85)(14.4-1.294)}{208} = 26.24 \text{ mm}$$

In US Customary units:

$$t_u = t_{tx} \text{ from first trial} = 1.071 \text{ in.}$$

$$t_L = 1.399 \text{ in.}$$

$$K = \frac{t_L}{t_u} = \frac{1.399}{1.071} = 1.306$$

$$K^{0.5} = 1.143$$

$$C = \frac{K^{0.5}(K-1)}{1+K^{1.5}} = \frac{(1.143)(0.306)}{1+1.493} = 0.140$$

$$(rt_u)^{0.5} = [(1680)(1.071)]^{0.5} = 42.42$$

$$\begin{aligned} x_1 &= 0.61(rt_u)^{0.5} + 3.84CH \\ &= 0.61(42.42) + 3.84(0.140)(48) = 25.88 + 25.80 = 51.68 \end{aligned}$$

$$x_2 = 12CH = 12(0.140)(48) = 80.64$$

$$x_3 = 1.22(rt_u)^{0.5} = 1.22(42.42) = 51.75$$

$$x = \min(x_1, x_2, x_3) = 51.68$$

$$x/12 = 4.31$$

$$t_{tx} = \frac{2.6D(H-x/12)}{S_t} = \frac{2.6(280)(48-4.31)}{30,000} = 1.060 \text{ in.}$$

With this value of t_{tx} , start the third trial.

K.2.3.2.3 Third Trial

In SI units:

$$t_u = t_{tx} \text{ from the second trial} = 26.24 \text{ mm}$$

$$t_L = 34.64 \text{ mm}$$

$$K = \frac{t_L}{t_u} = \frac{34.64}{26.24} = 1.320$$

$$K^{0.5} = 1.149$$

$$C = \frac{K^{0.5}(K-1)}{1+K^{1.5}} = \frac{(1.149)(0.320)}{1+1.320^{1.5}} = 0.146$$

$$(rt_u)^{0.5} = [(42,500)(26.24)]^{0.5} = 1056$$

$$\begin{aligned} x_1 &= 0.61(rt_u)^{0.5} + 320CH \\ &= 0.61(1056) + 320(0.146)(14.4) = 1317 \end{aligned}$$

$$x_2 = 1000CH = 1000(0.146)(14.4) = 2102$$

$$x_3 = 1.22(rt_u)^{0.5} = 1.22(1056) = 1288$$

$$x = \min(x_1, x_2, x_3) = 1288$$

$$x/1000 = 1.288$$

$$t_{tx} = \frac{4.9D(H-x/1000)}{S_t} = \frac{4.9(85)(14.4-1.288)}{208} = 26.26 \text{ mm for Course 3}$$

In US Customary units:

$$t_u = t_{tx} \text{ from second trial} = 1.060 \text{ in.}$$

$$t_L = 1.399 \text{ in.}$$

$$K = \frac{t_L}{t_u} = \frac{1.399}{1.060} = 1.320$$

$$K^{0.5} = 1.149$$

$$C = \frac{K^{0.5}(K-1)}{1+K^{1.5}} = \frac{(1.149)(0.320)}{1+1.517} = 0.146$$

$$(rt_u)^{0.5} = [(1680)(1.06)]^{0.5} = 42.20$$

$$\begin{aligned} x_1 &= 0.61(rt_u)^{0.5} + 3.84CH \\ &= 0.61(42.20) + 3.84(0.146)(48) = 25.74 + 26.91 = 52.65 \end{aligned}$$

$$x_2 = 12CH = 12(0.146)(48) = 84.10$$

$$x_3 = 1.22(rt_u)^{0.5} = 1.22(42.20) = 51.48$$

$$x = \min(x_1, x_2, x_3) = 51.48$$

$$x/12 = 4.29$$

$$t_{tx} = \frac{2.6D(H-x/12)}{S_t} = \frac{2.6(280)(48-4.29)}{30,000} = 1.061 \text{ in. for Course 3}$$

(Sample calculated shell-plate thicknesses for various tank sizes and allowable stresses are given in Tables K-1 through K-3.)

Table K-1—Shell-Plate Thicknesses Based on the Variable-Design-Point Method (See 5.6.4)
Using 2400-mm (96-in.) Courses and an Allowable Stress of 159 MPa (23,000 lbf/in.²) for the Test Condition

Tank Des. Liq. Lvl. m (ft)	Tank Diameter m (ft)	Weight of Shell Mg (tons)	Shell Plate Thickness for Course, mm (in.)								Nominal Tank Volume m ³ (bbl)
			1	2	3	4	5	6	7	8	
12 (40)	60 (200)	233 (272)	21.40 (0.871)	16.18 (0.659)	11.96 (0.487)	8.00 (0.317)	8.00 (0.313)	—	—	—	33,900 (224,000)
	65 (220)	282 (333)	22.99 (0.949)	17.42 (0.720)	12.90 (0.533)	10.00 (0.375)	10.00 (0.375)	—	—	—	39,800 (271,000)
	75 (240)	363 (389)	26.09 (1.025)	20.95 (0.807)	14.58 (0.574)	10.00 (0.375)	10.00 (0.375)	—	—	—	53,000 (322,500)
	80 (260)	408 (453)	27.59 (1.099)	22.97 (0.907)	15.39 (0.613)	10.02 (0.398)	10.00 (0.375)	—	—	—	60,300 (378,500)
	85 (280)	457 (522)	29.06 (1.171)	24.95 (1.004)	16.21 (0.653)	10.59 (0.427)	10.00 (0.375)	—	—	—	68,100 (439,000)
	90 (300)	510 (594)	30.51 (1.241)	26.88 (1.098)	17.01 (0.692)	11.16 (0.454)	10.00 (0.375)	—	—	—	76,300 (504,000)
	100 (320)	621 (671)	33.31 (1.310)	30.59 (1.189)	18.57 (0.730)	12.28 (0.482)	10.00 (0.375)	—	—	—	94,200 (573,400)
	105 (340)	680 (751)	34.66 (1.377)	32.40 (1.277)	19.32 (0.768)	12.84 (0.509)	10.00 (0.375)	—	—	—	103,900 (647,300)
	110 (360)	741 (835)	35.99 (1.433)	34.21 (1.362)	20.06 (0.804)	13.39 (0.536)	10.00 (0.375)	—	—	—	114,000 (725,700)
115 (380)	804 (923)	37.29 (1.506)	35.94 (1.448)	20.78 (0.840)	13.93 (0.562)	10.00 (0.375)	—	—	—	124,600 (808,600)	
14.4 (48)	55 (180)	276 (312)	23.90 (0.956)	18.85 (0.755)	14.99 (0.600)	11.06 (0.443)	8.00 (0.313)	8.00 (0.313)	—	—	34,200 (217,700)
	60 (200)	322 (376)	25.90 (1.055)	20.43 (0.832)	16.29 (0.664)	11.96 (0.487)	8.00 (0.317)	8.00 (0.313)	—	—	40,700 (268,800)
	65 (220)	388 (463)	27.85 (1.150)	22.54 (0.943)	17.49 (0.721)	12.89 (0.533)	10.00 (0.375)	10.00 (0.375)	—	—	47,800 (325,200)
	75 (240)	505 (543)	31.65 (1.243)	27.47 (1.063)	19.76 (0.776)	14.78 (0.579)	10.00 (0.375)	10.00 (0.375)	—	—	63,600 (387,000)
	80 (260)	569 (633)	33.50 (1.334)	29.85 (1.181)	20.92 (0.833)	15.71 (0.625)	10.00 (0.397)	10.00 (0.375)	—	—	72,400 (454,200)
	85 (280)	638 (729)	35.32 (1.423)	32.17 (1.295)	22.05 (0.889)	16.63 (0.669)	10.53 (0.424)	10.00 (0.375)	—	—	81,700 (526,800)
	90 (298)	711 (821)	37.11 (1.502)	34.44 (1.394)	23.17 (0.938)	17.54 (0.710)	11.08 (0.448)	10.00 (0.375)	—	—	91,600 (596,700)
16.8 (56)	50 (160)	306 (333)	25.42 (0.995)	20.83 (0.817)	17.30 (0.678)	13.69 (0.537)	10.15 (0.398)	8.00 (0.313)	8.00 (0.313)	—	33,000 (200,700)
	55 (180)	364 (412)	27.97 (1.119)	22.77 (0.912)	18.98 (0.760)	14.96 (0.599)	11.06 (0.443)	8.00 (0.313)	8.00 (0.313)	—	39,900 (254,000)
	60 (200)	428 (502)	30.42 (1.239)	25.25 (1.033)	20.54 (0.836)	16.27 (0.663)	11.96 (0.487)	8.00 (0.317)	8.00 (0.313)	—	47,500 (313,600)
	65 (220)	514 (615)	32.73 (1.351)	28.17 (1.175)	22.02 (0.908)	17.59 (0.727)	12.89 (0.532)	10.00 (0.375)	10.00 (0.375)	—	55,700 (379,400)
	75 (240)	671 (723)	37.24 (1.462)	33.81 (1.313)	25.01 (0.982)	20.17 (0.790)	14.72 (0.577)	10.00 (0.375)	10.00 (0.375)	—	74,200 (451,500)
	77 (247)	705 (764)	38.12 (1.500)	34.91 (1.361)	25.60 (1.007)	20.69 (0.812)	15.09 (0.592)	10.00 (0.379)	10.00 (0.375)	—	78,200 (478,300)
	19.2 (64)	50 (160)	390 (423)	29.12 (1.139)	24.42 (0.957)	20.95 (0.820)	17.28 (0.677)	13.69 (0.537)	10.15 (0.398)	8.00 (0.313)	8.00 (0.313)
55 (180)		466 (527)	32.03 (1.282)	27.03 (1.078)	22.92 (0.918)	18.95 (0.758)	14.98 (0.599)	11.06 (0.443)	8.00 (0.313)	8.00 (0.313)	45,600 (290,300)
60 (200)		551 (646)	34.95 (1.423)	30.39 (1.242)	24.75 (1.007)	20.63 (0.841)	16.27 (0.662)	11.96 (0.487)	8.00 (0.317)	8.00 (0.313)	54,300 (358,400)
62.5 (212)		610 (735)	36.29 (1.502)	32.04 (1.338)	25.66 (1.061)	21.47 (0.890)	16.91 (0.700)	12.41 (0.514)	10.00 (0.375)	10.00 (0.375)	58,900 (402,600)

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WELDED STEEL TANKS FOR OIL STORAGE

Table K-2—Shell-Plate Thicknesses Based on the Variable-Design-Point Method (See 5.6.4)
Using 2400-mm (96-in.) Courses and an Allowable Stress of 208 MPa (30,000 lbf/in.²) for the Test Condition

Tank Des. Liq. Lvl. m (ft)	Tank Diameter m (ft)	Weight of Shell Mg (tons)	Shell Plate Thickness for Course, mm (in.)								Nominal Tank Volume m ³ (bbl)
			1	2	3	4	5	6	7	8	
12 (40)	75 (240)	298 (320)	20.26 (0.798)	15.36 (0.603)	11.38 (0.447)	10.00 (0.375)	10.00 (0.375)	—	—	—	53,000 (322,500)
	80 (260)	332 (365)	21.45 (0.856)	16.48 (0.651)	12.06 (0.482)	10.00 (0.375)	10.00 (0.375)	—	—	—	60,300 (378,500)
	85 (280)	369 (417)	22.63 (0.914)	18.07 (0.729)	12.65 (0.511)	10.00 (0.375)	10.00 (0.375)	—	—	—	68,100 (439,000)
	90 (300)	409 (472)	23.78 (0.971)	19.63 (0.806)	13.27 (0.541)	10.00 (0.375)	10.00 (0.375)	—	—	—	76,300 (504,000)
	100 (320)	493 (530)	26.03 (1.026)	22.64 (0.880)	14.51 (0.572)	10.00 (0.375)	10.00 (0.375)	—	—	—	94,200 (573,400)
	105 (340)	537 (594)	27.12 (1.080)	24.10 (0.952)	15.12 (0.602)	10.00 (0.395)	10.00 (0.375)	—	—	—	103,900 (647,300)
	110 (360)	585 (661)	28.20 (1.133)	25.52 (1.022)	15.72 (0.632)	10.37 (0.416)	10.00 (0.375)	—	—	—	114,000 (725,700)
	115 (380)	636 (731)	29.25 (1.185)	26.92 (1.090)	16.31 (0.660)	10.79 (0.437)	10.00 (0.375)	—	—	—	124,600 (800,600)
	120 (400)	688 (803)	30.29 (1.235)	28.30 (1.156)	16.88 (0.689)	11.22 (0.458)	10.00 (0.375)	—	—	—	135,700 (896,000)
14.4 (48)	65 (220)	316 (374)	21.55 (0.892)	16.99 (0.704)	13.52 (0.561)	10.00 (0.412)	10.00 (0.375)	10.00 (0.375)	—	—	47,800 (325,200)
	75 (240)	406 (436)	24.54 (0.966)	19.96 (0.773)	15.41 (0.608)	11.37 (0.446)	10.00 (0.375)	10.00 (0.375)	—	—	63,600 (387,000)
	80 (260)	456 (505)	26.01 (1.038)	21.86 (0.866)	16.27 (0.650)	12.09 (0.482)	10.00 (0.375)	10.00 (0.375)	—	—	72,400 (454,200)
	85 (280)	509 (579)	27.45 (1.109)	23.73 (0.958)	17.14 (0.692)	12.81 (0.517)	10.00 (0.375)	10.00 (0.375)	—	—	81,700 (526,800)
	90 (300)	565 (656)	28.87 (1.178)	25.55 (1.047)	18.02 (0.736)	13.52 (0.552)	10.00 (0.375)	10.00 (0.375)	—	—	91,600 (604,800)
	100 (320)	684 (739)	31.64 (1.247)	29.10 (1.135)	19.76 (0.778)	14.92 (0.587)	10.00 (0.375)	10.00 (0.375)	—	—	113,100 (688,100)
	105 (340)	747 (827)	33.00 (1.314)	30.81 (1.220)	20.61 (0.820)	15.62 (0.621)	10.00 (0.392)	10.00 (0.375)	—	—	124,700 (776,800)
	110 (360)	814 (921)	34.33 (1.379)	32.49 (1.302)	21.44 (0.862)	16.31 (0.655)	10.28 (0.412)	10.00 (0.375)	—	—	136,800 (870,900)
	115 (380)	885 (1019)	35.65 (1.444)	34.18 (1.383)	22.26 (0.902)	17.01 (0.688)	10.68 (0.433)	10.00 (0.375)	—	—	149,600 (970,300)
120 (400)	958 (1121)	36.94 (1.507)	35.83 (1.462)	23.08 (0.942)	17.73 (0.721)	11.08 (0.452)	10.00 (0.375)	—	—	162,900 (1,075,200)	
16.8 (56)	60 (200)	341 (400)	23.32 (0.953)	19.05 (0.778)	15.85 (0.648)	12.51 (0.511)	9.27 (0.378)	8.00 (0.313)	8.00 (0.313)	—	47,500 (313,600)
	65 (220)	410 (490)	25.27 (1.048)	20.53 (0.858)	17.13 (0.709)	13.50 (0.560)	10.00 (0.412)	10.00 (0.375)	10.00 (0.375)	—	55,700 (379,400)
	75 (240)	533 (575)	28.84 (1.135)	24.92 (0.968)	19.40 (0.764)	15.51 (0.609)	11.36 (0.446)	10.00 (0.375)	10.00 (0.375)	—	74,200 (451,500)
	80 (260)	601 (668)	30.58 (1.220)	27.09 (1.075)	20.53 (0.819)	16.50 (0.658)	12.07 (0.481)	10.00 (0.375)	10.00 (0.375)	—	84,400 (529,900)
	85 (280)	672 (766)	32.29 (1.305)	29.23 (1.180)	21.68 (0.876)	17.48 (0.706)	12.76 (0.515)	10.00 (0.375)	10.00 (0.375)	—	95,300 (614,600)
	90 (300)	747 (871)	33.98 (1.387)	31.33 (1.283)	22.82 (0.932)	18.46 (0.754)	13.46 (0.549)	10.00 (0.375)	10.00 (0.375)	—	106,900 (705,600)
	100 (320)	907 (981)	37.29 (1.469)	35.41 (1.383)	25.05 (0.987)	20.42 (0.801)	14.82 (0.583)	10.00 (0.375)	10.00 (0.375)	—	131,900 (802,800)
	105 (340)	992 (1100)	38.91 (1.549)	37.39 (1.481)	26.14 (1.041)	21.46 (0.849)	15.48 (0.616)	10.00 (0.393)	10.00 (0.375)	—	145,500 (906,300)
	110 (360)	1083 (1225)	40.51 (1.627)	39.36 (1.577)	27.23 (1.094)	22.64 (0.895)	16.11 (0.649)	10.30 (0.413)	10.00 (0.375)	—	159,700 (1,016,000)
115 (380)	1179 (1358)	42.08 (1.705)	41.28 (1.671)	28.33 (1.148)	23.79 (0.951)	16.74 (0.679)	10.72 (0.434)	10.00 (0.375)	—	174,500 (1,132,000)	
120 (392)	1278 (1441)	43.63 (1.750)	43.14 (1.726)	29.44 (1.180)	24.94 (0.986)	17.36 (0.698)	11.14 (0.446)	10.00 (0.375)	—	190,000 (1,204,700)	
19.2 (64)	60 (200)	433 (508)	26.71 (1.092)	22.34 (0.913)	19.19 (0.784)	15.83 (0.647)	12.52 (0.511)	9.27 (0.378)	8.00 (0.313)	8.00 (0.313)	54,300 (358,400)
	65 (220)	520 (623)	28.94 (1.201)	24.70 (1.034)	20.63 (0.853)	17.11 (0.710)	13.51 (0.560)	10.00 (0.412)	10.00 (0.375)	10.00 (0.375)	63,700 (433,600)
	75 (240)	679 (734)	33.16 (1.304)	29.77 (1.159)	23.42 (0.922)	19.67 (0.772)	15.47 (0.608)	11.36 (0.447)	10.00 (0.375)	10.00 (0.375)	84,800 (516,000)
	80 (260)	766 (853)	35.17 (1.403)	32.22 (1.280)	24.85 (0.992)	20.93 (0.834)	16.45 (0.655)	12.06 (0.481)	10.00 (0.375)	10.00 (0.375)	96,500 (605,600)
	85 (280)	858 (981)	37.15 (1.501)	34.64 (1.399)	26.25 (1.061)	22.18 (0.896)	17.41 (0.703)	12.77 (0.516)	10.00 (0.375)	10.00 (0.375)	109,000 (702,400)
	90 (300)	955 (1116)	39.12 (1.597)	37.01 (1.515)	27.65 (1.129)	23.44 (0.957)	18.36 (0.749)	13.46 (0.550)	10.00 (0.375)	10.00 (0.375)	122,100 (806,400)
	100 (320)	1163 (1259)	42.96 (1.692)	41.63 (1.629)	30.38 (1.196)	26.27 (1.017)	20.19 (0.796)	14.85 (0.584)	10.00 (0.375)	10.00 (0.375)	150,800 (917,500)
	101 (332)	1185 (1350)	43.34 (1.748)	42.08 (1.696)	30.65 (1.236)	26.56 (1.059)	20.37 (0.822)	14.98 (0.604)	10.00 (0.384)	10.00 (0.375)	153,800 (987,600)

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K-10

API STANDARD 650

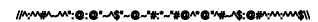


Table K-3—Shell-Plate Thicknesses Based on the Variable-Design-Point Method (See 5.6.4)
Using 2400-mm (96-in.) Courses and an Allowable Stress of 236 MPa (34,300 lbf/in.²) for the Test Condition

Tank Des. Liq. Lvl. m (ft)	Tank Diameter m (ft)	Weight of Shell Mg (tons)	Shell Plate Thickness for Course, mm (in.)								Nominal Tank Volume m ³ (bbl)
			1	2	3	4	5	6	7	8	
14.4 (48)	65 (220)	293 (341)	19.03 (0.784)	15.04 (0.619)	11.95 (0.492)	10.00 (0.375)	10.00 (0.375)	10.00 (0.375)	—	—	47,800 (325,200)
	75 (240)	368 (394)	21.76 (0.850)	17.19 (0.670)	13.70 (0.534)	10.05 (0.393)	10.00 (0.375)	10.00 (0.375)	—	—	63,600 (387,000)
	80 (260)	413 (453)	23.07 (0.914)	18.78 (0.736)	14.48 (0.574)	10.69 (0.423)	10.00 (0.375)	10.00 (0.375)	—	—	72,400 (454,200)
	85 (280)	460 (519)	24.36 (0.977)	20.45 (0.818)	15.24 (0.611)	11.33 (0.454)	10.00 (0.375)	10.00 (0.375)	—	—	81,700 (526,800)
	90 (300)	510 (588)	25.63 (1.039)	22.10 (0.898)	16.00 (0.649)	11.96 (0.485)	10.00 (0.375)	10.00 (0.375)	—	—	91,600 (604,800)
	100 (320)	617 (662)	28.12 (1.100)	25.30 (0.977)	17.56 (0.687)	13.21 (0.515)	10.00 (0.375)	10.00 (0.375)	—	—	113,100 (688,100)
	105 (340)	674 (738)	29.34 (1.160)	26.85 (1.053)	18.32 (0.724)	13.82 (0.545)	10.00 (0.375)	10.00 (0.375)	—	—	124,700 (776,800)
	110 (360)	733 (819)	30.54 (1.218)	28.37 (1.127)	19.07 (0.761)	14.44 (0.575)	10.00 (0.375)	10.00 (0.375)	—	—	136,800 (870,900)
	115 (380)	794 (904)	31.73 (1.276)	29.87 (1.200)	19.81 (0.797)	15.05 (0.605)	10.00 (0.381)	10.00 (0.375)	—	—	149,600 (970,300)
120 (400)	856 (994)	32.89 (1.333)	31.34 (1.271)	20.54 (0.832)	15.66 (0.634)	10.00 (0.399)	10.00 (0.375)	—	—	162,900 (1,075,200)	
16.8 (56)	60 (200)	308 (358)	20.56 (0.834)	16.86 (0.684)	14.00 (0.568)	11.08 (0.449)	8.21 (0.333)	8.00 (0.313)	8.00 (0.313)	—	47,500 (313,600)
	65 (220)	376 (441)	22.27 (0.917)	18.17 (0.747)	15.13 (0.623)	11.93 (0.491)	10.00 (0.375)	10.00 (0.375)	10.00 (0.375)	—	55,700 (379,400)
	75 (240)	480 (514)	25.56 (0.998)	21.48 (0.825)	17.24 (0.674)	13.70 (0.534)	10.05 (0.393)	10.00 (0.375)	10.00 (0.375)	—	74,200 (451,500)
	80 (260)	541 (596)	27.11 (1.074)	23.43 (0.921)	18.23 (0.723)	14.58 (0.577)	10.67 (0.422)	10.00 (0.375)	10.00 (0.375)	—	84,400 (529,900)
	85 (280)	604 (684)	28.64 (1.149)	25.35 (1.015)	19.23 (0.771)	15.45 (0.620)	11.29 (0.453)	10.00 (0.375)	10.00 (0.375)	—	95,300 (614,600)
	90 (300)	671 (777)	30.15 (1.222)	27.24 (1.107)	20.25 (0.821)	16.32 (0.662)	11.91 (0.483)	10.00 (0.375)	10.00 (0.375)	—	106,900 (705,600)
	100 (320)	815 (875)	33.12 (1.295)	30.92 (1.197)	22.24 (0.869)	18.04 (0.703)	13.12 (0.512)	10.00 (0.375)	10.00 (0.375)	—	131,900 (802,800)
	105 (340)	891 (978)	34.57 (1.366)	32.70 (1.284)	23.22 (0.918)	18.90 (0.745)	13.72 (0.542)	10.00 (0.375)	10.00 (0.375)	—	145,500 (906,300)
	110 (360)	970 (1086)	36.01 (1.436)	34.46 (1.370)	24.19 (0.965)	19.77 (0.786)	14.31 (0.571)	10.00 (0.375)	10.00 (0.375)	—	159,700 (1,016,000)
115 (380)	1053 (1200)	37.42 (1.505)	36.19 (1.454)	25.15 (1.012)	20.80 (0.827)	14.87 (0.600)	10.00 (0.382)	10.00 (0.375)	—	174,500 (1,132,000)	
120 (400)	1139 (1322)	38.82 (1.573)	37.92 (1.536)	26.11 (1.058)	21.83 (0.873)	15.43 (0.627)	10.00 (0.400)	10.00 (0.375)	—	190,000 (1,254,400)	
19.2 (64)	60 (200)	389 (453)	23.54 (0.955)	19.76 (0.801)	16.94 (0.687)	13.98 (0.567)	11.08 (0.449)	8.21 (0.333)	8.00 (0.313)	8.00 (0.313)	54,300 (358,400)
	65 (220)	471 (556)	25.51 (1.051)	21.32 (0.884)	18.31 (0.752)	15.10 (0.622)	11.94 (0.491)	10.00 (0.375)	10.00 (0.375)	10.00 (0.375)	63,700 (433,600)
	75 (240)	609 (653)	29.37 (1.146)	25.79 (0.994)	20.78 (0.812)	17.37 (0.677)	13.67 (0.533)	10.05 (0.393)	10.00 (0.375)	10.00 (0.375)	84,800 (516,000)
	80 (260)	687 (759)	31.17 (1.235)	27.99 (1.102)	22.02 (0.872)	18.49 (0.731)	14.53 (0.575)	10.68 (0.423)	10.00 (0.375)	10.00 (0.375)	96,500 (605,600)
	85 (280)	769 (872)	32.94 (1.321)	30.16 (1.208)	23.27 (0.933)	19.60 (0.786)	15.39 (0.617)	11.30 (0.453)	10.00 (0.375)	10.00 (0.375)	109,000 (702,400)
	90 (300)	855 (992)	34.69 (1.406)	32.29 (1.311)	24.51 (0.994)	20.70 (0.839)	16.24 (0.658)	11.92 (0.483)	10.00 (0.375)	10.00 (0.375)	122,100 (806,400)
	100 (320)	1041 (1119)	38.13 (1.490)	36.45 (1.413)	26.96 (1.053)	22.99 (0.893)	17.90 (0.699)	13.15 (0.513)	10.00 (0.375)	10.00 (0.375)	150,800 (917,500)
	105 (340)	1140 (1252)	39.82 (1.573)	38.47 (1.512)	28.16 (1.112)	24.27 (0.946)	18.70 (0.740)	13.76 (0.543)	10.00 (0.375)	10.00 (0.375)	166,300 (1,035,700)
	110 (360)	1243 (1394)	41.49 (1.655)	40.47 (1.610)	29.34 (1.170)	25.57 (1.007)	19.49 (0.779)	14.36 (0.572)	10.00 (0.375)	10.00 (0.375)	182,500 (1,161,200)
115 (380)	1351 (1543)	43.14 (1.735)	42.45 (1.705)	30.55 (1.228)	26.85 (1.071)	20.27 (0.817)	14.97 (0.601)	10.00 (0.382)	10.00 (0.375)	199,400 (1,293,800)	
117 (384)	1395 (1574)	43.80 ^a (1.751 ^a)	43.22 (1.724)	31.03 (1.240)	27.36 (1.083)	20.59 (0.824)	15.21 (0.607)	10.00 (0.385)	10.00 (0.375)	206,400 (1,321,200)	

^aExceeds maximum allowed material thickness.

APPENDIX L—API STD 650 STORAGE TANK DATA SHEET

• L.1 Introduction

L.1.1 PURPOSE

This appendix provides guidance to Purchasers (owners, engineering contractors, and other designated agents) and Manufacturers (fabricators and erectors) for the preparation and completion of the *Atmospheric Storage Tank Data Sheet* (hereafter referred to as the **Data Sheet**). The Data Sheet shall be prepared in conjunction with this Standard such that comprehensive proposals (bids) may be made and subsequent contracts may be placed for the fabrication and erection of tanks.

L.1.2 SCOPE

This appendix explains information to be placed on the Data Sheet primarily by Purchasers for use by Manufacturers. However, some of the instructions apply to either the Purchaser or the Manufacturer, depending on which party assumes certain responsibilities.

• L.2 Use of This Appendix

• L.2.1 DATA SHEET PURPOSE

The Data Sheet (attached to this appendix) shall be part of a complete tank specification. The Data Sheet provides space for defining specific technical information such as geometry, design loads, materials, and appurtenances, as well as an outline sketch of the tank. The Data Sheet may be used as part of the Owner's permanent record describing the tank. Because some information on the Data Sheet may be determined by the Manufacturer, the Data Sheet may also be used to facilitate gathering of the complete design requirements. The floating roof section of the Data Sheet may be omitted if no floating roof is required for the tank.

• L.2.2 PURCHASER'S RESPONSIBILITY

The preparer(s) of the Data Sheet shall have tank design experience and shall ensure that the requirements are both accurate and complete. The Purchaser is primarily responsible for initiating and completing the Data Sheet.

L.2.3 MANUFACTURER'S RESPONSIBILITY

The Manufacturer shall complete the Data Sheet as required to describe the proposal and shall provide the relevant information required on all lines marked with an asterisk (*) that have not been provided by the Purchaser. The Data Sheet shall be submitted at various times during the project as described in W.1.2(2).

• L.2.4 TEXT LEGIBILITY

All text placed on the Data Sheet shall be of size and quality to be readable and reproducible. Use additional sheets or extend the form electronically for more space or necessary additions.

• L.3 Specific Instructions

L.3.1 LINE-BY-LINE INSTRUCTIONS

Each place for data entry (numbered lines, boxes, table cells, etc.) on the Data Sheet shall be completed. In no case should a line be left blank. Marking "NA" (not applicable), "Later," "TBD" (to be determined), or other such terminology can be used. The "Later" and "TBD" notations shall be edited to reflect subsequent decisions and as-built configurations (see W.1.2).

Use consistent units for all dimensions and other data on the Data Sheet. *Show appropriate units for every appropriate numerical entry.*

The following numbered items correspond to the numbered lines and numbered tables on the Data Sheet:

- **Heading:**

Data Sheet Status: Typical entries include: For Quotation, Bid, For Design Review, For Design Revision, and As-Built. Revise to suit the status when submitted by the Purchaser or by the Manufacturer.

- **General:**

- Special Documentation Package Requirements: List any exceptions to the default requirements listed in Appendix W.
- Measurement Units to be used in API Std 650: Identify the set of units to be used when applying the rules in API Std 650.

- 1. Tank Manufacturer

- Manufacturer's name.*
- Contract number*: Enter proposed or assigned number.
- Address*: Enter physical address, not a post office box.
- Manufacturer's serial number for tank.*
- Year built.*
- Edition and Addendum of API Std 650 used for design and fabrication.*

- 2. Purchaser

- Purchaser's name.
- Contract number or designation.
- Address: Enter physical address, not a post office box.
- Tank designation: For example, item number, equipment tag number, or other description.

- 3. Owner/Operator

- Owner/operator name.
- Location of facility where tank will be operated.

- 4. Tank Dimensions

- Size Limitations*: Specify size limitations only when exact dimensions are to be determined by the Manufacturer (e.g., maximum and minimum diameters, shell heights, overall heights, etc.).
- Tank Diameter*: Specify diameter and indicate ID, OD, or CL/BSC (centerline diameter of bottom shell course).
- Shell Height*: Specify the distance from the top surface of the bottom plate or annular ring to the upper edge of the cylindrical shell including top angle, if any.
- Maximum Capacity* and Net Working Capacity*:
- Criteria*: Method used to determine capacity of tank: An example would be *API RP 2350*.

- 5. Products Stored

- Liquid: Specify liquid(s) to be stored in the tank.
- Maximum Specific Gravity: Enter specific gravity of the stored liquid(s) at designated temperatures. Use greatest value of all products when tanks are to be designed for multiple products.
- Blanketing Gas: Specify blanketing gas in the space above the liquid.
- Vapor Pressure: Specify absolute vapor pressure at the maximum operating temperature. Use the largest value for tanks designed for multiple products.
- % Aromatic: Specify percentage by weight of aromatic hydrocarbons in tank. Refer to any supplemental specification for protecting the materials of construction, as applicable.
- Hydrogen Sulfide Service? (Yes/No): If "Yes," a supplemental specification for material selection and hardness shall be required. See 5.3.4.
- Other Special Service Conditions: Include any conditions that may require further consideration. Consider thermal expansion or shock, cyclic vibratory fatigue, and issues or regulations concerning the product stored, e.g., chloride, caustic, amine, or ethanol corrosion, hydrogen blistering or embrittlement, oleum, sulfuric acid, or ammonia service, RCRA (Resource Conservation and Recovery Act), HON (Hazardous Organic National Emission Standard for Hazardous Air Pollutants), RMP (Clean Air Act Risk Management Plan), etc. Provide supplemental specifications as needed. See 5.3.3.

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- **Design and Testing**

Purchaser to Review Design Prior to Ordering Materials: Indicate if the Manufacturer is free to order materials prior to Purchaser reviewing the design documents. Schedule may be affected. See W.1.3.

6. Applicable Appendices*: See 1.1.6. Appendix E may be selected on Line 8 of the Data Sheet. If no appendices are chosen, the basic design of this Standard is intended.

7. Design Parameters

- Maximum Design Temperature: See 1.4 for definition. This differs from the operating temperature. For temperature limits, see 1.1.1, and Appendices M and S. If the roof design temperature is different than the shell temperature, as in the case of an uninsulated roof on an insulated shell, then use Line 23 to specify the roof maximum design temperature.
- Design Metal Temperature*: Enter either lowest 1-day mean temperature plus 8°C (15°F) or a lower temperature as specified by the Purchaser if operating conditions and/or local atmospheric conditions control fracture toughness issues.
- Design Liquid Level*: See 5.6.3.2, C.3.1.1, and E.2.2.
- Design Pressure: Specify pressure and units in the vapor space.
- External Pressure: See 5.2.5.
- Maximum Fill Rate: Specify rate and units (e.g., 100 gallons per minute).
- Maximum Emptying Rate: Specify rate and units (e.g., 75 gallons per minute).
- Flotation Considerations (Yes/No): Include design consideration that advise the Manufacturer about tank flotation anchorage, bottom uplift, and partial submersion pressures arising out of flood or dike impoundment.
- Flotation Supplemental Specifications*: Refer to any that may describe external liquid depth, external fluid specific gravity, minimum internal liquid level, and any other information necessary for design.
- Section 5.2.4 makes the design criteria here a matter of agreement between the Purchaser and the Manufacturer.
- Applied Supplemental Load Specification: Refer to supplemental specifications that provide concentrated loads applied to the shell, such as openings or appurtenances from attached equipment, valves, or piping, or reactions from stairs and platforms for determination of strength and stiffness issues by the Manufacturer. If this information is not provided, the requirements of W.2(5) still apply.

- 8. Seismic Design Data

- Seismic Design? (Yes/No): Indicate whether design for earthquakes is required. The Purchaser may specify Appendix E, or an alternate criterion.
- Appendix E: Mark the box provided if this appendix shall be used for seismic design.
- Alternate Seismic Criteria: Refer to any supplemental criteria different from this Standard that shall be followed. All required design factors shall be included in this supplemental specification.
- Seismic Use Group: See E.3.1.
- Site Class: See Table E.4-B.
- Vertical Seismic Design: Indicate if this design is required.
- Vertical Ground Motion Accelerator: Provide per E.6.1.3.
- Basis of Lateral Acceleration: Select one of the three methods listed, and specify the appropriate parameters. See E.4.
- Freeboard: For SUG I designs, indicate if freeboard is required. See E.7.2.
- Roof Tie Rods @ Outer Ring?* (Yes/No): See E.7.5

- 9. Design Wind Issues

- Top Wind Girder Style*: See 5.9, and Figure 5-24, for open-top and external floating roofs.
- Dimensions of Top Wind Girder*: For example, if style were “Curb Angle,” the dimension might be $3 \times 3 \times \frac{3}{8}$ (in.).
- Use Top Wind Girder as Walkway? (Yes/No): See 5.9, and Figure 5-25, and note 3 ft-6 in. dimension preference of 5.9.4 if choice is “Yes.”
- Intermediate Wind Girders* (Yes/No): Specify “Yes” whenever wind girders shall be added to the shell to satisfy shell stability stiffening predicated by wind loads. Specify “No” if shell stiffening is to be accomplished by increasing the shell thickness. If not specified by the Purchaser, the Manufacturer must select between the two alternatives and indicate the choice here.
- Intermediate Wind Girder Style*: See 5.9 and Figure 5-24, for all kinds of tanks whenever wind girders are specified.

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- Dimensions of Intermediate Wind Girders*: For example, if style were “formed plate,” dimension might be $b = 30$ in. per Figure 5-24.
- Check Buckling in Corroded Condition? (Yes/No): If “Yes,” the wind load shall be applied to the corroded shell (an option covered in 5.9.7.1) to establish the adequacy of the thicknesses and/or stiffening rings to resist the applied forces.

10. Shell Design

- 1-Foot Method?* (Yes/No): The Purchaser may select this shell thickness design method. The method is subject to the applicable limitations noted in 5.6.3, A.4, J.3.3, and S.3.2. If not selected by the Purchaser, the Manufacturer may select either this design method or one of the other two methods that this Standard lists, subject to the restrictions of this Standard and the Purchaser’s approval.
- Variable-Design-Point Method?* (Yes/No/Alternate): The Purchaser may select this shell thickness design method. This method is subject to the restrictions detailed in 5.6.4. If the 1-Foot Method or Elastic Analysis Method is selected by the Purchaser and the Variable-Design-Point Method is also selected as an “Alternate” by the Purchaser, the Variable-Point Design Method may be used in addition to the Purchaser-selected method, but the resulting proposal must be clearly marked as an “Alternate.” If the method is not selected by the Purchaser, the Manufacturer may select either this design method or one of the other two methods that this Standard lists, subject to the restrictions of this Standard and the Purchaser’s approval.
- Elastic Analysis Method?* (Yes/No/Alternate): The Purchaser may select this shell thickness design method. This method is subject to the restrictions detailed in 5.6.5. Cases when this method is mandatory are named in 5.6.5 as well as requirements on the analysis boundary conditions. When it is not mandatory, the Purchaser may select this shell design method. If the 1-Foot or Variable-Design-Point Method is selected by the Purchaser and the Elastic Analysis Method is also selected as an “Alternate” by the Purchaser, the Elastic Analysis Method may be used in addition to the Purchaser-selected method, but the resulting proposal must be clearly marked as an “Alternate.” If the method is not selected by the Purchaser, the Manufacturer may select either this design method or one of the other two methods that this Standard lists, subject to the restrictions of this Standard and the Purchaser’s approval.
- Plate-Stacking Criteria* Centerline-Stacked? (Yes/No) or Flush-Stacked on the Inside or Outside? (Yes/No)?:
- Plate Widths (Shell Course Heights) and Thicknesses*: Specify nominal shell course heights and thicknesses. The first course is attached to the bottom.
- Joint Efficiency*: Specify in percentage. Applicable only to Appendices A, J, and S designs. Mark “NA” for all other designs.
- Shell-to-Bottom Weld Type*: See Figure 5-3A (inside and outside corner fillets), Figure 5-3C (inside and outside partial penetration corner welds with fillet weld reinforcement), and J.3.2.4 (full penetration butt weld to flanged flat bottom).
- Shell-to-Bottom Weld Inspection Method*: Choose among the options listed in accordance with 7.2.4.

11. Open-Top and Fixed-Roof Data (see page 6 of the Data Sheet for Floating Roofs)

- Open Top?* (Yes/No) Specify “Yes” if tank has no fixed roof or has an external floating roof. Specify “No” for all other tanks.

Note: The remaining entries in this line apply to fixed roofs ONLY:

- Fixed Roof Type*: Enter description, such as supported cone with internal structure, supported cone with external structure, structurally-supported aluminum geodesic dome, self-supporting cone, self-supporting dome, self-supporting umbrella, flanged only flat top, or other. See 5.10.1 or Appendix G.
- Roof Support Columns*: Specify pipe or structural shape. If structural shape is specified, indicate the kind (e.g., wide flange, back-to-back channel, etc.).

Commentary: Pipe-type roof columns are preferred for internal floating roof tanks. In many cases the openings are $3/4$ NPT threaded couplings that allow the user to plug the openings when the tank is in service, to minimize corrosion of the supports and reduce emission from the tank. The openings are needed to allow the free drainage and cleaning of the columns when the tank is out of service.

- Cone Slope*: Specify rise to run as a dimensionless ratio, e.g., “ $3/4:12$ ”.
- Dome or Umbrella Radius*: See 5.10.6 for self-supporting approximate spherical radius of roof.

- Weld Joints*: Describe the type of roof plate weld joint, which may be lap joint, butt joint, or some combination thereof.

Note: Appendix F, Section F.7 roofs shall conform to API Std 620.

- Seal Weld Underside of Lap Joints? (Yes/No): May be required for internally coated roof plates or to prevent crevice corrosion.
- Seal Weld Underside of Wind Girder Joints? (Yes/No): See 5.1.5.8.
- Gas-tight? (Yes/No): See 7.3.7.
- Joint Efficiency*: Use only for Appendix F, Section F.7 roofs. See API Std 620, Table 3-2.
- Thickness*: Provide nominal thickness of roof plates.
- Snow-Load*: Purchaser to provide the snow load for non-U.S. Sites. For non-US sites, the Manufacturer should indicate the 50-year ground snow load selected. See 5.2.1e. For instructions on combining loads, see 5.10.2.1.
- Applied Supplemental Loads Specification*: Indicate supplementary specifications for both dead and live roof loads that are concentrated or have local distributions (e.g., the personnel loads of 5.8.6.2 and H.4.2.2). Specify any reactions from platforms or walking surfaces as well as loads applied by equipment, valves, and piping.
- Column Lateral Load: Purchaser may optionally specify lateral loads imposed upon roof-supporting columns in accordance with 5.10.2.9.
- Venting Devices*? Enter type and quantity of devices for normal venting per API Std 2000, and pressure settings. Also, enter type(s) and quantity of emergency venting devices that meet either API Std 2000, circulation venting per Appendix H, or a frangible roof design per 5.10.2.6, as applicable. The frangibility of tanks less than 50 ft in diameter may require additional design considerations beyond those required by this Standard.
- For Non-Frangible Roofs:
 - Seal Weld Roof Plates to Top Angle on the Inside? (Yes/No): When “Yes” is selected, the shell-to-roof-joint shall be seal-welded on the inside. For certain designs, this may adversely affect frangibility.
 - Weld Rafters to Roof Plates? (Yes/No):
- Roof-to-Shell Detail*: See Figures 5-3A and F-3, J.3.5, and API Std 620, Figure 3-6.
- Radial Projection of Horizontal Component to Top Angle*: Specify inward or outward projection.

• 12. Required Bottom Data

- Thickness*: Enter nominal thickness, including corrosion allowance.
- Style*: Enter one of the following: flat, cone up to center, cone down to center, side to side (tilted plane), cone down to off-center. Enter all sump requirements (number, size, location, etc.) in Data Sheet (Table 3, Line 23, or on the Tank Plan).
- Slope*: Enter rise versus run. For the off-center style above, the slope specified is the maximum slope.
- Weld Joint Type*: Enter one of the following: single-welded full-fillet lap joint, single-welded butt with backing strip that remains in place, double-welded butt without backing strip, double-welded full-fillet lap joints, or other, to be detailed on Data Sheet Line 23 if necessary.
- Provide Drip Ring (Yes/No): If required, a drip ring shall be provided per 3.4.5. Unless the following Alternate Specification is provided, the default drip ring shall be provided.
- Alternate Specification: Refer to an acceptable drip ring design specification if the Purchaser requires a drip ring but declines the default design of 5.4.5.
- Annular Ring* (Yes/No): The Purchaser may stipulate this type of detail even if not required by this Standard. A Purchaser’s choice of “No” does not relieve the Manufacturer from complying with the requirements of this Standard in this regard.
- Annular Ring Minimum Radial Width* and Thickness*: Specify width and thickness.

• 13. Foundation Information

- Furnished by*: Indicate Purchaser, Manufacturer, or others.
- Type*: Indicate materials and form. See Appendices B and I (e.g., concrete ring-wall or steel wide flange grillage on concrete pile cap).
- Soil Allowable Bearing Pressure*: Estimate pressure from geotechnical report, experience with similar tanks in the same area, etc.
- Per Specification*: Refer to any specification that describes soil allowable bearing pressure.
- Anchor Size*: See 5.3.1.1 and 5.12. Provide materials of construction, geometric forms, and corrosion allowance for anchors in Table 2 of the Data Sheet.

- Anchor Quantity*: Indicate the total number of anchors or anchor bolts to be provided.
- Foundation Design Loads: See W.3(15). These loads are unfactored after the manner of the Allowable Stress Design methodology. (Sign convention is as follows: positive acting downward, negative acting upward.)
 - Base Shear*: Indicate the values for the wind and seismic conditions in units of force.
 - Overturning Moment*: Indicate in units of force-distance. See 5.11 for wind, and Appendix E, or alternate seismic criteria as specified on Line 8 of the Data Sheet, for seismic criteria.
 - Ring Forces*: Indicate loads delivered by the shell in units of force per circumference of shell.

Note: The uniformly distributed loads are shell plus roof weight (both new and corroded), roof live load, internal pressure, and partial vacuum.

Note: The non-uniform loads are the peak magnitudes of the longitudinal compressive distributed force derived from the wind and seismic-overturning moments without regard to any other compressive or tensile loads in the shell.

- Bottom Forces*: Indicate support loads that are the uniformly applied forces to the bottom away from the shell ring in units of force per unit area. These include weight of bottom plates, product and test liquid weights, and pressure/vacuum loads. Mark all inapplicable entities as “NA.”
- Other Foundation Loads*: Provide an attachment to describe these loads such as lateral soil pressure, overburden, roof column reactions, pore pressure, uplift anchor forces, etc.
- Minimum Projection of Foundation Above Grade: Specify the minimum required projection of the foundation above grade, if any.

14. Pressure Test (See 7.3.5)

- Responsibility for Heating Test Water, if Required: Select one.
- Hydro-Test Fill Height*: See 7.3.5, F.4.4, and F.7.6.
- Settlement Measurements (Yes/No): Purchaser may waive the measurement of foundation settlement during the hydro-test in accordance with 7.3.6.5.
- Extended Duration of Hydro-Test: Provide the number of hours or days if the tank is to be kept full of water for an extended period.
- Predicted Settlement Profile is Attached: Check if the Purchaser elects to inform the Manufacturer of relevant settlement predictions.
- Responsibility for Setting Water Quality: Specify party responsible for setting water quality standards. Refer to supplemental specifications as required. For guidance, see 7.3.6.3.
- Test Water Source and Disposal Tie-In Locations: Provide the location of the supply and disposal points for hydro-test water that the Manufacturer shall use.
- Test Requirements for Appendix J Tanks: Hydrostatic Testing (Yes/No): If “No” is selected, the Purchaser must specify the required Alternative Test from J.4.2.2.
- Penetrant Testing Allowed in lieu of Hydro-Testing: Check if there is no means of providing test water at the tank site, e.g., very remote tank sites. See 7.3.5.
- Post-Pressure-Test Activities Required of the Manufacturer: Select the activities desired according to 7.3.6.2(4).

15. Optional Fabrication, Erection, Inspection, and Testing Requirements

- Inspection by: Designate Purchaser’s inspectors. See 7.3.1.1.
- Supplemental NDE (Non Destructive Examination) Responsibility and Supplemental NDE Specifications: Specify NDE options (e.g., see 8.3.5) or indicate additional NDE options, such as weld hardness testing or additional radiographs. For possible additional responsibilities, see 7.3.2.3.
- Positive Material Identification (Yes/No): Include criteria to be followed.
- Maximum Permissible Plate Thickness for Shearing: Specify the thickest plate to be butt-welded that may be sheared in accordance with 6.1.2.
- Must Welds not exceeding 6 mm ($1/4$ in.) or welds greater than 6 mm ($1/4$ in.) be Multi-Pass? (Yes/No): See 5.1.3.6
- Leak Test Method*: Describe leak tests for each component. For example, see 7.3.3, 7.3.4, 7.3.5, 7.3.7, C.3.6, and H.6.2.
- Modify or Waive API Dimensional Tolerances (see 7.5)? (No/Yes/Specify): If the API tolerances are not adequate, specify the required tolerances here.
- Specify Additional Tolerances, if any, and Circumferential and Vertical Measurement Locations: Indicate any supplemental tolerances for plumbness and roundness, giving the tolerance limit and the locations for the tolerance readings.

Note: If Additional Radial Tolerance measurements are specified, radial tolerances measured higher than 0.3 m (1 ft) above the shell-to-bottom weld shall be three times the tolerances given in 7.5.3, unless specified otherwise by the Purchaser.

- 16. Coating Data
 - Internal Coatings by: Describe responsible party or indicate “Not Req’d.”
 - Per Specification*: Refer to supplemental specifications to address the detailed coating/galvanizing requirements for items such as internal structural supports, inside surface of roof, bottom, piping flanges, stairs, platforms, ladders, underside of bottoms, and top surface of foundation. Ensure that all requirements address issues such as joint contour preparation (e.g., shell-to-bottom, sharp edges of laps, crevices, etc.) and reduced weld build-up or undercut. For guidance on internal bottom coatings, see API RP 652.
 - External Coating by: Describe responsible party or indicate “Not Req’d.”
 - Per Specification*: Refer to any supplemental specification fully describing the process.
 - Under-Bottom Coating by: Describe responsible party or indicate “Not Req’d.”
 - Per Specification*: Refer to a supplemental specification fully describing the process.
- 17. Cathodic Protection
 - Cathodic Protection System? (Yes/No): See API RP 651 for guidance.
 - Per Specification*: Describe requirements and responsible parties.
- 18. Leak Detection System
 - Leak Detection System? (Yes/No): Provide a passive leak detection system as described in Appendix I. Active elements may be specified; however, the system must also provide leak detection by passive means. If active leak detection schemes (e.g., volumetric inventory records, mass change, acoustic emissions sensing, and tracer element detection) are required, describe the requirements by means of a specification herein.
 - Per Specification*: Describe requirements and responsible parties.
- 19. Release Prevention Barrier (See Appendix I, I.1.1, Note, for definition.)
 - Release Prevention Barrier? (Yes/No): Examples of barriers are vault floors, double bottoms, and impermeable membranes.
 - Per Specification*: Describe requirements and responsible parties.
- 20. Tank Measurement System
 - Required? (Yes/No): Examples are float gauge, differential pressure level indicator, level alarm, radar, and level gauge.
 - Remote Capability Required? (Yes/No): Indicate whether level measurements are required to be relayed to remote control stations.
 - By*: Designate the provider of the measurement system.
 - Per Specification*: Refer to supplemental specification.
- 21. Tank Weights and Lifting Requirements
 - Full of Water*: Indicate weight filled with water to design liquid level.
 - Empty*: Indicate weight when empty. For specification of lift lugs, see Data Sheet, Line 28. For tanks that are to be lifted, rigging and handling instructions and temporary bracing may be required. Provide reference to a supplemental specification as required.
 - Shipping*: Specify weight for Appendix J tanks only.
 - Brace/Lift Specification*: Refer to any supplemental bracing/lifting specifications.
- 22. References: Include relevant documents.
- 23. Remarks: Use this for issues not adequately covered elsewhere. Include any alternate shell opening designs specified by the Purchaser in accordance with 5.7, with reference to the alternate criteria (e.g., API Std 620).

● Table 1 Materials of Construction

List material specifications (e.g., CSA G40.21M-260W, ASTM A573-65, ISO 630 Gr E355-C, etc.), and supplied thickness of items in the left column only.

State corrosion allowance for each component. See 5.3.2. For internals, indicate if the corrosion allowance is to be applied to each exposed surface. Unless indicated otherwise, it applies to the total thickness specified. Show units of measure.

Any materials that either have received any heat treatment, such as normalizing, beyond the minimum heat-treating requirements of the material specification or have been qualified by impact tests shall be identified by reference to notes located under the “remarks” lines. The notes shall define the heat treatment received and/or the energy acceptance levels, test temperature, and specimen orientation for impact tests.

When thermal stress relief is applied to a part in accordance with the requirements of 5.7.4, the part shall be identified by a note under the “remarks” lines.

● Table 2 Bolts and Anchors

Complete all bolting and anchorage information (see 4.7, 5.11.3, 5.12, E.6.2, E.7, F.7.4, and J.3.9), including head and nut shape and material specifications. Show units of measure for the corrosion allowance and see 5.3.2. Corrosion allowance may be marked “NA” for galvanized, special corrosion-resistant coated, or stainless steel anchor bolts.

● Table 3 Nozzle and Manhole Schedule* (for Fixed Roof, Shell, and Bottom)

Include nozzles (e.g., both blanked and piped-to connections), equipment and instrument attachment and access openings, sumps, inspection ports, and manholes in the fixed roof, shell and bottom.

The description of, and examples for, the information that may be specified in Table 3 is as follows:

Entry Field	Comments	Representative Example
Mark	Purchaser’s mark or designation	Nozzle “A-1” in shell
Service	Stated service or purpose	Product Out
Size, NPS, or Diameter (In.)	Conventional size description of pipe and tube	NPS 24
Neck Schedule or Wall Thickness	Pipe schedule or wall thickness	Sch 40S
Reinf. Plate Dimensions	Circular, Diamond, etc.	49.5" OD × 0.188"
Full Pen. On Open. (Y/N)	See 5.7.2.2	Yes
Flange Type	Fabricated, S.O., WN, LJ, etc.	ASME B16.5 Lap Joint
Flange Class or Thickness	ASME, ANSI, API Std 650 Table	Cl 150
Gasket Bearing Surface Dimension and Finish	Dimension and finish of bearing surface in contact with gasket	27.25" OD, 125-250 R_a μ -in
Gasket Thickness and Dimension		0.125" × 24" ID × 28.25" OD
Gasket Material and Description	Generic, Brand, ANSI Std, etc.	Non-asbestos sheet, per Manufacturer
Proj. to FF or CL or from Datum Lines	See paragraph below	18" FF

ASME B16.47 flanges are not available in all sizes, materials, and flange types (see 5.7.6.1).

Nozzle projections shall be measured from the outside of the shell to the face of the shell flange (FF) and from datum line to the face of the flange for roof and floor openings, unless otherwise specified. Shell opening elevations shall be from the datum line to the centerline of the opening, unless otherwise specified. Roof opening locations shall be measured radially from the centerline of the tank. Specify datum line and elevations with orientations on the “Tank Plans and Sketch” of the Data Sheet.

For fabricated flanges requiring ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1, UG-34 and Appendix 2 calculations, place the “m” and “y” values for the gasket in the “Remarks” section of the Data Sheet, Line 23. Clearly indicate to which gaskets these values apply.

Consider listing in Table 3, items such as:

- Water draw-offs.
- Thermowells (make, model, stem length).
- Suction trough (size, reference drawing).

- Couplings (number, size).
- Sump.
- Inspection hatches for observation of floating roofs (as specified on Line 34).

Some items require that supplemental information be supplied, such as reference drawings, model numbers, and other specifications. Provide any supplemental information on Line 23.

Other Tank Appurtenances:

- 24. Platform, Stairway and Railing: See 5.8.10 and C.3.14.6.
 - Galvanizing Required? (Yes/No)*: Examples are stairways, platforms, and handrails to be galvanized. Identify components in Remarks, Line 23. See S.2.1.3.
 - Stairway Style*: Specify whether straight along a radius or helical.
 - Walking Surface Type*: Describe type of walking surface on platform and stairs (e.g., diamond-checked pattern plate, bar and rod grating, expanded metal grating, etc.).
 - Stairway and Walkway Clear Width*: See 5.9.4, Table 5-17, and Table 5-18.
 - National Safety Standards*: Indicate all standards that shall be observed for ladders, stairs, walkways, platforms, and other architectural/structural items (e.g., OSHA 1910).
 - Architectural/Structural Specification*: Provide details for alloys, shapes, fasteners, coating, etc.
 - Gauger's Platform Required? (Yes/No).
 - Quantity of Gauger's Platforms Required*.
 - Per Specification*: Refer to any supplemental specification, if gauger's platform specification differs from the architectural/structural reference specification above.
- 25. Jackets and Other Heaters or Coolers
 - Is a Jacket Required? (Yes/No)*: If Yes, a supplemental specification may be required to address some or all of the following items:
 - Should the jacket be integral (utilize the shell as one boundary wall) or stand-alone (able to hold pressure when detached from shell).
 - How should the jacket be attached to the shell.? Specify whether welded, bolted, or otherwise attached.
 - What type of jacket is required? Consider annular cylinder, pipe coil, half-pipe helix, panel coil, or other types to be described.
 - Are Other Heaters or Coolers Required? (Yes/No)*: If Yes, a supplemental specification may be required to address some or all of the following items:
 - Specify the type of heater or cooler. For example, internal coils, bayonet heat exchangers, or below bottom piping
 - Provide specifications for any other heaters or coolers.
 - Specify design pressures for jacket or heaters or coolers, both internal pressure and partial vacuum.
 - Specify design temperatures for jackets and heaters/coolers.
- 26. Mixer/Agitator
 - Quantity: Indicate number required.
 - Size*:
 - Per Specification*: Provide reference to supplemental specification.
- 27. Insulation Data
 - Required? (Yes/No):
 - Thickness*: Indicate thickness of insulation in inches.

Note: If not uniform for entire tank shell and roof, defer to Purchaser-supplied supplemental insulation specification.

 - Material*: Designate material and density of insulation.

- Electrically Isolate Mechanism from Shoes? (Yes/No): Indicate if required to insulate to prevent possible arcing.
 - Wax Scrapers Required? (Yes/No): Such devices remove wax-like substances from the tank shell as the roof descends to provide a cleaner sealing surface.
 - Minimum Shoe Thickness*: Include units. See C.3.13 and H.4.4.4.
 - Carbon Steel Shoes to be Galvanized? (Yes/No): This option cannot be selected for stainless steel shoes.
 - Secondary Seal: Indicate the need for a secondary seal.
 - Supplementary Specification: Refer to supplementary specification for secondary rim seal.
- 32. Data for All Floating Roofs:
 - Overflow Openings in Shell Acceptable? (Yes/No): See C.3.1.1.
 - Shell Extension? (Yes/No): Select a winds skirt per C.3.1.1. If Yes is selected, this may affect capacity, design liquid level, and the need for an overflow indicator (alarm), requiring a Purchaser-supplied supplemental specification under Line 20. See API RP 2350.
 - Roof-Drain Check Valves Required? (Yes/No): See C.3.8.1.
 - Roof-Drain Isolation Valves Required? (Yes/No): See C.3.8.1.
 - Freeze Protection for Roof Drains Required? (Yes/No): See C.3.8.1. Freeze protection is not required in all climates.
 - Roof-Drain Piping to External Nozzles: Select the type of piping from the blocks provided. If “Other” is selected, provide description or reference supplemental specification. The number of roof drains required and sump details shall be shown on the construction drawings.
 - Foam Dam? (Yes/No): See C.3.15.2.
 - Supplementary Specification: Provide supplementary foam dam specification reference.
 - Minimum Deck Thickness*: Specify a minimum deck thickness greater than that stated in C.3.3.2. If not specified, the Manufacturer shall insert the thickness stated in the above reference.
 - Bulkhead Top Edges to be Liquid-Tight? (Yes/No): See H.4.1.8. This is mandatory for external floating roofs but is a Purchaser’s option for internal floating roofs.
 - Seal-Weld Underside of Roof?: Select “Yes” to provide increased corrosion protection or additional stiffness. This applies to seal welds in addition to the seal welding required in C.3.3.3 and H.4.3.5.
 - Electrical Bonding: Indicate if either shunts or cables will be used to bond the roof electrically to the shell, and provide a supplemental specification to designate any technical requirements.
 - Quantity of Non-Guide Pole Gauge Wells Required: See C.3.14.1(2), for manual gauging apparatus in wells not associated with a guide pole.
 - Quantity of Sample Hatches Required: See C.3.15.3 for sample hatches without gauging apparatus.
 - Guide Pole for Gauging? (Yes/No): Indicate whether the guide pole (anti-rotation device) shall be used for gauging.
 - Slots in Guide Pole? (Yes/No): Indicate whether guide pole, if used for gauging, shall be slotted.
 - Datum Plates? (Yes/No): Indicate if required. See C.3.14.4.
 - Striking Plates? (Yes/No): Indicate if required. See C.3.14.5.
 - Guide Pole Emissions-Limiting Devices: Indicate any required by regulation or any additional devices requested by the Purchaser for guide poles from the list provided. See C.3.14.1(1).
 - Quantity of Roof Manholes*: See C.3.5, C.3.11, and H.5.5.

- Minimum Roof Clearances Above Bottom: Indicate elevations above the bottom to the landed floating roof for both the minimum operating level and the minimum maintenance level. These choices affect access and capacity. See C.3.10.3, H.4.6.2, and API RP 2350.
- Removable Leg Storage Racks? (Yes/No): Indicate if required. For internal floating roofs with leg supports, specify whether a storage rack is required. For external floating roofs, the storage rack is required per C.3.10.1.
- Leg Sleeves or Fixed Low Legs: Mark the block that specifies whether the leg-supported floating roof shall be provided with a sleeve through the roof plate or with fixed low legs.

33. Additional Data for External Floating Roofs (See Appendix C):

- Weather Shield? (Yes/No): Indicate the need for a weather shield on external floating roofs. If secondary rim seals serve as weather shields, they shall not be additionally requested here.
- Supplementary Specification: Provide references for weather shield specifications.
- Rolling Ladder Required?* (Yes/No): Unless the Purchaser specifically declines here, a rolling ladder is to be provided in accordance with C.3.7.
- Must Each Leg be Field-Adjustable? (Yes/No): Indicate if required. If potential bottom settlement is an issue, the Purchaser has the option to require a two-position removable leg that can accommodate local adjustments that may differ for each leg. This option is for all floating roofs and is specifically discussed in C.3.10.3.
- Design Rainfall Intensity: Specify a rainfall rate, a minimum period of duration, and an association with a statistically occurring storm such as that found in Technical Report No. 40 (e.g., 0.5 in. per hour for 5 minutes for the 2-year storm).
- Design Accumulated 24-hour Rainfall: Specify height of water accumulated in 24 hours associated with a statistically occurring storm (e.g., 12 in. in 24 hours for the 100-year storm). See C.3.4 for minimum requirements.
- Distortion and Stability Determinations Required? (Yes/No): List option per C.3.4.2.
- Supplemental Specification: Document any established methodology chosen by agreement between the Purchaser and the Manufacturer.
- Landed Live Load*: See C.3.10.2. This space gives the Purchaser the option of specifying a larger live load for external floating roofs and for specifying the stated live load for internal floating roofs even if drains are provided that may normally negate the need for such live load design.

34. Additional Data for Internal Floating Roofs

- Two-Position Legs Required? (Yes/No): See H.4.6.2. If the two positions shall be field-adaptable to account for bottom settlement, indicate this in Line 23 of the Data Sheet.
- Cable-Supported Floating Roof? (Yes/No): Indicate if required. This is an internal floating roof option as found in H.4.6.5.
- Fixed-Roof Inspection Hatches Required? (Yes/No): Indicate number required for evaluation of condition of floating roof without having to enter the vapor space. See H.5.5.3.
- Internal Roof Drain Required? (Yes/No): See H.4.1.10
- Omit Distribution Pads Supporting Uniform Live Loads? (Yes/No): See H.4.6.6
- Corrosion Gauge Required? (Yes/No): See H.5.8.
- Fixed Ladder Required? (Yes/No): This applies to vertical ladders attached to the shell, which will also require a manhole in the fixed roof to be specified in Table 3.
- Modified Minimum Point Load? (Yes/No): Point or concentrated loads are stated in H.4.2.2 for internal floating roofs, but may be waived for tanks 9 m (30 ft) or smaller in diameter.

- Mfr. to Leak Test Compartments: Indicate the % of compartments to be tested by the Manufacturer and the location of the tests. If unknown prior to the Purchaser doing a field inspection, special contract terms may be required to cover the additional costs.
- Roof Erector’s Flotation Test: Indicate when this test is to be performed: See H.6.5, H.6.6 for restrictions on these options.
- Flotation Test Media: Indicate the media to be used and the water quality. See H.6.6. Provide a separate specification, if required, to stipulate requirements.
- Flotation Test Duration, Fill Height,: See H.6.6.
- Flotation Test Items provided by Purchaser: List any items being supplied including those (gaskets, fasteners, test blanks, etc.) after the test is completed. See H.6.6.
- Responsible Party for Conducting Flotation Test and Inspecting Roof during Test: Purchaser can delegate these. See H.6.6.

- **Table 5 Floating Roof Materials**

According to C.3.1.2, the application of corrosion allowances (C.A.) shall be a matter of agreement between the Purchaser and the Manufacturer. Document this agreement on the Data Sheet “Remarks” Line 23 (e.g., “Manufacturer affirms that the nominal thicknesses chosen for floating roof components include the corrosion allowances shown in the Table for Floating Roof Materials on page 7 of the Data Sheet”).

- **L.3.2 TANK PLAN AND SKETCHES (PAGE 8 AND SUPPLEMENTS)**

- **L.3.2.1 General**

Page 8 of the Data Sheet shall be used to show the shell and roof appurtenance orientations. A single sheet is normally adequate for this purpose; however additional sheets may be necessary to show special details or configurations. All sheets shall be identified and sequenced as part of the Data Sheet. Sketches may be made with CAD or manual drafting. All sheets shall be identified by revision date or other means of record change.

Note: Consider the prevailing wind direction when locating equipment requiring personnel access.

- **L.3.2.2 Sketch Views**

The sketch view shall include an orthographic “Plan View” that may be used for the orientation of shell, roof, and bottom openings. Other views may be added.

- **L.3.2.3 Drafting Practices for Data Sheet Sketches**

Drafting practices shall be consistent with the following items:

- Where practicable, sketches shall be to scale, but the scale need not be shown on the sketches.
- Bottom views are not allowed.
- Plant north or geographic north arrow shall point upward on the sketch.
- Plant north or geographic north shall be at the “0 degrees” orientation, as applicable.
- Component thicknesses need not be shown on the sketch.
- Internal details shall be identified and located. Provide only enough information to describe the item, or provide reference to standard details. These items shall also be itemized in the appropriate tables in the Data Sheet.
- External appurtenances may be omitted from the sketch; however they must be itemized in the appropriate tables in the Data Sheet.
- Foundation or anchorage details not clearly defined elsewhere shall be shown in the Data Sheet. This may require that an “Elevation View” be provided.

API	API Std 650 Storage Tank Data Sheet	Data Sheet Status: _____ _____ Page 1 of 8
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* For boxes marked with *, if blank, Mfr. shall determine and submit as per Appendix L. For all lines, see Appendix L for line-by-line instructions.

GENERAL Special Documentation Package Requirements: _____

Measurement Units to be used in API Std 650: SI US Customary

1. Manufacturer* _____ Contract No.* _____
 Address* _____
 Mfg. Serial No.* _____ Year Built* _____ Edition & Addendum to API 650* _____
2. Purchaser _____ Contract No. _____
 Address _____
 Tank Designation _____
3. Owner/Operator _____ Location _____
4. Size Limitations* _____ Tank Diameter* _____ Shell Height* _____
 Capacity: Maximum* _____ Net Working* _____ Criteria:* _____
5. Products Stored:
 Liquid _____ Max. S.G.: _____ at _____ °
 Blanketing Gas _____ Vapor Pressure _____ PSIA at Max. Operating Temp.
 % Aromatic _____ Suppl. Spec. _____ H₂S Service? Yes No Suppl. Spec. _____
 Other Special Service Conditions? Yes No Suppl. Specs. _____

DESIGN AND TESTING Purchaser to Review Design Prior to Ordering Material? Yes No

6. Applicable API Standard 650 Appendices:* A B C F G H I J L M O P S U V W

7. Max. Design. Temp. _____ ° Design Metal Temp.* _____ ° Design Liquid Level* _____
 Design Pressure _____ External Pressure _____ Maximum Fill Rate _____ Maximum Emptying Rate _____
 Flotation Considerations? Yes No Flot. Suppl. Spec.* _____ Applied Supplemental Load Spec. _____

8. Seismic Design? Yes No Appendix E Alternate Seismic Criteria _____ Seismic Use Group _____
 MBE Site Class _____ Vertical Seismic Design? Yes No Vertical Ground Motion Accelerator A_v: _____

Basis of Lateral Acceleration (Select one): Mapped Seismic Parameters? S_s _____ S₁ _____ S₀ _____; Site-Specific Procedures?: MCE

Design Required? Yes No ; Other (Non-ASCE) Methods _____

Freeboard Required for SUG I Design Roof Tie Rods @ Outer Ring?* Yes No

9. Wind Velocity for non-U.S. sites, 50-yr wind speed (3-sec Gust)* _____
 Top Wind Girder Style* _____ Dimensions* _____ Use Top Wind Girder as Walkway? Yes No
 Intermediate Wind Girders?* Yes No Intermediate Wind Girder Style* _____ Dimensions* _____
 Check Buckling in Corroded Cond.? Yes No

10. Shell Design: 1-Ft Mthd?* Yes No ; Variable-Des-Pt Mthd?* Yes No Alternate ; Elastic Anal. Mthd?* Yes No Alternate

Plate Stacking Criteria* Centerline-Stacked? Yes No Flush-Stacked? Yes No Inside Outside

Plate Widths (Shell course heights) and Thicknesses * Numbers below Indicate Course Number.

- | | | | | |
|-----------|-----------|-----------|-----------|-----------|
| 1. _____ | 2. _____ | 3. _____ | 4. _____ | 5. _____ |
| 6. _____ | 7. _____ | 8. _____ | 9. _____ | 10. _____ |
| 11. _____ | 12. _____ | 13. _____ | 14. _____ | 15. _____ |

Joint Efficiency* _____ % Shell-to-Bottom Weld Type* _____ Shell-to-Bottom Weld Insp Mthd* _____

Approvals:	Revisions:	Title: _____ By: _____ Ck'd: _____ Date: _____ Drawing No.: _____ Sheet ___ of ___
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* If box is blank, Manufacturer shall determine and submit as per Appendix L.

11. Open-Top and Fixed Roofs: (See Sheet 6 for Floating Roofs) Open Top? * Yes No
 Fixed Roof Type* _____ Roof Support Columns*: Pipe Or Structural Shape _____
 Cone Slope* _____ Dome or Umbrella Radius* _____ Weld Joints* _____
(Lap, Butt, Other)

Seal Weld Underside of: Lap-Joints? Yes No ; Seal Weld Underside of Wind Girder Joints? Yes No

Gas-tight? Yes No Joint Efficiency* _____%

Thickness* _____ In. Snow Load * _____ App. Suppl. Load Spec.* _____ Column Lateral Load _____

Normal Venting Devices* _____ Emergency Venting Devices* _____

For Non-Frangible Roofs: Seal Weld Roof Plates to Top Angle on the Inside? Yes No ; Weld rafters to Roof Plates Yes No

Roof-to-Shell Detail* _____ Radial Projection of Horizontal Component of Top Angle* Inward Outward

12. Bottom: Thickness* _____ Style* _____ Slope* _____ Weld Joint Type* _____
 Provide Drip Ring? Yes No Alternate Spec. _____
 Annular Ring? Yes No Annular Ring: Minimum Radial Width* _____ Thickness* _____

13. Foundation: Furnished by* _____ Type* _____
 Soil Allow. Bearing Pressure* _____ Per Spec.* _____ Anchors: Size* _____ Qty* _____
 Foundation Design Loads: Base Shear Force: Wind* _____ Seismic* _____ Overturning Moment: Wind* _____ Seismic* _____
 Ring Forces: Weight of Shell + Roof New* _____ Corroded* _____ Roof Live Load* _____ Internal Pressure* _____
 Partial Vacuum* _____ Wind* _____ Seismic* _____
 Bottom Forces: Floor Wt. New* _____ Corroded* _____ Product Wt.* _____ Water Wt.* _____ Internal Pressure* _____
 Partial Vacuum* _____ Other Foundation Loads* _____ Min. Projection of Fdn. Above Grade: _____

14. Responsibility for Heating Water, if Required: Purchaser Manufacturer
 Hydro-Test Fill Height* _____ Settlement Measurements Required? Yes No Extended Duration of Hydro-Test: _____
 Predicted Settlement Profile is Attached

Responsibility for Setting Water Quality: Purchaser Manufacturer Supplemental Test Water Quality Spec. _____
 Test Water Source & Disposal Tie-In Locations _____ Hydro-Test Appendix J Tank? Yes No
 Post-Pressure-Test Activities Required of the Manufacturer: Broom Clean Potable Water Rinse Dry Interior
 Other _____

15. Inspection by _____ in Shop; _____ in Field
 Supplemental NDE Responsibility _____ Supplemental NDE Spec. _____
(Purch., Mfg., Other)

Positive Material Identification? Yes No PMI Requirements: _____
 Max. Plate Thickness for Shearing _____
 Must Welds not exceeding 6 mm (1/4 in.) Be Multi-Pass? Yes No Must Welds greater than 6 mm (1/4 in.) Be Multi-Pass? Yes No
 Leak Test Mthd: Roof* _____ Shell* _____ Shell Noz./Manhole Reinf. Plt.* _____
 Bottom* _____ Floating Roof Components* _____

Modify or Waive API Dimensional Tolerances (see 7.5)? No Yes Specify: _____
 Specify Additional Tolerances, if any, and Circumferential and Vertical Measurement Locations:

- Allowable Plumbness: _____ Measure and Record at a Minimum of _____ Locations or Every _____ m (ft) around the Tank, at the Following Shell Heights: (select one box): 1/3 H, 2/3 H and H Top of Each Shell Course Other: _____
- Allowable Roundness: ** _____ Measure Radius and Record at a Minimum of _____ Locations or Every _____ m (ft) around the Tank, at the Following Shell Heights (select one box):
 Top of Tank, H 1/3 H, 2/3 H and H Top of Each Shell Course Other: _____

**See Data Sheet Instructions for the Maximum Allowable Additional Radial Tolerance.

Approvals:	Revisions:	Title:
		By: _____ Ck'd: _____ Date: _____
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16. Coatings:
 Internal Coatings by: _____ Per Spec.* _____
 (Not Req'd., Others, Tank Mfg.)
 External Coating by: _____ Per Spec.* _____
 (Not Req'd., Others, Tank Mfg.)
 Under-Bottom Coating by: _____ Per Spec.* _____
 (Not Req'd., Others, Tank Mfg.)
17. Cathodic Protection System? Yes No Per Spec.* _____
18. Leak Detection System? Yes No Per Spec.* _____
19. Release Prevention Barrier? Yes No Per Spec.* _____
20. Tank Measurement System: Required? Yes No Remote Capability Required? Yes No
 By:* _____ Per Spec.* _____
21. Weight of Tank: Full of Water* _____ Empty* _____ Shipping* _____ Brace/Lift Spec.* _____
22. References*: *API Std 650, Appendix L*

23. Remarks*:

Approvals:

Revisions:

Title:

By: _____ Ck'd: _____ Date: _____

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* If box is blank, Manufacturer shall determine and submit as per Appendix L.

FLOATING ROOF DATA

30. Floating Roof Selection

Design Basis: Appendix C Or Appendix H

Type of Roof: (External or Internal): Single Deck Pontoon* Double Deck*

(Internal Only): Tubular Pontoon* Metallic Sandwich Panel*

Other _____ Supplemental Spec.: _____

31. Seals

Primary Seal: Shoe Envelope Wiper/Compression Plate Other _____ Supplemental Spec.: _____

Shoe Mechanism: Mfg. Std. Other _____

Electrically Isolate Mechanism from Shoes? Yes No Wax Scrapers Required? Yes No

Minimum Shoe Thickness* _____ Carbon Steel Shoes to be Galvanized? Yes No

Secondary Seal: Shoe Envelope Wiper None Other _____ Supplemental Spec.: _____

32. Data for All Floating Roofs:

Overflow Openings in Shell Acceptable? Yes No Shell Extension? Yes No

Roof-Drain Check Valves Required? Yes No Roof-Drain Isolation Valves Required? Yes No

Freeze Protection for Roof Drains Required? No Yes Supplemental Requirements: _____

Roof-Drain Piping to External Nozzles: Mfg. Std. Armored Flexible Pipe Swivels in Rigid Pipe Other _____

Foam Dam? Yes No Supplemental Spec. _____

Minimum Deck Thickness* _____

Bulkhead Top Edges to be Liquid-Tight? Yes No Seal-weld Underside of Roof? Yes No

Electrical Bonding: Shunts: Yes No Cables: Yes No Supplemental Spec. _____

Qty of Non-Guide-Pole Gauge Wells Required _____ Qty of Sample Hatches Required _____

Guide Pole for Gauging? Yes No Slots in Guide Pole? Yes No Datum Plates? Yes No Striking Plates? Yes No

Guide Pole Emissions-Limiting Devices: Sliding Cover Pole Wiper Pole Sleeve Float Float Wiper Pole Cap

Qty. of Roof Manholes* _____ Minimum High-Roof Clearance Above Bottom: _____

Removable Leg Storage Racks? Yes No ; Leg Sleeves or Fixed Low Legs

33. Additional Data for External Floating Roofs:

Weather Shield? Yes No Suppl. Spec. _____

Rolling Ladder Req'd? Yes No Field Adjustable Legs? Yes No

Design Rainfall Intensity _____ In./Hr. (mm/hr) Based on a _____ Minute Duration Associated with the _____ Storm

Design Accumulated 24-Hour Rainfall _____ In. (mm) Based on the _____ Storm

Distortion and Stability Determinations Required? Yes No Supplemental Specification _____

Landed Live Load* _____

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		By:	Ck'd:	Date:
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34. Additional Data for Internal Floating Roofs:

Two-Position Legs? Yes No Cable-Supported Roof? Yes No Fixed-Roof Inspection Hatches Required?: Yes No

Internal Roof Drain Required? Yes No Omit Distribution Pads Supporting Uniform Live Loads? Yes No

Corrosion Gauge Required? Yes No Fixed Ladder Required?: Yes No ; Type of Roof Vent: * _____

Modified Minimum Point Load? Yes No Supplemental Specification _____

Mfr. to Leak Test * ___ % of Compartments in Assembly Yard in Erected Position Unknown; see separate contract terms

Roof Erector's Flotation Test: w/ tank hydro at completion of roof at later date _____ Not required

Flotation Test Media: Water Product (see H.6.6.1) Water Quality: Potable Other See Supplemental Spec _____

Flotation Test: Duration _____ Fill Height: _____

Flotation Test Items provided by Purchaser (see H.6.7): None List Attached

Responsible Party for Inspecting Roof during Initial Fill: Purchaser Other _____

Table 5 FLOATING ROOF MATERIALS

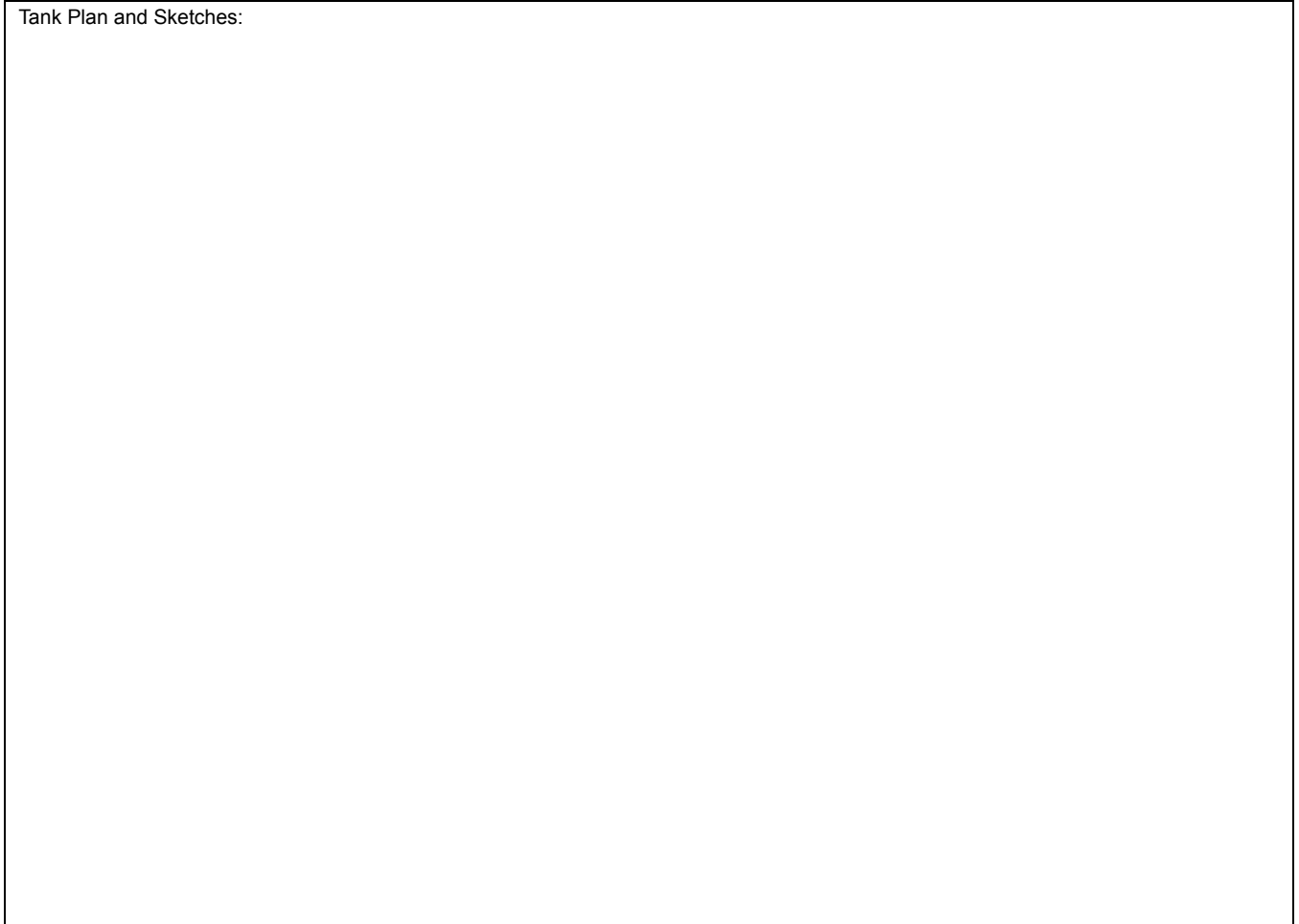
Component	Material*/Thickness*	C.A./Coating*	Component	Material*/Thickness*	C.A./Coating*
Deck Plate			Datum Plate		
Inner Rim Plate			Tubular Pontoon		
Outer Rim Plate			Pontoon Bulkhead		
Foam Dam			Submerged Pipe		
Sandwich Panel Face Plate			Guide Pole		
Sandwich Panel Core			Secondary Seal		
Gauge Well			Secondary Seal Fabric		
Drain Sumps			Wiper Tip		
Opening Sleeves			Wax Scraper		
Floating Suction Lines			Weather Seal		
Primary Fabric Seal			Envelope Fabric		
Foam Log Core			Shoe Mechanisms		
Landing Legs			Primary Seal Shoe		
Landing Leg Bottom Pads			Removable Covers		
Manhole Necks			Rolling Ladder		
Vents			Inlet Diffusers		

Approvals:	Revisions:	Title:		
		By:	Ck'd:	Date:
		Drawing No.:		Sheet ___ of ___

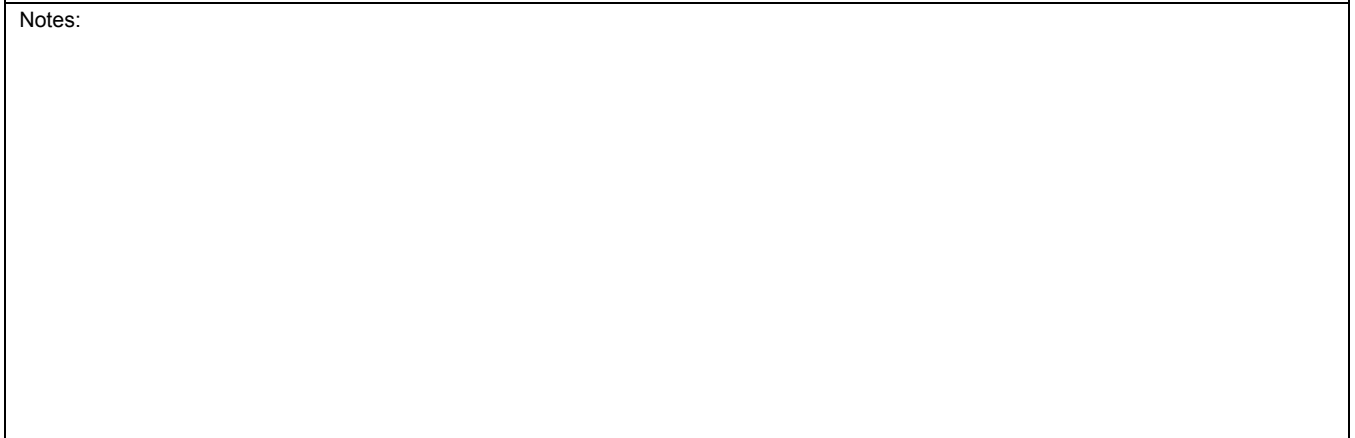
<h1>API</h1>	API Std 650 Storage Tank Data Sheet	Page 8 of 8
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* If box is blank, Manufacturer shall determine and submit as per Appendix L.

Tank Plan and Sketches:



Notes:



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Table L-1—Index of Decisions or Actions Which may be Required of the Tank Purchaser

Foreword	5.6.1.1 (Notes 1, 3)	6.1.3
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1.1.3	Table 5-2 (Note a)	6.2.3
1.1.5	5.6.3.2 (<i>H, G, CA</i>)	6.2.4
1.1.6	5.6.4.1	7.1.1
1.1.11	5.6.4.6 (<i>H</i>)	7.1.4
Table 1-1 (App. C, E, G, I, L, O, P, V, W)	5.7.1.4	7.2.1.1
1.1.15	5.7.1.8	7.2.1.7
1.1.18	Figure 5-6 (Note 5)	7.2.3.3
1.1.22	Figure 5-7A (Notes 1, 7)	7.2.4.1
1.1.28	Figure 5-7B (Note 6)	7.2.4.3
1.3.2	Figure 5-8 (Note 4)	7.3.1.3
1.3.3	5.7.2.2	7.3.2.1
1.4	5.7.2.3 (b)	7.3.2.3
4.1.1.4	Table 5-6 (Note c)	7.3.5, 1
4.1.2	Table 5-8 (Note d)	7.3.6.2 (2, 3, 4, 5, 7)
4.1.3	Table 5-9 (Note c)	7.3.6.3
4.1.5 (b)	Figure 5-12 (Note 4)	7.3.6.5 (Note)
4.2.1.3	5.7.3.4	7.3.7.2
4.2.5	5.7.4.5	7.4.1
Table 4-1 (Note 1)	5.7.5.2	7.4.4
Table 4-2 (Note C)	5.7.6.1.a	7.5.1
4.2.7.4	5.7.6.1.b	8.1.2.7
4.2.8.1	5.7.6.2	8.1.4
4.2.9.2	5.7.6.3	8.1.6
4.2.10.4	5.7.7.1	8.1.7.2
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4.9.1.1	5.8.7	8.6.11
4.9.1.4	5.8.10 (c)	9.2.1.1
4.9.1.5	5.8.11.2	10.1.1 (e, f, g, j, k)
4.9.2	5.8.11.3	Figure 10-1 (Note)
4.9.3.1	5.9.3.3	10.3 (Note)
5.1.3.6.1	5.9.6.1 (Note)	A.1.1
5.1.3.8	5.9.7.1 (<i>t, d</i>)	A.1.2
5.1.5.3 (b)	5.9.7.2 ($t_{\text{uniform}}, t_{\text{actual}}$)	A.3.4
5.1.5.4	5.9.7.7	A.4.1 (<i>G, CA</i>)
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5.1.5.8 (b)	5.10.2.4	A.8.2
5.1.5.9 (e)	5.10.2.6	A.9.2
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5.2.4	5.10.3.4	C.1
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5.3.2.1	5.10.4.5	C.3.1.5
5.3.2.3	5.10.5	C.3.3.2
5.3.2.6	5.10.6	C.3.4.1 (b)
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5.4.1	5.12.10	C.3.7
5.4.4	6.1.1.1	C.3.8.1 (1, 3)
5.4.5	6.1.2 (Note)	C.3.8.2

C.3.8.3	H.1.3	I.7.1
C.3.10.1	H.2.2 (f, g, h)	I.7.3.2 (CA)
C.3.10.3 (b)	H.3	I.7.6
C.3.10.4	H.4.1.6	J.1.2
C.3.10.8	H.4.1.7	J.3.6.2
C.3.10.9	H.4.1.8	J.3.7.1
C.3.12.3	H.4.1.9	J.3.7.2
C.3.13.2	H.4.1.10	J.3.8.2
C.3.13.5 (Primary, Secondary Seal)	H.4.2.1.1	J.4.2.2
C.3.14.1 (1)	H.4.2.1.3	Appendix L
C.3.14.2	H.4.2.2	M.1.2 (Note)
C.3.14.4	H.4.2.3.2	M.2
C.3.14.5	H.4.3.3	M.4.2 (C)
C.3.14.6	H.4.3.3.1	N.2.1
C.3.15.2	H.4.3.4	N.2.2
C.3.15.3	H.4.3.5	N.2.4
C.3.15.4 (a, e)	H.4.4	N.2.5
E.1	H.4.4.2	N.2.6
E.3.1	H.4.4.4	O.2.2
E.4.1	H.4.6.1	O.2.6
E.4.2	H.4.6.2	O.3.1.4
E.4.2.4	H.4.6.3	P.1
E.4.4	H.4.6.5	P.2.1
E.4.6.1	H.4.6.6	P.2.2
E.4.6.2	H.4.6.7	P.2.8.1
E.5.1.2	H.4.6.8	P.2.8.2
E.6.1.3	H.4.6.9	R.2
E.6.1.5	H.5.1.1	S.1.2
E.6.1.6	H.5.1.4	Table S-1a (Notes 1, 2, 3, 5)
E.6.2.1.2	H.5.2.1	Table S-1b (Notes 1, 2, 3, 5)
E.7.2	H.5.2.2.1	S.2.1.2
E.7.5	H.5.2.2.3	S.2.2
F.5.1	H.5.3.1	S.3.1
F.7.4	H.5.3.2	S.3.2 (G, CA)
G.1.3.2	H.5.3.3	S.4.3.2
G.1.3.3	H.5.5.3	S.4.4.3
G.1.4.1	H.5.6	S.4.5.1
G.1.4.2	H.5.7	Table S-2 (Notes 2, 3)
G.1.4.4	H.5.8	Table S-3 (Note 4)
G.2.1	H.5.9	S.4.9.2
G.2.4	H.6.1	S.4.10.2 (a, f)
G.4.3	H.6.2	S.4.10.3
G.5.3	H.6.4 (Note)	S.4.13
G.6.2	H.6.6	S.6 (a)
G.7	H.6.6.1	U.3.1
G.8.3	I.1.2	U.3.3
G.9	I.1.3	U.3.5
G.10.1.1	I.2 (c)	U.4.3
G.10.1.2	I.5.5	Appendix V
G.11.3	I.6.2	Appendix W
H.1.1	I.6.3	
H.1.2	I.6.4	

APPENDIX M—REQUIREMENTS FOR TANKS OPERATING AT ELEVATED TEMPERATURES

M.1 Scope

M.1.1 This appendix specifies additional requirements for API Std 650 tanks with a maximum design temperature exceeding 93°C (200°F) but not exceeding 260°C (500°F).

M.1.2 The following shall not be used for a maximum design temperature above 93°C (200°F):

- a. Open-top tanks (see 5.9).
- b. Floating-roof tanks (see Appendix C).
- c. Structurally-supported aluminum dome roofs (see G.1.1 and note below).
- d. Internal floating roofs constructed of aluminum (see H.2.2 and note below).
- e. Internal floating roofs constructed of composite material (see H.2.2). Lower temperature limits may apply for this roof material type.

• Note: An exception may be made by the Purchaser for Item e, if the following criteria is met:

- a. Allowable stress reductions for aluminum alloys are determined in accordance with ANSI/ASME B96.1 *Welded Aluminum Alloy Storage Tanks*, and alloys are evaluated for the potential of exfoliation.
- b. Gaskets and seals are evaluated for suitability at the maximum design temperature.

M.1.3 Internal floating roofs in accordance with Appendix H may be used for a maximum design temperature above 93°C (200°F), subject to the applicable requirements of this appendix. The vapor pressure of the liquid must be considered. Sealing devices, particularly those of fabric and nonmetallic materials, shall be suitable for the maximum design temperature.

M.1.4 Tanks for small internal pressures in accordance with Appendix F may be used for a maximum design temperature above 93°C (200°F), subject to the requirements of M.3.6, M.3.7, and M.3.8.

M.1.5 Shop-assembled tanks in accordance with Appendix J may be used for a maximum design temperature above 93°C (200°F), subject to the applicable requirements of this appendix.

M.1.6 The nameplate of the tank shall indicate that the tank is in accordance with this appendix by the addition of M to the information required by 10.1.1. In addition, the nameplate shall be marked with the maximum design temperature in the space indicated in Figure 10-1.

• M.2 Thermal Effects

This appendix does not provide detailed rules for limiting loadings and strains resulting from thermal effects, such as differential thermal expansion and thermal cycling, that may exist in some tanks operating at elevated temperatures. Where significant thermal effects will be present, it is the intent of this appendix that the Purchaser define such effects. The Manufacturer shall propose, subject to the Purchaser's acceptance, details that will provide strength and utility equivalent to those provided by the details specified by this Standard in the absence of such effects.

For a maximum design temperature above 93°C (200°F), particular consideration should be given to the following thermal effects:

- a. Temperature differences between the tank bottom and the lower portion of the shell. Such thermal differences may result from factors such as the method and sequence of filling and heating or cooling, the degree of internal circulation, and heat losses to the foundation and from the shell to the atmosphere. With such temperature differences, it may be necessary to provide for increased piping flexibility, an improved bottom-to-shell joint, and a thicker annular ring or bottom sketch plates to compensate for increased rotation of the bottom-to-shell joint (see M.4.2).
- b. The ability of the bottom to expand thermally, which may be limited by the method of filling and heating. With such a condition, it may be necessary to provide improved bottom welding in addition to the details suggested in Item a.
- c. Temperature differences or gradients between members, such as the shell and the roof or stairways, the shell and stiffeners, the roof or shell and the roof supports, and locations with insulation discontinuities.

- d. Whether or not the contents are allowed to solidify and are later reheated to a liquid, including the effect on columns, beams, and rafters. The possible build-up of solids on these components and the potential for plugging of the vent system should also be considered.
- e. The number and magnitude of temperature cycles the tank is expected to undergo during its design life.

M.3 Modifications in Stress and Thickness

M.3.1 For a maximum design temperature not exceeding 93°C (200°F), the allowable stress specified in 5.6.2 (see Table 5-2) for calculating shell thickness need not be modified.

M.3.2 For a maximum design temperature exceeding 93°C (200°F), the allowable stress specified in 5.6.2 shall be modified as follows: The allowable stress shall be two-thirds the minimum specified yield strength of the material multiplied by the applicable reduction factor given in Table M-1 or the value given in Table 5-2 for product design stress, whichever is less.

M.3.3 The allowable stress of 145 MPa (21,000 lbf/in.²) in the equation for shell-plate thickness in A.4.1 shall be multiplied by the applicable reduction factor given in Table M-1.

M.3.4 The requirements of 5.7.5 for shell manholes, 5.7.7 for flush-type cleanout fittings and of 5.7.8 for flush-type shell connections shall be modified. The thickness of bottom reinforcing plate for flush-type shell cleanouts and flush-type shell connections and bolting flange and cover plates for shell manhole and flush-type shell cleanouts shall be multiplied by the ratio of 205 MPa (30,000 lbf/in.²) to the material yield strength at the maximum design temperature if the ratio is greater than one.

M.3.5 The structural allowable stresses specified in 5.10.3, including the allowable stresses dependent on the modulus of elasticity, shall be multiplied by the yield strength reduction factors from Table M-1 at the maximum design temperature.

M.3.6 In the two equations in F.4.1 and F.5, the value 1.1 (or 30,800) shall be multiplied by the ratio of the material's yield strength at the maximum design temperature to 205 MPa (30,000 lbf/in.²) if the ratio is less than 1.0 (see Table M-1 for yield strength reduction factors).

M.3.7 The allowable stress specified in F.7.2 shall be multiplied by the ratio of the material's yield strength at the maximum design temperature to 188 MPa (or 27,300 lbf/in.²) if the ratio is less than 1.0 (see Table M-1 for yield strength reduction factors).

M.3.8 If the anchors are insulated, the allowable stresses specified in Tables 5-21 and 5-22 shall be multiplied by the ratio of the material's yield strength at the maximum design temperature to 205 MPa (30,000 lbf/in.²) if the ratio is less than 1.0 (see Table M-1 for yield strength reduction factors).

M.4 Tank Bottoms

M.4.1 Tanks with diameters exceeding 30 m (100 ft) shall have butt-welded annular bottom plates (see 5.1.5.6).

M.4.2 The following simplified procedure is offered as a recommended design practice for elevated-temperature tanks where significant temperature differences between the tank bottom and the lowest shell course are expected. The use of the procedure is not intended to be mandatory. It is recognized that other analytical procedures can be employed as well as that operating conditions may preclude the need for such a procedure.

Table M-1—Yield Strength Reduction Factors

Temperature		Minimum Specified Yield Strength (MPa [lbf/in. ²])		
		< 310 MPa (< 45,000 lbf/in. ²)	From ≥ 310 to < 380 MPa (≥ 45,000 to < 55,000 lbf/in. ²)	≥ 380 MPa (≥ 55,000 lbf/in. ²)
(°C)	(°F)			
94	201	0.91	0.88	0.92
150	300	0.88	0.81	0.87
200	400	0.85	0.75	0.83
260	500	0.80	0.70	0.79

Note: Linear interpolation shall be applied for intermediate values.

Shell-to-bottom junctions in elevated-temperature tanks may be evaluated for liquid head and temperature cycles with the formulas, procedures, and exclusions given below. (See Conditions a and b in the note below, which exclude tanks from such analyses.)

Note: A cyclic design life evaluation need not be made if all the criteria of either of the following conditions are met:

- The design temperature difference (T) is less than or equal to 220°C (400°F), K is less than or equal to 2.0, and C is less than or equal to 0.5.
- A heated liquid head, in feet, greater than or equal to $0.3(Dt)^{0.5}$ is normally maintained in the tank, except for an occasional cool-down (about once a year) to ambient temperatures; T is less than or equal to 260°C (500°F); and K is less than or equal to 4.0. (For background information on the development of the stress formulas, design life criteria, and C and B factors, see G.G. Karcher, "Stresses at the Shell-to-Bottom Junction of Elevated-Temperature Tanks.")

In SI units:

$$N = \left(\frac{9.7 \times 10^3}{KS} \right)^{2.44}$$

(If N is greater than or equal to 1300, cycling at the shell-to-bottom junction is not a controlling factor.)

where

N = number of design liquid level and temperature cycles estimated for the tank design life (usually less than 1300). This design procedure contains a conservative safety margin. It is not necessary to monitor actual in-service temperature and liquid head cycles

K = stress concentration factor for the bottom plate at the toe of the inside shell-to-bottom fillet weld

= 4.0 for shell-to-bottom fillet welds and lap-welded bottom plates

= 2.0 for butt-welded annular plates where the shell-to-bottom fillet welds have been inspected by 100% magnetic particle examination (see 8.2). This magnetic particle examination shall be performed on the root pass at every 13 mm of deposited weld metal while the weld is being made and on the completed weld. The examination shall be performed before hydrostatic testing

$$S = \frac{0.028D^2 t_b^{0.25}}{t} \times \left[\frac{58HG}{(Dt)^{0.5}} + \frac{26.2CTt^{0.5}}{D^{1.5}} - \frac{4.8BS_y t_b^2}{(Dt)^{1.5}} - G \right]$$

= one-half the maximum stress range that occurs in the annular plate at the shell-to-bottom junction weld, in MPa. The H and CT terms must be large enough to cause a positive S . A negative S indicates that loading conditions are not sufficient to satisfy the development assumptions of this formula. Specifically stated, the following inequality must be satisfied when the equation for S is used:

$$\left[\frac{58HG}{(Dt)^{0.5}} + \frac{26.2CTt^{0.5}}{D^{1.5}} - G \right] > \frac{4.8BS_y t_b^2}{(Dt)^{1.5}}$$

When the equation for S is used, the shell thickness t must be greater than or equal to the annular-plate thickness t_b

T = difference between the minimum ambient temperature and the maximum design temperature (°C)

S_y = specified minimum yield strength of the bottom plate at the maximum design temperature (MPa)

D = nominal tank diameter (m)

H = difference in filling height between the full level and the low level (m)

G = design specific gravity of the liquid

t = nominal thickness of the tank's bottom shell course (mm)

t_b = nominal thickness of the annular bottom plate (mm)

- C = factor to account for radial restraint of the tank's shell-to-bottom junction with respect to free thermal expansion ($C_{\max} = 1.0$; $C_{\min} = 0.25$). The actual design value of C shall be established considering the tank's operating and warm-up procedure and heat transfer to the subgrade²⁶

= 0.85 if no C factor is specified by the Purchaser

B = foundation factor²⁶

= 2.0 for tanks on earth foundations

= 4.0 for tanks on earth foundations with a concrete ringwall

In US Customary units:

$$N = \left(\frac{1.4 \times 10^6}{KS} \right)^{2.44}$$

(If N is greater than or equal to 1300, cycling at the shell-to-bottom junction is not a controlling factor.)

where

- N = number of design liquid level and temperature cycles estimated for the tank design life (usually less than 1300). This design procedure contains a conservative safety margin. It is not necessary to monitor actual in-service temperature and liquid head cycles
- K = stress concentration factor for the bottom plate at the toe of the inside shell-to-bottom fillet weld

= 4.0 for shell-to-bottom fillet welds and lap-welded bottom plates

= 2.0 for butt-welded annular plates where the shell-to-bottom fillet welds have been inspected by 100% magnetic particle examination (see 8.2). This magnetic particle examination shall be performed on the root pass at every 1/2 in. of deposited weld metal while the weld is being made and on the completed weld. The examination shall be performed before hydrostatic testing

$$S = \frac{0.033D^2t_b^{0.25}}{t} \times \left[\frac{6.3HG}{(Dt)^{0.5}} + \frac{436CTt^{0.5}}{D^{1.5}} - \frac{BS_y t_b^2}{(Dt)^{1.5}} - G \right]$$

- = one-half the maximum stress range that occurs in the annular plate at the shell-to-bottom junction weld, in pounds per square inch. The H and CT terms must be large enough to cause a positive S . A negative S indicates that loading conditions are not sufficient to satisfy the development assumptions of this formula. Specifically stated, the following inequality must be satisfied when the equation for S is used:

$$\left[\frac{6.3HG}{(Dt)^{0.5}} + \frac{436CTt^{0.5}}{D^{1.5}} - G \right] > \frac{BS_y t_b^2}{(Dt)^{1.5}}$$

When the equation for S is used, the shell thickness t must be greater than or equal to the annular-plate thickness t_b

- T = difference between the minimum ambient temperature and the maximum design temperature (°F)
- S_y = specified minimum yield strength of the bottom plate at the maximum design temperature (lbf/in.²)
- D = nominal tank diameter (ft)
- H = difference in filling height between the full level and the low level (ft)

²⁶G. G. Karcher, "Stresses at the Shell-to-Bottom Junction of Elevated-Temperature Tanks," *1981 Proceedings—Refining Department*, Volume 60, American Petroleum Institute, Washington D.C. 1981, pp. 154 – 159.

G = design specific gravity of the liquid

t = nominal thickness of the tank's bottom shell course (in.)

t_b = nominal thickness of the annular bottom plate (in.)

C = factor to account for radial restraint of the tank's shell-to-bottom junction with respect to free thermal expansion ($C_{\max} = 1.0$; $C_{\min} = 0.25$). The actual design value of C shall be established considering the tank's operating and warm-up procedure and heat transfer to the subgrade²⁶

= 0.85 if no C factor is specified by the Purchaser

B = foundation factor²⁶

= 2.0 for tanks on earth foundations

= 4.0 for tanks on earth foundations with a concrete ringwall

M.5 Self-Supporting Roofs

M.5.1 The requirements of 5.10.5 and 5.10.6, which are applicable to self-supporting roofs, shall be modified. For a maximum design temperature above 93°C (200°F), the calculated minimum thickness of roof plates, as defined in 5.10.5 and 5.10.6, shall be increased by the ratio of 199,000 MPa (28,800,000 lbf/in.²) to the material's modulus of elasticity at the maximum design temperature.

M.5.2 Table M-2 shall be used to determine the material's modulus of elasticity at the maximum operating temperature.

M.6 Wind Girders

In the equation for the maximum height of unstiffened shell in 3.9.7.1, the maximum height (H_1) shall be reduced by the ratio of the material's modulus of elasticity at the maximum design temperature to 199,000 MPa (28,800,000 lbf/in.²) when the ratio is less than 1.0 (see Table M-2 for modulus of elasticity values).

Table M-2—Modulus of Elasticity at the Maximum Design Temperature

Maximum Design Temperature		Modulus of Elasticity	
°C	°F	MPa	lbf/in. ²
93	200	199,000	28,800,000
150	300	195,000	28,300,000
200	400	191,000	27,700,000
260	500	188,000	27,300,000

Note: Linear interpolation shall be applied for intermediate values.

APPENDIX O—RECOMMENDATIONS FOR UNDER-BOTTOM CONNECTIONS

O.1 Scope

This appendix contains recommendations to be used for the design and construction of under-bottom connections for storage tanks. The recommendations are offered to outline good practice and to point out certain precautions that are to be observed. Reference should be made to Appendix B for considerations involving foundation and subgrade.

O.2 Recommendations

O.2.1 The recommendations of this appendix are intended for use only where significant foundation settlement is not expected. It is not possible to establish precise limits, but if predicted settlement exceeds 13 mm ($1/2$ in.), the recommendations should be subjected to detailed engineering review for possible additions, modifications, or elimination of bottom connections. Particular consideration shall be given to possible differential settlement in the immediate area of the bottom connection and with respect to connecting piping.

- **O.2.2** The arrangement and details of bottom connections may be varied to achieve the utility, tightness, and strength required for the prevailing foundation conditions. The details shown in Figures O-1, O-2, and O-3 are examples. Figures O-1 and O-2 show details used on a concrete ringwall foundation, but similar designs may be used on earth foundations. Figure O-3 shows another detail used on earth foundations. Other arrangements of foundation and connection (including combination sump and pipe) may be used under the provisions of O.2.6. When required by the Purchaser, seismic considerations (see Appendix E) shall be included.

O.2.3 Support of the pipe by the soil and bottom connection shall be evaluated to confirm adequacy and resistance to liquid, static, and dynamic loads. Both deflection and stress shall be considered in the evaluation.

O.2.4 Consideration shall be given to predicted settlement that would affect the relative positions of the tank and pipe or pipe supports outside the tank (see O.2.1).

O.2.5 Bottom connections used in floating-roof tanks shall be provided with a baffle to prevent impingement of the inlet product stream directly against the floating roof.

- **O.2.6** All details are subject to agreement between the Purchaser and the Manufacturer.

O.3 Guideline Examples

O.3.1 CONCRETE VAULT AND RINGWALL (SEE FIGURES O-1 AND O-2)

O.3.1.1 The concrete ceiling vault shown in Figure O-2 provides improved support of the tank bottom and shell and provides more uniform reinforcing-bar distribution around the ringwall opening than the details shown in Figure O-1 provide.

O.3.1.2 Particular attention is required for the backfill specifications and placement of the backfill around the vault area and around the inside of the entire ringwall. Compaction shall be adequate to prevent significant localized settlement.

O.3.1.3 Consideration should be given to the soil characteristics at the different elevations at the bottom of the ringwall and the vault, especially for the deeper vaults to accommodate the larger connections.

- **O.3.1.4** Recommended details and dimensions are shown in Figures O-1 and O-2 and Table O-1. Dimension *K* is considered adequate to place the connection out of the influence of shell-to-bottom rotation when the tank is statically loaded. Seismic loading shall be analyzed for additional considerations. The method shall be a matter of agreement between the Manufacturer and the Purchaser. When the tank bottom has annular plates (thicker than the tank bottom), it is recommended either to provide at least 300 mm (12 in.) between the edge of the pipe connection or reinforcing plate and the inner edge of the annular plate or to locally extend the annular plate, thickened if necessary, to encompass the bottom connection. The dimensions in Table O-1 may be changed to achieve desired clearances for installations, inspections, and the like.

O.3.1.5 Concrete walls, floors, and ceilings shall be designed to meet the minimum requirements of ACI 318 and local soil conditions.

Table O-1—Dimensions of Under-Bottom Connections

Inlet Diameter NPS <i>D</i>	mm (in.)										
	<i>B/2</i>	<i>E</i>	<i>F</i>	<i>G</i>	<i>H</i>	<i>J</i>	<i>K</i>	<i>L</i>	<i>W/2</i>	<i>T^a</i>	<i>ST^b</i>
6	525 (21)	225 (9)	350 (14)	750 (30)	575 (23)	300 (12)	1125 (44)	1975 (78)	925 (36)	16 (⁵ / ₈)	ST4WF8.5
8	550 (22)	250 (10)	400 (16)	825 (32)	650 (26)	300 (12)	1150 (45)	2050 (81)	950 (37)	16 (⁵ / ₈)	ST4WF8.5
12	600 (24)	300 (12)	450 (18)	875 (34)	750 (30)	300 (12)	1200 (47)	2150 (85)	1000 (39)	16 (⁵ / ₈)	ST6WF13.5
18	675 (27)	375 (15)	500 (20)	950 (37)	900 (35)	300 (12)	1300 (51)	2325 (92)	1075 (42)	16 (⁵ / ₈)	ST6WF13.5
24	750 (30)	450 (18)	600 (24)	1050 (41)	1075 (42)	300 (12)	1400 (55)	2550 (100)	1150 (45)	16 (⁵ / ₈)	ST6WF13.5
30	850 (33)	525 (21)	750 (30)	1150 (45)	1300 (51)	300 (12)	1500 (59)	2750 (108)	1225 (48)	16 (⁵ / ₈)	ST6WF13.5
36	925 (36)	625 (25)	925 (36)	1275 (50)	1550 (61)	300 (12)	1625 (64)	3000 (118)	1300 (51)	16 (⁵ / ₈)	ST8WF18.0
42	1000 (39)	700 (28)	1075 (42)	1375 (54)	1775 (70)	300 (12)	1725 (68)	3200 (126)	1375 (54)	16 (⁵ / ₈)	ST8WF18.0
48	1075 (42)	825 (32)	1225 (48)	1475 (58)	2025 (80)	300 (12)	1825 (72)	3400 (134)	1450 (57)	16 (⁵ / ₈)	ST8WF18.0

^aApplies only to Figure O-1. For tank heights greater than 19.2 mm – 21.6 mm (64 ft – 72 ft) inclusive, 19-mm (³/₄-in.) plate shall be used. *T* shall not be less than the thickness of the annular plate.

^bOther composite sections may be used to support the load.

Note: See Figures O-1 and O-2. For diameters not shown, the dimensions of the next larger size shall be used.

O.3.2 EARTH FOUNDATION (SEE FIGURE O-3)

O.3.2.1 The detail shown in Figure O-3 provides an alternative arrangement for tanks where a concrete ringwall is not provided.

O.3.2.2 Soil and backfill support capability shall be evaluated to ensure that reasonably uniform settlement (if any) will occur under the loads imposed.

O.3.2.3 When the pipe is connected to the bottom at an angle, consideration should be given to design for unbalanced forces if the pipe is trimmed flush with the bottom.

O.3.2.4 When seismically-induced loadings are specified, such loadings under the tank bottom and shell shall be considered when the depth and type of backfill around and over the pipe are selected.

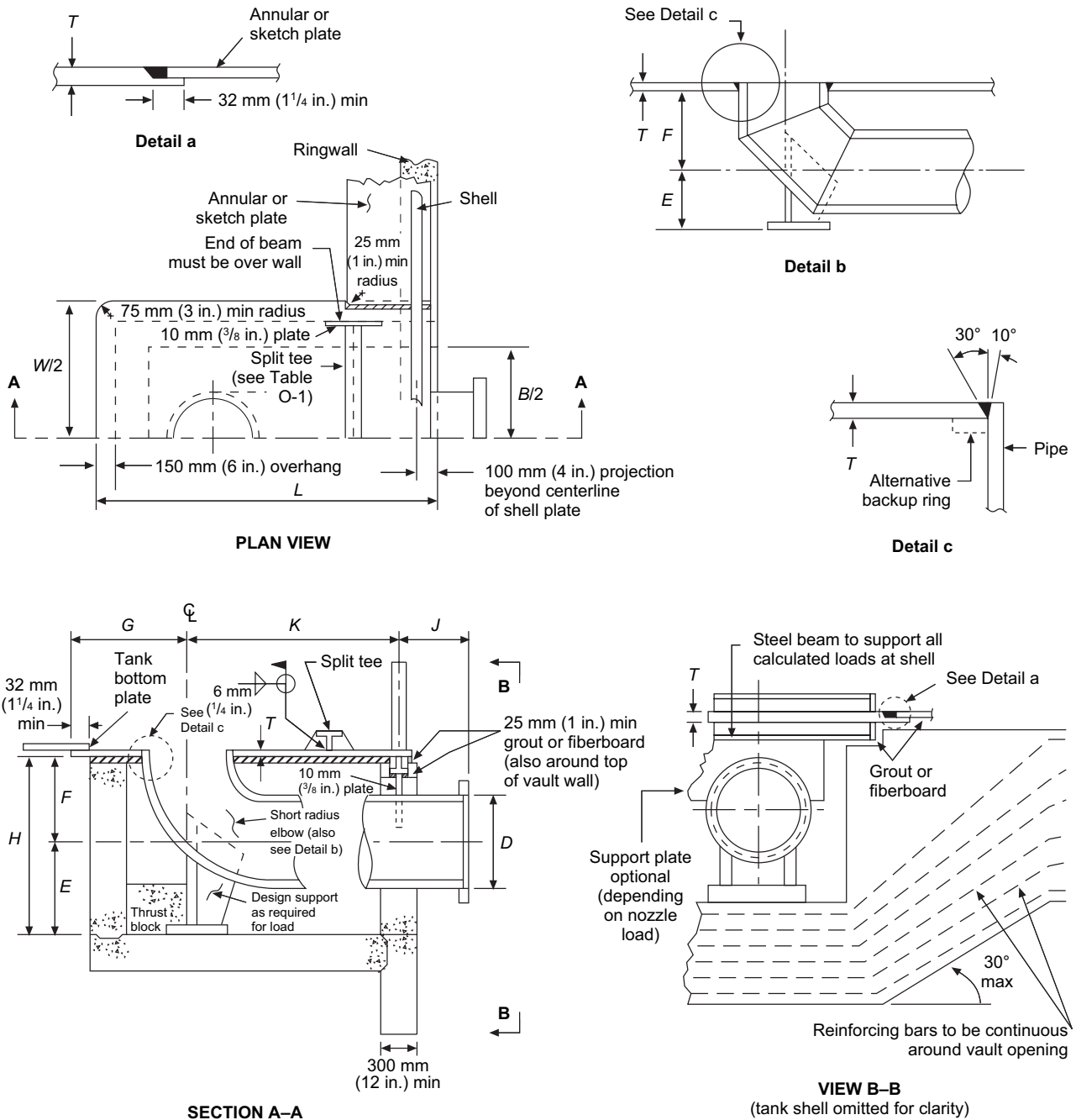
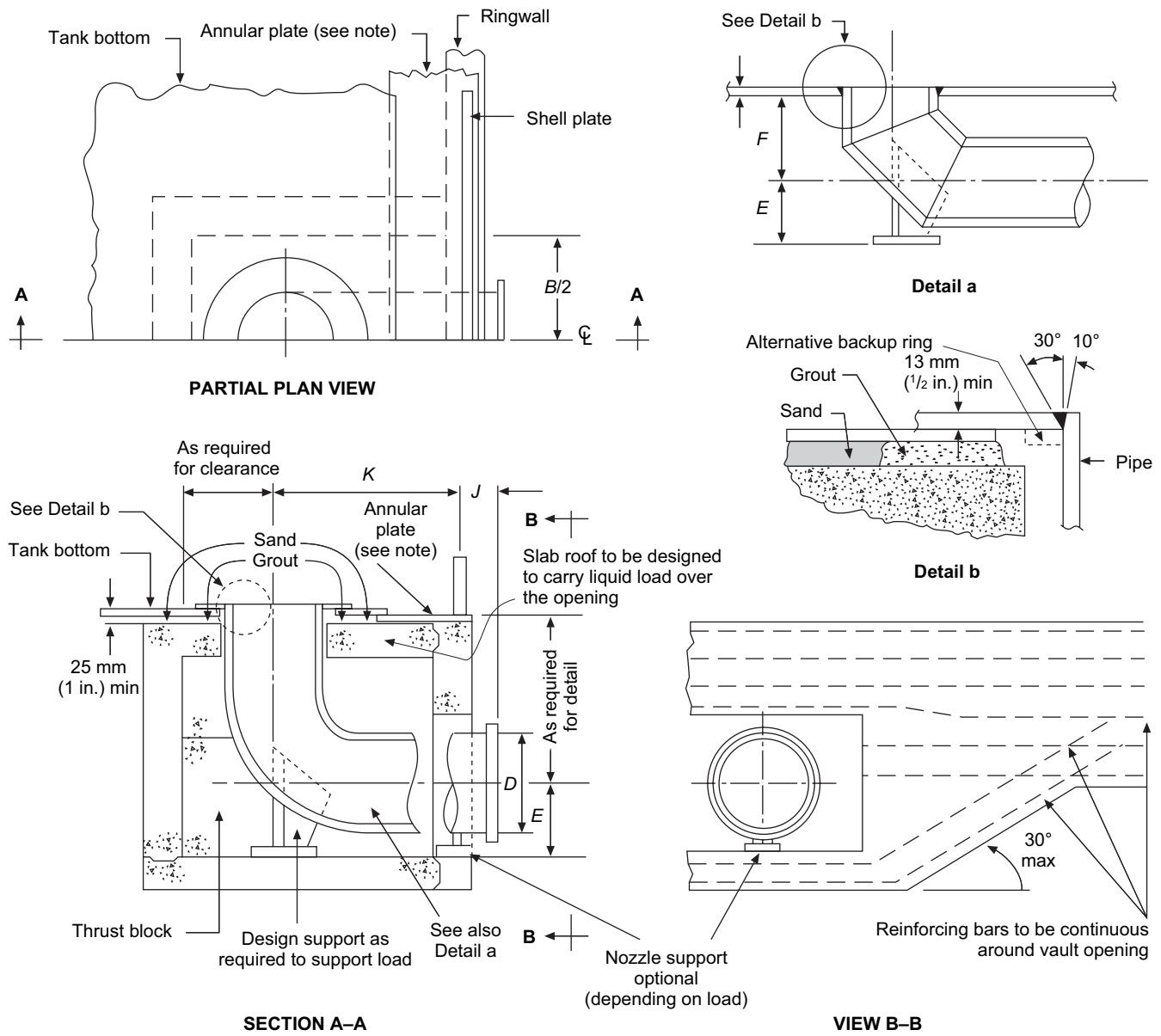
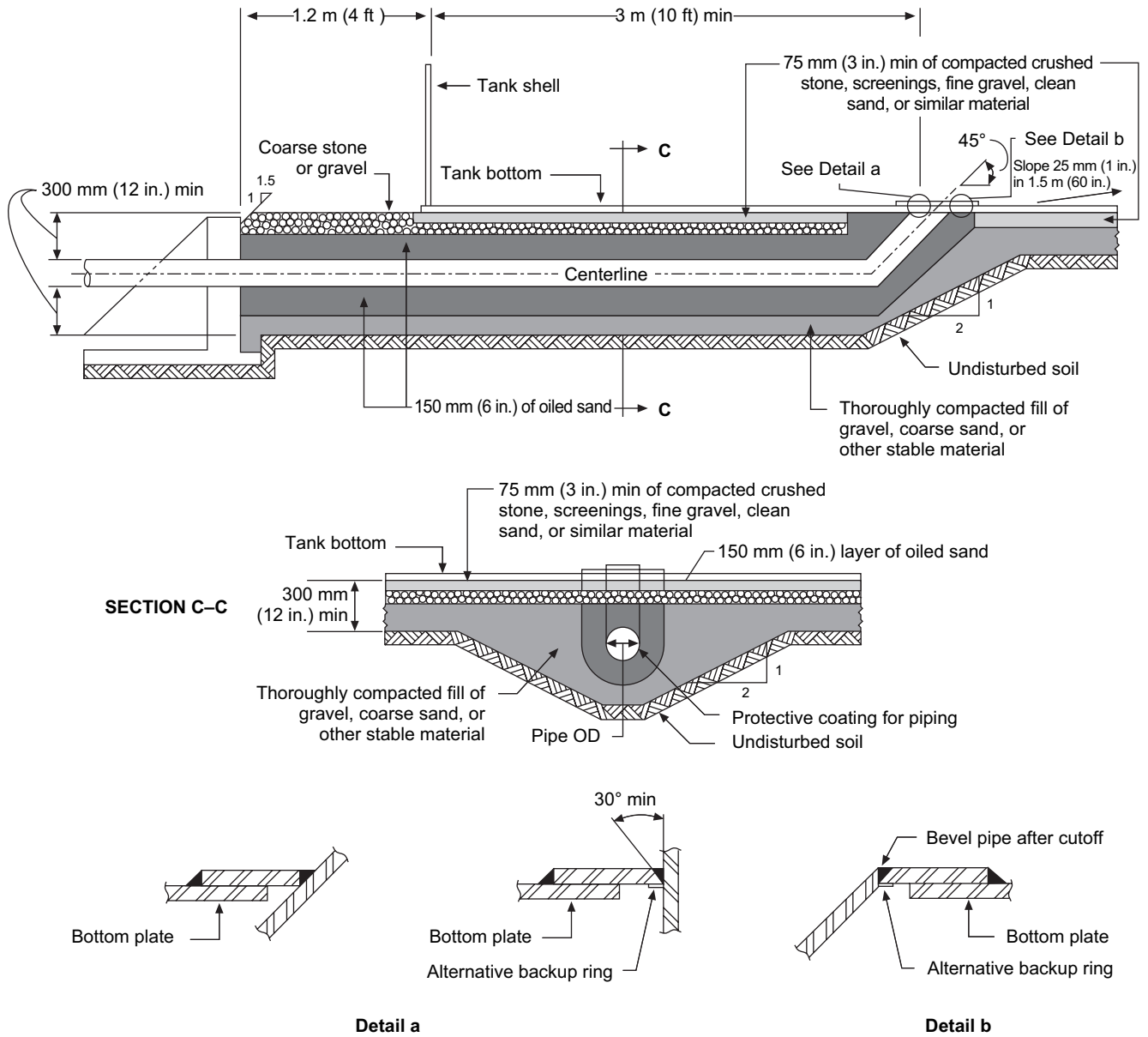


Figure O-1—Example of Under-Bottom Connection with Concrete Ringwall Foundation



Note: If sketch plates are used, a full plate shall be located over the vault.

Figure O-2—Example of Under-Bottom Connection with Concrete Ringwall Foundation and Improved Tank Bottom and Shell Support



Note: This type of connection shall not be used for tanks with a diameter of less than 6 m (20 ft).

Figure O-3—Example of Under-Bottom Connection with Earth-Type Foundation

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APPENDIX P—ALLOWABLE EXTERNAL LOADS ON TANK SHELL OPENINGS

• P.1 Introduction

This appendix shall be used (unless specified otherwise by the Purchaser on Line 29 of the Data Sheet) for tanks larger than 36 m (120 ft) in diameter, and only when specified by the Purchaser for tanks 36 m (120 ft) in diameter and smaller. See W.2(5) for additional requirements.

This appendix presents two different procedures to determine external loads on tank shells. Section P.2 establishes limit loads and P.3 is based on allowable stresses. This appendix is based on H. D. Billimoria and J. Hagstrom's "Stiffness Coefficients and Allowable Loads for Nozzles in Flat Bottom Storage Tanks" and H. D. Billimoria and K. K. Tam's "Experimental Investigation of Stiffness Coefficients and Allowable Loads for a Nozzle in a Flat Bottom Storage Tank."

P.2 Limit Loads

• P.2.1 SCOPE

This appendix establishes requirements for the design of storage-tank openings that conform to Table 5-6 and will be subjected to external piping loads. The requirements of this appendix represent accepted practice for the design of shell openings in the lower half of the bottom shell course that have a minimum elevation from the tank bottom and meet the requirements of Table 5-6. It is recognized that the Purchaser may specify other procedures, special factors, and additional requirements. Any deviation from these requirements shall be mutually agreed upon by the Purchaser and the Manufacturer.

• P.2.2 GENERAL

The design of an external piping system that will be connected to a thin-walled, large-diameter cylindrical vertical storage tank may pose a problem in the analysis of the interface between the piping system and the tank opening connections. The piping designer must consider the stiffness of the tank shell and the radial deflection and meridional rotation of the shell opening at the opening-shell connection resulting from product head, pressure, and uniform or differential temperature between the shell and the bottom. The work of the piping designer and the tank designer must be coordinated to ensure that the piping loads imposed on the shell opening by the connected piping are within safe limits. Although three primary forces and three primary moments may be applied to the mid-surface of the shell at an opening connection, only one force, F_R , and two moments, M_L and M_C , are normally considered significant causes of shell deformation (see P.2.3 for a description of the nomenclature).

P.2.3 NOMENCLATURE

a = outside radius of the opening connection (mm) (in.)

E = modulus of elasticity (MPa) (lbf/in.²) (see Table P-1)

F_R = radial thrust applied at the mid-surface of the tank shell at the opening connection (N) (lbf)

F_P = pressure end load on the opening for the pressure resulting from the design product head at the elevation of the opening centerline, $\pi a^2 P$ (N) (lbf)

G = design specific gravity of the liquid

H = maximum allowable tank filling height (mm) (in.)

K_C = stiffness coefficient for the circumferential moment (N-mm/radian) (in.-lbf/radian)

K_L = stiffness coefficient for the longitudinal moment (N-mm/radian) (in.-lbf/radian)

K_R = stiffness coefficient for the radial thrust load (N/mm) (lbf/in.)

L = vertical distance from the opening centerline to the tank bottom (mm) (in.)

M_C = circumferential moment applied to the mid-surface of the tank shell (N-mm) (in.-lbf)

M_L = longitudinal moment applied to the mid-surface of the tank shell (N-mm) (in.-lbf)

Table P-1—Modulus of Elasticity and Thermal Expansion Coefficient at the Design Temperature

Design Temperature		Modulus of Elasticity MPa (lbf/in. ²) <i>E</i>	Thermal Expansion Coefficient ^a (mm × 10 ⁻⁶ /[mm-°C]) (in. × 10 ⁻⁶ per in.-°F)
°C	°F		
20	70	203,000 (29,500,000)	—
93	200	199,000 (28,800,000)	12.0 (6.67)
150	300	195,000 (28,300,000)	12.4 (6.87)
200	400	191,000 (27,700,000)	12.7 (7.07)
260	500	188,000 (27,300,000)	13.1 (7.25)

^aMean coefficient of thermal expansion, going from 20°C (70°F) to the temperature indicated.

Note: Linear interpolation may be applied for intermediate values.

P = pressure resulting from product head at the elevation of the opening centerline (MPa) (lbf/in.²)

R = nominal tank radius (mm) (in.)

t = shell thickness at the opening connection (mm) (in.)

ΔT = normal design temperature minus installation temperature (°C) (°F)

W = unrestrained radial growth of the shell (mm) (in.)

W_R = resultant radial deflection at the opening connection (mm) (in.)

$X_A = L + a$ (mm) (in.)

$X_B = L - a$ (mm) (in.)

$X_C = L$ (mm) (in.)

Y_C = coefficient determined from Figure P-4B

Y_F, Y_L = coefficients determined from Figure P-4A

α = thermal expansion coefficient of the shell material (mm/[mm-°C]) (in./[in.-°F]) (see Table P-1)

β = characteristic parameter, $1.285/(Rt)0.5$ (1/mm) (1/in.)

$\lambda = a/(Rt)0.5$

θ = unrestrained shell rotation resulting from product head (radians)

θ_C = shell rotation in the horizontal plane at the opening connection resulting from the circumferential moment (radians)

θ_L = shell rotation in the vertical plane at the opening connection resulting from the longitudinal moment (radians)

P.2.4 STIFFNESS COEFFICIENTS FOR OPENING CONNECTIONS

The stiffness coefficients K_R , K_L , and K_C corresponding to the piping loads F_R , M_L , and M_C at an opening connection, as shown in Figure P-1, shall be obtained by the use of Figures P-2A through P-2L. Figures P-2A through P-2L shall be used to interpolate intermediate values of coefficients.

P.2.5 SHELL DEFLECTION AND ROTATION

P.2.5.1 Radial Growth of Shell

The unrestrained outward radial growth of the shell at the center of the opening connection resulting from product head and/or thermal expansion shall be determined as follows:

In SI units:

$$W = \frac{9.8 \times 10^{-6} GHR^2}{Et} \times \left[1 - e^{-\beta L} \cos(\beta L) - \frac{L}{H} \right] + \alpha R \Delta T$$

In US Customary units:

$$W = \frac{0.036 GHR^2}{Et} \times \left[1 - e^{-\beta L} \cos(\beta L) - \frac{L}{H} \right] + \alpha R \Delta T$$

P.2.5.2 Rotation of Shell

The unrestrained rotation of the shell at the center of the nozzle-shell connection resulting from product head shall be determined as follows:

In SI units:

$$\theta = \frac{9.8 \times 10^{-6} GHR^2}{Et} \times \left\{ \frac{1}{H} - \beta e^{-\beta L} [\cos(\beta L) + \sin(\beta L)] \right\}$$

In US Customary units:

$$\theta = \frac{0.036 GHR^2}{Et} \times \left\{ \frac{1}{H} - \beta e^{-\beta L} [\cos(\beta L) + \sin(\beta L)] \right\}$$

P.2.6 DETERMINATION OF LOADS ON THE OPENING CONNECTION

The relationship between the elastic deformation of the opening connection and the external piping loads is expressed as follows:

$$W_R = \frac{F_R}{K_R} - L \tan\left(\frac{M_L}{K_L}\right) + W$$

$$\theta_L = \frac{M_L}{K_L} - \tan^{-1}\left(\frac{F_R}{LK_R}\right) + \theta$$

$$\theta_C = \frac{M_C}{K_C}$$

K_R , K_L , and K_C are the shell stiffness coefficients determined from Figures P-2A through P-2L. W_R , θ_L , and θ_C are the resultant radial deflection and rotation of the shell at the opening connection resulting from the piping loads F_R , M_L , and M_C and the product head, pressure, and uniform or differential temperature between the shell and the tank bottom. F_R , M_L , and M_C shall be obtained from analyses of piping flexibility based on consideration of the shell stiffness determined from Figures P-2A through P-2L, the shell deflection and rotation determined as described in P.2.5.1 and P.2.5.2, and the rigidity and restraint of the connected piping system.

P.2.7 DETERMINATION OF ALLOWABLE LOADS FOR THE SHELL OPENING

P.2.7.1 Construction of Nomograms

P.2.7.1.1 Determine the nondimensional quantities $X_A/(Rt)0.5$, $X_B/(Rt)0.5$, and $X_C/(Rt)0.5$ for the opening configuration under consideration.

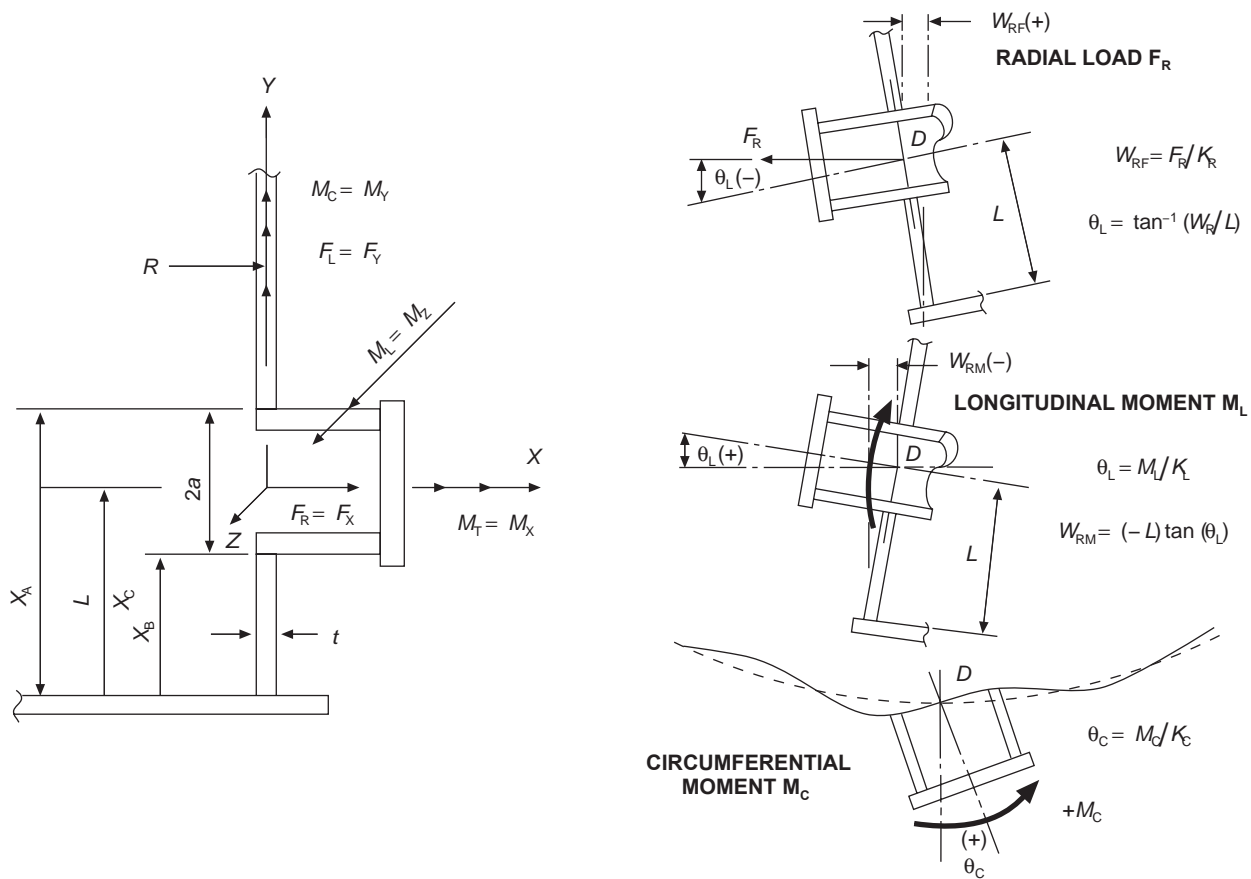


Figure P-1—Nomenclature for Piping Loads and Deformation

P.2.7.1.2 Lay out two sets of orthogonal axes on graph paper, and label the abscissas and ordinates as shown in Figures P-3A and P-3B, where Y_C , Y_F , and Y_L are coefficients determined from Figures P-4A and P-4B.

P.2.7.1.3 Lay out two sets of orthogonal axes on graph paper, and label the abscissas and ordinates as shown in Figures P-3A and P-3B, where Y_C , Y_F , and Y_L are coefficients determined from Figures P-4A and P-4B.

P.2.7.1.4 Construct four boundaries for Figure P-3A and two boundaries for Figure P-3B. Boundaries b_1 and b_2 shall be constructed as lines at 45-degree angles between the abscissa and the ordinate. Boundaries c_1 , c_2 , and c_3 shall be constructed as lines at 45-degree angles passing through the calculated value indicated in Figures P-3A and P-3B plotted on the positive x axis.

P.2.7.2 Determination of Allowable Loads

P.2.7.2.1 Use the values for F_R , M_L , and M_C obtained from the piping analyses to determine the quantities $(\lambda/2Y_F)(F_R/F_P)$, $(\lambda a Y_L)(M_L/F_P)$, and $(\lambda a Y_C)(M_C/F_P)$.

P.2.7.2.2 Plot the point $(\lambda/2Y_F)(F_R/F_P)$, $(\lambda a Y_L)(M_L/F_P)$ on the nomogram constructed as shown in Figure P-5A.

P.2.7.2.3 Plot the point $(\lambda/2Y_F)(F_R/F_P)$, $(\lambda a Y_C)(M_C/F_P)$ on the nomogram constructed as shown in Figure P-5B.

P.2.7.2.4 The external piping loads F_R , M_L , and M_C to be imposed on the shell opening are acceptable if both points determined from P.2.7.2.2 and P.2.7.2.3 lie within the boundaries of the nomograms constructed for the particular opening-tank configuration.

P.2.8 MANUFACTURER AND PURCHASER RESPONSIBILITY

- P.2.8.1** The Manufacturer is responsible for furnishing to the Purchaser the shell stiffness coefficients (see P.2.4) and the unrestrained shell deflection and rotation (see P.2.5). The Purchaser is responsible for furnishing to the Manufacturer the magnitude of

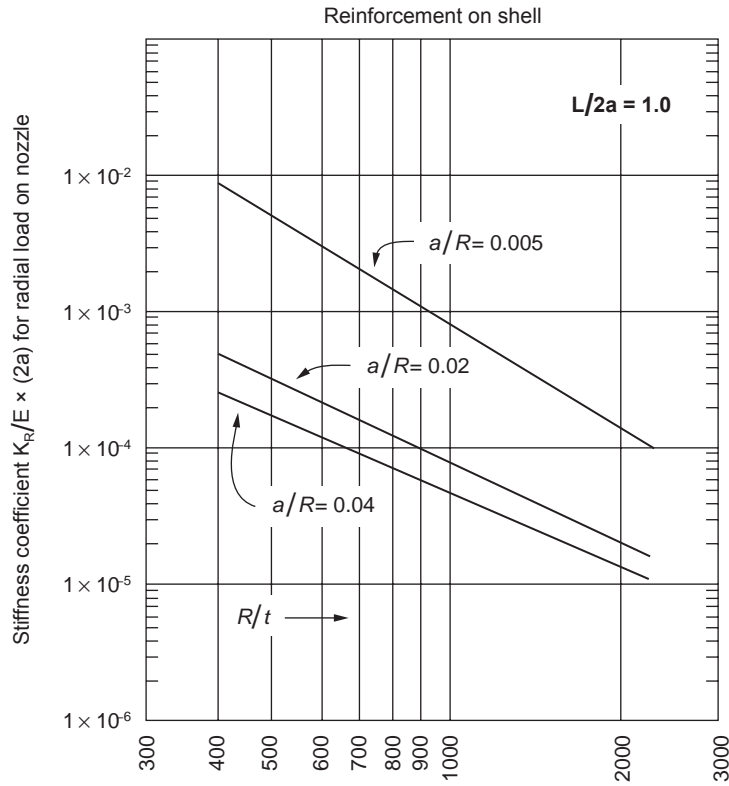


Figure P-2A—Stiffness Coefficient for Radial Load: Reinforcement on Shell ($L/2a = 1.0$)

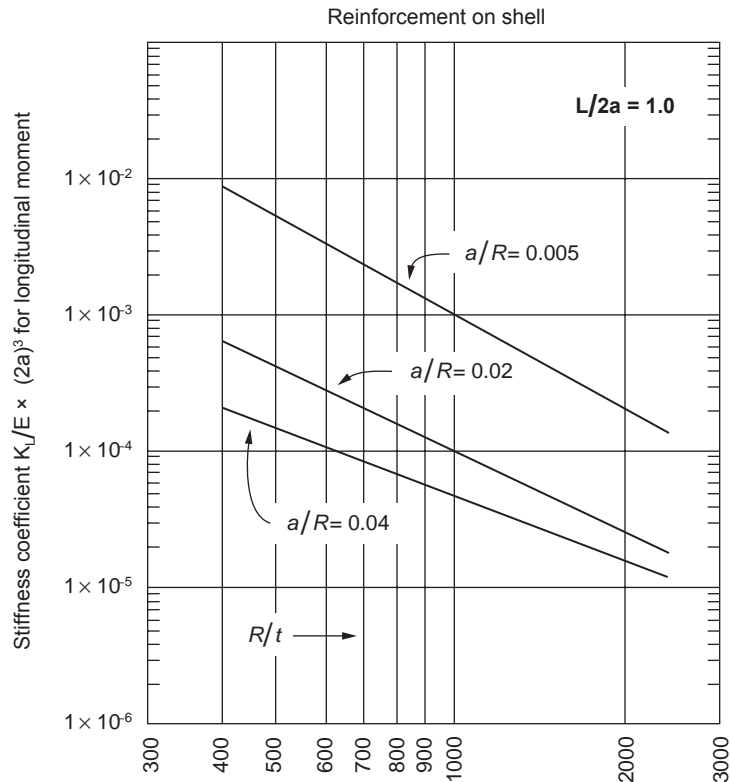


Figure P-2B—Stiffness Coefficient for Longitudinal Moment: Reinforcement on Shell ($L/2a = 1.0$)

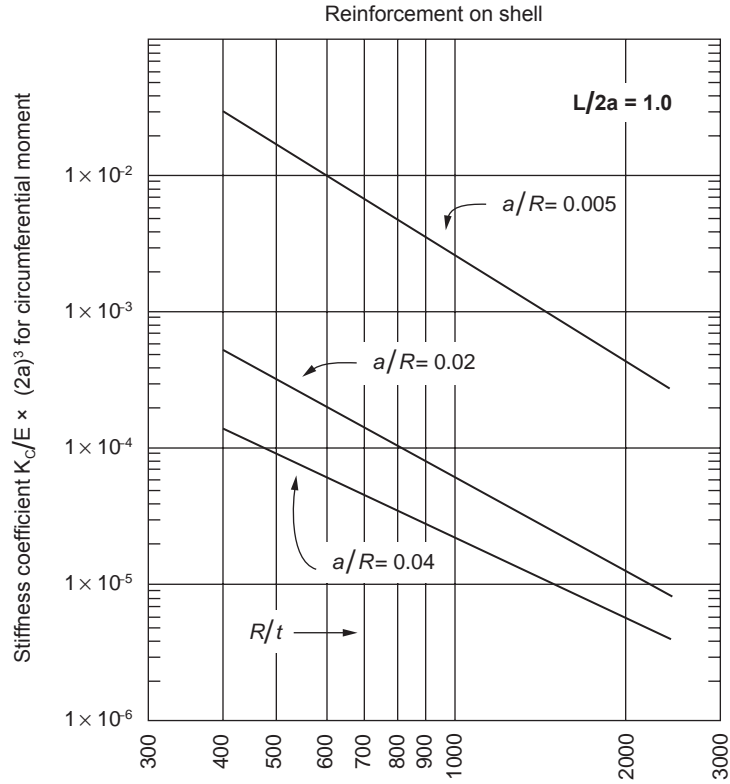


Figure P-2C—Stiffness Coefficient for Circumferential Moment: Reinforcement on Shell ($L/2a = 1.0$)

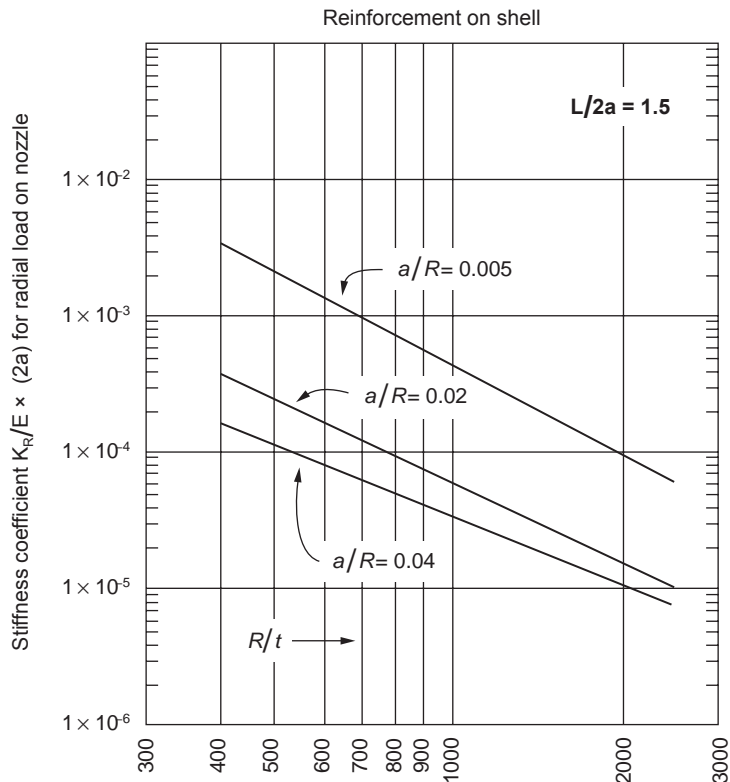


Figure P-2D—Stiffness Coefficient for Radial Load: Reinforcement on Shell ($L/2a = 1.5$)

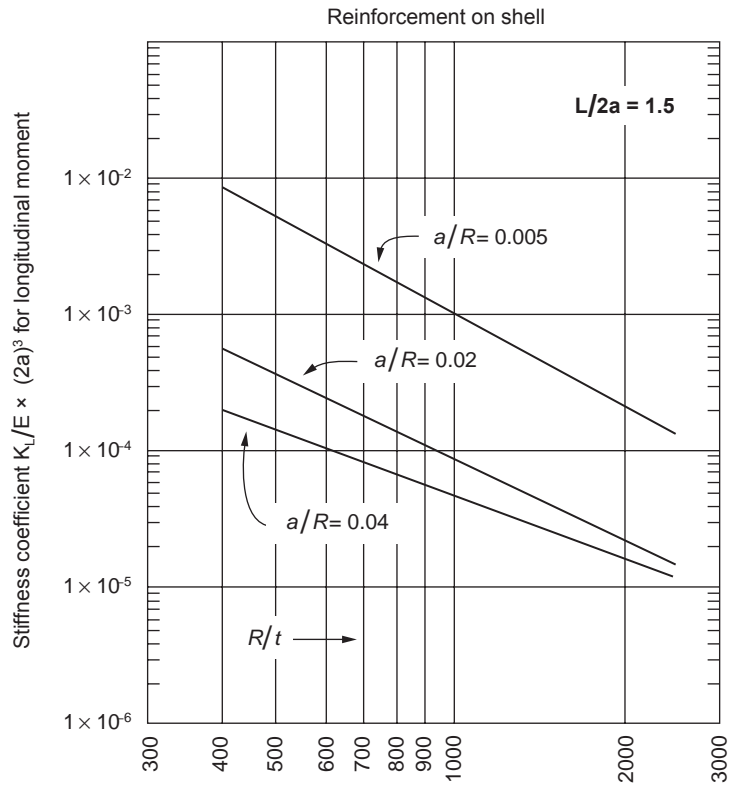


Figure P-2E—Stiffness Coefficient for Longitudinal Moment: Reinforcement on Shell ($L/2a = 1.5$)

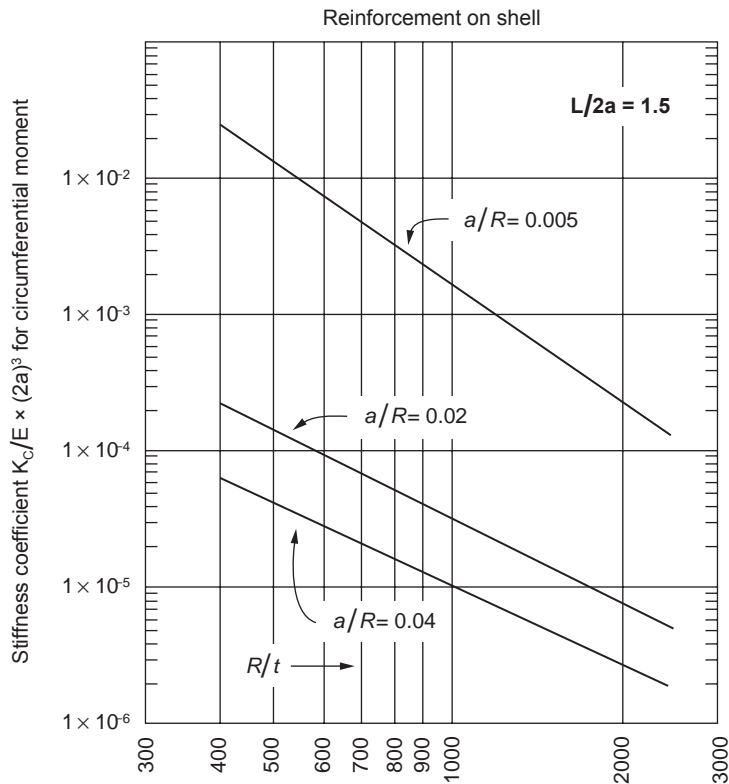


Figure P-2F—Stiffness Coefficient for Circumferential Moment: Reinforcement on Shell ($L/2a = 1.5$)

<http://www.aipetroleum.com>

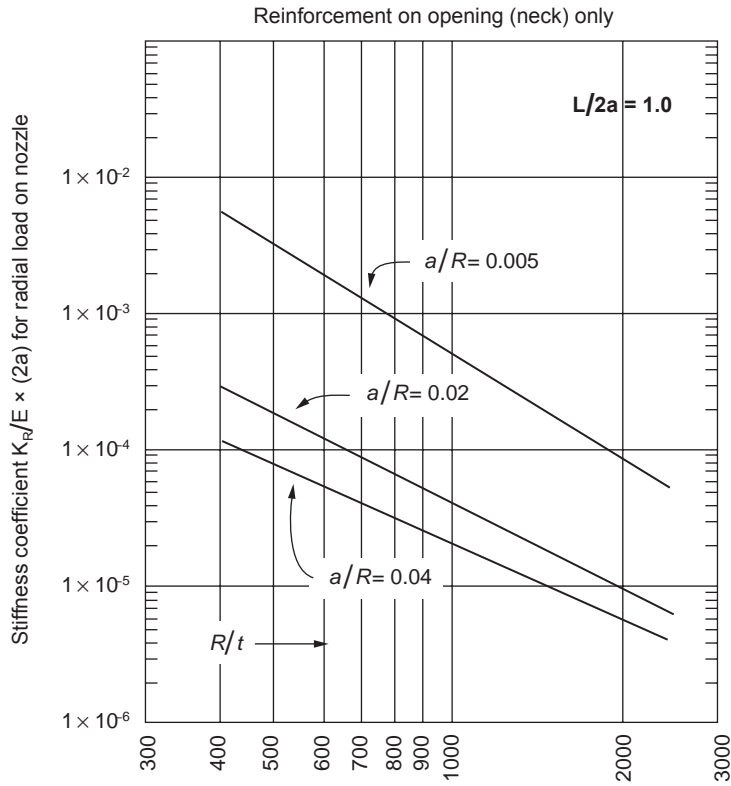


Figure P-2G—Stiffness Coefficient for Radial Load: Reinforcement in Nozzle Neck Only ($L/2a = 1.0$)

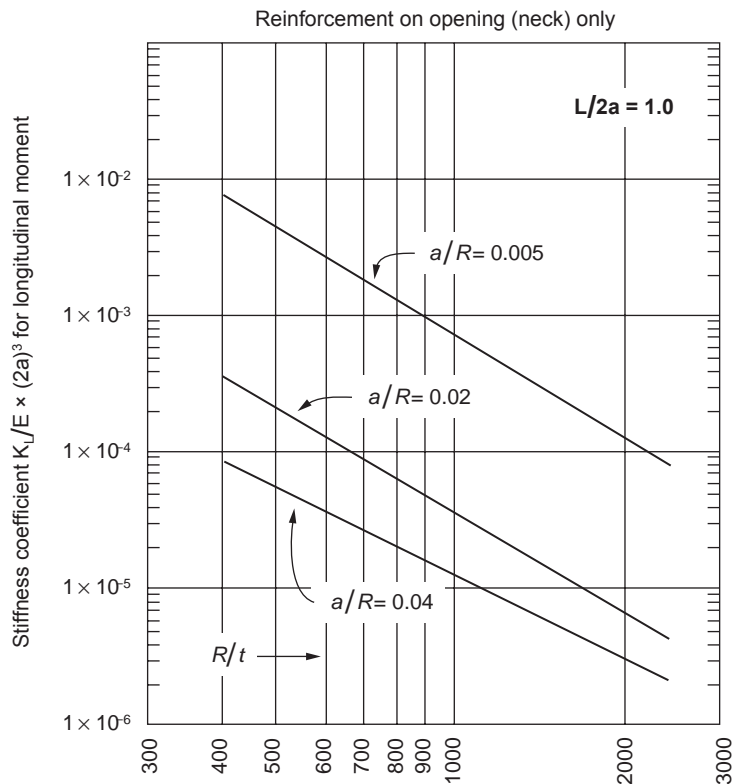


Figure P-2H—Stiffness Coefficient for Longitudinal Moment: Reinforcement in Nozzle Neck Only ($L/2a = 1.0$)

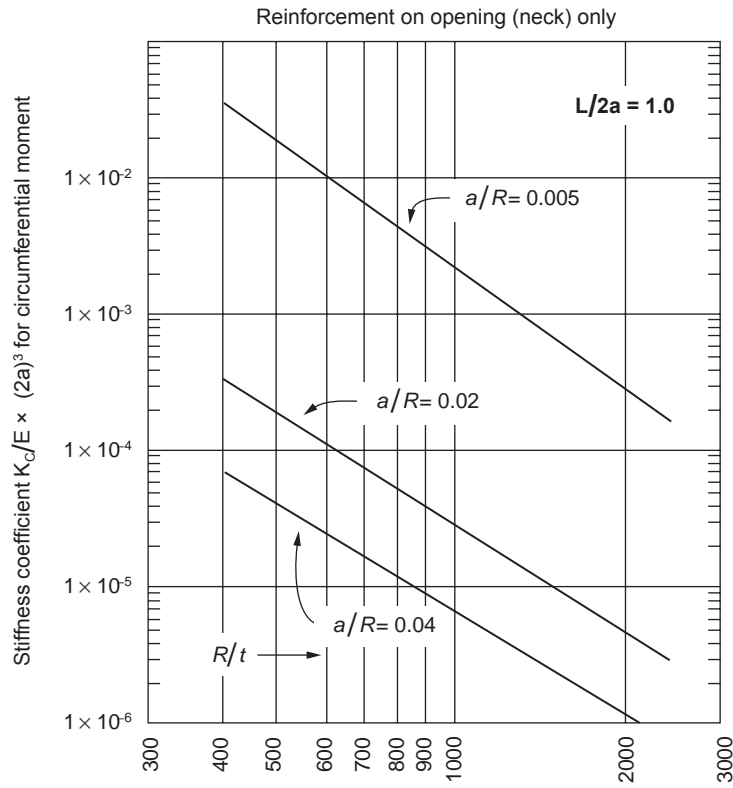


Figure P-2I—Stiffness Coefficient for Circumferential Moment: Reinforcement in Nozzle Neck Only ($L/2a = 1.0$)

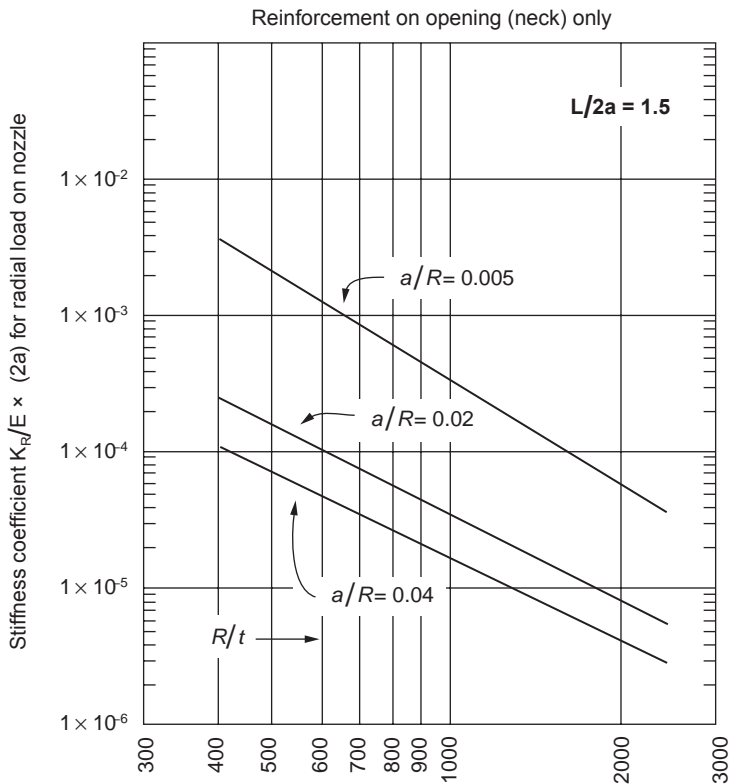


Figure P-2J—Stiffness Coefficient for Radial Load: Reinforcement in Nozzle Neck Only ($L/2a = 1.5$)

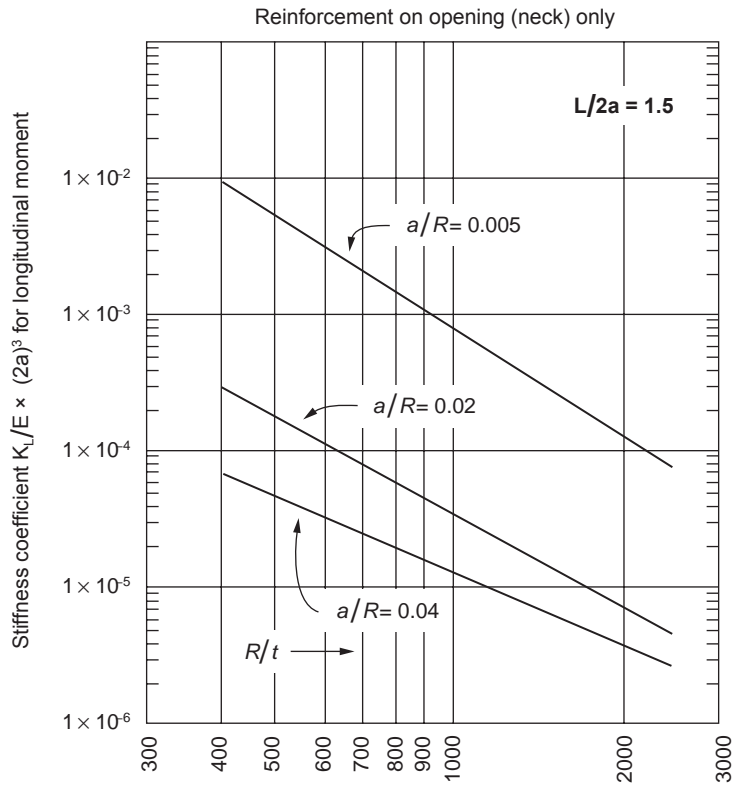


Figure P-2K—Stiffness Coefficient for Longitudinal Moment:
Reinforcement in Nozzle Neck Only ($L/2a = 1.5$)

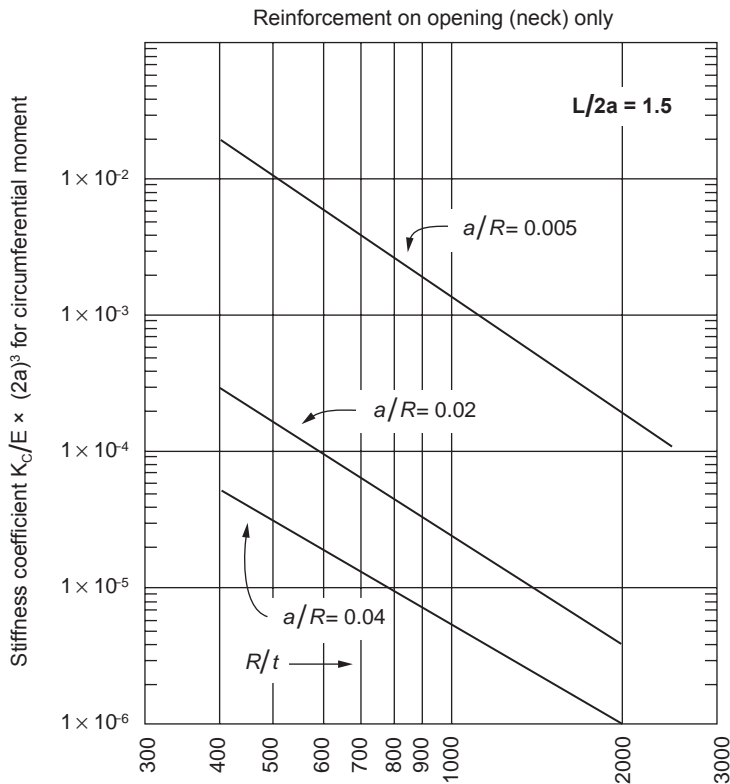


Figure P-2L—Stiffness Coefficient for Circumferential Moment:
Reinforcement in Nozzle Neck Only ($L/2a = 1.5$)

the shell-opening loads (see P.2.6). The Manufacturer shall determine, in accordance with P.2.7, the acceptability of the shell-opening loads furnished by the Purchaser. If the loads are excessive, the piping configuration shall be modified so that the shell-opening loads fall within the boundaries of the nomograms constructed as in P.2.7.1.

- **P.2.8.2** Changing the elevation of the opening and changing the thickness of the shell are alternative means of reducing stresses, but because these measures can affect fabrication, they may be considered only if mutually agreed upon by the Purchaser and the Manufacturer.

P.2.9 SAMPLE PROBLEM

P.2.9.1 Problem

A tank is 80 m (260 ft) in diameter and 19.2 m (64 ft) high, and its bottom shell course is 34 mm (1.33 in.) thick. The tank has a low-type nozzle with an outside diameter of 610 mm (24 in.) in accordance with API Std 650, and the nozzle centerline is 630 mm (24.75 in.) up from the bottom plate, with reinforcement on the opening (neck) only (see Figure P-6). What are the end conditions (W , θ , K_R , K_L , and K_C) for an analysis of piping flexibility? What are the limit loads for the nozzle?

$$a = 305 \text{ mm (12 in.)},$$

$$L = 630 \text{ mm (24.75 in.)},$$

$$H = 19,200 \text{ mm (64} \times 12 = 768 \text{ in.)},$$

$$\Delta T = 90 - 20 = 70^\circ\text{C (200} - 70 = 130^\circ\text{F)},$$

$$R = 80,000/2 = 40,000 \text{ mm ((260} \times 12)/2 = 1560 \text{ in.)},$$

$$t = 34 \text{ mm (1.33 in.)}.$$

P.2.9.2 Solution

P.2.9.2.1 Calculate the stiffness coefficients for the nozzle-tank connection:

$$R/t = 40,000/34 = 1176 \text{ (1560/1.33} = 1173)$$

$$a/R = 305/40,000 = 0.008 \text{ (12/1560} = 0.008)$$

$$L/2a = 630/610 @ 1.0 \text{ (24.75/24} @ 1.0)$$

For the radial load (from Figure P-2G),

In SI units:

$$\frac{K_R}{E(2a)} = 3.1 \times 10^{-4}$$

$$K_R = (3.1 \times 10^{-4})(199,000 \text{ N/mm}^2)(610 \text{ mm}) \\ = 37.6 \text{ N/mm}$$

In US Customary units:

$$\frac{K_R}{E(2a)} = 3.1 \times 10^{-4}$$

$$K_R = (3.1 \times 10^{-4})(28.8 \times 10^6 \text{ lb/in.}^2)(24 \text{ in.}) \\ = 214 \times 10^3 \text{ lbf/in.}$$

For the longitudinal moment (from Figure P-2H),

In SI units:

$$\frac{K_L}{E(2a)^3} = 3.0 \times 10^{-4}$$

$$K_L = (3.0 \times 10^{-4})(199,000 \text{ N/mm}^2)(610 \text{ mm}) \\ = 13.6 \times 10^9 \text{ N-mm/rad}$$

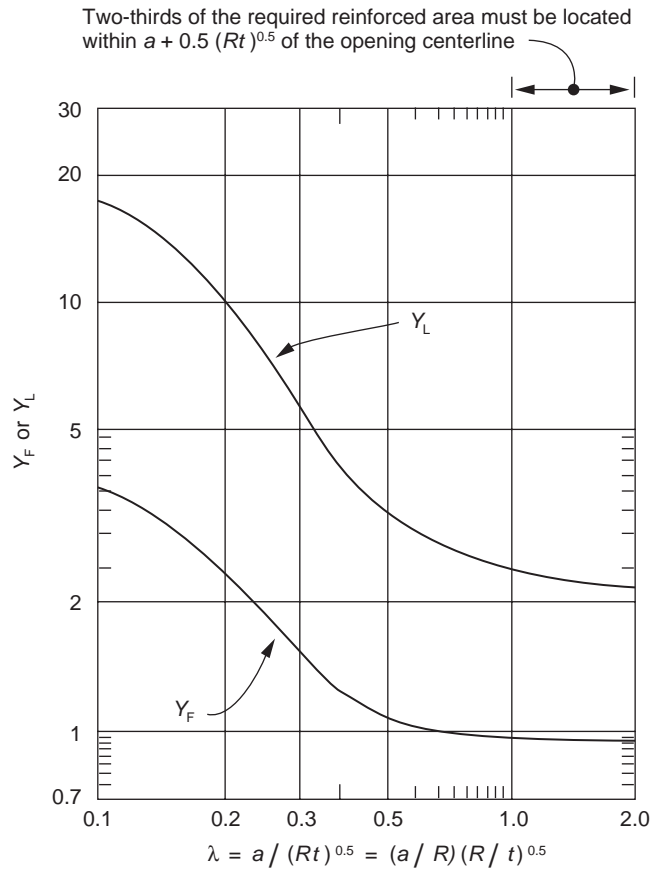


Figure P-4A—Obtaining Coefficients Y_F and Y_L

In US Customary units:

$$\frac{K_L}{E(2a)^3} = 3.0 \times 10^{-4}$$

$$K_L = (3.0 \times 10^{-4})(28.8 \times 10^6)(24)^3$$

$$= 119 \times 10^6 \text{ in.-lb/rad}$$

For the circumferential moment (from Figure P-2I),

In SI units:

$$\frac{K_C}{E(2a)^3} = 5.0 \times 10^{-4}$$

$$K_C = (5.0 \times 10^{-4})(199,000 \text{ N/mm}^2)(610 \text{ mm})^3$$

$$= 22.6 \times 10^9 \text{ N-mm/rad}$$

In US Customary units:

$$\frac{K_C}{E(2a)^3} = 5.0 \times 10^{-4}$$

$$K_C = (5.0 \times 10^{-4})(28.8 \times 10^6)(24)^3$$

$$= 199 \times 10^6 \text{ in.-lb/rad}$$

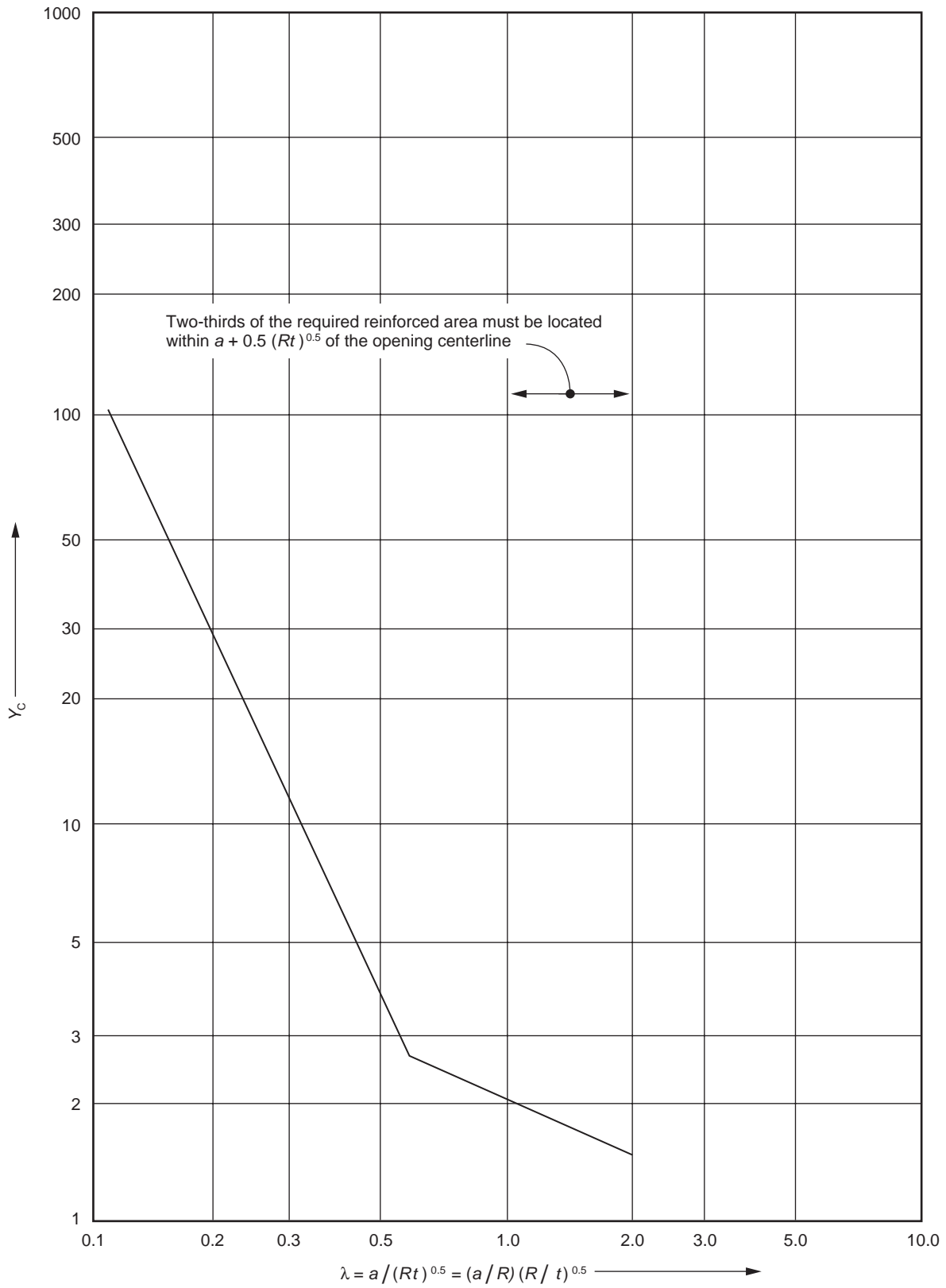


Figure P-4B—Obtaining Coefficient Y_C

P.2.9.2.2 Calculate the unrestrained shell deflection and rotation at the nozzle centerline resulting from the hydrostatic head of the full tank:

In SI units:

$$\beta = \frac{1.285}{(Rt)^{0.5}} = \frac{1.285}{(40,000 \times 34)^{0.5}} = 0.00110 \text{ mm}$$

$$\beta L = (0.00110)(630) = 0.7 \text{ rad}$$

$$\begin{aligned} W &= \frac{9.8 \times 10^{-6} GHR^2}{Et} \left[1 - e^{-\beta L} \cos(\beta L) - \frac{L}{H} \right] + \alpha R \Delta T \\ &= \frac{(9.8 \times 10^{-6})(1)(19,200)(40,000)^2}{(199,000)(34)} \\ &\quad \left[1 - e^{-0.7} \cos(0.7) - \frac{630}{19,200} \right] + (12.0 \times 10^{-6})(40,000)(70) \\ &= 59.77 \text{ mm} \end{aligned}$$

$$\begin{aligned} \theta &= \frac{9.8 \times 10^{-6} GHR^2}{Et} \left\{ \frac{1}{H} - \beta e^{-\beta L} [\cos(\beta L) + \sin(\beta L)] \right\} \\ &= \frac{(9.8 \times 10^{-6})(1)(19,200)(40,000)^2}{(199,000)(34)} \\ &\quad \left\{ \frac{1}{19,200} - 0.0011 e^{-0.7} [\cos(0.7) + \sin(0.7)] \right\} \\ &= -0.032 \text{ rad} \end{aligned}$$

In US Customary units:

$$\beta = \frac{1.285}{(Rt)^{0.5}} = \frac{1.285}{(1560 \times 1.33)^{0.5}} = 0.0282 \text{ in.}$$

$$\beta L = (0.0282)(24.75) = 0.7$$

$$\begin{aligned} W &= \frac{0.036 GHR^2}{Et} \left[1 - e^{-\beta L} \cos(\beta L) - \frac{L}{H} \right] + \alpha R \Delta T \\ &= \frac{0.036(1)(768)(1560)^2}{(28.8 \times 10^6)(1.33)} \left[1 - e^{-0.7} \cos(0.7) - \frac{24.75}{768} \right] \\ &\quad + (6.67 \times 10^{-6})(1560)(130) \\ &= 2.39 \text{ in.} \end{aligned}$$

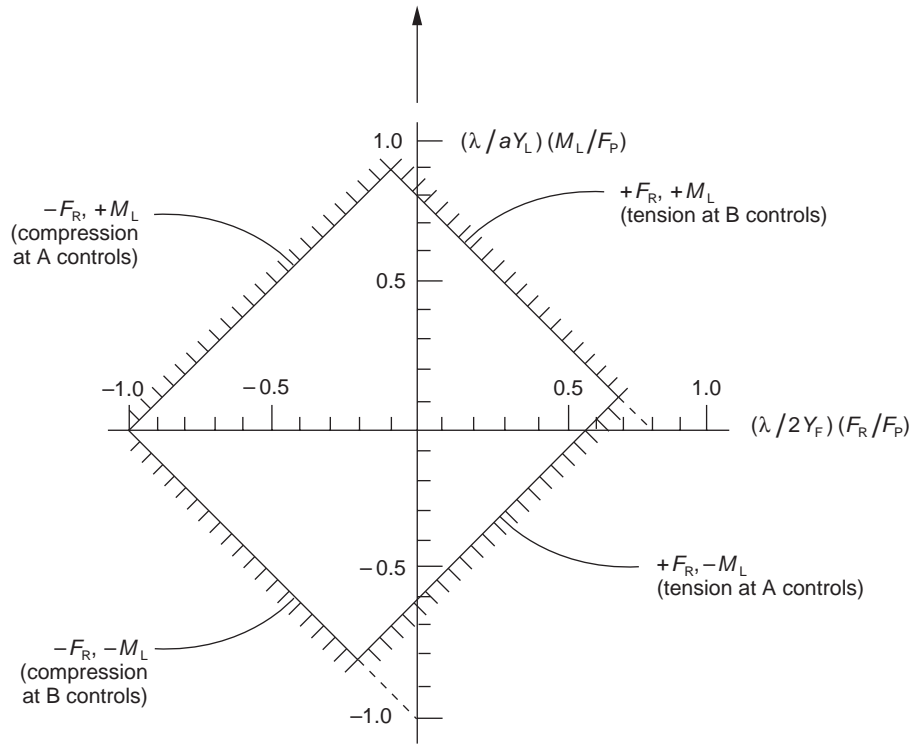


Figure P-5A—Determination of Allowable Loads from Nomogram: F_R and M_L

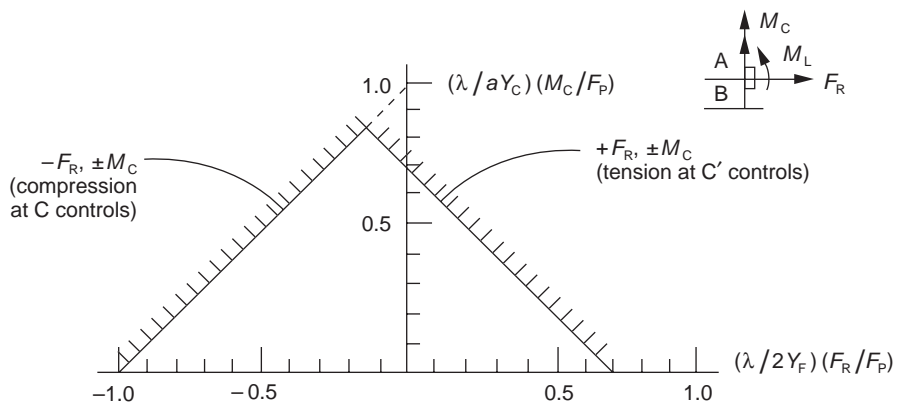


Figure P-5B—Determination of Allowable Loads from Nomogram: F_R and M_C

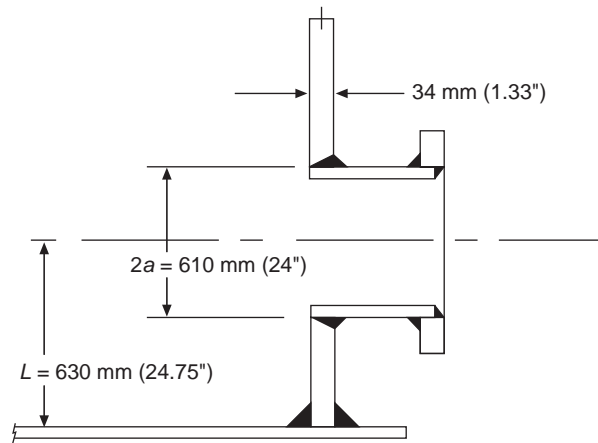


Figure P-6—Low-Type Nozzle with Reinforcement in Nozzle Neck Only (for Sample Problem)

$$\begin{aligned}\theta &= \frac{0.036GHR^2}{Et} \left\{ \frac{1}{H} - \beta e^{-\beta L} [\cos(\beta L) + \sin(\beta L)] \right\} \\ &= \frac{0.036(1)(768)(1560)^2}{(28.8 \times 10^6)(1.33)} \left\{ \frac{1}{768} - \beta e^{-0.7} [\cos(0.7) + \sin(0.7)] \right\} \\ &= -0.032 \text{ rad}\end{aligned}$$

Perform the analysis of piping flexibility using W , θ , K_R , K_L , and K_C as the end conditions at the nozzle-to-piping connection.

$$X_A = 935 \text{ mm (36.75 in.)}$$

$$X_B = 325 \text{ mm (12.75 in.)}$$

$$X_C = 630 \text{ mm (24.75 in.)}$$

Determine the allowable loads for the shell opening, as in P.9.2.3.

P.2.9.2.3 Determine the nondimensional quantities:

In SI units:

$$\frac{X_A}{(Rt)^{0.5}} = \frac{935}{[(40,000)(34)]^{0.5}} = 0.80$$

$$\frac{X_B}{(Rt)^{0.5}} = \frac{325}{[(40,000)(34)]^{0.5}} = 0.28$$

$$\frac{X_C}{(Rt)^{0.5}} = \frac{630}{[(40,000)(34)]^{0.5}} = 0.54$$

$$\lambda = \frac{A}{(Rt)^{0.5}} = \frac{305}{[(40,000)(34)]^{0.5}} = 0.26$$

In US Customary units:

$$\frac{X_A}{(Rt)^{0.5}} = \frac{36.75}{[(1560)(1.33)]^{0.5}} = 0.81$$

$$\frac{X_B}{(Rt)^{0.5}} = \frac{12.75}{[(1560)(1.33)]^{0.5}} = 0.28$$

$$\frac{X_C}{(Rt)^{0.5}} = \frac{24.75}{[(1560)(1.33)]^{0.5}} = 0.54$$

$$\lambda = \frac{A}{(Rt)^{0.5}} = \frac{12}{[(1560)(1.33)]^{0.5}} = 0.26$$

From Figures P-4A and P-4B,

$$Y_L = 7.8 \text{ mm (in.)}$$

$$Y_F = 2.0 \text{ mm (in.)}$$

$$Y_C = 15.0 \text{ mm (in.)}$$

P.2.9.2.4 Construct the load nomograms (see Figure P-7):

In SI units:

$$1.0 - 0.75 \frac{X_B}{(Rt)^{0.5}} = 1.0 - 0.75 \left(\frac{325}{1166} \right) = 0.79$$

$$1.0 - 0.75 \frac{X_A}{(Rt)^{0.5}} = 1.0 - 0.75 \left(\frac{935}{1166} \right) = 0.40$$

$$1.0 - 0.75 \frac{X_C}{(Rt)^{0.5}} = 1.0 - 0.75 \left(\frac{630}{1166} \right) = 0.59$$

$$\begin{aligned} F_p &= P\pi a^2 = (9800)(1.0)(19.2 - 0.630)\pi(0.305)^2 \\ &= 53,200 \text{ N} \end{aligned}$$

$$\frac{\lambda}{2Y_F} \left(\frac{F_R}{F_p} \right) = \frac{0.26}{(2)(2.0)} \left(\frac{F_R}{53,200} \right) = 1.22 \times 10^{-6} F_R$$

$$\frac{\lambda}{aY_L} \left(\frac{M_L}{F_p} \right) = \frac{0.26}{(305)(7.8)} \left(\frac{M_L}{53,200} \right) = 2.05 \times 10^{-9} M_L$$

$$\frac{\lambda}{aY_C} \left(\frac{M_C}{F_p} \right) = \frac{0.26}{(305)(15)} \left(\frac{M_C}{53,200} \right) = 1.07 \times 10^{-9} M_C$$

In US Customary units:

$$1.0 - 0.75 \frac{X_B}{(Rt)^{0.5}} = 1.0 - 0.75 \left(\frac{12.75}{45.6} \right) = 0.79$$

$$1.0 - 0.75 \frac{X_A}{(Rt)^{0.5}} = 1.0 - 0.75 \left(\frac{36.75}{45.6} \right) = 0.40$$

$$1.0 - 0.75 \frac{X_C}{(Rt)^{0.5}} = 1.0 - 0.75 \left(\frac{24.75}{45.6} \right) = 0.59$$

$$F_P = P\pi a^2 = \left[\frac{(62.4)(1.0)}{1728} \right] [(64)(12) - 24.75] \pi 12^2$$

$$= 12,142 \text{ pounds}$$

$$\frac{\lambda}{2Y_F} \left(\frac{F_R}{F_P} \right) = \frac{0.26}{(2)(2.0)} \left(\frac{F_R}{12,142} \right) = 5.35 \times 10^{-6} F_R$$

$$\frac{\lambda}{aY_L} \left(\frac{M_L}{F_P} \right) = \frac{0.26}{(12)(7.8)} \left(\frac{M_L}{12,142} \right) = 229 \times 10^{-9} M_L$$

$$\frac{\lambda}{aY_C} \left(\frac{M_C}{F_P} \right) = \frac{0.26}{(12)(15)} \left(\frac{M_C}{12,142} \right) = 119 \times 10^{-9} M_C$$

P.2.9.2.5 Determine the limiting piping loads.

In SI units:

For $M_L = 0$ and $M_C = 0$,

$$\text{For } F_R, \quad \frac{\lambda}{2Y_F} \left(\frac{F_R}{F_P} \right) = 1.22 \times 10^{-6} F_R \leq 0.4$$

Therefore,

$$F_{R\max} = \frac{0.4}{1.22 \times 10^{-6}} = 328,000 \text{ N (tension at A controls)}$$

For $M_L = 0$ and $F_R = 0$,

$$\text{For } M_C, \quad \frac{\lambda}{aY_C} \left(\frac{M_C}{F_P} \right) = 1.07 \times 10^{-9} M_C \leq 0.59$$

Therefore,

$$M_{C\max} = \frac{0.59}{1.07 \times 10^{-9}} = 550 \times 10^6 \text{ N-mm (tension at C' controls)}$$

For $F_R = 0$ and $M_C = 0$,

$$\text{For } M_L, \quad \frac{\lambda}{aY_L} \left(\frac{M_L}{F_P} \right) = 2.05 \times 10^{-9} M_L \leq 0.79$$

Therefore,

$$M_{L\max} = \frac{0.79}{2.05 \times 10^{-9}} = 385 \times 10^6 \text{ N-mm (tension at B controls)}$$

In US Customary units:

For $M_L = 0$ and $M_C = 0$,

$$\text{For } F_R, \quad \frac{\lambda}{2Y_F} \left(\frac{F_R}{F_P} \right) = 5.35 \times 10^{-6} F_R \leq 0.4$$

Therefore,

$$F_{R\max} = \frac{0.4}{5.35 \times 10^{-6}} = 74,800 \text{ lbf (tension at A controls)}$$

For $M_L = 0$ and $F_R = 0$,

$$\text{For } M_C, \quad \frac{\lambda}{aY_C} \left(\frac{M_C}{F_P} \right) = 119 \times 10^{-9} M_C \leq 0.59$$

Therefore,

$$M_{C\max} = \frac{0.59}{1.19 \times 10^{-7}} = 4.95 \times 10^6 \text{ in.-lbf (tension at C' controls)}$$

For $F_R = 0$ and $M_C = 0$,

$$\text{For } M_L, \quad \frac{\lambda}{aY_L} \left(\frac{M_L}{F_P} \right) = 229 \times 10^{-9} M_L \leq 0.79$$

Therefore,

$$M_{L\max} = \frac{0.4}{2.3 \times 10^{-7}} = 1.74 \times 10^6 \text{ in.-lbf (tension at A controls)}$$

P.2.9.3 Summary

The limiting piping loads are as follows:

In SI units:

$$F_{R\max} = 328,000 \text{ N (tension at A controls)}$$

$$M_{C\max} = 550 \times 10^6 \text{ N-mm (tension at C' controls)}$$

$$M_{L\max} = 195 \times 10^6 \text{ N-mm (tension at A controls)}$$

In US Customary units:

$$F_{R\max} = 74,800 \text{ pounds (tension at A controls)}$$

$$M_{C\max} = 4.95 \times 10^6 \text{ in.-lbs (tension at C' controls)}$$

$$M_{L\max} = 1.74 \times 10^6 \text{ in.-lbs (tension at A controls)}$$

Note: This section is based on the paper "Analysis of Nozzle Loads in API 650 Tanks"²⁷

²⁷Analysis of Loads for Nozzles in API 650 Tanks, M. Lengsfeld, K.L. Bardia, J. Taagepera, K. Hathaitham, D.G. LaBounty, M.C. Lengsfeld. Paper PVP-Vol 430, ASME, New York, 2001

P.3 Alternate Procedure for the Evaluation of External Loads on Tank Shell Openings

P.3.1 SCOPE

This alternative method expands the data presented in the WRC Bulletin 297. Maximum stress factors are presented in figures as well as in tables. WRC Bulletin 297 was used to calculate the maximum stress factors f_i at the junction of the nozzle and tank shell. The recommended limitations for WRC 297 are $D/T \leq 2500$, $d/t \leq 100$. The method is valid for all practical sizes of tanks.

P.3.2 NOMENCLATURE

B = $2(Dt)^{1/2}$, distance of nozzle removed from any other gross structural stress continuity, (mm) (in.)

D = nominal diameter of tank, (mm) (in.)

D_o = diameter of reinforcing plate (mm) (in.)

F_R = radial thrust applied at the mid-surface of the tank shell at the opening connection, (N) (lbf)

L = vertical distance from opening centerline to tank bottom, (mm) (in.)

M_C = circumferential moment applied to the mid-surface of the tank shell, (N-mm) (in.-lbf)

M_i = generic moment, (N-mm) (in.-lbs)

M_L = longitudinal moment applied to the mid-surface of the tank shell, (N-mm) (in.-lbf)

M_T = torsional moment applied to the mid-surface of the tank shell, (N-mm) (in.-lbf)

S = stress intensity, (MPa) (lbf/in.²)

S_{all} = allowable stress intensity due to applied load on nozzles, (MPa) (lbf/in.²)

$1 \times S_d$ for mechanical loads

$1.5 \times S_d$ for thermal loads

S_d = allowable design stress, (MPa) (lbf/in.²)

V_C = shear force in transverse (circumferential) direction, (N) (lbf)

V_L = shear force in longitudinal direction, (N) (lbs)

W_r = resultant radial deflection at opening connection, (mm) (in.)

a = outside radius of opening connection, (mm) (in.)

d = outside diameter of nozzle, (mm) (in.)

f_C = stress factor due to circumferential moment, (dimensionless)

f_L = stress factor due to longitudinal moment, (dimensionless)

f_R = stress factor due to radial thrust, (dimensionless)

f_i = stress factor (generic), (dimensionless)

h = L/B , height ratio, (dimensionless)

m_r = radial bending stress component, (dimensionless)

m = transverse bending stress component, (dimensionless)

m_i = generic bending stress component, (dimensionless)

n_r = radial membrane stress component, (dimensionless)

n = transverse (circumferential) membrane stress component, (dimensionless)

n_i = generic stress component (membrane), (dimensionless)

t = thickness of tank shell at location of nozzle, (mm) (in.)

t_n = thickness of nozzle neck, (mm) (in.)

t_r = thickness of reinforcing plate (mm) (in.)

$u = (d/D)(D/T)^{1/2}$, geometric parameter, (dimensionless)

z = stress reduction factor, (dimensionless)

σ_r = calculated radial stress, (MPa) (lbf/in.²)

σ_θ = calculated membrane stress, (MPa) (lbf/in.²)

σ_i = calculated generic stress, (MPa) (lbf/in.²)

τ = calculated shear stress, (MPa) (lbf/in.²)

P.3.3 DESCRIPTION

Figures P-8 through P-10 provide stress factors for nozzles located away from a gross structural discontinuity. A gross structural discontinuity is defined as a major change of geometry, like a ring or the closeness of the bottom/shell junction. The stress factors are a combination of membrane and bending components for each load applied. Equations created from the data in WRC Bulletin 297 were used to produce the graphs in Figure P-8 through P-10. The graphs represent the absolute maximum value, which will result in a conservative estimate of the maximum stresses at the nozzle-to-shell junction. Each graph includes the mathematical expression for the plotted graph. The mathematical equations are summarized in Tables P-2 through P-4. Use of the mathematical equations will simplify the creation of computer programs for the calculation of stresses at the nozzle-to-shell junction

P.3.4 STRESS FACTORS DUE TO F_R , M_C , M_L

Total stress has three components: bending, membrane, and shear. The stress factors for calculation of stresses in the shell at the nozzle junction have been presented for the stress equations. Moment loads include circumferential and longitudinal moments.

$$\sigma_r = (FR/t^2)(n_r \pm 6m_r) \quad (\text{Radial Load}) \quad (1)$$

$$\sigma_\theta = (FR/t^2)(n_\theta \pm 6m_\theta) \quad (\text{Radial Load}) \quad (2)$$

$$\sigma_r = [M_i/(dt^2)](n_r \pm 6m_r) \quad (\text{Moment Load}) \quad (3)$$

$$\sigma_\theta = [M_i/(dt^2)](n_\theta \pm 6m_\theta) \quad (\text{Moment Load}) \quad (4)$$

The dimensionless factors n_i and m_i were obtained from WRC Bulletin 297, Figures 3 through 58 for various nozzle sizes, tank diameters and thicknesses. The absolute maximum of these values as used in the stress Equations 1 through 4 have been combined into the dimensionless stress factors:

$$f_i = (n_i \pm 6m_i) \quad (5)$$

The factors were plotted after transformation into mathematical equivalents in Figures P-8 through P-10. The actual maximum stresses for specific nozzles in a tank can be calculated by:

$$\sigma_i = (P/t^2)f_i \quad \text{for radial load} \quad (6a)$$

and

$$\sigma_i = [M_i / (dt^2)] f_i \quad \text{for moment load} \quad (6b)$$

P.3.5 SHEAR STRESSES DUE TO M_T , V_C , V_L

Shear stresses in the tank shell at the nozzle junction may be estimated by:

$$\tau_{MT} = 2M_i / (\pi d t) \quad \text{for torsional moment} \quad (7a)$$

$$\tau_{Vi} = 2V_i / (\pi d t) \quad \text{for shear force} \quad (7b)$$

where

$$V_i = V_C \text{ or } V_L$$

The total shear stress is the summation of the three components:

$$\tau_{\text{Total}} = \tau_{MT} + \tau_{VC} + \tau_{VL} \quad (8a)$$

However, if shear stresses due to V_C and V_L become significant, it should be recognized that their maximum value and zero value occur 90° apart from each other. In this case the components shall be separated into:

$$\tau_L = \tau_{MT} + \tau_{VL} \quad (8b)$$

and

$$\tau_C = \tau_{MT} + \tau_{VC} \quad (8c)$$

The larger shear stress from the above expression should be used for combined stresses.

P.3.6 STRESS REDUCTION FACTORS

Stress reduction factors are presented in Figure P-8. These factors compare the values shown in Figures P-8 through P-10 as derived from the equations in Table P-2 through P-4 with values obtained using finite element analysis (FEA) for nozzles closer to a gross structural discontinuity. It should be noted that the stresses decrease as the nozzles move closer to a discontinuity. Depending on the location of the nozzles, the value for the stresses will be multiplied by the stress reduction factor.

An array of reduction factors were found, but for simplicity Figure P-8 shows only one line. This line represents conservative reduction factors. Height factors greater than 1 have a 'z' value of 1.

P.3.7 COMBINING STRESSES

For stresses due to the different nozzle loads, WRC Bulletin 297 suggests the following equation to calculate the stress intensity.

$$S = \text{largest absolute magnitude of} \quad (9)$$

$$= 0.5 [(\sigma_r + \sigma) \pm [(\sigma_r - \sigma)^2 + 4\tau^2]^{0.5}]$$

It should be noted that the maximum stresses due to a circumferential moment, M_C , and a longitudinal moment, M_L , are 90° apart. Thus the maximum stress for the transverse plane is:

$$\sigma_i = \sigma_i(F_R) + \sigma_i(M_C) + \tau_i \quad (10a)$$

for the longitudinal plane:

$$\sigma_i = \sigma_i(F_R) + \sigma_i(M_L) + \tau_i \quad (10b)$$

Where $i = r$ or θ , $\sigma_i(F_R)$ = stress due to radial load, and similarly $\sigma_i(M_C)$, $\sigma_i(M_L)$ and τ_i .

P.3.8 ALLOWABLE STRESSES

An acceptable guideline for establishing allowable stress values may be found in Appendix 4 of the ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 2.

The stress factors have been derived from the highest stress at the junction of the nozzle to the shell. The simplified recommendations for allowable stresses for the different loads are as follows:

$$\begin{aligned} S_{\text{all}} &= 1 \times S_d \text{ for mechanical loads (seismic, thrust due to liquid flow in pipe, etc.)} \\ &= 1.5 \times S_d \text{ for thermal loads} \end{aligned}$$

In this recommendation it is assumed that the tank is stressed to $1 \times S_d$ due to the hydrostatic head of its contents.

P.3.9 ANALYSIS PROCEDURE

The procedure for the evaluation of nozzle loads is as follows:

- Establish the value of u , d/t_n , and t/t_n from given tank data.
- Find the stress factor value from Figures P-8 through P-10 or from the equations of Table P-2 through P-4 for different nozzle sizes, thickness, and tank diameters.
- Use stress formula to calculate stresses at nozzle-to-shell junction. Include stress reduction factors as required.
- Combine various stress components
- Compare actual stress to allowable stress based on the nature of the load (thermal or mechanical).

P.3.10 SAMPLE PROBLEM NO. 1

P.3.10.1 Data

Calculate the stresses for a tank nozzle using the following data.

Tank Diameter	D	9.144 m (30 ft)
Tank Shell Thickness	t_s	12.7 mm (0.5 in.)
Nozzle Outside Diameter	d	457 mm (18 in.)
Nozzle Neck Thickness	t_n	12.7 mm (0.5 in.)
Nozzle Location From Bottom	L	476 mm (18.75 in.)
Reinforcing Pad Thickness	t_r	12.7 mm (0.5 in.)
Material	A 36M (A 36)	
Design Stress	S_d	160 MPa (23,200 lbf/in. ²)

The loading from the attached piping system to the nozzle is as follows:

Radial Thrust	F_R	77,843 N (17,500 lbs)
Circular Moment	M_C	8.5×10^6 N·mm (75,000 in·lbs)
Longitudinal Moment	M_L	11.3×10^6 N·mm (100,000 in·lbs)
Torsional Moment	M_T	5.6×10^6 N·mm (50,000 in·lbs)
Transverse Shear Force	V_C	0 N (0 lbs)
Longitudinal Shear Force	V_L	44,500 N (10,000 lbs)

Table P-2—Equations for Stress Factors Due to Radial Thrust F_R

d/t_n	t/t_n	Equation	Upper Limit (u)	Equation No.
Figure P-8A				
10	0	$f_r = -0.9414\text{Ln}(u) + 1.6578$	5	11
10	1	$f_r = -0.9384\text{Ln}(u) + 1.2638$	2	12
10	2	$f_r = -0.7910\text{Ln}(u) + 0.8044$	1	13
10	5	$f_r = -0.4167\text{Ln}(u) + 0.3728$	0.3	14
Figure P-8B				
30	0	$f_r = -0.9450\text{Ln}(u) + 1.648$	5	15
30	1	$f_r = -0.9074\text{Ln}(u) + 1.3398$	3	16
30	2	$f_r = -0.7596\text{Ln}(u) + 0.9036$	2	17
30	5	$f_r = -0.3465\text{Ln}(u) + 0.2971$	1	18
30	10	$f_r = -0.1496\text{Ln}(u) + 0.1187$	0.5	19
Figure P-8C				
50	0	$f_r = -0.9507\text{Ln}(u) + 1.6453$	5	20
50	1	$f_r = -0.8732\text{Ln}(u) + 1.4563$	5	21
50	2	$f_r = -0.7608\text{Ln}(u) + 0.9842$	3	22
50	5	$f_r = -0.3333\text{Ln}(u) + 0.316$	2	23
50	10	$f_r = -0.1304\text{Ln}(u) + 0.1071$	1	24
Figure P-8D				
100	0	$f_r = -0.9549\text{Ln}(u) + 1.6506$	5	25
100	1	$f_r = -0.8772\text{Ln}(u) + 1.4815$	5	26
100	2	$f_r = -0.7641\text{Ln}(u) + 1.0928$	4	27
100	5	$f_r = -0.3344\text{Ln}(u) + 0.33$	2	28
100	10	$f_r = -0.1176\text{Ln}(u) + 0.0941$	1	29
Figure P-8E				
10	0	$f_\theta = -0.2827\text{Ln}(u) + 0.4845$	5	30
10	1	$f_\theta = -0.3427\text{Ln}(u) + 0.5338$	2	31
10	2	$f_\theta = -0.5255\text{Ln}(u) + 0.4772$	0.9	32
10	5	$f_\theta = -0.8780\text{Ln}(u) + 0.7936$	0.3	33
Figure P-8F				
30	0	$f_\theta = -0.2833\text{Ln}(u) + 0.4878$	5	34
30	1	$f_\theta = -0.3440\text{Ln}(u) + 0.6352$	3	35
30	2	$f_\theta = -0.4868\text{Ln}(u) + 0.7312$	2	36
30	5	$f_\theta = -0.8929\text{Ln}(u) + 0.8883$	1	37
30	10	$f_\theta = -1.0961\text{Ln}(u) + 1.1698$	0.5	38
Figure P-8G				
50	0	$f_\theta = -0.2840\text{Ln}(u) + 0.4893$	5	39
50	1	$f_\theta = -0.3355\text{Ln}(u) + 0.6771$	5	40
50	2	$f_\theta = -0.4712\text{Ln}(u) + 0.7731$	2	41
50	5	$f_\theta = -0.8775\text{Ln}(u) + 1.051$	2	42
50	10	$f_\theta = -1.0986\text{Ln}(u) + 1.1733$	1	43
Figure P-8H				
100	0	$f_\theta = -0.2796\text{Ln}(u) + 0.4815$	5	44
100	1	$f_\theta = -0.3302\text{Ln}(u) + 0.6764$	5	45
100	2	$f_\theta = -0.4346\text{Ln}(u) + 0.8077$	2	46
100	5	$f_\theta = -0.8724\text{Ln}(u) + 1.1447$	1.5	47
100	10	$f_\theta = -1.0774\text{Ln}(u) + 1.145$	1	48

Table P-4—Equations for Stress Factors Due to Longitudinal Moment M_L

d/t_n	t/t_n	Equation	Upper Limit (u)	Equation No.
Figure P-10A				
10	0	$f_r = 0.0783(u)^2 - 0.7302(u) + 2.0393$	3	87
10	1	$f_r = -0.0359(u)^2 - 0.5507(u) + 1.9629$	2	88
10	2	$f_r = -0.2708(u)^2 - 0.239(u) + 1.6377$	1	89
10	5	$f_r = 0.5506(u)^2 - 0.262(u) + 0.8681$	0.3	90
Figure P-10B				
30	0	$f_r = 0.0612(u)^2 - 0.6723(u) + 2.0355$	4	91
30	1	$f_r = 0.0658(u)^2 - 0.695(u) + 2.0052$	3	92
30	2	$f_r = -0.0225(u)^2 - 0.4703(u) + 1.6789$	2	93
30	5	$f_r = -0.1112(u)^2 - 0.0737(u) + 0.7396$	1	94
30	10	$f_r = -0.1097(u)^2 - 0.0077(u) + 0.8462$	0.5	95
Figure P-10C				
50	0	$f_r = 0.0598(u)^2 - 0.6602(u) + 2.0144$	4	96
50	1	$f_r = 0.0878(u)^2 - 0.7827(u) + 2.092$	3	97
50	2	$f_r = 0.0399(u)^2 - 0.5612(u) + 1.7047$	3	98
50	5	$f_r = -0.0363(u)^2 - 0.1429(u) + 0.7231$	2	99
50	10	$f_r = -0.0349(u)^2 - 0.0123(u) + 0.2684$	1	100
Figure P-10D				
100	0	$f_r = 0.0604(u)^2 - 0.6672(u) + 2.0341$	4	101
100	1	$f_r = 0.0572(u)^2 - 0.6343(u) + 1.9951$	4	102
100	2	$f_r = 0.0649(u)^2 - 0.6297(u) + 1.7638$	4	103
100	5	$f_r = 0.0059(u)^2 - 0.205(u) + 0.7263$	3	104
100	10	$f_r = -0.0199(u)^2 - 0.0254(u) + 0.2424$	2	105
Figure P-10E				
10	0	$f_\theta = 0.0186(u)^2 - 0.2026(u) + 0.6093$	4	106
10	1	$f_\theta = 0.0769(u)^2 - 0.42(u) + 0.8174$	2	107
10	2	$f_\theta = 0.4177(u)^2 - 0.9351(u) + 1.3637$	1	108
10	5	$f_\theta = -1.655(u)^2 - 0.3351(u) + 2.0292$	0.3	109
Figure P-10F				
30	0	$f_\theta = 0.0189(u)^2 - 0.2054(u) + 0.6136$	4	110
30	1	$f_\theta = 0.0205(u)^2 - 0.2132(u) + 0.7797$	3	111
30	2	$f_\theta = 0.0737(u)^2 - 0.4233(u) + 1.2067$	2	112
30	5	$f_\theta = 0.0201(u)^2 - 0.3208(u) + 2.0191$	1	113
30	10	$f_\theta = 1.0841(u)^2 - 0.7196(u) + 2.4196$	0.5	114
Figure P-10G				
50	0	$f_\theta = 0.019(u)^2 - 0.2047(u) + 0.6084$	4	115
50	1	$f_\theta = 0.0064(u)^2 - 0.1406(u) + 0.7319$	3	116
50	2	$f_\theta = 0.0223(u)^2 - 0.294(u) + 1.1225$	3	117
50	5	$f_\theta = -0.1135(u)^2 - 0.2031(u) + 2.0016$	2	118
50	10	$f_\theta = -0.2506(u)^2 + 0.0373(u) + 2.3705$	1	119
Figure P-10H				
100	0	$f_\theta = 0.0191(u)^2 - 0.2068(u) + 0.6145$	5	120
100	1	$f_\theta = 0.0035(u)^2 - 0.0968(u) + 0.6486$	5	121
100	2	$f_\theta = 0.0119(u)^2 - 0.2151(u) + 1.0336$	5	122
100	5	$f_\theta = -0.0554(u)^2 - 0.2536(u) + 1.9884$	3	123
100	10	$f_\theta = -0.1413(u)^2 - 0.0926(u) + 2.4238$	3	124

P.3.10.2 Solution

P.3.10.2.1 Establish the values for t , u , d/t_n , B , h , and z from the data provided. To determine the stresses at the junction of the nozzle and the shell, the shell and the reinforcing pad thickness are combined, hence:

In SI Units:

$$\begin{aligned} t &= t_s + t_r \\ &= 12.7 \text{ mm} + 12.7 \text{ mm} \\ &= 25.4 \text{ mm} \end{aligned}$$

$$\begin{aligned} u &= (d/D) \times (D/t)^{0.5} \\ &= (457/9144) \times (9144/25.4)^{0.5} \\ &= 0.95 \end{aligned}$$

$$\begin{aligned} d/t_n &= 457/12.7 \\ &= 36 \end{aligned}$$

$$\begin{aligned} B &= 2 \times (D \times t)^{0.5} \\ &= 2 \times (9144 \times 25.4)^{0.5} \\ &= 964 \text{ mm} \end{aligned}$$

$$\begin{aligned} h &= L/B \\ &= 476/964 \\ &= 0.49 \end{aligned}$$

$$z = 0.67 \text{ from Figure P-11}$$

$$\begin{aligned} t/t_n &= 25.4/12.7 \\ &= 2 \end{aligned}$$

In US Customary units:

$$\begin{aligned} t &= t_s + t_r \\ &= 0.5 \text{ in.} + 0.5 \text{ in.} \\ &= 1.0 \text{ in.} \end{aligned}$$

$$\begin{aligned} u &= [18/(30 \times 12)] \times [(30 \times 12)/1]^{0.5} \\ &= 0.95 \end{aligned}$$

$$\begin{aligned} d/t_n &= 18/0.5 \\ &= 36 \end{aligned}$$

$$\begin{aligned} B &= 2 \times (30 \times 12 \times 1)^{0.5} \\ &= 38 \text{ in.} \end{aligned}$$

$$\begin{aligned} h &= 18.75/38 \\ &= 0.49 \end{aligned}$$

$$z = 0.67 \text{ from Figure P-11}$$

$$\begin{aligned} t/t_n &= 1/0.5 \\ &= 2 \end{aligned}$$

P.3.10.2.2 Calculate the stresses.

In SI Units:

The charts and equations list values for d/t_n of 30 and 50. To derive the stress factor values for $d/t_n = 36$ one must interpolate between the presented values.

Stress factors are provided in Table P-5.

Combine the stresses.

$$\begin{aligned} S_{\max} &= \text{largest absolute magnitude of} \\ &= 0.5z \times [(\sigma_r + \sigma_\theta) \pm \{(\sigma_r - \sigma_\theta)^2 + 4\tau^2\}^{0.5}] \end{aligned}$$

Combine the stress values from F_R and M_C .

$$\begin{aligned} \sigma_r &= 106.7 + 42 \\ &= 148.7 \text{ MPa} \end{aligned}$$

$$\begin{aligned} \sigma_\theta &= 92.3 + 29.7 \\ &= 122 \text{ MPa} \end{aligned}$$

Combine the stress values from F_R and M_L .

$$\begin{aligned} \sigma_r &= 106.7 + 46 \\ &= 152.7 \text{ MPa} \end{aligned}$$

$$\begin{aligned} \sigma_\theta &= 92.3 + 33.7 \\ &= 126 \text{ MPa} \end{aligned}$$

The maximum stress is a combination of the radial thrust and the longitudinal moment.

$$\begin{aligned} S_{\max} &= 0.5 \times 0.67 \times [(162.8 + 126) \pm \{(152.7 - 126)^2 + 4 \times 3.11^2\}^{0.5}] \\ &= 102.5 \text{ MPa} \end{aligned}$$

$$\begin{aligned} S_{\text{all}} &= 1.0 \times S_d && \text{(mechanical load)} \\ &= 1.5 \times S_d && \text{(thermal load)} \\ &= 1.5 \times 160 && \text{(thermal load)} \\ &= 240 \text{ MPa} \end{aligned}$$

$$S_{\text{all}} > S_{\max}$$

In US Customary units:

The charts and equations list values for d/t_n of 30 and 50. To derive the stress factor values for $d/t_n = 36$ one must interpolate between the presented values.

Using the stress factors from Table P-5:

Stresses due to F_R

$$\begin{aligned} \sigma_r &= (F_R/t^2) \times f_r \\ &= (17,500/1^2) \times 0.884 \\ &= 15,470 \text{ lbf/in.}^2 \end{aligned}$$

$$\begin{aligned} \sigma_\theta &= (F_R/t^2) \times f_\theta \\ &= (17,500/1^2) \times 0.765 \\ &= 13,388 \text{ lbf/in.}^2 \end{aligned}$$

Stresses due to M_C

$$\begin{aligned} \sigma_r &= (M_C/d \times t^2) \times f_r \\ &= \{(75,000)/(18 \times 1^2)\} \times 1.46 \\ &= 6083 \text{ lbf/in.}^2 \end{aligned}$$

$$\begin{aligned}
 \sigma_{\theta} &= (M_C/d \times t^2) \times f_{\theta} \\
 &= \{(75,000)/(18 \times 1^2)\} \times 1.03 \\
 &= 4292 \text{ lbf/in.}^2
 \end{aligned}$$

Stresses due to M_L

$$\begin{aligned}
 \sigma_r &= (M_L/d \times t^2) \times f_r \\
 &= \{(100,000)/(18 \times 1^2)\} \times 1.2 \\
 &= 6670 \text{ lbf/in.}^2 \\
 \sigma_{\theta} &= (M_L/d \times t^2) \times f_{\theta} \\
 &= \{(100,000)/(18 \times 1^2)\} \times 0.88 \\
 &= 4890 \text{ lbf/in.}^2
 \end{aligned}$$

Shear stress

$$\begin{aligned}
 \tau_{MT} &= 2 \times (M_T)/(\pi \times d^2 t) \\
 &= 2 \times (50,000)/(\pi \times 18^2 \times 1) \\
 &= 98 \text{ lbf/in.}^2
 \end{aligned}$$

$$\tau_{VC} = 0$$

$$\begin{aligned}
 \tau_{VL} &= 2 \times (V_L)/(\pi \times d \times t) \\
 &= 2 \times (10,000)/(\pi \times 18 \times 1) \\
 &= 354 \text{ lbf/in.}^2
 \end{aligned}$$

$$\begin{aligned}
 \tau_{\text{tot}} &= \tau_{MT} + \tau_{VC} + \tau_{VL} \\
 &= 98 + 0 + 354 \\
 &= 452 \text{ lbf/in.}^2
 \end{aligned}$$

Combine the stresses.

$$\begin{aligned}
 S_{\text{max}} &= \text{largest absolute magnitude of} \\
 &= 0.5z \cdot [(\sigma_r + \sigma_{\theta}) \pm \{(\sigma_r - \sigma_{\theta})^2 + 4\tau^2\}^{0.5}]
 \end{aligned}$$

Combine the stress values from F_R and M_C .

$$\begin{aligned}
 \sigma_r &= 15,470 + 6083 \\
 &= 21,553 \text{ lbf/in.}^2 \\
 \sigma_{\theta} &= 13,388 + 4292 \\
 &= 17,680 \text{ lbf/in.}^2
 \end{aligned}$$

Combine stress values from F_R and M_L .

$$\begin{aligned}
 \sigma_r &= 15,470 + 6670 \\
 &= 22,140 \text{ lbf/in.}^2 \\
 \sigma_{\theta} &= 13,388 + 4890 \\
 &= 18,278 \text{ lbf/in.}^2
 \end{aligned}$$

The maximum stress is a combination of the radial thrust and the longitudinal moment.

$$\begin{aligned}
 S_{\text{max}} &= 0.5 \times 0.67 \times [(22,140 + 18,278) \pm \{(22,140 - 18,278)^2 + 4 \times 452^2\}^{0.5}] \\
 &= 14,869 \text{ lbf/in.}^2
 \end{aligned}$$

$$\begin{aligned}
 S_{\text{all}} &= 1.0 \times S_d && \text{(mechanical load)} \\
 &= 1.5 \times S_d && \text{(thermal load)} \\
 &= 1.5 \times 23,200 && \text{(thermal load)} \\
 &= 34,800 \text{ lbf/in.}^2 \\
 S_{\text{all}} &> S_{\text{max}}
 \end{aligned}$$

P.3.10.3 Conclusion

Since the allowable stress is greater than the maximum stress, the attached piping system is acceptable.

P.3.11 SAMPLE PROBLEM NO. 2

P.3.11.1 Data

Calculate the stresses for a tank nozzle using the following data.

Tank material: A 36M (A 36), $S_d = 160 \text{ MPa}$ (23,200 lbf/in.²)

$$D = 36,500 \text{ mm (120 ft)}$$

$$t = 12.7 \text{ mm (0.5 in.)}$$

$$d = 610 \text{ mm (24 in.)}$$

$$t_n = 12.7 \text{ mm (0.5 in.)}$$

$$L = 630 \text{ mm (24.75 in.)}$$

No reinforcing pad is provided

The mechanical loads from the attached piping system are as follows:

$$F_R = 87,700 \text{ N (20,000 lbs)}$$

$$M_C = 11 \times 10^6 \text{ N-mm (100,000 in.-lbs)}$$

$$M_L = 13.3 \times 10^6 \text{ N-mm (120,000 in.-lbs)}$$

$$M_T = V_C = V_L = 0$$

P.3.11.2 Solution

P.3.11.2.1 Establish the values for t , u , d/t_n , B , and h from the data provided.

In SI units:

$$u = (d/D) \times (D/t)^{0.5}$$

$$\begin{aligned}
 u &= (610/36,500) \times (36,500/12.7)^{0.5} \\
 &= 0.9
 \end{aligned}$$

$$\begin{aligned}
 d/t_n &= 610/12.7 \\
 &= 48.03
 \end{aligned}$$

$$\text{Use } d/t_n = 50$$

$$\begin{aligned}
 t/t_n &= 12.7/12.7 \\
 &= 1
 \end{aligned}$$

$$B = 2 \times (Dt)^{0.5}$$

$$B = 2(36,500 \times 12.7)^{0.5}$$

$$= 1362 \text{ mm}$$

$$h = L/B$$

$$h = 630/1362$$

$$= 0.46$$

In US Customary units:

$$u = (d/D) \times (D/t)^{0.5}$$

$$u = (24/[120 \times 12]) \times (120 \times 12/0.5)^{0.5}$$

$$= 0.9$$

$$d/t_n = 24/0.5$$

$$= 48$$

Use $d/t_n = 50$

$$t/t_n = 0.5/0.5$$

$$= 1$$

$$B = 2 \times (Dt)^{0.5}$$

$$= 2 \times (120 \times 12 \times 0.5)^{0.5}$$

$$= 53.67 \text{ in.}$$

$$h = L/B$$

$$= 24.75/53.67$$

$$= 0.46$$

P.3.11.2.2 Calculate the stresses.

In SI units:

Stress factors are provided in Table P-6.

Stress due to F_R ,

$$\sigma_r = (F_R/t^2) \times f_r$$

$$\sigma_r = (87,700/12.7^2) \times 1.72$$

$$= 935 \text{ N/mm}^2$$

$$\sigma_\theta = 87,700 \times 1.15/12.7^2$$

$$= 625 \text{ MPa}$$

Table P-6—Stress Factors for Sample Problem No. 1

Load	Stress Factor	Figure	Equation
F_R	$f_r = 1.72$	P-8c	21
F_R	$f_\theta = 1.15$	P-8g	40
M_C	$f_r = 1.8$	P-9c	59
M_C	$f_\theta = 0.68$	P-9g	78
M_L	$f_r = 1.43$	P-10c	97
M_L	$f_\theta = 0.62$	P-10g	116

Stress due to M_C ,

$$\begin{aligned}\sigma_r &= (M_C/d \times t^2) \times f_r \\ \sigma_r &= (11 \times 10^6)/(610 \times 12.7^2) \times 1.8 \\ &= 201 \text{ MPa} \\ \sigma_\theta &= (11 \times 10^6)/(610 \times 12.7^2) \times 0.68 \\ &= 76 \text{ MPa}\end{aligned}$$

Stress due to M_L ,

$$\begin{aligned}\sigma_r &= (M_L/d \times t^2) \times f_r \\ \sigma_r &= (13.3 \times 10^6)/(610 \times 12.7^2) \times 1.2 \\ &= 193.3 \text{ MPa} \\ \sigma_\theta &= (M_L/d \times t^2) \times f_\theta \\ \sigma_\theta &= (13.3 \times 10^6)/(610 \times 12.7^2) \times 0.62 \\ &= 83.81 \text{ MPa}\end{aligned}$$

Calculate the stress intensities.

$$S = 0.5 \times [(\sigma_r + \sigma_\theta) \pm \{(\sigma_r - \sigma_\theta)^2 + 4\tau^2\}^{0.5}]$$

Radial thrust and circular moment (bending)

$$\begin{aligned}\sigma_r &= \sigma_{rFR} + \sigma_{rC} \\ \sigma_r &= 935 + 201 \\ &= 1136 \text{ MPa}\end{aligned}$$

Radial thrust and circular moment (membrane)

$$\begin{aligned}\sigma_\theta &= \sigma_{\theta FR} + \sigma_{\theta C} \\ \sigma_\theta &= 625 + 76 \\ &= 701 \text{ MPa}\end{aligned}$$

Radial thrust and longitudinal moment (bending)

$$\begin{aligned}\sigma_r &= \sigma_{rFR} + \sigma_{rL} \\ \sigma_r &= 935 + 193.3 \\ &= 1128.3 \text{ MPa}\end{aligned}$$

Radial thrust and longitudinal moment (membrane)

$$\begin{aligned}\sigma_\theta &= \sigma_{\theta FR} + \sigma_{\theta L} \\ \sigma_\theta &= 625 + 83.81 \\ &= 708.81 \text{ MPa}\end{aligned}$$

$$S_{\max} = 0.5 \times [(\sigma_{r\max} + \sigma_{\theta\max}) \pm \{(\sigma_{r\max} - \sigma_{\theta\max})^2 + 4\tau_{\max}^2\}^{0.5}]$$

$$\begin{aligned}S_{\max} &= 0.5 \times [(1136 + 708.81) \pm \{(1136 - 708.81)^2 + 4 \times 0^2\}^{0.5}] \\ &= 1136 \text{ MPa}\end{aligned}$$

From Figure P-8 with a height factor of $h = 0.46$, the stress reduction factor $z = 0.64$.

Multiply S_{\max} with the stress reduction factor.

$$\begin{aligned}S &= S_{\max} \times z \\ S &= 1136 \times 0.64 \\ &= 727 \text{ MPa}\end{aligned}$$

Compare S with the allowable stress.

$$S_d = 160 \text{ MPa (see Table 5-2)}$$

For thermal loads:

$$S_{\text{all}} = 1.5 \times S_d$$

$$\begin{aligned} S_{\text{all}} &= 1.5 \times 160 \\ &= 240 \text{ MPa} \end{aligned}$$

$$S > S_{\text{all}}$$

$$727 \text{ MPa} > 240 \text{ MPa}$$

In US Customary units:

Using the stress factors from Table P-6,

Stress due to F_R ,

$$\begin{aligned} \sigma_r &= (F_R/t^2) \times f_r \\ &= (20,000/0.5^2) \times 1.72 \\ &= 13,7600 \text{ lbf/in.}^2 \end{aligned}$$

$$\begin{aligned} \sigma_\theta &= (F_R/t^2) \times f_\theta \\ &= 20,000 \times 1.15/0.5^2 \\ &= 92,000 \text{ lbf/in.}^2 \end{aligned}$$

Stress due to M_C ,

$$\begin{aligned} \sigma_r &= (M_C/d \times t^2) \times f_r \\ &= (100,000)/(24 \times 0.5^2) \times 1.8 \\ &= 30,000 \text{ lbf/in.}^2 \end{aligned}$$

$$\begin{aligned} \sigma_\theta &= (M_C/d \times t^2) \times f_\theta \\ &= 10 \times 10^6/(24 \times 0.5^2) \times 0.68 \\ &= 11,333 \text{ lbf/in.}^2 \end{aligned}$$

Stress due to M_L ,

$$\begin{aligned} \sigma_r &= (M_L/d \times t^2) \times f_r \\ &= (120,000)/(24 \times 0.5^2) \times 1.43 \\ &= 28,600 \text{ lbf/in.}^2 \end{aligned}$$

$$\begin{aligned} \sigma_\theta &= (M_L/d \times t^2) \times f_\theta \\ &= (120,000)/(24 \times 0.5^2) \times 0.62 \\ &= 12,400 \text{ lbf/in.}^2 \end{aligned}$$

Calculate the stress intensities.

$$S = 0.5 \times [(\sigma_r + \sigma_\theta) \pm \{(\sigma_r - \sigma_\theta)^2 + 4\tau^2\}^{0.5}]$$

Radial thrust and circular moment (bending)

$$\begin{aligned} \sigma_r &= \sigma_{rFR} + \sigma_{rC} \\ &= 137,600 + 30,000 \\ &= 167,600 \text{ lbf/in.}^2 \end{aligned}$$

Radial thrust and circular moment (membrane)

$$\begin{aligned}\sigma_{\theta} &= \sigma_{\theta FR} + \sigma_{\theta C} \\ &= 92,000 + 11,333 \\ &= 103,333 \text{ lbf/in.}^2\end{aligned}$$

Radial thrust and longitudinal moment (bending)

$$\begin{aligned}\sigma_r &= \sigma_{r FR} + \sigma_{r L} \\ &= 137,600 + 28,600 \\ &= 166,200 \text{ lbf/in.}^2\end{aligned}$$

Radial thrust and longitudinal moment (membrane)

$$\begin{aligned}\sigma_{\theta} &= \sigma_{\theta FR} + \sigma_{\theta L} \\ &= 92,000 + 12,400 \\ &= 104,400 \text{ lbf/in.}^2 \\ S_{\max} &= 0.5 \times [(\sigma_{r \max} + \sigma_{\theta \max}) \pm \{(\sigma_{r \max} - \sigma_{\theta \max})^2 + 4\tau_{\max}^2\}^{0.5}] \\ &= 0.5 \times [(167,600 + 104,400) \pm \{(167,600 - 104,400)^2 + 4 \times 0^2\}^{0.5}] \\ &= 167,600 \text{ lbf/in.}^2\end{aligned}$$

From Figure P-8, with a height factor of $h = 0.46$, the stress reduction factor $Z = 0.64$.

Multiplying S_{\max} with the stress reduction factor:

$$\begin{aligned}S &= S_{\max} \times Z \\ &= 167,600 \times 0.64 \\ &= 107,264 \text{ lbf/in.}^2\end{aligned}$$

Compare S with the allowable stress

$$S_d = 23,200 \text{ lbf/in.}^2 \text{ (see Table 5-2)}$$

For thermal loads

$$\begin{aligned}S_{\text{all}} &= 1.5 \times S_d \\ &= 1.5 \times 23,200 \\ &= 34,800 \text{ lbf/in.}^2\end{aligned}$$

$$S > S_{\text{all}}$$

$$107,264 \text{ lbf/in.}^2 > 34,800 \text{ lbf/in.}^2$$

P.3.11.2.3 Conclusion

Since the actual stress exceeds the allowable stress, $S > S_{\text{all}}$, a reinforcing plate shall be attached.

P.3.11.2.4 Reinforcing Plate Calculations

Refer to Table 5-6 for the size of reinforcing pad.

In SI units:

$$\begin{aligned}D_o &= 1525 \text{ mm} \\ t_r &= 12.7 \text{ mm}\end{aligned}$$

To calculate the stress at the junction of the nozzle to the shell, the combined thickness of the shell and reinforcing plate is used in the calculations. In this case:

$$t = 12.7 + 12.7$$

$$= 25.4 \text{ mm}$$

$$u = (d/D) \times (D/t)^{0.5}$$

$$u = (610/36,500) \times (36,500/25.4)^{0.5}$$

$$= 0.63$$

$$d/t_n = 610/12.7$$

$$= 48$$

$$\text{Use } d/t_n = 50$$

$$t/t_n = 25.4/12.7$$

$$= 2$$

$$B = 2 \times (Dt)^{0.5}$$

$$B = 2 \times (36,500 \times 25.4)^{0.5}$$

$$= 1926 \text{ mm}$$

$$h = L/B$$

$$h = 630/1926$$

$$= 0.327$$

$$z = 0.55$$

Calculated Stresses

$$F_R: \sigma_r = 177 \text{ MPa}$$

$$F_R: \sigma_\theta = 136 \text{ MPa}$$

$$M_C: \sigma_r = 42 \text{ MPa}$$

$$M_C: \sigma_\theta = 29 \text{ MPa}$$

$$M_L: \sigma_r = 46 \text{ MPa}$$

$$M_L: \sigma_\theta = 30 \text{ MPa}$$

Calculate stress intensity

$$F_R \& M_C: \sigma_r = 177 + 42$$

$$\sigma_r = 219 \text{ MPa}$$

$$F_R \& M_C: \sigma_\theta = 136 + 29$$

$$\sigma_\theta = 165 \text{ MPa}$$

$$F_R \& M_L: \sigma_r = 177 + 46$$

$$\sigma_r = 223 \text{ MPa}$$

$$F_R \& M_L: \sigma_\theta = 136 + 30$$

$$\sigma_\theta = 166 \text{ MPa}$$

$$S_{\max} = 0.5 \times [(\sigma_{r\max} + \sigma_{\theta\max}) \pm \{(\sigma_{r\max} - \sigma_{\theta\max})^2 + 4\tau_{\max}^2\}^{0.5}]$$

$$S_{\max} = 0.5 \times [(223 + 166) \pm \{(223 - 166)^2 + 4 \times 0^2\}^{0.5}]$$

$$= 223 \text{ MPa}$$

$$S = S_{\max} \times z$$

$$S = 223 \times 0.55$$

$$= 123 \text{ MPa}$$

$$S > S_{\text{all}}$$

$$223 \text{ MPa} > 123 \text{ MPa}$$

In US Customary units:

$$D_o = 60 \text{ in.}$$

$$t_r = 0.5 \text{ in.}$$

To calculate the stress at the junction of the nozzle to the shell, the combined thickness of the shell and reinforcing plate is used in the calculations. In this case:

$$t = 0.5 + 0.5$$

$$= 1.0 \text{ in.}$$

$$u = (d/D) \times (D/t)^{0.5}$$

$$u = [24/(120 \times 12)] \times [(120 \times 12)/1.0]^{0.5}$$

$$= 0.63$$

$$d/t_n = 24/0.5$$

$$= 48$$

Use $d/t_n = 50$

$$t/t_n = 1.0/0.5$$

$$= 2$$

$$B = 2 \times (Dt)^{0.5}$$

$$B = 2 \times (120 \times 12 \times 1.0)^{0.5}$$

$$= 76 \text{ in.}$$

$$h = L/B$$

$$h = 24.75/76$$

$$= 0.326$$

$$z = 0.55$$

Using the stress reduction factors in Table P-7, the stresses can be calculated as follows:

$$F_R = 26,000 \text{ lbf/in.}^2$$

$$F_R = 20,000 \text{ lbf/in.}^2$$

$$M_C = 6250 \text{ lbf/in.}$$

$$M_C = 4375 \text{ lbf/in.}^2$$

$$M_L = 6750 \text{ lbf/in.}^2$$

$$M_L = 4500 \text{ lbf/in.}^2$$

Table P-7—Stress Factors for the Reinforcing Plate

Load	Stress Factor	Figure	Equation
F_R	$f_r = 1.3$	P-8C	22
F_R	$f_\theta = 1.0$	P-8G	41
M_C	$f_r = 1.5$	P-9C	60
M_C	$f_\theta = 1.05$	P-9G	79
M_L	$f_r = 1.35$	P-10C	98
M_L	$f_\theta = 0.9$	P-10G	117

Calculate stress intensities.

$$\begin{aligned} F_R \& M_C &= 26,000 + 6250 \\ &= 32,250 \text{ lbf/in.}^2 \end{aligned}$$

$$\begin{aligned} F_R \& M_C &= 20,000 + 4375 \\ &= 24,375 \text{ lbf/in.}^2 \end{aligned}$$

$$\begin{aligned} F_R \& M_L &= 26,000 + 6750 \\ &= 32,750 \text{ lbf/in.}^2 \end{aligned}$$

$$\begin{aligned} F_R \& M_L &= 20,000 + 4500 \\ &= 24,500 \text{ lbf/in.}^2 \end{aligned}$$

$$S_{\max} = 0.5 \times [(\sigma_{r\max} + \sigma_{\theta\max}) \pm \{(\sigma_{r\max} - \sigma_{\theta\max})^2 + 4\tau_{\max}^2\}^{0.5}]$$

$$\begin{aligned} S_{\max} &= 0.5[(32,750 + 24,500) \pm \{(32,750 - 24,500)^2 + 4 \times 0^2\}^{0.5}] \\ &= 32,750 \text{ lbf/in.}^2 \end{aligned}$$

$$S = S_{\max} \times z$$

$$\begin{aligned} S &= 32,750 \times 0.55 \\ &= 18,013 \text{ lbf/in.}^2 \end{aligned}$$

$$S > S_{\text{all}}$$

$$32,750 \text{ lbf/in.}^2 > 18,013 \text{ lbf/in.}^2$$

P.3.11.2.5 Conclusion

The attached piping system with the reinforcing plate is acceptable for the tank since the actual stress is less than the maximum stress.

P.3.12 SAMPLE PROBLEM NO. 3

This sample problem uses the alternative method on the data presented in the sample problem in P.9. The calculated limit loads from in P.2.9 are assumed to be from thermal loads. The stresses are calculated using the equations from Tables P-2 through P-4.

P.3.12.1 Data

Tank diameter	$D = 80 \text{ m (260 ft or 3120 in)}$
Tank shell thickness	$t = 34 \text{ mm (1.33 in)}$
Nozzle outside diameter	$d = 610 \text{ mm (24 in)}$
Nozzle neck thickness (assumed)	$t_n = 31 \text{ mm (1.218 in)}$
Nozzle location from bottom	$L = 630 \text{ mm (24.75 in)}$
Design stress	$S_d = 160 \text{ MPa (23,200 lbf/in.}^2)$

Using the limit loads from P.9.3:

$$F_R = 320,000 \text{ N (74800 lbs)}$$

$$M_C = 550 \times 10^6 \text{ N}\cdot\text{mm (4.95} \times 10^6 \text{ in}\cdot\text{lbs)}$$

$$M_L = 195 \times 10^6 \text{ N}\cdot\text{mm (1.74} \times 10^6 \text{ in}\cdot\text{lbs)}$$

$$M_T = V_C = V_L = 0$$

P.3.12.2 Solution**P.3.12.2.1** Establish the values for t , u , d/t_n , and t/t_n from the data provided.

In SI units:

$$u = (d/D) \times (D/t)^{0.5}$$

$$\begin{aligned} u &= (610/80,000) \times (80,000/34)^{0.5} \\ &= 0.37 \end{aligned}$$

$$\begin{aligned} d/t_n &= 610/31 \\ &= 20 \end{aligned}$$

$$\begin{aligned} t/t_n &= 34/31 \\ &= 1.096 \end{aligned}$$

$$\text{Use } t/t_n = 1$$

In US Customary units:

$$u = (d/D) \times (D/t)^{0.5}$$

$$\begin{aligned} u &= (24/3120) \times (3120/1.33)^{0.5} \\ &= 0.37 \end{aligned}$$

$$\begin{aligned} d/t_n &= 24/1.218 \\ &= 20 \end{aligned}$$

$$\begin{aligned} t/t_n &= 1.33/1.218 \\ &= 1.092 \end{aligned}$$

$$\text{Use } t/t_n = 1$$

P.3.12.2.2 To calculate the stress factors, interpolation is required between $d/t = 10$ and 30 to arrive at the values for $d/t = 18$

$$F_R \quad f_T \text{ for } d/t_n = 10 \text{ and } t/t_n = 1 \tag{12}$$

$$\begin{aligned} f_r &= -0.9384 \times \ln(u) + 1.2638 \\ &= -0.9384 \times \ln(0.37) + 1.2638 \\ &= 2.197 \end{aligned}$$

$$f_T \text{ for } d/t_n = 30 \text{ and } t/t_n = 1 \tag{16}$$

$$\begin{aligned} f_r &= -0.9074 \times \ln(u) + 1.3398 \\ &= -0.9074 \times \ln(0.37) + 1.3398 \\ &= 2.242 \end{aligned}$$

$$f_T \text{ for } d/t_n = 20 \text{ and } t/t_n = 1$$

$$\begin{aligned} f_r &= 0.5(2.197 + 2.242) \\ &= 2.219 \end{aligned}$$

$$F_R \quad f_\theta \text{ for } d/t_n = 20 \text{ and } t/t_n = 1 \tag{31 and 35}$$

$$\begin{aligned} f_\theta &= 0.5\{(-0.3427 \times \ln(u) + 0.5338) + (-0.344 \times \ln(u) + 0.6352)\} \\ &= 0.9259 \end{aligned}$$

$$M_C \quad f_r \text{ for } d/t_n = 20 \text{ and } t/t_n = 1 \tag{50 and 54}$$

$$\begin{aligned}
 f_r &= 0.5\{(-0.0233 \times u^2 - 0.1 \times u + 1.9416) + (-0.0207 \times u^2 - 0.0936 \times u + 1.9026)\} \\
 &= 1.883 \\
 f_\theta &= 0.5\{(0.0229 \times u^2 - 0.1966 \times u + 0.8826) + (0.0048 \times u^2 - 0.0649 \times u + 0.7661)\} \\
 &= 1.322
 \end{aligned} \tag{69 and 73}$$

$$\begin{aligned}
 M_L \quad f_\theta &= 0.5\{(0.0769 \times u^2 - 0.42 \times u + 0.8174) + (0.0205 \times u^2 - 0.2132 \times u + 0.7797)\} \\
 &= 0.688
 \end{aligned} \tag{107 and 111}$$

$$\begin{aligned}
 f_r &= 0.5\{(-0.0359 \times u^2 - 0.5507 \times u + 1.9629) + (0.0658 \times u^2 - 0.695 \times u + 2.0052)\} \\
 &= 1.7556
 \end{aligned} \tag{88 and 92}$$

P.3.12.2.3 Calculate the stresses.

In SI units:

Stress due to F_R ,

$$\begin{aligned}
 \sigma_r &= (F_R/t^2) \times f_r \\
 \sigma_r &= (328,000/34^2) \times 2.219 \\
 &= 629 \text{ MPa}
 \end{aligned}$$

$$\begin{aligned}
 \sigma_\theta &= (F_R/t^2) \times f_\theta \\
 \sigma_\theta &= 328,000 \times 0.9259/34^2 \\
 &= 263 \text{ MPa}
 \end{aligned}$$

Stress due to M_C ,

$$\begin{aligned}
 \sigma_r &= (M_C/d \times t^2) \times f_r \\
 \sigma_r &= (550 \times 10^6)/(610 \times 34^2) \times 1.883 \\
 &= 1469 \text{ MPa}
 \end{aligned}$$

$$\begin{aligned}
 \sigma_\theta &= (M_C/d \times t^2) \times f_\theta \\
 \sigma_\theta &= (550 \times 10^6)/(610 \times 34^2) \times 1.322 \\
 &= 1031 \text{ MPa}
 \end{aligned}$$

Stress due to M_L ,

$$\begin{aligned}
 \sigma_r &= (M_L/d \times t^2) \times f_r \\
 \sigma_r &= (195 \times 10^6)/(610 \times 34^2) \times 1.7556 \\
 &= 485 \text{ MPa}
 \end{aligned}$$

$$\begin{aligned}
 \sigma_\theta &= (M_L/d \times t^2) \times f_\theta \\
 \sigma_\theta &= (195 \times 10^6)/(610 \times 34^2) \times 0.688 \\
 &= 190 \text{ MPa}
 \end{aligned}$$

In US Customary units:

Stress due to F_R ,

$$\begin{aligned}
 \sigma_r &= (F_R/t^2) \times f_r \\
 &= (74,800/1.33^2) \times 2.219 \\
 &= 93,833 \text{ lbf/in.}^2
 \end{aligned}$$

$$\begin{aligned}\sigma_{\theta} &= (F_R/t^2) \times f_{\theta} \\ &= 74,800 \times 0.9259/1.33^2 \\ &= 39,153 \text{ lbf/in.}^2\end{aligned}$$

Stress due to M_C ,

$$\begin{aligned}\sigma_r &= (M_C/d \times t^2) \times f_r \\ &= (4.95 \times 10^6)/(24 \times 1.33^2) \times 1.883 \\ &= 199,594 \text{ MPa}\end{aligned}$$

$$\begin{aligned}\sigma_{\theta} &= (M_C/d \times t^2) \times f_{\theta} \\ &= (4.95 \times 10^6)/(24 \times 1.33^2) \times 1.322 \\ &= 140,129 \text{ lbf/in.}^2\end{aligned}$$

Stress due to M_L ,

$$\begin{aligned}\sigma_r &= (M_L/d \times t^2) \times f_r \\ &= (1.74 \times 10^6)/(24 \times 1.33^2) \times 1.7556 \\ &= 71,955 \text{ lbf/in.}^2\end{aligned}$$

$$\begin{aligned}\sigma_{\theta} &= (M_L/d \times t^2) \times f_{\theta} \\ &= (1.74 \times 10^6)/(24 \times 1.33^2) \times 0.688 \\ &= 28,198 \text{ lbf/in.}^2\end{aligned}$$

P.3.12.2.4 Calculate the stress reduction factors.

In SI units:

$$\begin{aligned}B &= 2 \times (D \times t)^{0.5} \\ B &= 2 \times (80,000 \times 34)^{0.5} \\ &= 3298 \text{ mm}\end{aligned}$$

$$\begin{aligned}h &= L/B \\ h &= 630/3298 \\ &= 0.19\end{aligned}$$

In US Customary units:

$$\begin{aligned}B &= 2 \times (D \times t)^{0.5} \\ &= 2 \times (3120 \times 1.33)^{0.5} \\ &= 129 \text{ in.}\end{aligned}$$

$$\begin{aligned}h &= L/B \\ &= 24.75/129 \\ &= 0.19\end{aligned}$$

P.3.12.2.5 Calculate the stress intensity.

$$S = 0.5 \times z \times [(\sigma_r + \sigma_{\theta}) \pm \{(\sigma_r - \sigma_{\theta})^2 + 4\tau^2\}^{0.5}]$$

Where $z = 0.47$ from Figure P-11, and S_{max} is from the combination of F_R and M_C .

In SI units:

$$\begin{aligned} S_{max} &= 0.5 \times 0.47 \times [(629 + 263) \pm \{(629 - 263)^2 + 4 \cdot 0^2\}^{0.5}] \\ &= 296 \text{ MPa} \end{aligned}$$

In US Customary units:

$$\begin{aligned} S_{max} &= 0.5 \times 0.47 \times [(93833 + 39153) \pm \{(93833 - 39153)^2 + 4 \cdot 0^2\}^{0.5}] \\ &= 44,102 \text{ lbf/in.}^2 \end{aligned}$$

For this sample problem it is assumed that the limit loads include the liquid load from the tank, therefore the preceding stresses are total stresses. In this case the allowable stress is:

$$\begin{aligned} S_{all} &= 2.0 S_d && \text{Mechanical Load} \\ &= 3.0 S_d && \text{Thermal Load} \end{aligned}$$

In this problem it is assumed that the loads are of thermal nature, therefore the allowable stresses are:

In SI units:

$$\begin{aligned} S_{all} &= 3.0 \times 160 \text{ MPa} \\ &= 480 \text{ MPa} \\ S_{all} &> S_{max} \\ 480 \text{ MPa} &> 296 \text{ MPa} \end{aligned}$$

In US Customary units:

$$\begin{aligned} S_{all} &= 3.0 \times 23,200 \text{ lbf/in.}^2 \\ &= 69,600 \text{ lbf/in.}^2 \\ S_{all} &> S_{max} \\ 69,600 \text{ lbf/in.}^2 &> 44,102 \text{ lbf/in.}^2 \end{aligned}$$

P.3.12.3 Conclusion

Based on the assumptions made, this analysis indicates that the piping arrangement for example P.2.9 is acceptable.

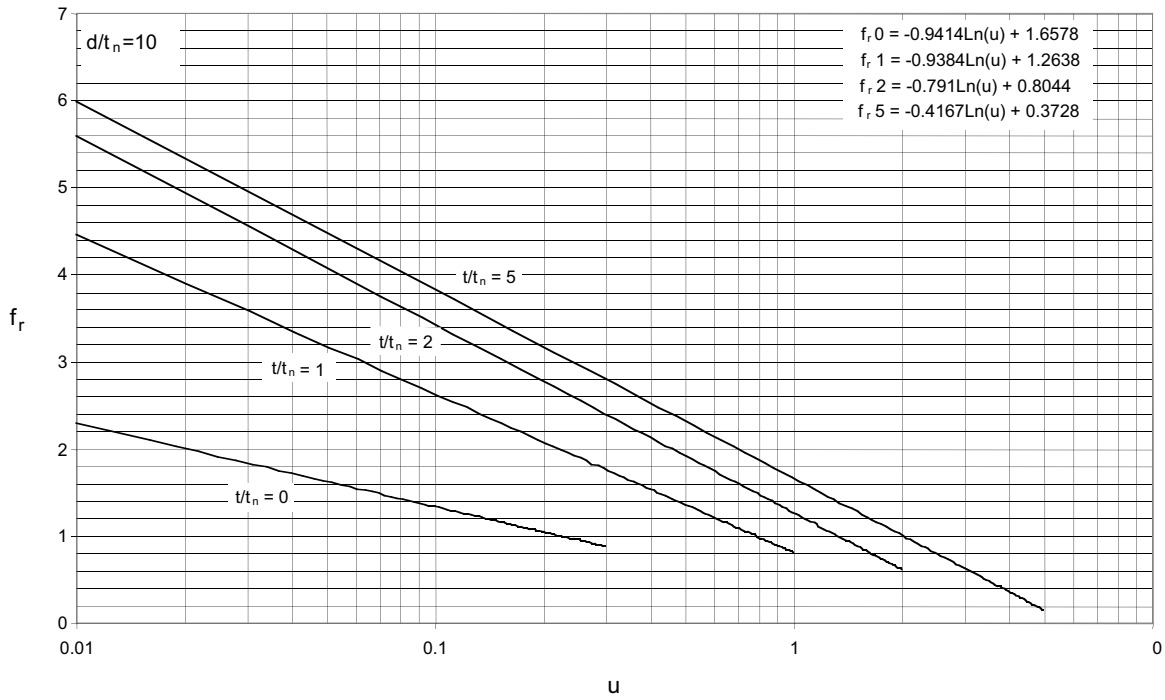


Figure P-8A—Stress Factor f_R Due to Radial Thrust F_R , $d/t_n = 10$

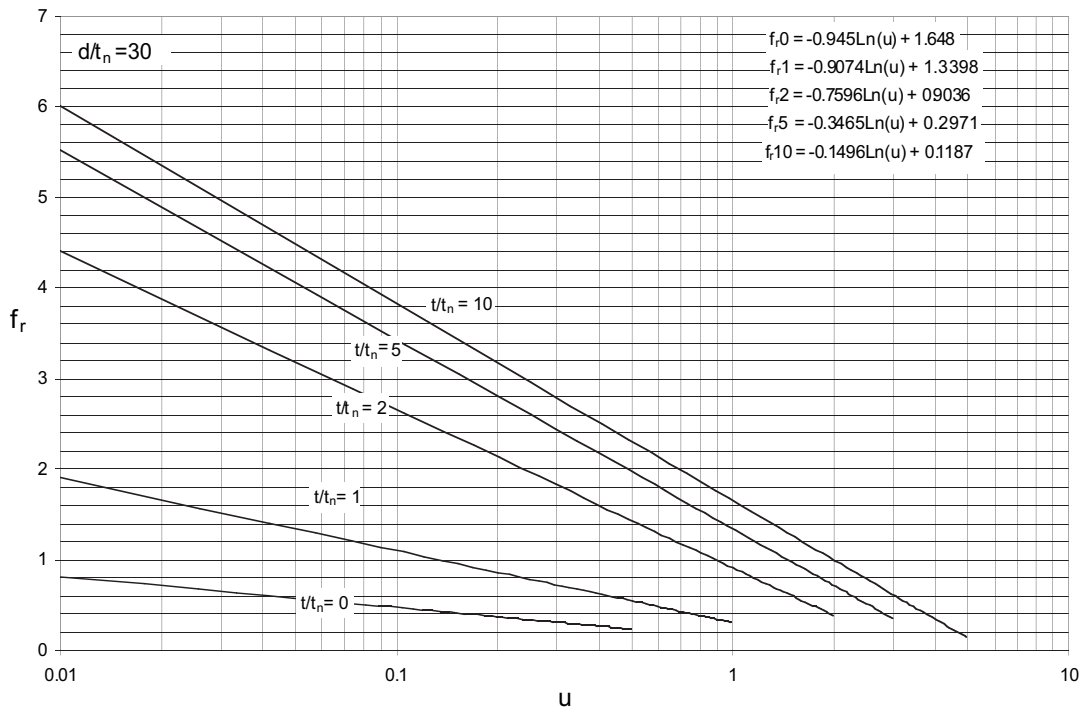


Figure P-8B—Stress Factor f_R Due to Radial Thrust F_R , $d/t_n = 30$

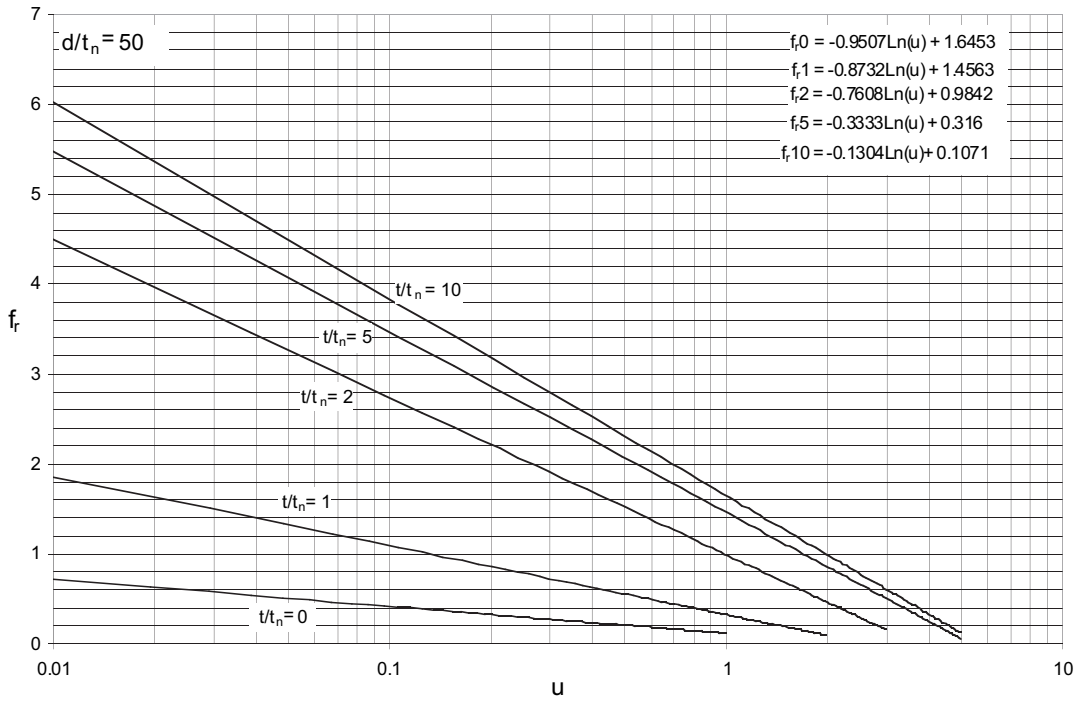


Figure P-8C—Stress Factor f_R Due to Radial Thrust F_R , $d/t_n = 50$

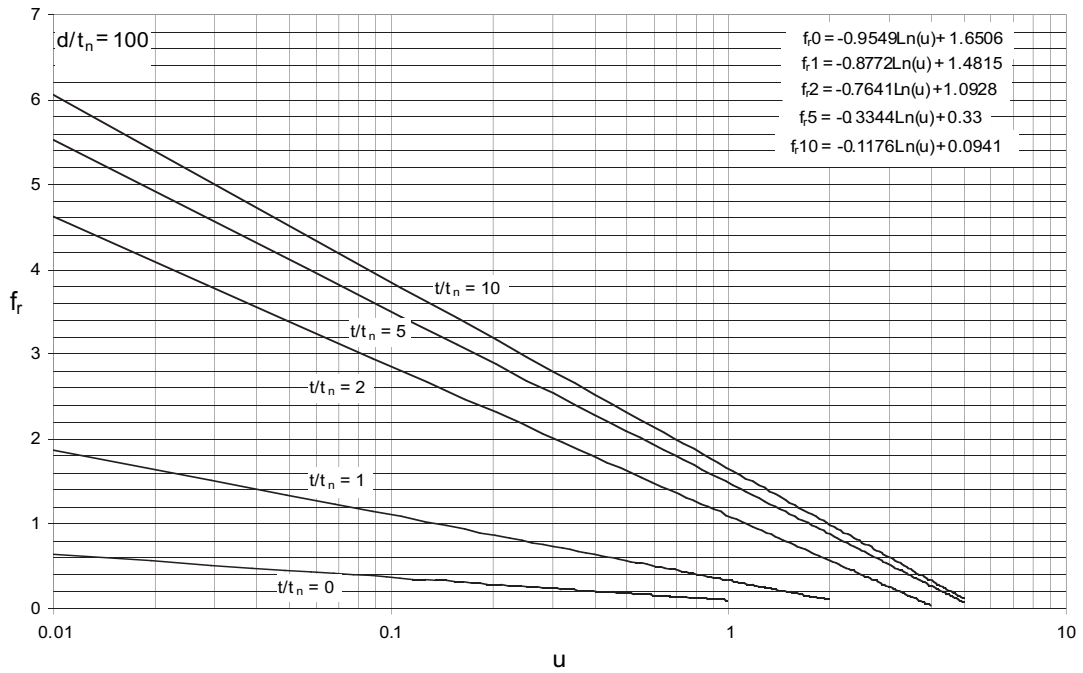


Figure P-8D—Stress Factor f_R Due to Radial Thrust F_R , $d/t_n = 100$

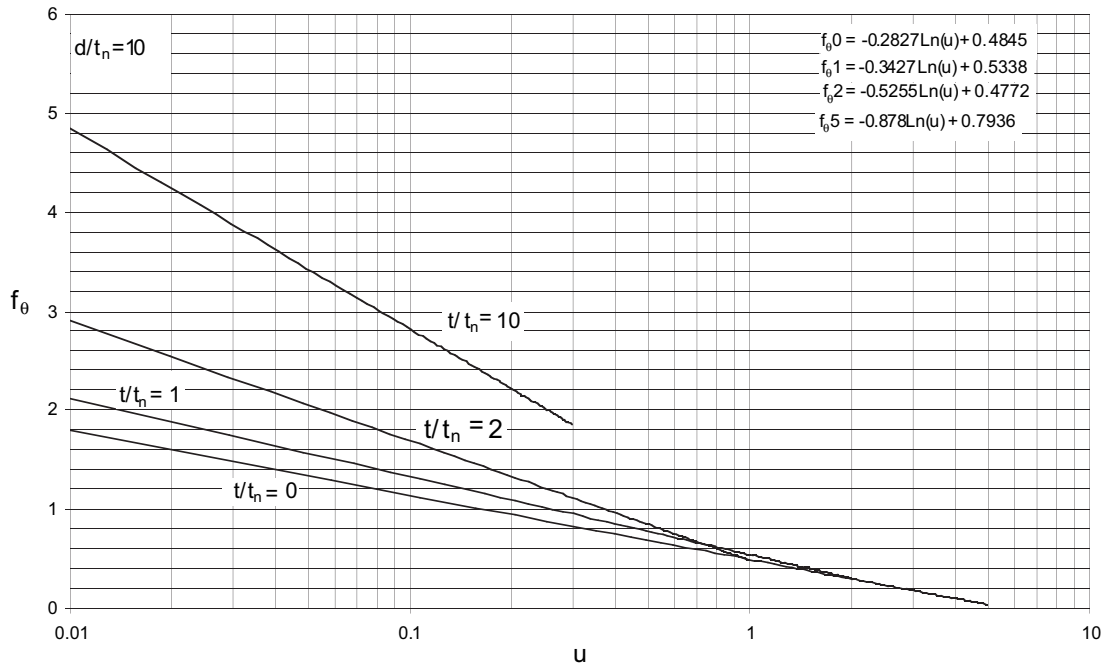


Figure P-8E—Stress Factor f_{θ} Due to Radial Thrust F_R , $d/t_n = 10$

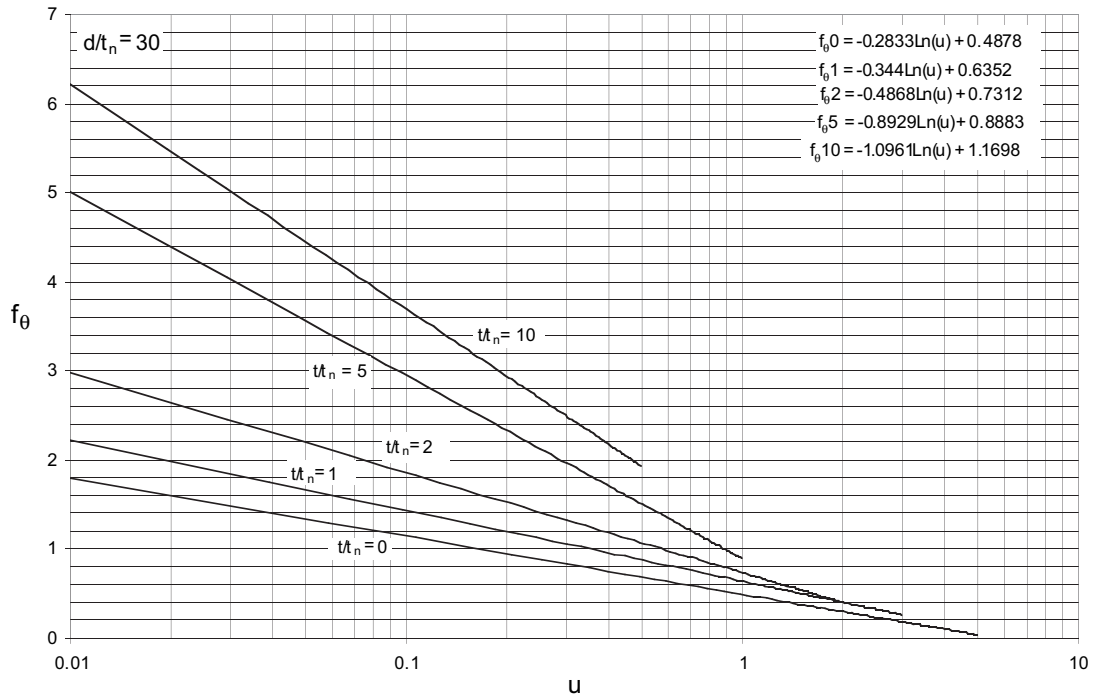


Figure P-8F—Stress Factor f_{θ} Due to Radial Thrust F_R , $d/t_n = 30$

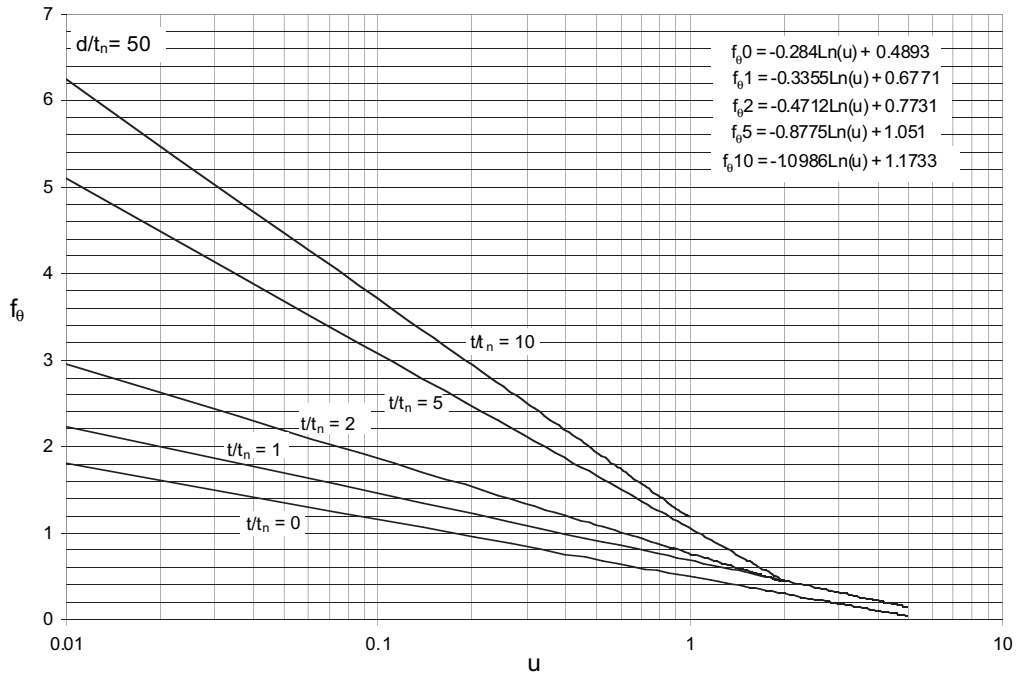


Figure P-8G—Stress Factor f_0 Due to Radial Thrust F_R , $d/t_n = 50$

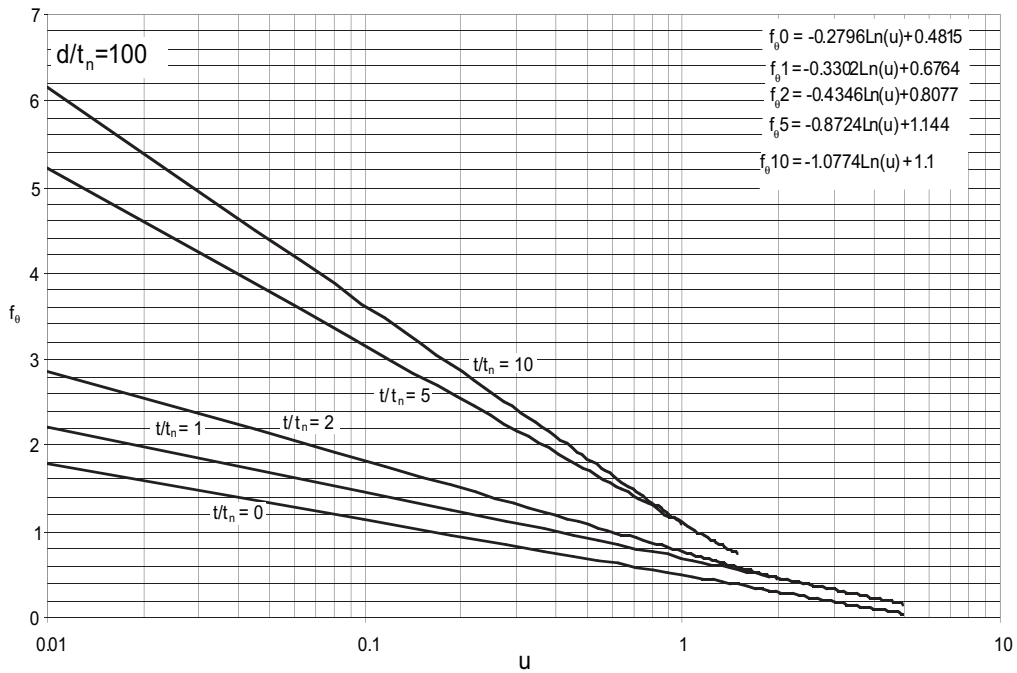


Figure P-8H—Stress Factor f_0 Due to Radial Thrust F_R , $d/t_n = 100$

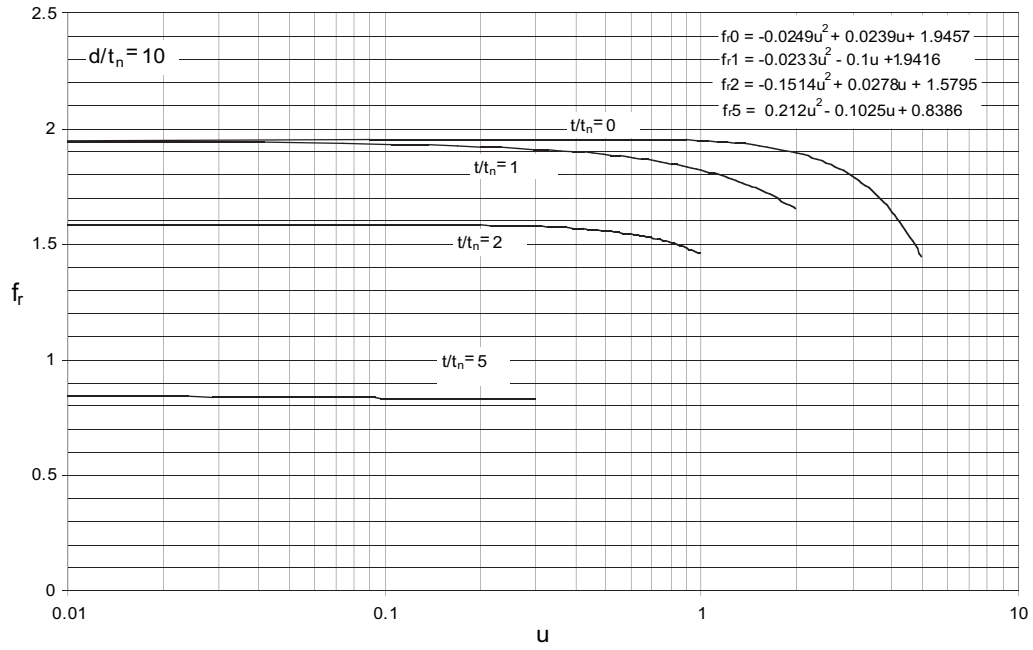


Figure P-9A—Stress Factor f_r Due to Circumferential Moment M_C , $d/t_n = 10$

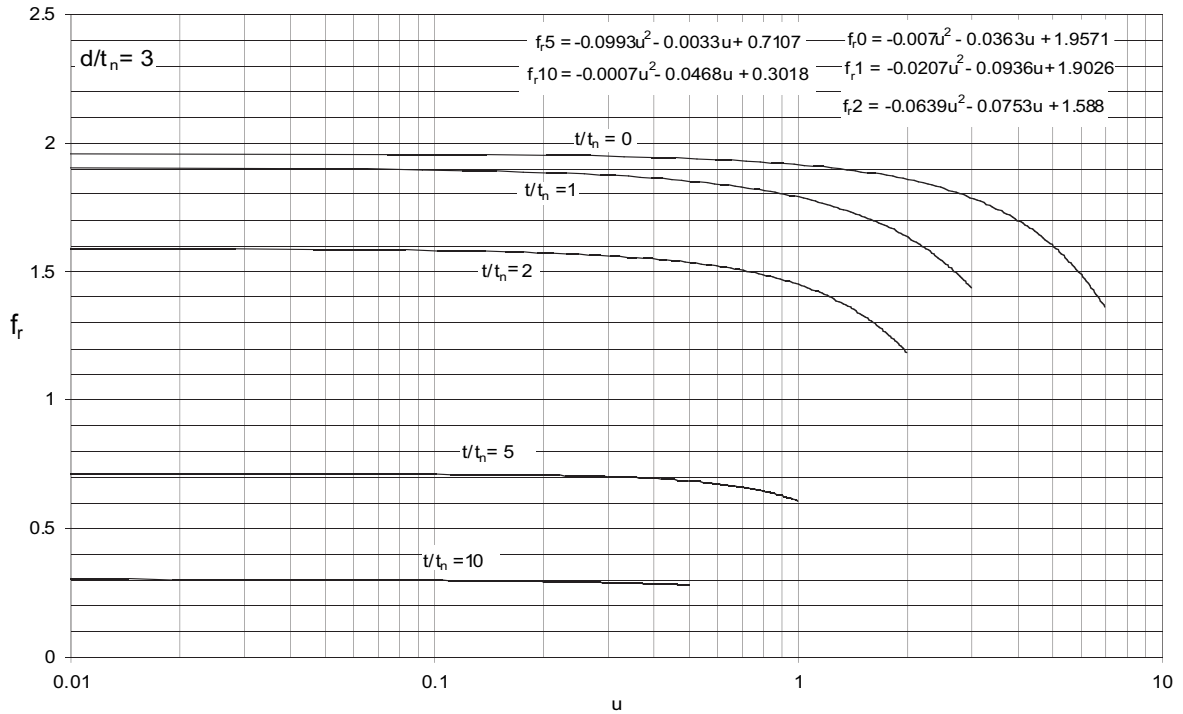


Figure P-9B—Stress Factor f_r Due to Circumferential Moment M_C , $d/t_n = 30$

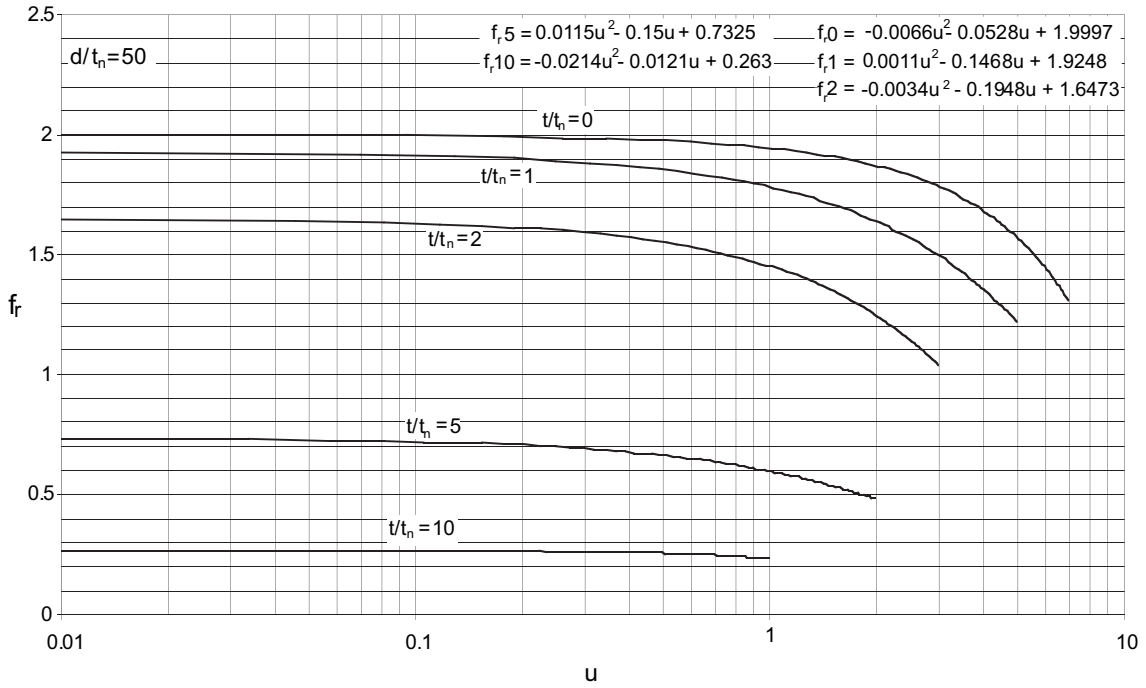


Figure P-9C—Stress Factor f_r Due to Circumferential Moment M_C , $d/t_n = 50$

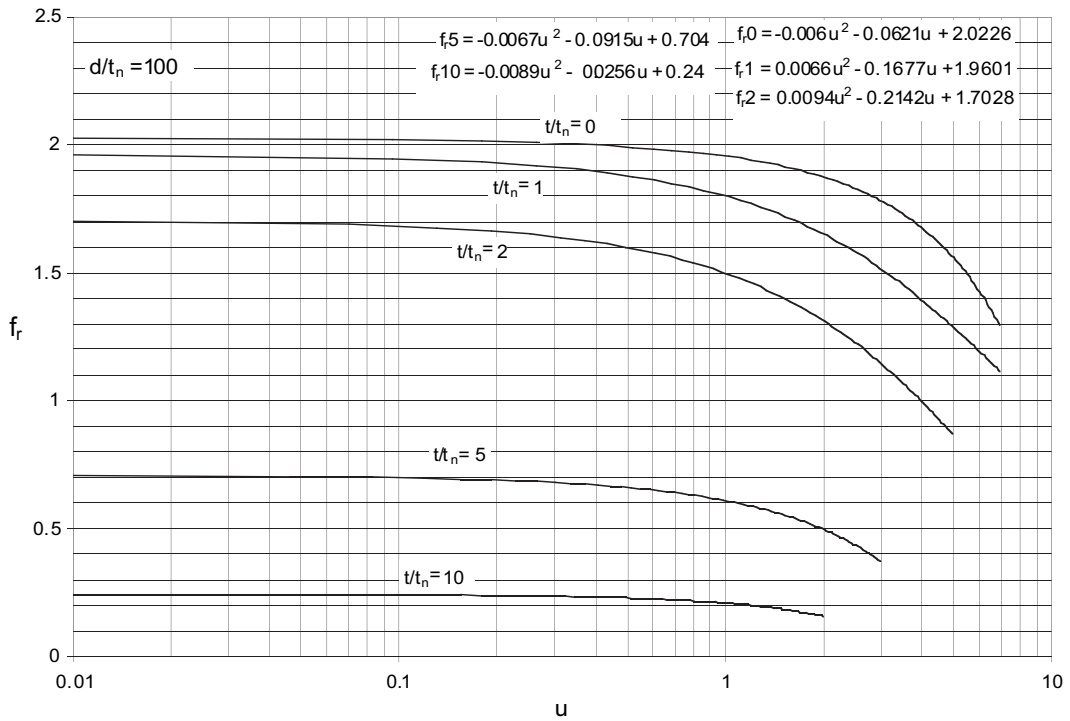


Figure P-9D—Stress Factor f_r Due to Circumferential Moment M_C , $d/t_n = 100$

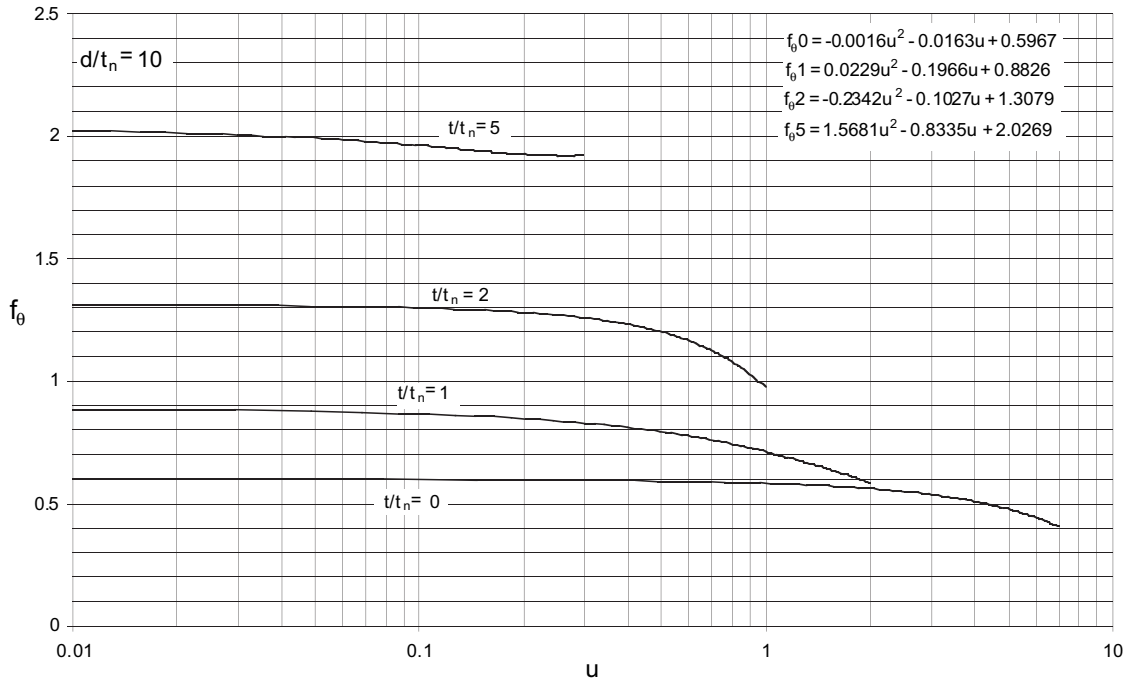


Figure P-9E—Stress Factor f_0 Due to Circumferential Moment M_C , $d/t_n = 10$

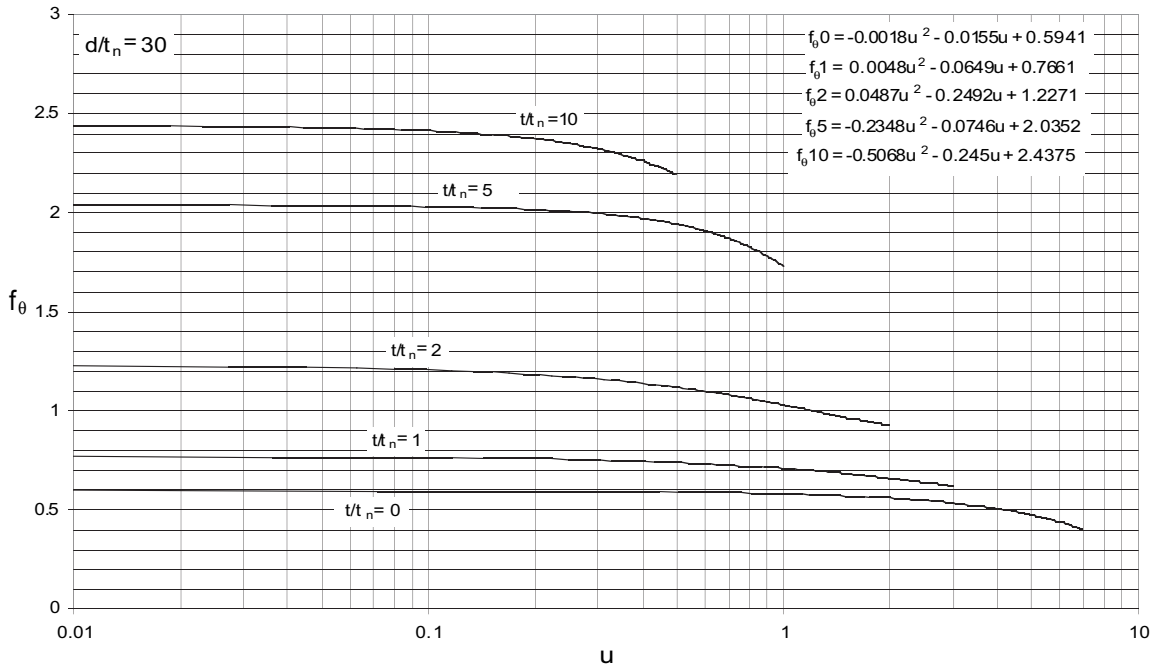


Figure P-9F—Stress Factor f_0 Due to Circumferential Moment M_C , $d/t_n = 30$

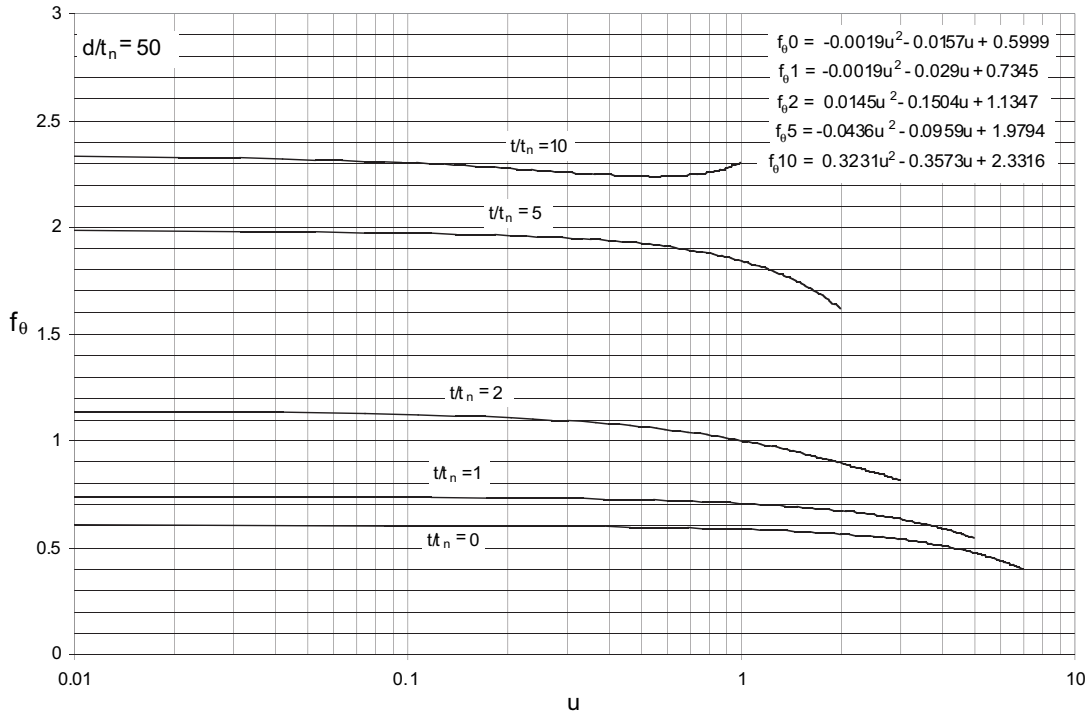


Figure P-9G—Stress Factor f_{θ} Due to Circumferential Moment M_C , $d/t_n = 50$

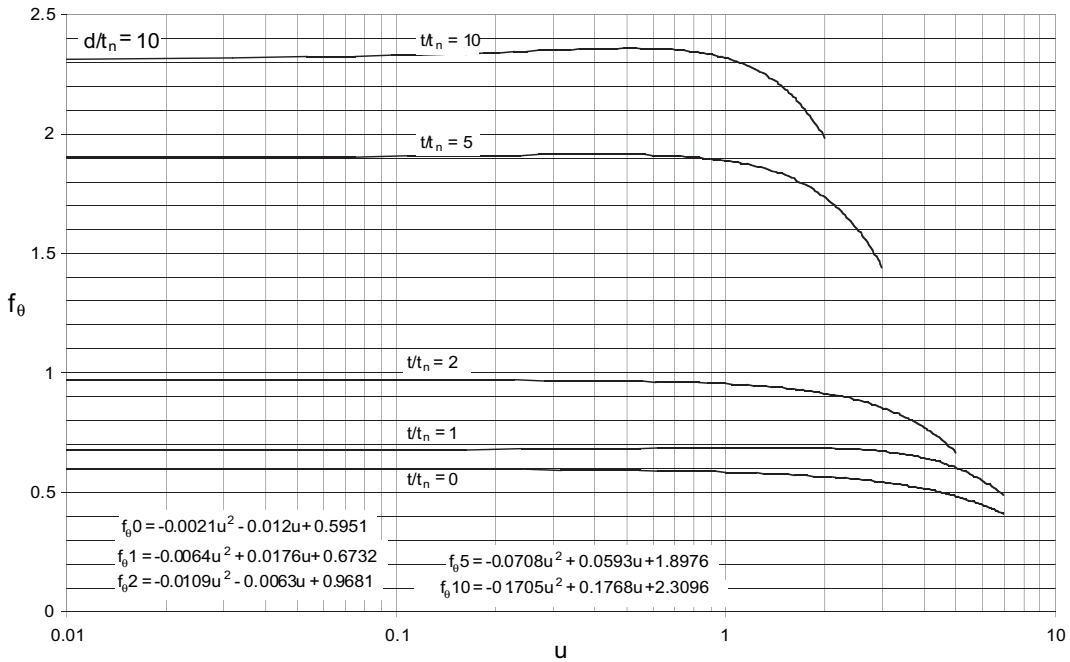


Figure P-9H—Stress Factor f_{θ} Due to Circumferential Moment M_C , $d/t_n = 100$

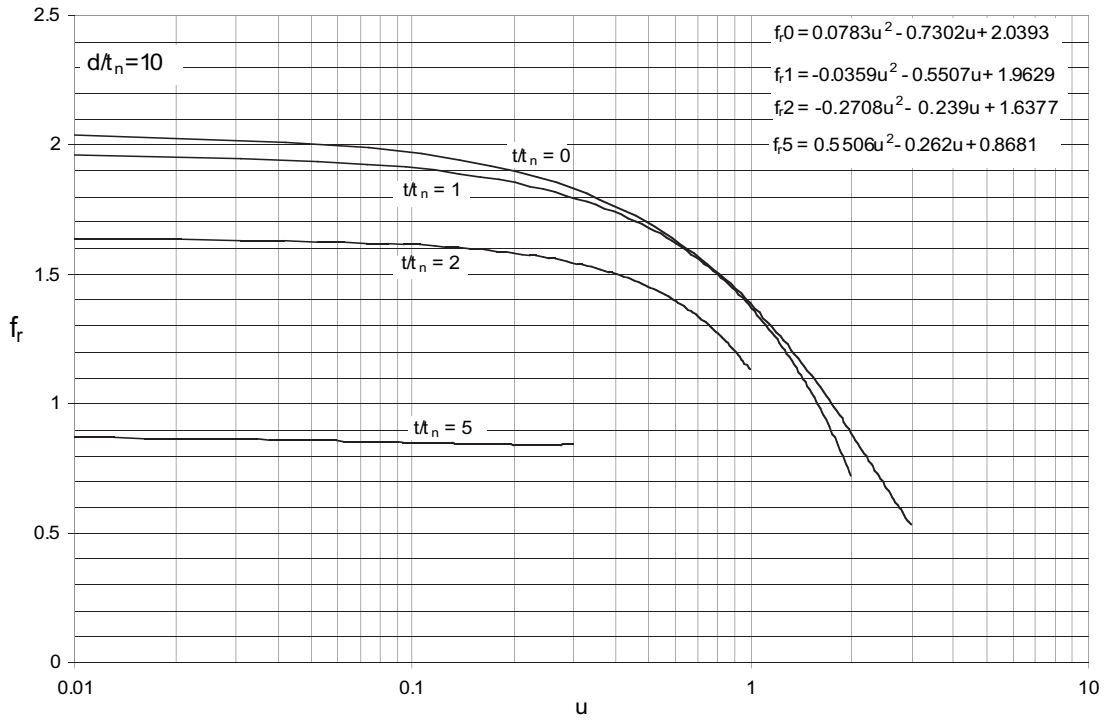


Figure P-10A—Stress Factor f_r Due to Longitudinal Moment M_L , $d/t_n = 10$

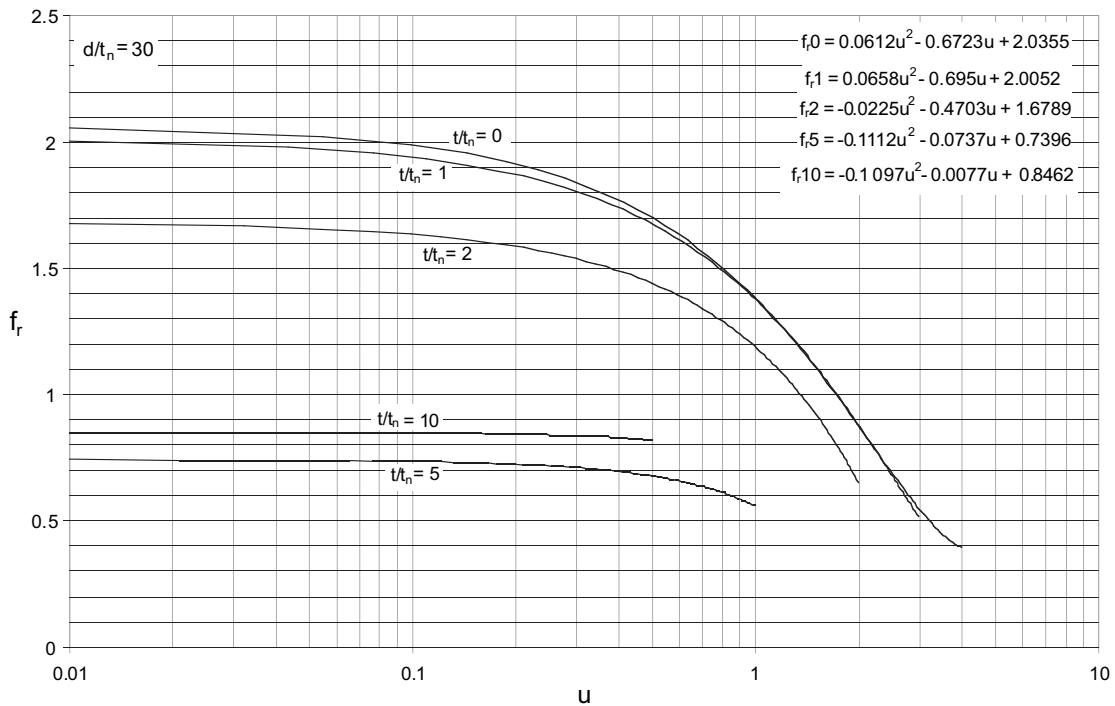


Figure P-10B—Stress Factor f_r Due to Longitudinal Moment M_L , $d/t_n = 30$

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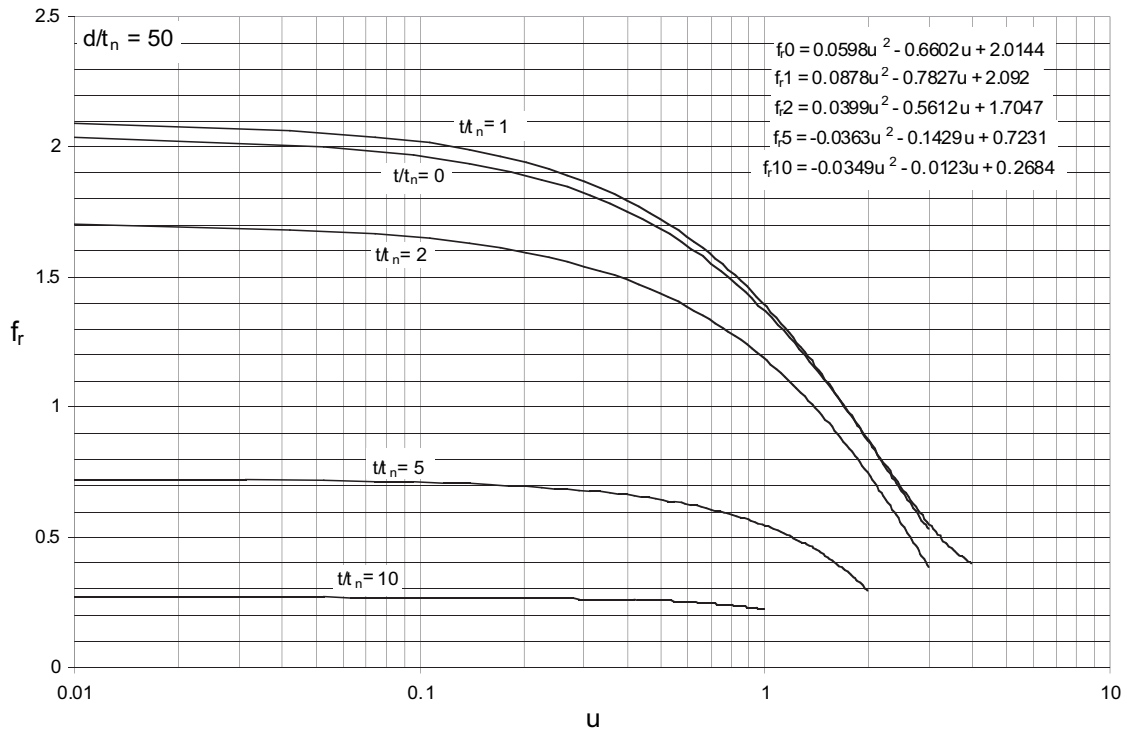


Figure P-10C—Stress Factor f_r Due to Longitudinal Moment M_L , $d/t_n = 50$

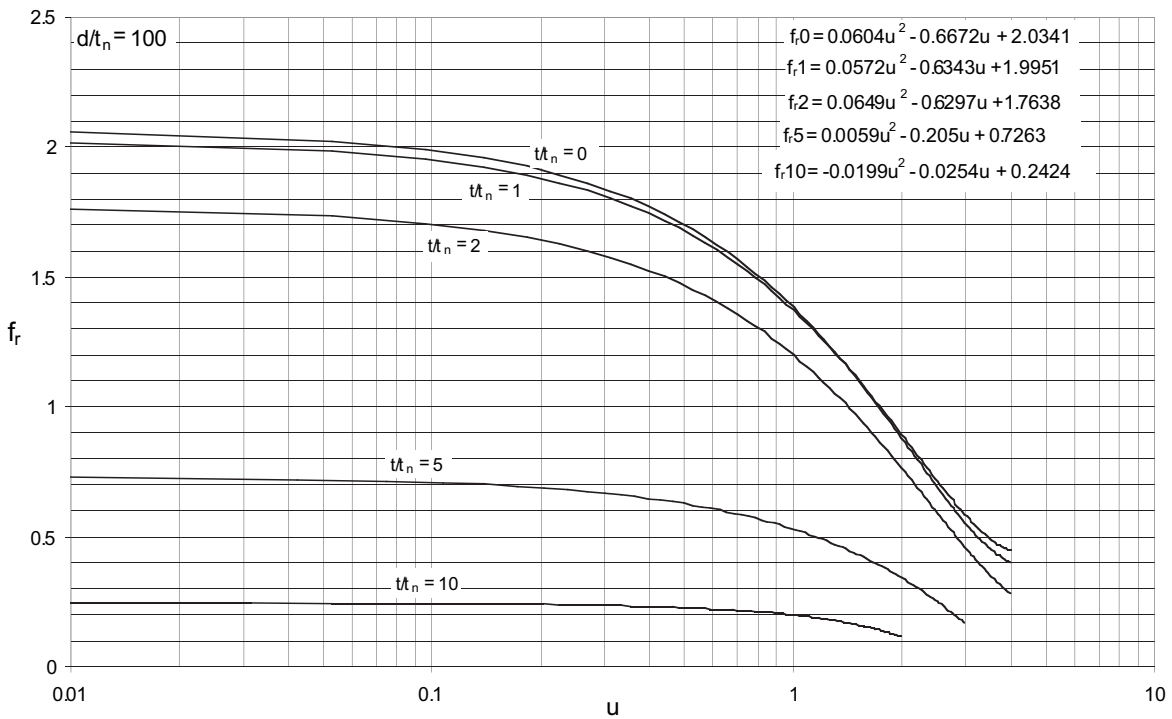


Figure P-10D—Stress Factor f_r Due to Longitudinal Moment M_L , $d/t_n = 100$

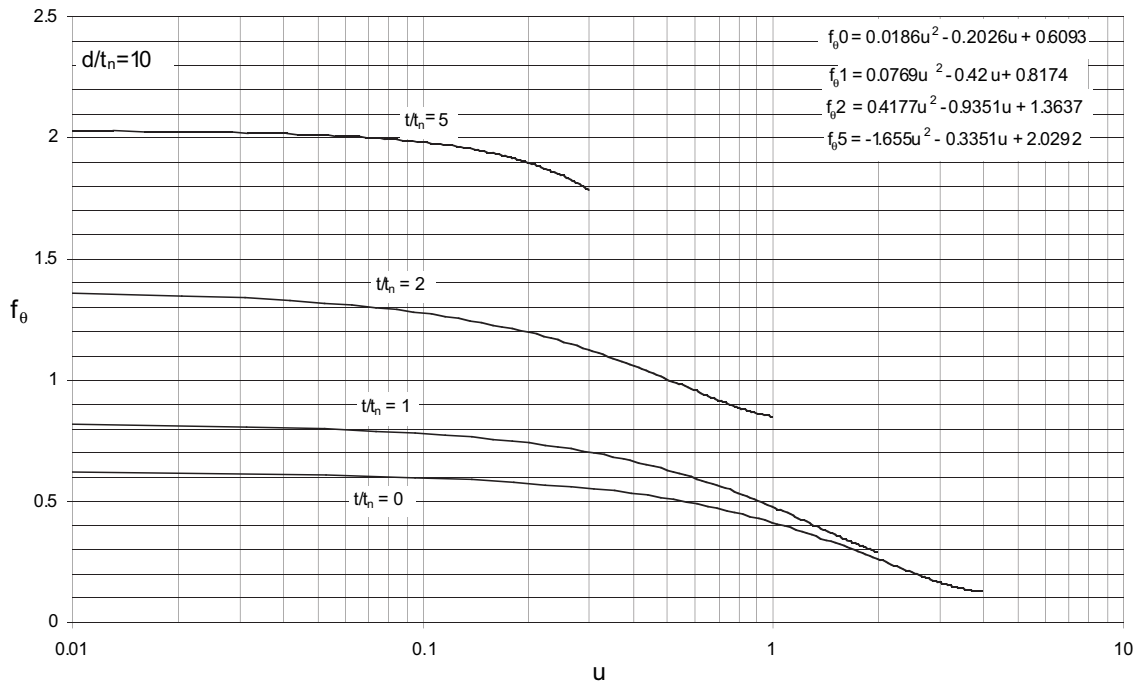


Figure P-10E—Stress Factor f_{θ} Due to Longitudinal Moment M_L , $d/t_n = 10$

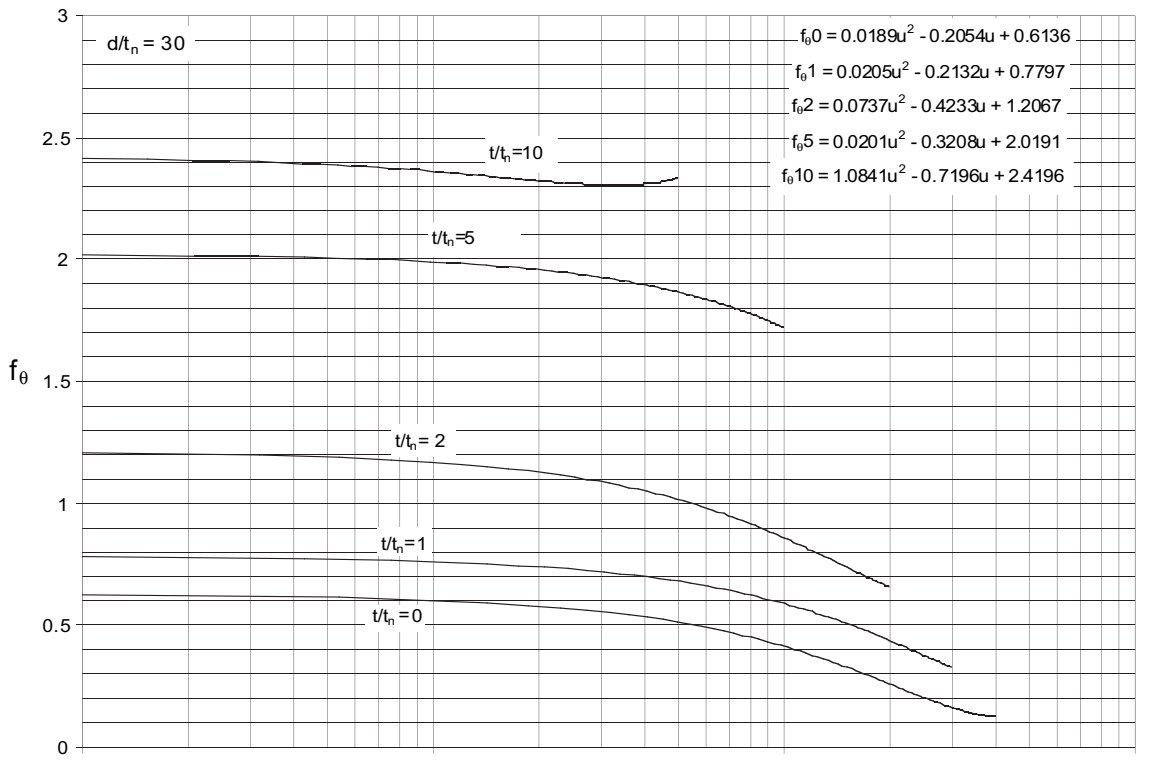


Figure P-10F—Stress Factor f_{θ} Due to Longitudinal Moment M_L , $d/t_n = 30$

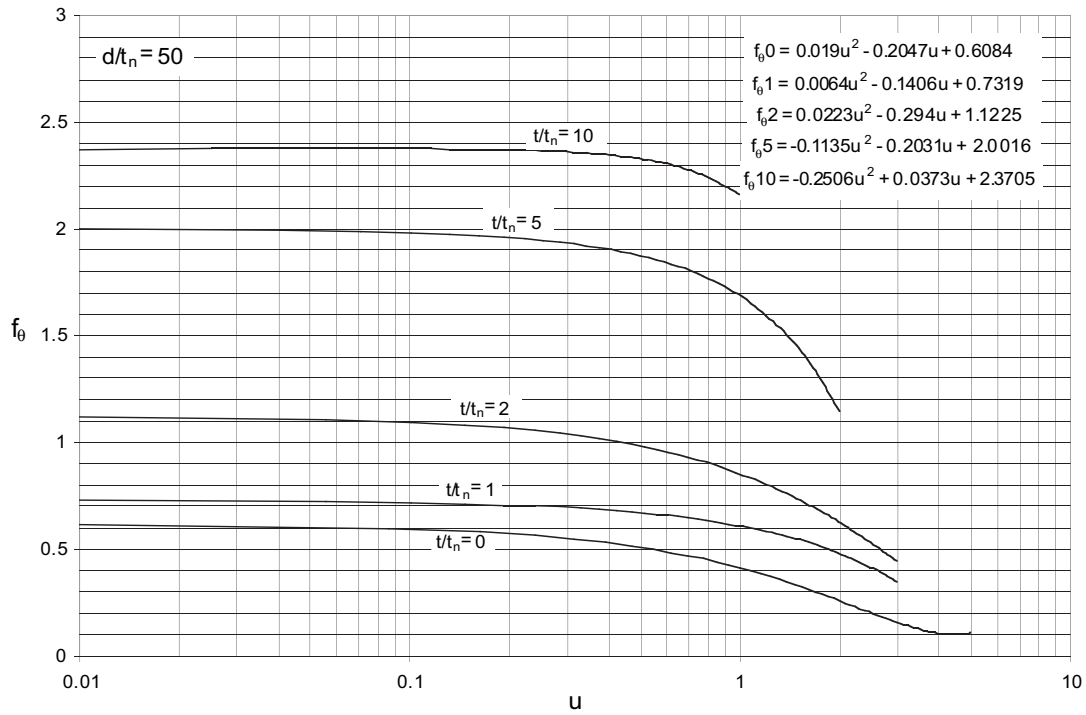


Figure P-10G—Stress Factor f_{θ} Due to Longitudinal Moment M_L , $d/t_n = 50$

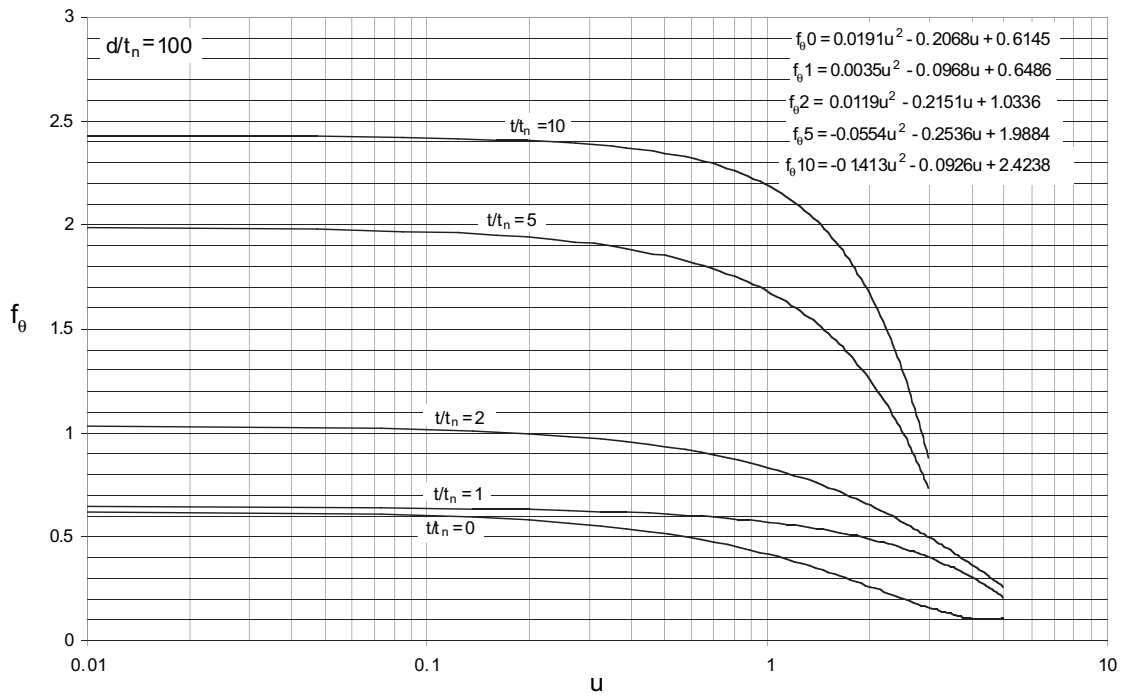


Figure P-10H—Stress Factor f_{θ} Due to Longitudinal Moment M_L , $d/t_n = 100$



APPENDIX R—LOAD COMBINATIONS

R.1 For the purposes of this Standard, loads are combined in the following manner. Design rules account for these load combinations, including the absence of any load other than D_L in the combinations:

(a) Fluid and Internal Pressure:

$$D_L + F + P_i$$

(b) Hydrostatic Test:

$$D_L + (H_t + P_t)$$

(c) Wind and Internal Pressure:

$$D_L + W + 0.4P_i$$

(d) Wind and External Pressure:

$$D_L + W + 0.4P_e$$

(e) Gravity Loads:

$$1) D_L + (L_r \text{ or } S) + 0.4P_e$$

$$2) D_L + P_e + 0.4(L_r \text{ or } S)$$

(f) Seismic:

$$D_L + F + E + 0.1S + 0.4P_i$$

- **R.2** If the ratio of operating pressure to design pressure exceeds 0.4, the Purchaser should consider specifying a higher factor on design pressure in (c), (d), (e)(1), and (f).

07

APPENDIX S—AUSTENITIC STAINLESS STEEL STORAGE TANKS

S.1 Scope

S.1.1 This appendix covers materials, design, fabrication, erection, and testing requirements for vertical, cylindrical, above-ground, closed- and open-top, welded, austenitic stainless steel storage tanks constructed of material grades 304, 304L, 316, 316L, 317, and 317L. This appendix does not cover stainless steel clad plate or strip-lined construction.

- **S.1.2** This appendix applies only to tanks in nonrefrigerated services with a maximum design temperature not exceeding 260°C (500°F). Tanks designed to this appendix shall be assigned a maximum design temperature no less than 40°C (100°F). It is cautioned that exothermic reactions occurring inside unheated storage tanks can produce temperatures exceeding 40°C (100°F).

S.1.3 This appendix is intended to provide the petroleum industry, chemical industry, and other users with tanks of safe design for containment of fluids within the design limits.

S.1.4 The minimum thicknesses in this appendix do not contain any allowance for corrosion.

S.1.5 This appendix states only the requirements that differ from the basic rules in this Standard. For requirements not stated, the basic rules must be followed.

S.2 Materials

S.2.1 SELECTION AND ORDERING

S.2.1.1 Materials shall be in accordance with Table S-1.

Table S-1a—ASTM Materials for Stainless Steel Components (SI Units)

Plates and Structural Members (Note 1)	Piping and Tubing—Seamless or Welded (Note 2)	Forgings (Notes 2, 3)	Bolting and Bars (Notes 4, 5)
A 240M, Type 304	A 213M, Grade TP 304	A 182M, Grade F 304	A 193M, Class 1, Grades B8, B8A, and B8M
A 240M, Type 304L	A 213M, Grade TP 304L	A 182M, Grade F 304L	A 194M, Grades B8, B8A, B8M, and B8MA
A 240M, Type 316	A 213M, Grade TP 316	A 182M, Grade F 316	A 320M, Grades B8, B8A, B8M, and B8MA
A 240M, Type 316L	A 213M, Grade TP 316L	A 182M, Grade F 316L	A 479M, Type 304
A 240M, Type 317	A 213M, Grade TP 317	A 182M, Grade F 317	A 479M, Type 304L
A 240M, Type 317L	A 213M, Grade TP 317L	A 182M, Grade F 317L	A 479M, Type 316
	A 312M, Grade TP 304		A 479M, Type 316L
	A 312M, Grade TP 304L		A 479M, Type 317
	A 312M, Grade TP 316		
	A 312M, Grade TP 316L		
	A 312M, Grade TP 317		
	A 312M, Grade TP 317L		
	A 358M, Grade 304		
	A 358M, Grade 304L		
	A 358M, Grade 316		
	A 358M, Grade 316L		
	A 403M, Class WP 304		
	A 403M, Class WP 304L		
	A 403M, Class WP 316		
	A 403M, Class WP 316L		
	A 403M, Class WP 317		
	A 403M, Class WP 317L		

Notes:

- 1. Unless otherwise specified by the Purchaser, plate, sheet, or strip shall be furnished with a No. 1 finish and shall be hot-rolled, annealed, and descaled.
- 2. Carbon steel flanges and/or stub ends may be used by agreement between the Purchaser and the Manufacturer, providing the design and details consider the dissimilar properties of the materials used and are suitable for the intended service.
- 3. Castings shall not be used unless specified by the Purchaser. If specified, castings shall meet ASTM A 351 and shall be inspected in accordance with ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1, Appendix 7.
- 4. All bars in contact with the product shall be furnished in the hot-rolled, annealed, and descaled condition.
- 5. Other bolting materials may be used by agreement between the Purchaser and the Manufacturer.

Table S-1b—ASTM Materials for Stainless Steel Components (US Customary units)

Plates and Structural Members (Note 1)	Piping and Tubing—Seamless or Welded (Note 2)	Forgings (Notes 2, 3)	Bolting and Bars (Notes 4, 5)
A 240, Type 304	A213, Grade TP 304	A 182, Grade F 304	A 193, Class 1, Grades B8, B8A, and B8M
A 240, Type 304L	A213, Grade TP 304L	A 182, Grade F 304L	A 194, Grades 8, 8A, 8M, and 8MA
A 240, Type 316	A213, Grade TP 316	A 182, Grade F 316	A320, Grades B8, B8A, B8M, and B8MA
A 240, Type 316L	A213, Grade TP 316L	A 182, Grade F 316L	A 479, Type 304
A 240, Type 317	A213, Grade TP 317	A 182, Grade F 317	A 479, Type 304L
A 240, Type 317L	A213, Grade TP 317L	A 182, Grade F 317L	A 479, Type 316
A 276, Type 304	A 312, Grade TP 304		A 479, Type 316L
A 276, Type 304L	A 312, Grade TP 304L		A 479, Type 317
A 276, Type 316	A 312, Grade TP 316		
A 276, Type 316L	A 312, Grade TP 316L		
A 276, Type 317	A 312, Grade TP 317		
	A 312, Grade TP 317L		
	A 358, Grade 304		
	A 358, Grade 304L		
	A 358, Grade 316		
	A 358, Grade 316L		
	A 403, Class WP 304		
	A 403, Class WP 304L		
	A 403, Class WP 316		
	A 403, Class WP 316L		
	A 403, Class WP 317		
	A 403, Class WP 317L		

Notes:

- 1. Unless otherwise specified by the Purchaser, plate, sheet, or strip shall be furnished with a No. 1 finish and shall be hot-rolled, annealed, and descaled.
- 2. Carbon steel flanges and/or stub ends may be used by agreement between the Purchaser and the Manufacturer, providing the design and details consider the dissimilar properties of the materials used and are suitable for the intended service.
- 3. Castings shall not be used unless specified by the Purchaser. If specified, castings shall meet ASTM A 351 and shall be inspected in accordance with ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1, Appendix 7.
- 4. All bars in contact with the product shall be furnished in the hot-rolled, annealed, and descaled condition.
- 5. Other bolting materials may be used by agreement between the Purchaser and the Manufacturer.

- **S.2.1.2** Selection of the type/grade of stainless steel depends on the service and environment to which it will be exposed and the effects of fabrication processes (see S.4.3.2 and S.4.4.3). The Purchaser shall select the type/grade.

- 07 • **S.2.1.3** External structural attachments may be carbon steels meeting the requirements of Section 4 of this Standard, providing they are protected from corrosion and the design and details consider the dissimilar properties of the materials used. (This does not include shell, roof, or bottom openings and their reinforcement.) Carbon steel attachments (e.g., clips for scaffolding) shall not be welded directly to any internal surface of the tank. For stainless steel tanks subject to external fire impingement, the use of galvanizing on attachments, including ladders and platforms, is not recommended.

- **S.2.2 PACKAGING**

Packaging stainless steel for shipment is important to its corrosion resistance. Precautions to protect the surface of the material will depend on the surface finish supplied and may vary among manufacturers. Normal packaging methods may not be sufficient to protect the material from normal shipping damage. If the intended service requires special precautions, special instructions should be specified by the Purchaser.

- **S.2.3 IMPACT TESTING**

Impact tests are not required for austenitic stainless steel base metals.

S.3 Design

• S.3.1 BOTTOM PLATES

All bottom plates shall have a minimum nominal thickness of 5 mm ($3/16$ in.), exclusive of any corrosion allowance. Unless otherwise agreed to by the Purchaser, all rectangular and sketch plates (bottom plates on which the shell rests that have one end rectangular) shall have a minimum nominal width of 1200 mm (48 in.).

• S.3.2 SHELL DESIGN

Unless otherwise agreed to by the Purchaser, the shell plates shall have a minimum width of 1200 mm (48 in.). The required minimum thickness of shell plates shall be the greater of the values computed by the following formulas and the shell thickness shall not be less than the nominal plate thickness listed in 5.6.1.1:

In SI units:

$$t_d = \frac{4.9D(H-0.3)G}{(S_d)E} + CA$$

$$t_t = \frac{4.9D(H-0.3)}{(S_t)(E)}$$

where

t_d = design shell thickness (mm),

t_t = hydrostatic test shell thickness (mm),

D = nominal diameter of tank (m) (see 5.6.1.1),

H = design liquid level (m) (see 5.6.3.2),

- G = specific gravity of the liquid to be stored, as specified by the Purchaser,

E = joint efficiency, 1.0, 0.85, or 0.70 (see Table S-4),

- CA = corrosion allowance (mm), as specified by the Purchaser (see 5.3.2),

S_d = allowable stress for the design condition (MPa) (see Table S-2),

S_t = allowable stress for hydrostatic test condition (MPa) (see Table S-3).

In US Customary units:

$$t_d = \frac{2.6D(H-1)G}{(S_d)E} + CA$$

$$t_t = \frac{2.6D(H-1)}{(S_t)(E)}$$

where

t_d = design shell thickness (in.),

t_t = hydrostatic test shell thickness (in.),

D = nominal diameter of tank (ft) (see 5.6.1.1),

H = design liquid level (ft) (see 5.6.3.2),

G = specific gravity of the liquid to be stored, as specified by the Purchaser,

E = joint efficiency, 1.0, 0.85, or 0.70 (see Table S-4),

CA = corrosion allowance (in.), as specified by the Purchaser (see 5.3.2),

S_d = allowable stress for the design condition (lbf/in.²) (see Table S-2),

S_t = allowable stress for hydrostatic test condition (lbf/in.²) (see Table S-2).

Note: The allowable stresses recognize the increased toughness of stainless steels over carbon steels and the relatively low yield/tensile ratios of the stainless steels. The increased toughness permits designing to a higher proportion of the yield strength, however, the Manufacturer and Purchaser shall be aware that this may result in permanent strain (see Table S-2).

S.3.3 SHELL OPENINGS

S.3.3.1 The minimum nominal thickness of connections and openings shall be as follows:

Size of Nozzle	Minimum Nominal Neck Thickness
NPS 2 and less	Schedule 80S
NPS 3 and NPS 4	Schedule 40S
Over NPS 4	6 mm (0.25 in.)

Note: Reinforcement requirements of 5.7 must be maintained.

S.3.3.2 Thermal stress relief requirements of 5.7.4 are not applicable.

S.3.3.3 Shell manholes shall be in conformance with 5.7.5 except that the minimum thickness requirements shall be multiplied by the greater of (a) the ratio of the material yield strength at 40°C (100°F) to the material yield strength at the maximum design temperature, or (b) the ratio of 205 MPa (30,000 psi) to the material yield strength at the maximum design temperature.

S.3.3.4 As an alternative to S.3.3.3, plate ring flanges may be designed in accordance with API Std 620 rules using the allowable stresses given in Table S-3.

S.3.3.5 Allowable weld stresses for shell openings shall conform to 5.7.2.8 except S_d = the maximum allowable design stress (the lesser value of the base materials joined) permitted by Table S-2.

S.3.4 ROOF MANHOLES

All stainless steel components of the roof manhole shall have a minimum thickness of 5 mm ($3/16$ in.).

S.3.5 APPENDIX F—MODIFICATIONS

S.3.5.1 In F.4.1 and F.5.1, the values of 1.1 in the SI formula and 212 MPa (30,800 psi) in the US Customary formula shall be multiplied by the ratio of the material yield strength at the maximum design temperature to 220 MPa (32,000 psi). (See Table S-5 for yield strength.)

S.3.5.2 In F.7.1, the shell thickness shall be as specified in S.3.2 except that the pressure P (in kPa [in. of water]) divided by 9.8 G (12 G) shall be added to the design liquid height in meters (ft).

S.3.5.3 In F.7.2, the allowable compressive stress of 140 MPa (20,000 psi) shall be multiplied by the ratio of the material yield stress at the maximum design temperature to 220 MPa (32,000 psi). (See Table S-5 for yield strength.)

S.3.6 APPENDIX M—MODIFICATIONS

S.3.6.1 Appendix M requirements shall be met for stainless steel tanks with a maximum design temperature over 40°C (100°F) as modified by S.3.6.2 through S.3.6.7.

S.3.6.2 Allowable shell stress shall be in accordance with Table S-2.

S.3.6.3 In M.3.4, the requirements of 5.7.7 for flush-type cleanout fittings and of 5.7.8 for flush-type shell connections shall be modified. The thickness of the bottom reinforcing plate, bolting flange, and cover plate shall be multiplied by the greater of (a) the ratio of the material yield strength at 40°C (100°F) to the material yield strength at the maximum design temperature, or (b) the ratio of 205 MPa (30,000 psi) to the material yield strength at the maximum design temperature. (See Table S-5 for yield strength.)

S.3.6.4 In M.3.5, the stainless steel structural allowable stress shall be multiplied by the ratio of the material yield strength at the maximum design temperature to the material yield strength at 40°C (100°F). (See Table S-5 for yield strength.)

S.3.6.5 The requirements of M.3.6 and M.3.7 are to be modified per S.3.5.1.

S.3.6.6 In M.5.1, the requirements of 5.10.5 and 5.10.6 shall be multiplied by the ratio of the material modulus of elasticity at 40°C (100°F) to the material modulus of elasticity at the maximum design temperature. (See Table S-6 for modulus of elasticity.)

S.3.6.7 In M.6 (the equation for the maximum height of unstiffened shell in 3.9.7.1), the maximum height shall be multiplied by the ratio of the material modulus of elasticity at the maximum design temperature to the material modulus of elasticity at 40°C (100°F).

S.4 Fabrication and Construction

S.4.1 GENERAL

Special precautions must be observed to minimize the risk of damage to the corrosion resistance of stainless steel. Stainless steel shall be handled so as to minimize contact with iron or other types of steel during all phases of fabrication and construction. The following sections describe the major precautions that should be observed during fabrication and handling.

S.4.2 STORAGE

Storage should be under cover and well removed from shop dirt and fumes from pickling operations. If outside storage is necessary, provisions should be made for rainwater to drain and allow the material to dry. Stainless steel should not be stored in contact with carbon steel. Materials containing chlorides, including foods, beverages, oils, and greases, should not come in contact with stainless steel.

S.4.3 THERMAL CUTTING

S.4.3.1 Thermal cutting of stainless steel shall be by the iron powder burning carbon arc or the plasma-arc method.

- **S.4.3.2** Thermal cutting of stainless steel may leave a heat-affected zone and intergranular carbide precipitates. This heat-affected zone may have reduced corrosion resistance unless removed by machining, grinding, or solution annealing and quenching. The Purchaser shall specify if the heat-affected zone is to be removed.

S.4.4 FORMING

S.4.4.1 Stainless steels shall be formed by a cold, warm, or hot forming procedure that is noninjurious to the material.

S.4.4.2 Stainless steels may be cold formed, providing the maximum strain produced by such forming does not exceed 10% and control of forming spring-back is provided in the forming procedure.

- **S.4.4.3** Warm forming at 540°C (1000°F) – 650°C (1200°F) may cause intergranular carbide precipitation in 304, 316, and 317 grades of stainless steel. Unless stainless steel in this sensitized condition is acceptable for the service of the equipment, it will be necessary to use 304L, 316L, or 317L grades or to solution anneal and quench after forming. Warm forming shall be performed only with agreement of the Purchaser.

S.4.4.4 Hot forming, if required, may be performed within a temperature range of 900°C (1650°F) – 1200°C (2200°F).

S.4.4.5 Forming at temperatures between 650°C (1200°F) and 900°C (1650°F) is not permitted.

S.4.5 CLEANING

- **S.4.5.1** When the Purchaser requires cleaning to remove surface contaminants that may impair the normal corrosion resistance, it shall be done in accordance with ASTM A 380, unless otherwise specified. Any additional cleanliness requirements for the intended service shall be specified by the Purchaser.

S.4.5.2 When welding is completed, flux residue and weld spatter shall be removed mechanically using stainless steel tools.

S.4.5.3 Removal of excess weld metal, if required, shall be done with a grinding wheel or belt that has not been previously used on other metals.

S.4.5.4 Chemical cleaners used shall not have a detrimental effect on the stainless steel and welded joints and shall be disposed of in accordance with laws and regulations governing the disposal of such chemicals. The use of chemical cleaners shall always be followed by thorough rinsing with water and drying (see S.4.9).

S.4.6 BLAST CLEANING

If blast cleaning is necessary, it shall be done with sharp acicular grains of sand or grit containing not more than 2% by weight iron as free iron or iron oxide. Steel shot or sand used previously to clean nonstainless steel is not permitted.

Table S-2—Allowable Stresses for Plate Ring Flanges

Type	Min. Yield MPa (psi)	Min. Tensile MPa (psi)	Allowable Stress (in MPa [psi]) for Maximum Design Temperature Not Exceeding (S_d)					
			40°C (100°F)	90°C (200°F)	150°C (300°F)	200°C (400°F)	260°C (500°F)	S_t Ambient
304	205 (30,000)	515 (75,000)	155 (22,500)	155 (22,500)	140 (20,300)	128 (18,600)	121 (17,500)	186 (27,000)
304L	170 (25,000)	485 (70,000)	145 (21,000)	132 (19,200)	119 (17,200)	109 (15,800)	101 (14,700)	155 (22,500)
316	205 (30,000)	515 (75,000)	155 (22,500)	155 (22,500)	145 (21,000)	133 (19,300)	123 (17,900)	186 (27,000)
316L	170 (25,000)	485 (70,000)	145 (21,000)	131 (19,000)	117 (17,000)	107 (15,500)	99 (14,300)	155 (22,500)
317	205 (30,000)	515 (75,000)	155 (22,500)	155 (22,500)	145 (21,000)	133 (19,300)	123 (17,900)	186 (27,000)
317L	205 (30,000)	515 (75,000)	155 (22,500)	155 (22,500)	145 (21,000)	133 (19,300)	123 (17,900)	186 (27,000)

Notes:

- S_d may be interpolated between temperatures.
- The design stress shall be the lesser of 0.3 of the minimum tensile strength or 0.9 of the minimum yield strength. The factor of 0.9 of yield corresponds to a permanent strain of 0.10%. When a lower level of permanent strain is desired, the Purchaser shall specify a reduced yield factor in accordance with Table Y-2 of ASME Section II, Part D. The yield values at the different maximum design temperatures can be obtained from Table S-5.
- For dual-certified materials (e.g., ASTM A 182M/A 182 Type 304L/304), use the allowable stress of the grade specified by the Purchaser.

Table S-3—Allowable Stresses for Plate Ring Flanges

Type	Allowable Stress (in MPa [psi]) for Maximum Design Temperature Not Exceeding (S_t)				
	40°C (100°F)	90°C (200°F)	150°C (300°F)	200°C (400°F)	260°C (500°F)
304	140 (20,000)	115 (16,700)	103 (15,000)	95 (13,800)	89 (12,900)
304L	117 (16,700)	99 (14,300)	88 (12,800)	81 (11,700)	75 (10,900)
316	140 (20,000)	119 (17,200)	107 (15,500)	99 (14,300)	92 (13,300)
316L	117 (16,700)	97 (14,100)	87 (12,600)	79 (11,500)	73 (10,600)
317	140 (20,000)	119 (17,300)	108 (15,600)	99 (14,300)	92 (13,300)
317L	140 (20,000)	119 (17,300)	108 (15,600)	99 (14,300)	92 (13,300)

Notes:

- Allowable stresses may be interpolated between temperatures.
- The allowable stresses are based on a lower level of permanent strain.
- The design stress shall be the lesser of 0.3 of the minimum tensile strength or $2/3$ of the minimum yield strength.
- For dual-certified materials (e.g., ASTM A 182M/A 182 Type 304L/304), use the allowable stress of the grade specified by the Purchaser.

Table S-4—Joint Efficiencies

Joint Efficiency	Radiograph Requirements
1.0	Radiograph per 8.1.2
0.85	Radiograph per A.5.3
0.70	No radiography required

Table S-5—Yield Strength Values in MPa (psi)

Type	Yield Strength (in MPa [psi]) for Maximum Design Temperature Not Exceeding				
	40°C (100°F)	90°C (200°F)	150°C (300°F)	200°C (400°F)	260°C (500°F)
304	205 (30,000)	170 (25,000)	155 (22,500)	143 (20,700)	134 (19,400)
304L	170 (25,000)	148 (21,400)	132 (19,200)	121 (17,500)	113 (16,400)
316	205 (30,000)	178 (25,800)	161 (23,300)	148 (21,400)	137 (19,900)
316L	170 (25,000)	145 (21,100)	130 (18,900)	119 (17,200)	110 (15,900)
317	205 (30,000)	179 (25,900)	161 (23,400)	148 (21,400)	138 (20,000)
317L	205 (30,000)	179 (25,900)	161 (23,400)	148 (21,400)	138 (20,000)

Notes:

- Interpolate between temperatures.
- Reference: Table Y-1 of ASME Section II, Part D.

Table S-6—Modulus of Elasticity at the Maximum Design Temperature

Maximum Design Temperature (C° [°F]) Not Exceeding	Modulus of Elasticity (MPa [psi])
40 (100)	193,000 (28,000,000)
90 (200)	189,000 (27,400,000)
150 (300)	183,000 (26,600,000)
200 (400)	180,000 (26,100,000)
260 (500)	174,000 (25,200,000)

Note: Interpolate between temperatures.

S.4.7 PICKLING

If pickling of a sensitized stainless steel is necessary, an acid mixture of nitric and hydrofluoric acids shall not be used. After pickling, the stainless steel shall be thoroughly rinsed with water and dried.

S.4.8 PASSIVATION OR IRON FREEING

When passivation or iron freeing is specified by the Purchaser, it may be achieved by treatment with nitric or citric acid. The use of hydrofluoric acid mixtures for passivation purposes is prohibited for sensitized stainless.

S.4.9 RINSING

S.4.9.1 When cleaning and pickling or passivation is required, these operations shall be followed immediately by rinsing, not allowing the surfaces to dry between operations.

- S.4.9.2** Rinse water shall be potable and shall not contain more than 200 parts per million chloride at temperatures below 40°C (100°F), or no more than 100 parts per million chloride at temperatures above 40°C (100°F) and below 65°C (150°F), unless specified otherwise by the Purchaser.

S.4.9.3 Following final rinsing, the equipment shall be completely dried.

S.4.10 HYDROSTATIC TESTING

S.4.10.1 The rules of 7.3.5 apply to hydrostatic testing except that the penetrating oil test in 7.3.5(2) shall be replaced with liquid penetrant examination conducted by applying the penetrant on one side and developer on the opposite side of the welds. The dwell time must be at least one hour.

- **S.4.10.2** The materials used in the construction of stainless steel tanks may be subject to severe pitting, cracking, or rusting if they are exposed to contaminated test water for extended periods of time. The Purchaser shall specify a minimum quality of test water that conforms to the following requirements:
 - a. Unless otherwise specified by the Purchaser, water used for hydrostatic testing of tanks shall be potable and treated, containing at least 0.2 parts per million free chlorine.
 - b. Water shall be substantially clean and clear.
 - c. Water shall have no objectionable odor (that is, no hydrogen sulfide).
 - d. Water pH shall be between 6 and 8.3.
 - e. Water temperature shall be below 50°C (120°F).
 - f. The chloride content of the water shall be below 50 parts per million, unless specified otherwise by the Purchaser.
- **S.4.10.3** When testing with potable water, the exposure time shall not exceed 21 days, unless specified otherwise by the Purchaser.

S.4.10.4 When testing with other fresh waters, the exposure time shall not exceed 7 days.

S.4.10.5 Upon completion of the hydrostatic test, water shall be completely drained. Wetted surfaces shall be washed with potable water when nonpotable water is used for the test and completely dried. Particular attention shall be given to low spots, crevices, and similar areas. Hot air drying is not permitted.

S.4.11 WELDING

S.4.11.1 Tanks and their structural attachments shall be welded by any of the processes permitted in 7.2.1.1 or by the plasma arc process. Galvanized components or components coated with zinc-rich coating shall not be welded directly to stainless steel.

S.4.11.2 Filler metal chemistry shall match the type of base metals joined. Dissimilar welds to carbon steels shall use filler metals of E309 or higher alloy content.

S.4.12 WELDING PROCEDURE AND WELDER QUALIFICATIONS

Impact tests are not required for austenitic stainless steel weld metal and heat-affected zones.

- **S.4.13 POSTWELD HEAT TREATMENT**

Postweld heat treatment of austenitic stainless steel materials need not be performed unless specified by the Purchaser.

S.4.14 INSPECTION OF WELDS

S.4.14.1 Radiographic Inspection of Butt-Welds

Radiographic examination of butt-welds shall be in accordance with 8.1 and Table S-4.

S.4.14.2 Inspection of Welds by Liquid Penetrant Method

The following component welds shall be examined by the liquid penetrant method before the hydrostatic test of the tank:

- a. The shell-to-bottom inside attachment weld.
- b. All welds of opening connections in tank shell that are not completely radiographed, including nozzle and manhole neck welds and neck-to-flange welds.
- c. All welds of attachments to shells, such as stiffeners, compression rings, clips, and other nonpressure parts for which the thickness of both parts joined is greater than 19 mm ($3/4$ in.).
- d. All butt-welded joints in tank annular plates on which backing strips are to remain.

S.5 Marking

Brazing shall be deleted from 10.1.2.

S.6 Appendices

The following appendices are modified for use with austenitic stainless steel storage tanks:

- a. Appendix C is applicable; however, the Purchaser shall identify all materials of construction.
- b. Appendix F is modified as outlined in S.3.5 of this appendix.
- c. Appendix J is applicable, except the minimum shell thickness for all tank diameters is 5 mm ($3/16$ in.).
- d. Appendix K is not applicable to tanks built to this appendix.
- e. Appendix M is modified as outlined in S.3.6 of this appendix.
- f. Appendix N is not applicable.
- g. Appendix O is applicable; however, the structural members of Table O-1 shall be of an acceptable grade of material.
- h. All other appendices are applicable without modifications.

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RT	Shell plate butt welds unless examined by UT with Purchaser approval. RT is not required for Appendix A, J, and S tanks where the Joint Efficiency of 0.7 is used.	7.3.2.1, A.5.3, S.4.14.1
RT	Butt welds of annular plates that are required by 7.5.1 or M.4.1.	8.1.2.9
RT	Flush-type shell connections: 100% of all longitudinal butt welds in the nozzle neck and transition piece, if any, and the first circumferential butt weld in the neck closest to the shell, excluding the neck-to-flange weld.	5.7.8.11
RT	Shell vertical and horizontal welds which have intersecting openings and repads—100% over weld length 3 times the diameter of the opening.	5.7.3.4
Tracer Gas	Entire length of bottom weld joints as an alternative to vacuum-box testing.	7.3.3.b
UT	Shell plate butt welds if approved by Purchaser.	7.3.2.1
VB	First pass of the internal shell-to-bottom weld if approved instead of MT, PT, or Pen. Oil.	7.2.4.1e
VB	Bottom welds.	7.3.4a
VB	Welds of roofs designed to be gas-tight if not air tested.	7.3.7.1
VB	All seams of internal floating roofs exposed to liquid or vapors if not tested by penetrating oil.	H.6.2
VB	Seams of flexible membrane liners for leak protection.	I.6.2
VB	Welded shell joints above the hydrostatic test water level unless tested with penetrating oil.	7.3.6.1
VB	Shell-to-bottom weld joints.	7.2.4.3c
VE	Flush type shell connections: Nozzle-to-tank shell, repad welds, shell-to-bottom reinforcing pad welds on the root pass, each 20 mm ($1/2$ in.) of weld, and completed weld. After stress relieving before hydro-test.	5.7.8.11
VE	Tack of shell butt welds left in place.	7.2.1.8
VE	Permanent attachment welds and temporary weld removal areas on Group IV, IVA, V, and VI materials.	7.2.3.5
VE	Completed welds of stress relieved assemblies before hydro-test.	7.2.3.6
VE	First pass and final weld inside and outside of the internal shell-to-bottom weld.	7.2.4.1, 7.2.4.2, 7.2.4.3
VE	All shell plate butt welds.	7.3.2.1
VE	All fillet welds including roof plate welds.	7.3.2.2
VE	Upper side of the upper deck welds of pontoon and double deck floating roofs.	C.4.4
VE	All aluminum structural welds and components joined by welding.	G.11.3
VE	Joint fit-up of butt welds of bottoms supported by grillage and each weld pass.	I.7.4
VE	Non-structural small attachments such as insulation clips (not supports) studs and pins including those welded by capacitor discharge.	7.2.1.11
VE	Leak barrier, leak barrier penetrations, attachments to ringwalls and other appurtenances.	I.6.1
VE	Bottom welds.	7.3.3
VE	Roof welds not designed to be gas-tight.	7.3.7.2
Water	Bottom welds if not vacuum-box or tracer gas tested.	7.3.3c
Water	External floating roofs—flotation test.	C.4.3
Water	External floating roof drain pipe and hose systems with pressure.	C.4.5
Water	Aluminum dome roofs after completion.	G.10.1.1
Water	Internal floating roofs flotation test.	H.7.3

Definitions:

MT = Magnetic Particle Examination
Pen Oil = Penetrating Oil Test
PT = Liquid Penetrant Examination
RT = Radiographic Testing
VB = Vacuum-Box Testing
VE = Visual Examination

Acceptance Standards:

MT: ASME Section VIII, Appendix 6 (Paragraphs 6-3, 6-4, 6-5)
PT: ASME Section VIII, Appendix 8, (Paragraphs 8-3, 8-4, 8-5)
RT: ASME Section VIII, Paragraph UW-51(b)
Tracer Gas: API Std 650, Section 8.6.11
UT: For welds examined by UT in lieu of RT, acceptance standards are in Appendix U. For UT when RT is used for the requirements of 7.3.2.1, the acceptance standard is as agreed upon by the Manufacturer and Purchaser.
VB: API Std 650, Section 8.6
VE: API Std 650, Section 8.5

Examiner Qualifications:

MT: API Std 650, Section 8.2.3.
PT: API Std 650, Section 8.2.3
RT: ASNT SNT-TC-1A Level II or III. Level-I personnel may be used under the supervision of a Level II or Level III with a written procedure in accordance with ASME Section V, Article 2.
Tracer Gas: None
UT: For welds examined by UT in lieu of RT, the inspector must be ASNT-TC-1A or CP-189 Level II or Level III. For UT when RT is used for the requirements of 7.3.2.1, the required qualifications are ASNT-TC-1A Level II or Level III. A Level I may be used with restrictions—see API Std 650, Section 8.3.2.
VB: None
VE: None

Procedure Requirements:

MT: ASME Section V, Article 7
PT: ASME Section V, Article 6
RT: A procedure is not required. However, the examination method must comply with ASME Section V, Article 2. Acceptance standards shall be in accordance with ASME Section VIII, Paragraph UW-51(b).
UT: For shell welds examined by UT in lieu of RT, ASME, Section V, Article 4 and U.3.5. For welds when RT is used for the requirements of 7.3.2.1, ASME Section V.
VB: None
VE: None
Tracer Gas: API Std 650, Section 8.6.11.a.

APPENDIX U—ULTRASONIC EXAMINATION IN LIEU OF RADIOGRAPHY

U.1 General

U.1.1 PURPOSE

This appendix provides detailed rules for the use of the ultrasonic examination (UT) method for the examination of tank seams as permitted by 7.3.2.1. This alternative is limited to joints where the thickness of the thinner of the two members joined is greater than or equal to 10 mm ($3/8$ in.).

U.1.2 APPLICATION AND EXTENT

The provisions of 8.1 governing:

- a. When adjacent plates may be regarded as the same thickness,
- b. Application (see 8.1.1), and
- c. Number and Locations (see 8.1.2)

shall apply to this ultrasonic method. When these sections refer to radiography, for purposes of this appendix, they shall be read as applied to UT.

U.2 Definitions

- a. **documenting:** Preparation of text and/or and figures.
- b. **evaluation:** All activities required in U.6.3 through U.6.6 to determine the acceptability of a flaw.
- c. **flaw:** A reflector that is not geometric or metallurgical in origin that may be detectable by nondestructive testing but is not necessarily rejectable.
- d. **flaw categorization:** Whether a flaw is a surface flaw or is a subsurface flaw (see U.6.4). Note that a flaw need not be surface-breaking to be categorized as a surface flaw.
- e. **flaw characterization:** The process of quantifying the size, location and shape of a flaw. See U.6.3 for size and location. The only shape characterization required by this appendix is applied to the results of supplemental surface examination by MT or PT (see U.6.6.2).
- f. **indication:** That which marks or denotes the presence of a reflector.
- g. **interpretation:** The determination of whether an indication is relevant or non-relevant. i.e., whether it originates from a geometric or metallurgical feature or conversely originates from a flaw (see U.6.2).
- h. **investigation:** Activities required to determine the interpretation of an indication (see U.6.1 and U.6.2).
- i. **recording:** The writing of ultrasonic data onto an appropriate electronic medium.
- j. **reflector:** An interface at which an ultrasonic beam encounters a change in acoustic impedance and at which at least part of the energy is reflected.

U.3 Technique

- **U.3.1** The UT volume shall include the weld metal, plus the lesser of 25 mm (1 in.) or t of adjoining base metal on each side of the weld unless otherwise agreed upon by the Purchaser and the Manufacturer.
U.3.2 UT for the detection of flaws shall be performed using automated, computer-based data acquisition except that scanning of adjacent base metal for flaws that can interfere with the examination may be performed manually. UT for sizing of flaws shall be performed as described in U.6.3.1
- **U.3.3** A documented examination strategy or scan plan shall be provided showing transducer placement, movement, and component coverage that provides a standardized and repeatable methodology for weld acceptance. The scan plan shall also include ultrasonic beam angle to be used, beam directions with respect to weld centerline, and tank material volume examined for each weld. The documentation shall be made available to the Owner upon request.

U.3.4 Data from the examination volume, per U.3.1, shall be recorded and/or documented as follows:

- a. For automated computer-based scans, data shall be recorded using the same system essential variables, specified value or range of values, used for the demonstration of the procedure per U.4.3.
- b. For manual scans, results shall be documented in a written report.

- **U.3.5** The UT shall be performed in accordance with a written procedure which has been reviewed and approved by the Purchaser and conforms to the requirements of Section V, Article 4, except that:

- a. the calibration block shown in Figure T-542.2.1 of Section V, Article 5 shall be used, and
- b. for examination techniques that provide plate quality information (e.g., TOFD), the initial base material straight-beam examination need not be performed.

U.3.6 The examination methodology (including U.6.6) shall be demonstrated to be effective over the full weld volume. It is recognized that Time of Flight Diffraction (TOFD) may have limitations in detection of flaws at the surface such that it may be necessary to supplement TOFD with pulse-echo techniques suitable for the detection of near-field and far-field flaws. The variety of surface and sub-surface category flaws in the test plate mandated by U.4.3a are intended to ensure that any such limitations are adequately addressed.

U.4 Personnel Qualifications and Training

U.4.1 Personnel Qualifications—Personnel performing and evaluating UT examinations shall be qualified and certified in accordance with their employer's written practice. ASNT SNT-TC-IA or CP-189 shall be used as a guideline. Only Level-II or Level-III personnel shall perform UT examinations, analyze the data, or interpret the results.

U.4.2 Qualification Records—Qualification records of certified personnel shall be approved by the Manufacturer and maintained by their employer.

- **U.4.3 Personnel Testing**—Personnel who acquire and analyze UT data shall be trained using the equipment of U.3.2, and the procedure of U.3.5 above. Additionally, they shall pass a practical examination based on the technique on a blind test plate. The testing program details shall be by agreement between the Purchaser and the inspection company but shall in any case include the following elements as a minimum:

- a. The test plate shall contain a variety of surface and sub-surface category flaws including multiple flaws described in U.6.5. Some of the flaws shall be acceptable and others unacceptable per the applicable criteria of Table U-1 or U-2.
- b. The practical examination should cover detection, interpretation, sizing, plotting, categorization, grouping, and characterization that is sufficient to cover the cases outlined in U.6.
- c. Criteria for passing the test shall include limits on the number of miscalls, both of rejectable flaws missed or accepted and acceptable regions rejected.
- d. Testing shall be facilitated by a third-party or by the Purchaser.

U.5 Level III Review

U.5.1 The final data package shall be reviewed by a UT Level-III individual qualified in accordance with U.4.1 and U.4.3 above. The review shall include:

- a. The ultrasonic data record.
- b. Data interpretations.
- c. Evaluations of indications performed by another qualified Level-II or Level-III individual. The data review may be performed by another individual from the same organization.

U.5.2 Alternatively, the review may be achieved by arranging for a data acquisition and initial interpretation by a Level-II individual qualified in accordance with U.4.1 and U.4.3 above, and a final interpretation and evaluation shall be performed by a Level-III individual qualified per U.5.1.

U.6 Interpretation and Evaluation

U.6.1 Investigation Criteria—Reflectors that produce a response greater than 20% of the reference level shall be investigated. Alternatively, for methods or techniques that do not use amplitude recording levels, sized reflectors longer than 40% of the

acceptable surface or subsurface flaws in Table U-1 shall be investigated. The investigation shall interpret whether the indication originates from a flaw or is a geometric indication in accordance with U.6.2 below. When the reflector is determined to be a flaw, the flaw shall be evaluated and acceptance criteria of Table U-1 as applicable shall apply.

U.6.2 Interpretation as Geometric/Metallurgical—Ultrasonic indications of geometric and metallurgical origin shall be interpreted as follows:

U.6.2.1 Indications that are determined to originate from the surface configurations (such as weld reinforcement or root geometry) or variations in metallurgical structure of materials may be interpreted as geometric indications, and

- a. Need not be sized or categorized in accordance with U.6.3 and U.6.4 below;
- b. Need not be compared to the allowable flaw acceptance criteria of Table U-1;
- c. The maximum indication amplitude (if applicable) and location shall be documented, for example: internal attachments, 200% DAC maximum amplitude, one (1) in. above the weld centerline, on the inside surface, from 90° to 95°.

U.6.2.2 The following steps shall be taken to classify an indication as geometric:

- a. Interpret the area containing the indication in accordance with the applicable examination procedure;
- b. Plot and verify the indication's coordinates, provide a cross-sectional display showing the indication's position and any surface conditions such as root or counter-bore; and
- c. Review fabrication or weld prep drawings.

U.6.2.3 Alternatively, other NDE methods or techniques may be applied to interpret an indication as geometric (e.g., alternative UT beam angles, radiography, ID and/or OD profiling).

U.6.3 FLAW SIZING

U.6.3.1 Flaws shall be sized using automated, computer-based data acquisition or by a supplemental manual technique that has been demonstrated to perform acceptably per U.4.3 above.

U.6.3.2 The dimensions of the flaw shall be defined by the rectangle that fully contains the area of the flaw. The length (l) of the flaw shall be drawn parallel to the inside pressure-retaining surface of the component. The height (h) of the flaw shall be drawn normal to the inside pressure-retaining surface.

U.6.4 FLAW CATEGORIZATION

If the space between the surface and the flaw in the through-thickness direction is less than one-half the measured height of the flaw, then the flaw shall be categorized as a surface flaw with flaw height extending to the surface of the material.

U.6.5 GROUPING OF MULTIPLE FLAWS

U.6.5.1 Discontinuous flaws that are oriented primarily in parallel planes shall be considered to lie in a single plane if the distance between the adjacent planes is equal to or less than 12 mm (in.).

U.6.5.2 If the space between two flaws aligned along the axis of weld is less than the length of the longer of the two, the two flaws shall be considered a single flaw.

U.6.5.3 If the space between two flaws aligned in the through-thickness direction is less than the height of the flaw of greater height, the two flaws shall be considered a single flaw.

U.6.6 FLAW ACCEPTANCE CRITERIA

U.6.6.1 Acceptance Criteria Tables—Flaw dimensions resulting after the application of the rules of U.6.3, U.6.4 and U.6.5 shall be evaluated for acceptance using the criteria of Table U-1.

U.6.6.2 Surface Examination—Flaws categorized as surface flaws during the UT examination may or may not be surface-connected. Therefore, unless the UT data analysis confirms that the flaw is not surface-connected, a supplemental surface examination (MT or PT) shall be performed in accordance with 8.2 or 8.4 as applicable for all surface flaws. Any flaws which are detected by MT or PT and characterized as planar are unacceptable regardless of length.

U.7 Repairs

All repaired areas, plus the lesser of 25 mm (1 in.) or t of the adjoining weld on each side of the repair, shall be reinspected per this Appendix.

U.8 Flaw Documentation

In addition to the data record prescribed by U.3.4, written documentation shall be produced for each unacceptable flaw and those acceptable flaws that either exceed 50% of reference level for amplitude based techniques or exceed 75% of the acceptable length for non-amplitude techniques.

Table U-1—Flaw Acceptance Criteria for UT Indications May be Used for All Materials

Thickness at Weld (t) ⁽¹⁾ mm (in.)	ACCEPTABLE FLAW LENGTHS – (l) mm (in.)							
	For Surface Flaw ⁽²⁾ With Height, (h) mm (in.)			For SubSurface Flaw With Height, (h) mm (in.)				
	2 (0.08)	2.5 (0.10)	3 (0.12)	2 (0.08)	3 (0.12)	4 (0.16)	5 (0.2)	6 (0.24)
10 (0.375) to <13 (0.50)	8 (0.30)	8 (0.30)	4 (0.15)	14 (0.55)	5 (0.20)	4 (0.15)	Not allowed	Not allowed
13 (0.50) to < 19 (0.75)	8 (0.30)	8 (0.30)	4 (0.15)	38 (1.50)	8 (0.30)	5 (0.20)	4 (0.15)	3 (0.10)
19 (0.75) to < 25 (1.0)	8 (0.30)	8 (0.30)	4 (0.15)	75 (3.00)	13 (0.50)	8 (0.30)	6 (0.25)	5 (0.20)
25 (1.0) to < 32 (1.25)	9 (0.35)	8 (0.30)	4 (0.15)	100 (4.00)	20 (0.80)	9 (0.35)	8 (0.30)	6 (0.25)
32 (1.25) to < 38 (1.50)	9 (0.35)	8 (0.30)	4 (0.15)	125 (5.00)	30 (1.20)	10 (0.40)	8 (0.30)	8 (0.30)
38 (1.50) to < 44 (1.75)	9 (0.35)	8 (0.30)	4 (0.15)	150 (6.00)	38 (1.50)	10 (0.40)	9 (0.35)	8 (0.30)

t = thickness of the weld excluding any allowable reinforcement. For a butt weld joining members having different thickness at the weld, t is the thinner of the two. Any surface flaw, to be deemed acceptable, must satisfy both the size limitations of this table and additionally satisfy the MT/PT characterization limitations of U.6.6.2

APPENDIX V—DESIGN OF STORAGE TANKS FOR EXTERNAL PRESSURE

• V.1 Scope

This appendix provides minimum requirements that may be specified by the Purchaser for tanks that are designed to operate with external pressure (vacuum) loading as a normal operating condition. This appendix is intended to apply to tanks for which the normal operating external pressure exceeds 0.25 kPa (0.036 lbf/in.²) but does not exceed 6.9 kPa (1.0 lbf/in.²). This appendix is intended for use with tanks subject to uniform external pressure. The requirements in this appendix represent accepted practice for application to flat-bottom tanks. However, the Purchaser may specify other procedures or additional requirements. Any deviation from the requirements of this appendix must be by agreement between the Purchaser and the Manufacturer. See V.11 for a discussion of the technical basis for this appendix.

V.2 General

The design procedures presented in this appendix are intended to allow the user to evaluate the design of the bottom, shell and fixed roof of tanks that operate under partial vacuum conditions. See Appendix R for requirements for combining external pressure loads with other design loads. The requirements of this appendix are not intended to supersede the requirements of other appendices of this Standard that may be specified. For Appendix M and S tanks, the variables in the equations prescribed in this appendix shall be modified in accordance with the requirements of Appendices M and S, respectively.

V.3 Nomenclature and Definitions

V.3.1 NOMENCLATURE

- θ = angle between a horizontal plane and the surface of the roof plate (degrees)
- A_{reqd} = total required cross-sectional area of the stiffener region, mm² (in.²)
- A_{stiff} = required cross-sectional area of stiffener, mm² (in.²) Note: A_{stiff} must be at least $1/2 \times A_{\text{total}}$
- D = nominal tank diameter, m (ft)
- D_L = dead load, the weight of the tank or tank component, including any corrosion allowance unless otherwise specified, kPa (lb/ft²)
- E = modulus of elasticity of the roof plate material, MPa, (lb/in.²)
- f = smallest of the allowable tensile stresses (see Table 3-2) of the roof plate material, shell plate material or stiffener ring material at the maximum operating temperature, MPa (lb/in.²)
- f_c = smallest of the allowable compressive stresses of the roof plate material, shell plate material, bottom plate material or stiffener ring material at the maximum operating temperature, MPa (lb/in.²). $f_c = 0.4F_y$, of components considered for the intermediate and bottom stiffener regions. However, f_c need not be less than 103 MPa (15,000 lb/in.²). $f_c = 0.6F_y$, of components considered for the top end stiffener region. However, f_c need not be less than 140 MPa (20,000 lb/in.²).
- F_y = yield strength of the component at the maximum operating temperature, MPa (lb/in.²)
- G_{in} = unit weight of liquid inside tank, kg/m³ (lb/ ft³)
- G_{out} = unit weight of flood liquid, kg/m³ (lb/ ft³) (1000 kg/m³ [62.4 lb/ ft³] for water)
- H = shell height, m (ft)
- $h_1, h_2 \dots h_n$ = height of shell courses 1, 2, 3, through n, respectively, m (ft)
- H_{in} = height or depth of liquid inside tank, m (ft)
- H_{safe} = maximum height of unstiffened shell permitted, based on the calculated minimum thickness, m (ft)
- HTS = Transformed height of tank shell, m (ft)
- I_{act} = The actual moment of inertia of the stiffener ring region, cm⁴ (in.⁴)
- I_{reqd} = required moment of inertia of the stiffener ring, cm⁴ (in.⁴)
- JE_b = Joint efficiency of bottom plate. $JE_b = 1.0$ for bottom joints
- JE_r = joint efficiency of roof plate. $JE_r = 0.35$ for single lap welds, 0.70 for double lap welds, and 1.0 for butt welds

- JE_s = joint efficiency of shell plate. $JE_s = 1.0$ for shell with full radiography, or 0.85 with spot radiography
 JE_{st} = joint efficiency of splice of stiffener sections. $JE_{stiff} = 1.0$ for 100% radiography of all splice welds, 0.85 for spot radiography of selected splice welds, and 0.70 for no radiography
 L_1, L_2 = distances between adjacent intermediate stiffeners or intermediate stiffener and top of shell or bottom of shell, respectively, m (ft)
 L_r = minimum roof live load on horizontal projected area of the roof, kPa (lb/ft²) = 1.0kPa (20 lb/ft²)
 L_s = $(L_1 + L_2) / 2$, m (ft)
 N = number of waves into which a shell will buckle under external pressure
 N_s = number of intermediate stiffeners
 P_e = specified external pressure, kPa (lb/ft²)
 P_r = total design external pressure for design of roof, kPa (lb/ft²).
 P_s = total design external pressure for design of shell, kPa (lb/ft²). P_s = the greater of 1) the specified design external pressure, P_e , excluding wind or 2) $W + 0.4P_e$
 Q = radial load imposed on the intermediate stiffener by the shell, N/m (lb/in.)
 q_s = first moment of area of stiffener for design of stiffener attachment weld, mm³ (in.³)
 R = roof dish radius, m (ft)
 S = specified snow load, kPa (lb/ft²)
 S_d = allowable design stress, Mpa, (lb/in.²)
 t = shell thickness, including corrosion allowance, mm (in.)
 t_b = thickness of bottom plate under the shell, including corrosion allowance, mm (in.)
 t_{cone} = required thickness of cone roof plate, including corrosion allowance, mm (in.). (Maximum 12.5 mm (0.5 in.) excl. corrosion allowance)
 t_{dome} = required thickness of dome roof plate, including corrosion allowance, mm (in.) (Maximum 12.5 mm (0.5 in.) excl. corrosion allowance)
 $t_{s1}, t_{s2} \dots t_{sn}$ = thickness of cylindrical shell course 1, 2...n, mm (in.), where the subscript numbering is from top to bottom of the shell. Note: The subscript 1 denotes the top shell course and n denotes the lowest shell course.
 t_{shell} = actual thickness of shell at level under consideration, including corrosion allowance, mm (in.)
 t_{smin} = minimum thickness of thinnest shell course, mm (in.)
 V_1 = radial load imposed on the stiffener by the shell, N/m (lb/ft)
 V_{s1} = radial pressure load imposed on the stiffener from the shell for sizing the stiffener attachment weld, N/m (lb/ft)
 v_s = radial shear load on stiffener for sizing the stiffener attachment weld, N (lb)
 V_{s2} = weld shear flow load imposed for sizing the stiffener attachment weld, N/m (lb/ft)
 W = maximum wind pressure consistent with the specified design wind velocity, kPa (lb/ft²). The maximum wind pressure shall be calculated as follows:

In SI units:

$$W = 0.0000333(V)^2(K_g)(K_h)$$

In US Customary units:

$$W = 0.001776(V)^2(K_g)(K_h)$$

where

• V = specified design wind velocity (3-sec gust), kph (mph),

K_g = wind gust factor = 1.1,

K_h = wind height factor = 1.1.

W_{bott} = weight of bottom plate, kg/m² (lb/ft²)

w_{shell} = contributing width of shell on each side of intermediate stiffener, mm (in.)

- X_{btm} = length of bottom plate within tension/compression ring region, mm (in.). $X_{btm} = 16 t_b$
 X_{cone} = length of cone roof within tension/compression ring region, mm (in.)
 X_{dome} = length of umbrella or dome roof within tension/compression ring region, mm (in.)
 X_{shell} = length of shell within tension/compression ring region, mm (in.)

V.3.2 DEFINITIONS

- **V.3.2.1 specified external pressure:** External pressure specified on the tank data sheet (see Appendix L) by the Purchaser. This specified value excludes any external pressure due to wind.
- V.3.2.2 total design external pressure for the roof (P_r):** Sum of the specified external pressure and the roof live load or snow load and the dead load as provided in V.7.1.
- V.3.2.3 total design external pressure for the shell (P):** Sum of the specified external pressure and the external pressure due to wind as combined in V.8.1.2.

V.4 Construction Tolerances

The procedures prescribed in this appendix are only valid for tanks that satisfy the construction tolerances of 7.5.

• V.5 Corrosion Allowance

Unless specified otherwise by the Purchaser, the evaluation of tanks in accordance with the requirements of this appendix may be based on the as-built thickness of the pressure-resisting components, including any specified corrosion allowance. If the nature of the tank service conditions is such that corrosion will result in a uniform loss of thickness of the affected components, the Purchaser should specify that corrosion allowance be deducted from the as-built thickness used in the evaluation.

• V.6 Testing

Testing of the tank design for external pressure is not required by this appendix, but may be performed if specified by the Purchaser.

V.7 Fixed Roof

The total design external pressure loading, P_r , on the roof is determined by the following equation:

$$P_r = \text{The greater of } D_L + (L_r \text{ or } S) + 0.4 P_e \text{ or } D_L + P_e + 0.4 (L_r \text{ or } S)$$

V.7.1 COLUMN-SUPPORTED CONE ROOF

Column-supported cone roofs may be used on tanks designed for external pressure, providing the design and construction satisfy the following requirements.

- **V.7.1.1** The roof plate spanning between support rafters may be designed as a simple beam spanning several supports, or as a catenary beam spanning between supports, or as a diaphragm, by agreement between the Purchaser and the Manufacturer. Regardless of the design method selected, the following considerations shall be addressed in the design:
 - a. Allowable stress for both membrane and bending.
 - b. Joint efficiency of welds joining the roof plates together.
 - c. Assumed end fixity conditions for plate (beam) span.
 - d. Allowable deflection criteria.

If the roof plate is designed as a catenary beam, the following additional considerations shall be addressed in the design.

- e. Possibility of stress reversal and fatigue loading of welds at and between supports of the roof plate.

V.7.1.2 Additional guidance on the design of supported cone roof plates for pressure loading may be found in References 8 and 9, for example, and in other published texts.

V.7.2 SELF-SUPPORTING CONE ROOF

V.7.2.1 The required thickness of the roof plate is determined by the following equation. However, the thickness shall not be less than that required by 5.10.5.1.

In SI units:

$$t_{\text{cone}} = \frac{83D}{\text{sine}} \sqrt{\frac{P_r}{1.72E}}$$

In US Customary units:

$$t_{\text{cone}} = \frac{D}{\text{sine}} \sqrt{\frac{P_r}{0.248E}}$$

V.7.2.2 The total required cross-sectional area in the cone roof-to-shell joint region for external pressure on the roof is determined by the following equation.

In SI units:

$$A_{\text{reqd}} = \frac{125P_r D^2}{ft_{\text{ane}}}$$

In US Customary units:

$$A_{\text{reqd}} = \frac{P_r D^2}{8ft_{\text{ane}}}$$

V.7.2.3 The length of cone roof considered to be within the top tension/compression ring region is determined by the following equation (see Figure V.1A):

In SI units:

$$X_{\text{cone}} = 13.4 \sqrt{\frac{Dt_{\text{cone}}}{\text{sine}}}$$

In US Customary units:

$$X_{\text{cone}} = 1.47 \sqrt{\frac{Dt_{\text{cone}}}{\text{sine}}}$$

V.7.2.4 The vertical dimension measured from the top of the shell or top angle considered to be within the tension/compression ring region is determined by the following equation (see Figure V.1A):

In SI units:

For the top tension/compression region:

$$X_{\text{shell}} = 13.4 \sqrt{Dt_{st}}$$

For the bottom tension/compression region:

$$X_{\text{shell}} = 13.4 \sqrt{Dt_{sn}}$$

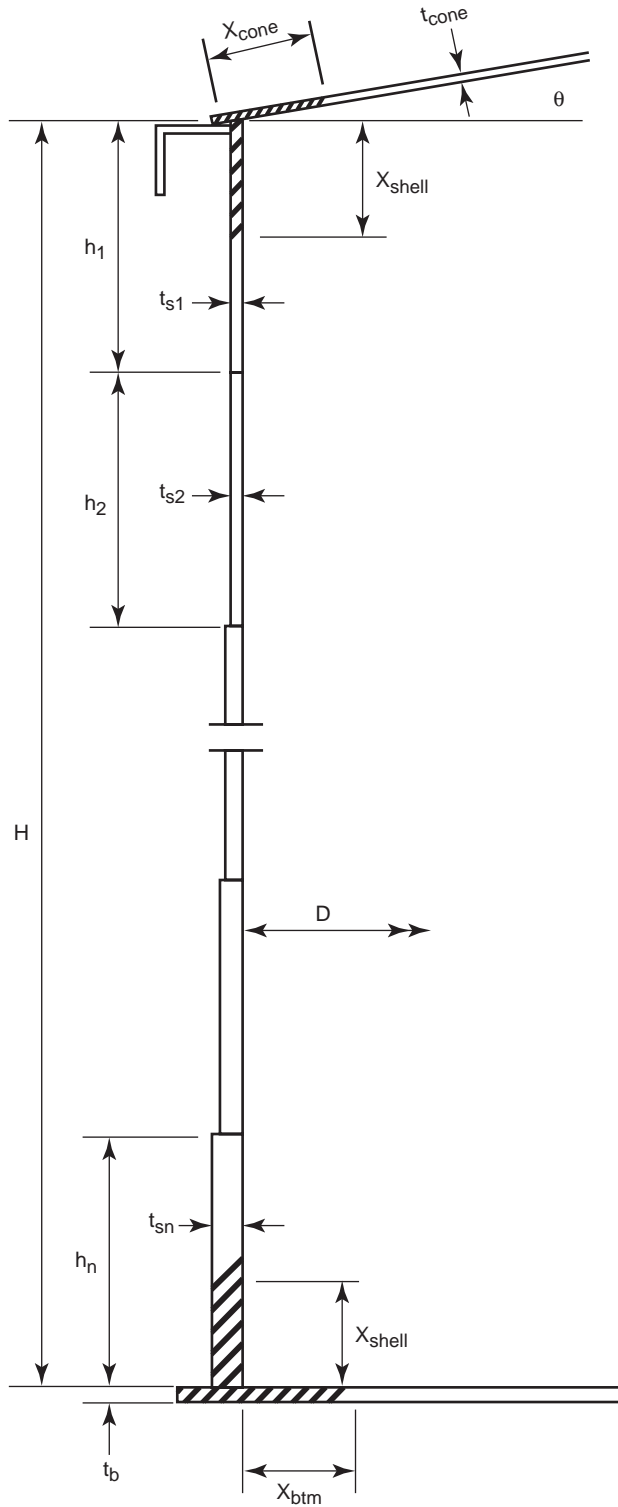
In US Customary units:

For the top tension/compression region:

$$X_{\text{shell}} = 1.47 \sqrt{Dt_{st}}$$

For the bottom tension/compression region:

$$X_{\text{shell}} = 1.47 \sqrt{Dt_{sn}}$$



Note: See Appendix F, Figure F-2 for alternative configurations and associated limitations on structural section used for top stiffener.

Figure V-1A—Dimensions for Self-Supporting Cone Roof

V.7.2.5 The required cross-sectional area of the top stiffener structural shape is determined by the following equation:

$$JE_{st}A_{stiff} = A_{reqd} - JE_{st}t_{s1}X_{shell} - JE_{r}t_{cone}X_{cone}$$

V.7.3 SELF-SUPPORTING DOME OR UMBRELLA ROOF

V.7.3.1 The required thickness of the roof plate is determined by the following equations. However, the thickness shall not be less than that required by 5.10.6.1. (Note that design in accordance with API Std 620 is permitted for dished dome roofs meeting the requirements of API Std 620, 5.10.5.1.)

In SI units:

$$t_{dome} = 127R \sqrt{\frac{P_r}{E}} \text{ (for umbrella and dome roofs)}$$

In US Customary units:

$$t_{dome} = 4.47R \sqrt{\frac{P_r}{E}} \text{ (for umbrella and dome roofs)}$$

V.7.3.2 The total required cross-sectional area in the dome or umbrella roof-to-shell joint region for external pressure on the roof is determined by the following equation. However, the area shall not be less than that required by 5.10.6.2.

In SI units:

$$A_{reqd} = \frac{300P_rRD}{f}$$

In US Customary units:

$$A_{reqd} = \frac{P_rRD}{3.375f}$$

V.7.3.3 The length of dome or umbrella roof considered to be within the top tension/compression ring region is determined by the following equation:

In SI units:

$$X_{dome} = 2.1 \sqrt{RT_{dome}}$$

In US Customary units:

$$X_{dome} = 2.1 \sqrt{RT_{dome}}$$

V.7.3.4 The length of shell considered to be within the top tension/compression ring region is determined by the following equation (see Figure V.1B):

In SI units:

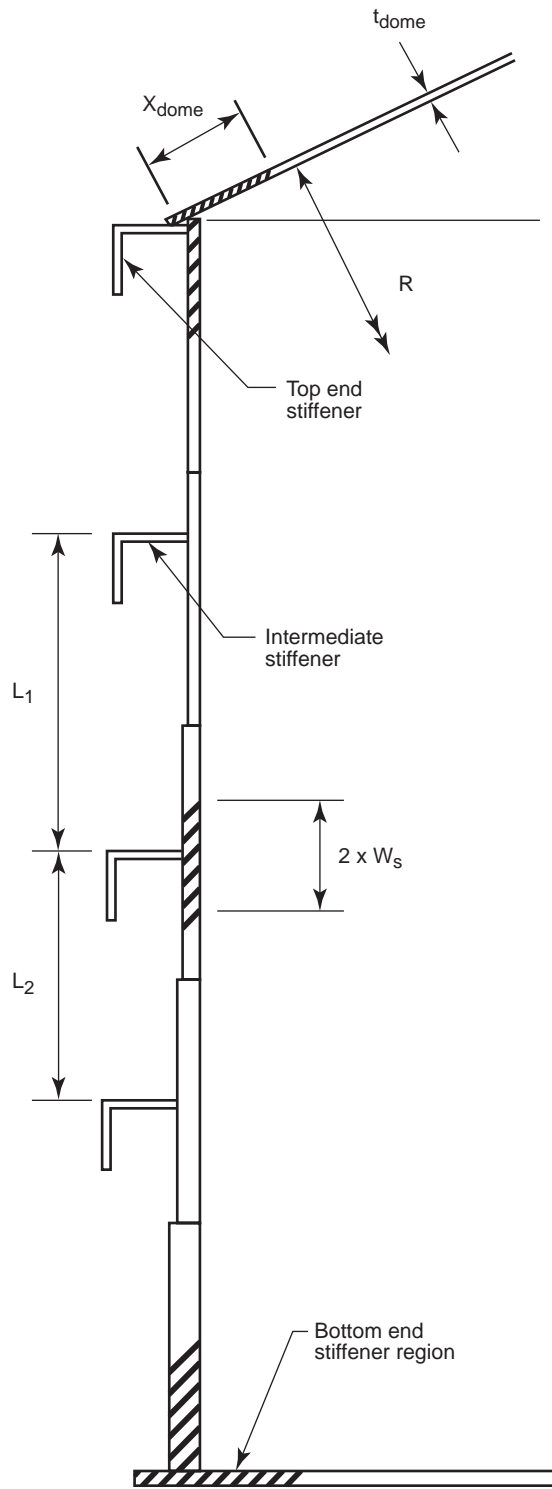
$$X_{shell} = 1.47 \sqrt{Dt_{st}}$$

In US Customary units:

$$X_{shell} = 1.47 \sqrt{Dt_{st}}$$

V.7.3.5 The required cross-sectional area of the top stiffener structural shape is determined by the following equation:

$$JE_{st}A_{stiff} = A_{reqd} - JE_{st}t_{s1}X_{shell} - JE_{r}t_{dome}X_{dome}$$



Note: See Appendix F, Figure F-2 for alternative configurations and associated limitations on structural section used for top stiffener.

Figure V-1B—Dimensions for Self-Supporting Dome Roof

V.8 Shell

• V.8.1 UNSTIFFENED SHELLS

The rules included herein are intended to be consistent with ASME/ANSI B96.1 except that the equations have been modified to reflect the higher modulus of elasticity for steel as compared to aluminum. The procedure utilizes the minimum thickness and the transformed shell method to establish intermediate stiffener number and locations. The equations are based on a factor of safety (F.O.S) of 3.0. If a F.O.S other than 3.0 is desired, the equations in V.8.1.2 and V.8.1.3 may be modified accordingly, with the written approval of the Purchaser. Additionally, if the specified vacuum pressure is less than or equal to 0.72 kPa (15 psf), a F.O.S of 2.0 may be used instead of 3.0. The equations also include a 0.8 “knockdown” factor for imperfections in the cylindrical shell geometry.

V.8.1.1 For an unstiffened tank 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 tanks. If this criterion is not satisfied, external pressure effects should be evaluated in accordance with the requirements of the ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1.

In SI units:

$$\left(\frac{D}{t_{s\min}}\right)^{0.75} \left[\left(\frac{H_{TS}}{D}\right) \left(\frac{F_y}{E}\right)^{0.5} \right] \geq 0.00675$$

In US Customary units:

$$\left(\frac{D}{t_{s\min}}\right)^{0.75} \left[\left(\frac{H_{TS}}{D}\right) \left(\frac{F_y}{E}\right)^{0.5} \right] \geq 0.19$$

The equations in the following sections are applicable, providing the shell satisfies the criterion of this section.

V.8.1.2 The design external pressure for an unstiffened tank shell shall not exceed:

In SI units:

$$P_s \leq \frac{E}{45,609 \left(\frac{H_{TS}}{D}\right) \left(\frac{D}{t_{s\min}}\right)^{2.5}}$$

In US Customary units:

$$P_s \leq \frac{0.2E}{\left(\frac{H_{TS}}{D}\right) \left(\frac{D}{t_{s\min}}\right)^{2.5}}$$

V.8.1.3 The equation in V.8.1.2 can be rewritten to calculate the minimum shell thickness required for a specified design external pressure as

In SI units:

$$t_{s\min} \geq \frac{73.05(H_{TS}P_s)^{0.4} D^{0.6}}{(E)^{0.4}}$$

In US Customary units:

$$t_{s\min} \geq \frac{1.903(H_{TS}P_s)^{0.4} D^{0.6}}{(E)^{0.4}}$$

* Source is The Structural Research Council (SSRC) text “Guide to Stability Design Criteria for Metal Structures,” Section 14.3.5.

V.8.1.4 For tanks with shell courses of varying thickness, the transformed shell height, H_{TS} , for the tank shell is determined in accordance with the following procedure:

- The transformed height of the shell is calculated as the sum of the transformed widths of the individual shell courses as described in Item b.
- The transformed width of each individual shell course is calculated by multiplying the actual shell height by the ratio $(t_{s1}/t_{act})^{2.5}$. Note that $t_{s1} = t_{act}$ for the top shell course.

The transformed shell height is determined from the following equation:

$$H_{TS} = h_1 \left(\frac{t_{s1}}{t_{s1}} \right)^{2.5} + h_2 \left(\frac{t_{s1}}{t_{s2}} \right)^{2.5} + \dots + h_n \left(\frac{t_{s1}}{t_{sn}} \right)^{2.5}$$

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

V.8.2 CIRCUMFERENTIALLY STIFFENED SHELLS

Tank shells may be strengthened with circumferential stiffeners to increase the resistance to buckling under external pressure loading. When circumferential stiffeners are used to strengthen the cylindrical shell to resist buckling due to external pressure, the design of the stiffeners shall meet the following requirements.

V.8.2.1 Number and Spacing of Intermediate Stiffener Rings

V.8.2.1.1 Calculate the transformed shell height in accordance with V.8.1.4. (See V.10 for a numerical example of the calculation of the transformed shell height.)

V.8.2.1.2 Calculate the maximum spacing of intermediate stiffeners. The equation in V.8.1.3 can be rearranged to solve for a “safe height” of shell, H_{safe} , as follows. H_{safe} is the maximum height of unstiffened shell permitted, based on the transformed shell thickness (t_{s1}).

In SI units:

$$H_{safe} = \frac{(t_{smin})^{2.5}(E)}{45,609D^{1.5}(P_s)}$$

In US Customary units:

$$H_{safe} = \frac{0.2(t_{smin})^{2.5}(E)}{D^{1.5}(P_s)}$$

V.8.2.1.3 Calculate the number of intermediate stiffeners required, N_s , based on H_{safe} , 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 V.8.2.1.4 and subsequent calculations.

$$N_s + 1 = L_s / H_{safe},$$

V.8.2.1.4 Calculate the spacing of intermediate stiffeners on the transformed shell height in accordance with the following equation:

$$\text{Spacing} = L_s / (N_s + 1),$$

V.8.2.2 Intermediate Stiffener Ring Design

V.8.2.2.1 The number of waves, N , into which a shell will theoretically buckle under uniform external pressure is determined in accordance with the following equation:

In SI units:

$$N^2 = \frac{445D^3}{\sqrt{t_{smin}H_{TS}^2}} \leq 100$$

In US Customary units:

$$N^2 = \frac{5.33D^3}{\sqrt{t_{smin}H_{TS}^2}} \leq 100$$

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.

V.8.2.2.2 The distance between adjacent intermediate stiffeners on the actual shell for shells of non-uniform thickness is determined in accordance with the following procedures.

- Maximum spacing, L_s , on minimum shell thickness, $t_{smin} = H_{TS} / (N_s + 1)$
- Maximum spacing, L_s on other shell thicknesses = $[H_{TS} / (N_s + 1)](t_{sx} / t_{smin})^{2.5}$, where t_{sx} is the individual shell thickness.
- Where the spacing between stiffeners includes different shell thicknesses, adjust the actual spacing using the transformed shell spacings adjusted accordingly. See V.10 for a numerical example of this procedure.

V.8.2.2.3 The radial load imposed on the stiffener by the shell is determined in accordance with the following equation:

In SI units:

$$Q = 1000P_sL_s$$

In US Customary units:

$$Q = \frac{P_sL_s}{12}$$

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

V.8.2.2.4 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} = The 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:

In SI units:

$$w_{shell} = 13.4\sqrt{Dt_{shell}} \text{ on each side of stiffener}$$

In US Customary units:

$$w_{shell} = 1.47\sqrt{Dt_{shell}} \text{ on each side of stiffener}$$

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

V.8.2.2.5 The required moment of inertia of the intermediate stiffener region, I_{reqd} is determined in accordance with the following equation:

In SI units

$$I_{reqd} = \frac{37.5 QD^3}{E(N^2 - 1)}$$

In US Customary units:

$$I_{reqd} = \frac{648 QD^3}{E(N^2 - 1)}$$

V.8.2.2.6 In addition to the moment of inertia requirements stated above, the intermediate stiffener region shall satisfy the following area requirements.

V.8.2.2.6.1 The total required cross-sectional area of the intermediate stiffener region, A_{reqd} , is determined in accordance with the following equation:

In SI units:

$$A_{reqd} = \frac{QD}{2f_c}$$

In US Customary units:

$$A_{reqd} = \frac{6QD}{f_c}$$

V.8.2.2.6.2 The required cross-sectional area of the intermediate stiffener structural shape alone, A_{stiff} , is determined in accordance with the following equation:

In SI units:

$$A_{stiff} = A_{reqd} - 26.84 t_{shell} \sqrt{D t_{shell}}$$

In US Customary units:

$$A_{stiff} = A_{reqd} - 2.94 t_{shell} \sqrt{D t_{shell}}$$

A_{stiff} (actual) must be greater than or equal to A_{stiff} required.

A_{stiff} (actual) must also be greater than or equal to $0.5 A_{reqd}$.

V.8.2.3 End Stiffeners

The actual moment of inertia of the end stiffener region, I_{act} must be greater than or equal to the total required moment of inertia of this region, I_{reqd} , where:

I_{act} = the actual moment of inertia of the end stiffener ring region, consisting of the combined moment of inertia of the end stiffener and the shell within a contributing distance on one side of the end stiffener. No credit shall be taken for the roof portion in this region, however credit may be taken for a portion of the bottom plate. The width of bottom plate considered effective as an end stiffener shall be not more than $16t_b$, where t_b is the thickness of the bottom or annular plates, unless a detailed stress analysis demonstrates that a greater width may be used. The contributing distance on one side of the stiffener is determined in accordance with the following equation:

In SI units:

For the top end stiffener:

$$w_{\text{shell}} = 13.4 \sqrt{Dt_{sl}}$$

For the bottom end stiffener:

$$w_{\text{shell}} = 13.4 \sqrt{Dt_{sn}}$$

In US Customary units:

For the top end stiffener:

$$w_{\text{shell}} = 1.47 \sqrt{Dt_{sl}}$$

For the bottom end stiffener:

$$w_{\text{shell}} = 1.47 \sqrt{Dt_{sn}}$$

V.8.2.3.1 The radial load imposed on the end stiffener by the shell is determined in accordance with the following equation:

In SI units:

$$V_1 = 250P_sH$$

In US Customary units:

$$V_1 = \frac{P_sH}{48}$$

V.8.2.3.2 The required moment of inertia of the end stiffener region, I_{reqd} is determined in accordance with the following equation:

In SI units

$$I_{\text{reqd}} = \frac{37.5V_1D^3}{E(N^2 - 1)}$$

In US Customary units:

$$I_{\text{reqd}} = \frac{684V_1D^3}{E(N^2 - 1)}$$

V.8.2.3.3 In addition to the moment of inertia requirements stated above, the end stiffener region shall satisfy the following area requirements.

V.8.2.3.3.1 The total required cross-sectional area of the end stiffener region, A_{reqd} , is determined in accordance with the following equation:

In SI units:

$$A_{\text{reqd}} = \frac{V_1D}{2f}$$

In US Customary units:

$$A_{\text{reqd}} = \frac{6V_1D}{f}$$

V.8.2.3.3.2 The required cross-sectional area of the end stiffener structural shape alone, A_{stiff} , is determined in accordance with the following equation:

For cone roof top end stiffener:

$$A_{\text{stiff}} = A_{\text{reqd}} - JE_r t_{\text{cone}} X_{\text{cone}} - JE_s t_{s1} X_{\text{shell}}$$

For dome or umbrella roof top end stiffener:

$$A_{\text{stiff}} = A_{\text{reqd}} - JE_r t_{s1} X_{\text{shell}} - JE_r t_{\text{dome}} X_{\text{dome}}$$

For bottom end stiffener:

$$A_{\text{stiff}} = A_{\text{reqd}} - JE_b t_b X_{\text{btm}} - JE_s t_{sn} X_{\text{shell}}$$

A_{stiff} (actual) must be greater than or equal to A_{stiff} (required).

V.8.2.4 Strength of Stiffener Attachment Weld

Stiffening ring attachment welds shall be sized to resist the full radial pressure load from the shell between stiffeners, and shear loads acting radially across the stiffener caused by external design loads carried by the stiffener (if any) and a computed radial shear equal to 2% of the stiffening ring's compressive load.

V.8.2.4.1 The radial pressure load from the shell shall be determined in accordance with the following formula:

$$V_{s1} = P_s L_s$$

V.8.2.4.2 The radial shear load shall be determined in accordance with the following formula:

$$v_s = 0.01 P_s L_s D$$

V.8.2.4.3 The weld shear flow due to the radial shear load shall be determined in accordance with the following formula:

$$V_{s2} = v_s q_s / I_s, \text{ where } q_s \text{ is the first moment of area of the stiffener.}$$

V.8.2.4.4 The combined load for the design of the weld shall be determined in accordance with the following formula:

$$W_w = (V_{s1}^2 + V_{s2}^2)^{1/2}$$

V.8.2.4.5 The minimum fillet weld leg size shall be the smallest of the shell thickness at the location of the stiffener, the stiffener thickness at the weld location, or 6 mm ($1/4$ in.).

V.8.2.5 Lateral Bracing of Stiffener

The projecting part of a stiffening ring without an outer vertical flange need not be braced if the width of the projecting part in a radial vertical plane does not exceed 16 times its thickness. When this condition is not satisfied, the stiffening ring shall be laterally braced in accordance with the requirements of API Std 620, 5.12.5.8.

V.9 Bottom

- **V.9.1** The bottom of the tank shall be evaluated for external pressure loading if either of the following conditions is applicable. These conditions do not need to be considered simultaneously unless specified by the Purchaser.

1. If the total design external pressure force on the bottom plate exceeds the sum of the weight of the bottom plates plus the weight of any product required by the Purchaser to remain in the tank when external pressure is acting, membrane stresses in the bottom must be evaluated.
2. If the area around the tank will be subject to flooding with liquid, provisions should be included in the design of the tank and its operating procedures to ensure that the tank contains sufficient liquid to counteract bottom uplift resulting from exter-

nal flooding conditions. If the tank cannot be filled with liquid of sufficient depth to counteract the uplift from the liquid pressure under the bottom of the tank, membrane stresses in the bottom must be evaluated.

V.9.2 In both of the above cases, the bottom may be evaluated as a membrane subjected to uniform loading and restrained by the compression ring characteristics of the bottom-to-shell junction. For column-supported roofs, the design of the columns shall consider the additional axial loading due to external pressure.

V.9.3 The following provisions apply when Condition 2 in V.9.1 exists.

V.9.3.1 Calculation of external (flooding) pressure:

The calculation of the hydrostatic external pressure due to flooding is performed using the equation:

$$P = G_{\text{out}}H,$$

Rule 1:

When flooding of the area surrounding a tank is possible, the most effective way to prevent damage to the shell or bottom is to maintain an equivalent or higher level of liquid inside the tank whenever flooding occurs. The required minimum level of liquid to be maintained inside the tank is calculated as follows:

$$(G_{\text{in}} \times H_{\text{in}}) + W_{\text{bott}}/(\pi \times R^2) \geq G_{\text{out}} \times H_{\text{out}},$$

Rule 2:

When it is not possible to satisfy the equation in Rule 1, the tank and anchorage, if used, shall be designed to safely resist the unbalanced pressure resulting from flood liquid. As a minimum, the following components shall be evaluated:

- **V.9.3.2 allowable stress:** Unless otherwise specified, the flooding described above may be considered a temporary loading and the allowable stress increased accordingly. However, the increase in allowable stress shall not exceed 33% of the basic allowable stress for the subject component when evaluating the component for flood loading.

V.9.3.3 anchorage: For tanks that are mechanically anchored, the anchorage devices shall be adequate to resist the uplift and shear forces resulting from the pressure due to external flood liquid. If the tank is not mechanically anchored, provisions should be made to guide the tank back into its original position when the flooding conditions recede.

V.9.3.4 attached piping and sump: Piping and other components connecting the tank to the ground or another structure shall be capable of withstanding, without damage or failure, loads and movements due to any unbalanced pressures resulting from flooding of the area around the tank. If a sump is used, the design of the sump shall consider the possibility of the sump floating out of its pit during a flooding event.

V.9.3.5 bottom plate: Under the pressure of external flood liquid without counterbalancing internal liquid, the bottom plate will tend to deform or “balloon” upwards. As the bottom deforms and is subject to additional unbalanced pressure, membrane stresses increase in the bottom plate. The bottom plate shall be capable of withstanding this deformation without overstress of the plate or the attaching welds.

V.9.3.6 corner joint: As the bottom plate deforms upwards, compressive stresses and bending stresses in the shell-to-bottom joint increase. The shell plate and bottom plate components of the shell-to-bottom joint within the effective compression ring limits shall be proportioned to maintain combined stresses within the yield strength corresponding to the weaker of the two components.

V.10 Example Calculations

The following example calculations illustrate, in US Customary units, the use of this appendix.

V.10.1 DATA

Tank diameter = 75 ft-0 in.

Tank shell height = 48 ft-0 in.

Design liquid level = 48 ft-0 in.

Specific gravity of liquid = 1.0

Allowable design stress, $S_d = 23,200 \text{ lb/in.}^2$

Allowable stress in tension ring, $f = 21,600 \text{ lb/in.}^2$

Minimum yield strength of all steel = $36,000 \text{ lb/in.}^2$

Specified corrosion allowance = None

Tank bottom plate thickness = $3/8 \text{ in.}$

Design external pressure = 0.6 lb/in.^2 g (86.4 lb/ft^2)

Design wind velocity (3-sec gust) = 120 mph (Maximum wind pressure, $W = 31 \text{ lb/ft}^2$)

Design snow load = 0 lb/ft^2

Roof design live load = 25 lb/ft^2

Modulus of Elasticity, $E = 30,000,000 \text{ lb/in.}^2$

Shell course heights and thicknesses calculated by the one-foot method are as follows:

Course Number	(H - 1) (ft)	Required Thickness (in.)	Minimum Thickness (in.)
1	7	0.059	$5/16^*$
2	15	0.126	$5/16^*$
3	23	0.193	$5/16^*$
4	31	0.261	$5/16^*$
5	39	0.328	0.328
6	47	0.395	0.395

* The thicknesses of the upper four shell courses were increased from those required for hydrostatic pressure to eliminate need for an intermediate wind girder.

V.10.2 EXTERNAL PRESSURE CALCULATIONS

1. Select roof type: Try a self-supporting cone roof with a 20-degree slope from horizontal.

From V.7,

$$P_r = \text{The greater of } D_L + (L_r \text{ or } S) + 0.4P_e \text{ or } D_L + P_e + 0.4(L_r \text{ or } S),$$

where:

$$D_L = 20.4 \text{ lb/ft}^2 \text{ (Estimated assuming } 1/2\text{-in. roof plate),}$$

$$L_r = 25 \text{ lb/ft}^2,$$

$$S = 0 \text{ lb/ft}^2,$$

$$P_e = 0.6 \text{ lb/in.}^2 = 86.4 \text{ lb/ft}^2,$$

$$P_r = 20.4 + 25 + 0.4(86.4) = 80.0 \text{ lb/ft}^2, \text{ or,}$$

$$P_r = 20.4 + 86.4 + 0.4(25) = 116.8 \text{ lb/ft}^2 \text{ (Governs).}$$

The required thickness of the cone roof plate is calculated from V.7.2.1, as follows:

$$t_{\text{cone}} = \frac{D}{\text{sine}} \sqrt{\frac{P_r}{0.248E}}$$

$$t_{\text{cone}} = \frac{75}{0.342} \sqrt{\frac{116.8}{7,440,000}}$$

$t_{\text{cone}} = 0.869 \text{ in.}$, this thickness is not practical. Consider a supported cone roof or a self-supporting dome roof.

Try a lap-welded dome roof with a dish radius of $1.0 \times D = 1.0 \times 75 = 75$ ft. Assuming the plate weight does not change significantly, the required thickness of the dome plate is calculated from **V.7.3.1** as follows:

$$t_{\text{dome}} = 4.47R \sqrt{\frac{P_r}{E}}$$

$$t_{\text{dome}} = 4.47(75) \sqrt{\frac{116.8}{30,000,000}}$$

$t_{\text{dome}} = 0.661$ in., this thickness is not practical for lap-welding.

Consider a butt-welded dome roof with a dish radius of $0.8 \times D = 0.8 \times 75 = 60$ ft-0 in. Again assuming the plate weight does not change significantly, the required thickness of the dome plate is calculated from **V.7.3.1** as follows:

$$t_{\text{dome}} = 4.47R \sqrt{\frac{P_r}{E}}$$

$$t_{\text{dome}} = 4.47(60) \sqrt{\frac{116.8}{30,000,000}}$$

$t_{\text{dome}} = 0.529$ in., this thickness is practical for butt-welding. (Alternatively, a supported cone roof could be used.)

2. Calculate the roof tension ring area required at the junction of the roof and cylindrical shell:

From **V.7.3.2**, the required tension ring area is calculated as follows:

$$A_{\text{reqd}} = \frac{P_r R D}{3.375 f}$$

$$A_{\text{reqd}} = \frac{116.8(60)(75)}{3.375(21,600)}$$

$$A_{\text{reqd}} = 7.21 \text{ sq. in.}$$

From **V.7.3.3**, the length of effective roof plate contributing to the tension ring area is calculated as follows:

$$X_{\text{dome}} = 2.1 \sqrt{R T_{\text{dome}}}$$

$$X_{\text{dome}} = 2.1 \sqrt{60(0.529)}$$

$$X_{\text{dome}} = 11.7 \text{ in.}$$

From **V.7.3.4**, the length of effective shell plate contributing to the tension ring area is calculated as follows:

$$X_{\text{shell}} = 0.43 \sqrt{D t_{s1}}$$

$$X_{\text{shell}} = 0.43 \sqrt{75(12)(0.3125)}$$

$X_{\text{shell}} = 7.21$ in. (Note: This value should be recalculated, if necessary, after selection of final shell thickness.)

From **V.7.3.5**, the required area of the stiffener (assuming $JE_{st} = 1.0$) is calculated as follows:

$$JE_{st} A_{\text{stiff}} = A_{\text{reqd}} - E_1 t_{s1} X_{\text{shell}} - E_1 t_{\text{dome}} X_{\text{dome}}$$

$$(1.0) A_{\text{stiff}} = 7.21 - (0.85)(0.3125)(7.21) - (0.85)(0.529)(11.7)$$

$$A_{\text{stiff}} = 0.03 \text{ sq. in., use a stiffener with an area } \geq 0.03 \text{ sq. in.}$$

Note: This value should be recalculated, if necessary, after selection of final shell thickness.)

3. Check that buckling will occur elastically in the unstiffened cylindrical shell:

From V.8.1.1, elastic buckling will occur if the following equation is satisfied:

$$\left(\frac{D}{t_{smin}}\right)^{0.75} \left[\left(\frac{H_{TS}}{D}\right)\left(\frac{F_y}{E}\right)^{0.5}\right] \geq 0.00675$$

$$\left(\frac{75}{0.3125}\right)^{0.75} \left[\left(\frac{43.54}{75}\right)\left(\frac{36}{30,000}\right)^{0.5}\right] = 1.23 \geq 0.19, \text{ thus buckling will be elastic.}$$

Note: This value should be recalculated, if necessary, after selection of final shell thickness.)

4. Calculate the minimum shell thickness required for the combined loading from design external pressure and wind:

From V.8.1.3, the required minimum shell thickness is calculated as follows:

$$t_{smin} \geq \frac{1.903(H_{TS}P_s)^{0.4} D^{0.6}}{(E)^{0.4}}$$

where

P_s = the greater of 1) the specified design external pressure excluding wind or 2) $W + 0.4P_e$, where W is the specified design wind pressure, lb/ft²,

$$P_s = 0.6 \text{ lb/in}^2 = 86.4 \text{ lb/ft}^2 \text{ or } 31 + 0.4(86.4) = 65.6 \text{ lb/ft}^2.$$

$$t_{smin} \geq \frac{1.903(43.54(86.4))^{0.4} 75^{0.6}}{(30,000,000)^{0.4}}$$

$$t_{avg} \geq 0.703 \text{ in.}$$

5. Calculate the transformed shell height:

Course Number	Actual Shell Course Height (ft)	Thickness (in.)	Transformed Shell Course Height * (ft)
1	8	0.3125	8.00
2	8	0.3125	8.00
3	8	0.3125	8.00
4	8	0.3125	8.00
5	8	0.328	7.09
6	8	0.395	4.45
Sum =	48 ft	Sum =	43.54 ft
* For example, the transformed height of No. 5 shell course = $(0.3125/0.328)^{2.5}(8) = 7.09$ ft (see V.8.1.4.b)			

The required minimum thickness is greater than the available thickness and the shell must be stiffened.

6. Calculate the maximum spacing of intermediate stiffeners:

From V.8.2.1.2,

$$H_{safe} = \frac{0.2(t_{smin})^{2.5}(E)}{D^{1.5}(P_s)}$$

$$H_{safe} = \frac{0.2(0.3125)^{2.5}(30,000,000)}{(75)^{1.5}(733.36)(86.4)}$$

$$H_{safe} = 5.84 \text{ ft}$$

7. Calculate the number of intermediate stiffeners required, N_s , based on H_{safe} :

From V.8.2.1.3,

$$N_s + 1 = H_{TS} / H_{\text{safe}}$$

$$N_s + 1 = 43.54 / 5.84 = 7.46$$

$$N_s = 7$$

$$\text{Actual spacing for 7 stiffeners} = 43.54 / 8 = 5.44 \text{ ft}$$

8. Calculate the intermediate stiffener spacing for the non-uniform shell thickness:

From V.8.2.2.2,

Intermediate stiffener spacing on 0.3125-in. shell plate is,

$$L_s = H_{TS} / (N_s + 1) = 43.54 / (7 + 1) = 5.44 \text{ ft}$$

Intermediate stiffener spacings on 0.328 in. and 0.395 in. shell plate are,

$$L_s = [H_{TS} / (N_s + 1)](t_{sx} / t_{smin})^{2.5}$$

$$L_s = [43.54 / (8)](0.328 / 0.3125)^{2.5} = 6.14 \text{ ft}$$

$$L_s = [43.54 / (8)](0.395 / 0.3125)^{2.5} = 9.77 \text{ ft}$$

Locate 5 stiffeners on 0.3125 in. shell at spacing = 5.44 ft

Locate the 6th stiffener as follows:

$$\text{Available } 5/16\text{-in. shell plate} = (4 \times 8 \text{ ft}) - (5 \times 5.44 \text{ ft}) = 4.8 \text{ ft}$$

$$\text{Length of 0.328-in. shell required} = (5.44 - 4.8) \times (0.328 / 0.3125)^{2.5} = 0.722 \text{ ft}$$

$$\text{Location of 6}^{\text{th}} \text{ stiffener} = 32 + 0.722 = 32.722 \text{ ft from top of tank}$$

$$\text{Location of 7}^{\text{th}} \text{ stiffener} = 32.722 + 6.14 = 38.862 \text{ ft}$$

Check that the remaining unstiffened shell length is equal to the transformed shell stiffener spacing:

$$\text{Difference between actual and transformed shell height} = 48 - 43.55 = 4.45 \text{ ft}$$

$$\text{Length of 0.328-in. shell below stiffener} = 40 - 38.862 = 1.138 \text{ ft}$$

$$\text{Transformed shell stiffener spacing} = 1.138 \times (0.3125 / 0.328)^{2.5} + 4.45 = 5.44 \text{ ft} - \text{OK}$$

9. If fewer stiffeners and thicker shell plates is a more economical solution, the design can be adjusted as follows:

Assume, for this example, a uniform shell thickness equal to the thickness of the lowest shell course, i.e., $t_{\text{avg}} = 0.395$ in.

H_{safe} is then calculated as follows:

$$H_{\text{safe}} = \frac{0.2(0.395)^{2.5}(30,000,000)}{(75)^{1.5}(733.36)(86.4)}$$

$$H_{\text{safe}} = 10.48 \text{ ft}$$

For $t_{\text{avg}} = 0.395$ in., H_{TS} is recalculated to be equal to 48 ft

The number of stiffeners required is:

$$N_s + 1 = 48 / 10.48 = 4.58; N_s = 4$$

$$\text{Actual spacing for 4 stiffeners} = 48 / 5 = 9.6 \text{ ft}$$

10. Calculate the number of buckling waves:

From V.8.2.2.1,

$$N^2 = \sqrt{\frac{5.33D^3}{t_{s\min}L_s^2}} \leq 100; L_s = (L_1 + L_2)/2 = (9.6 + 9.6)/2 = 9.6\text{ ft.}$$

$$N^2 = \sqrt{\frac{5.33(75)^3}{(0.395)(9.6)^2}} = 249 > 100; N = > 10, \text{ therefore use } 10.$$

11. Calculate the radial load on a circumferential stiffener placed 9.6 ft from the top of the shell.

From V.8.2.2.3, the radial load is calculated as follows:

$$Q = \frac{P_s L_s}{12}; \text{ where } P_s = 86.4 \text{ lb/ft}^2$$

$$Q = \frac{(86.4)(9.6)}{12} = 69.1 \text{ lb/in.}$$

12. Calculate the total contributing shell width acting with the intermediate stiffener:

From V.8.2.2.4,

$$2 \times w_{\text{shell}} = 2 \times 1.47 \sqrt{Dt_{\text{shell}}}; \text{ where } t_{\text{shell}} = 0.395 \text{ in.}$$

$$2 \times 1.47 \sqrt{(75)(0.395)}; 16.0 \text{ in.}$$

13. Calculate the required moment of inertia of the intermediate stiffener region:

From V.8.2.2.5, the required moment of inertia is calculated as follows:

$$I_{\text{reqd}} = \frac{648QD^3}{E(N^2 - 1)}$$

$$I_{\text{reqd}} = \frac{648(69.1)(75)^3}{30,000,000(100 - 1)}$$

$$I_{\text{reqd}} = 6.36 \text{ in.}^4$$

14. Calculate the total area required in the intermediate stiffener region:

From V.8.2.2.6.1, the required area is calculated as follows:

$$A_{\text{reqd}} = \frac{6QD}{f}$$

$$A_{\text{reqd}} = \frac{6(69.1)(75)}{(14,400)}$$

$$A_{\text{reqd}} = 2.16 \text{ in.}^2$$

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07 | 15. Calculate the required area of the stiffener section:

From V.8.2.2.6.2, the required area is calculated as follows:

$$A_{\text{stiff}} = A_{\text{reqd}} - 2.94t_{\text{shell}}\sqrt{Dt_{\text{shell}}}$$

$$A_{\text{stiff}} = 2.16 - 2.94(0.395)\sqrt{(75)(0.395)}$$

$$A_{\text{stiff}} = -4.2 \text{ in.}^2; \text{ the stiffener section area must be } \geq 1.08 \text{ sq. in. } (= 1/2 \times A_{\text{reqd}})$$

Select a rolled section that will satisfy the area and inertia requirements. By inspection, since the stiffener spacing is constant, the section selected is adequate for all 4 stiffeners.

07 | 16. Calculate the required properties of the top stiffener:

From V.8.2.3, the contributing distance of the cylindrical shell is calculated as follows:

$$W_{\text{shell}} = 1.47\sqrt{Dt_{s1}}$$

$$W_{\text{shell}} = 1.47\sqrt{(75)(0.395)}$$

$$W_{\text{shell}} = 8.0 \text{ in.}$$

From V.8.2.3.1, the radial load on the top stiffener is calculated as follows:

$$V_1 = \frac{P_s H}{48}$$

$$V_1 = \frac{86.4(48)}{48}$$

$$V_1 = 86.4 \text{ lb/in.}$$

From V.8.2.3.2, the required moment of inertia of the top stiffener is calculated as follows:

$$I_{\text{reqd}} = \frac{684V_1 D^3}{E(N^2 - 1)}$$

$$I_{\text{reqd}} = \frac{684(86.4)(75)^3}{30,000,000(99)}$$

$$I_{\text{reqd}} = 8.39 \text{ in.}^4$$

From V.8.2.3.3.1, the required area of the top stiffener region is calculated as follows:

$$A_{\text{reqd}} = \frac{6V_1 D}{f}$$

$$A_{\text{reqd}} = \frac{6(86.4)(75)}{21,600}$$

$$A_{\text{reqd}} = 1.80 \text{ sq. in.}$$

From V.8.2.3.3.2, the required area of the top stiffener section is calculated as follows:

$$A_{\text{stiff}} = A_{\text{reqd}} - JE_s t_s X_{\text{shell}} - JE_r t_{\text{dome}} X_{\text{dome}}$$

$$A_{\text{stiff}} = 1.80 - (0.85)(.395)(8.0) - (0.85)(0.529)(11.7) = -6.15 \text{ in.}$$

The stiffener section area must be ≥ 0.90 sq. in. ($= 1/2 \times A_{\text{total}}$)

Select a rolled section that will satisfy the area and inertia requirements.

17. Calculate the required properties of the bottom stiffener region:

From V.8.2.3, the contributing distance of the cylindrical shell is calculated as follows:

$$W_{\text{shell}} = 1.47 \sqrt{Dt_{sn}}$$

$$W_{\text{shell}} = 1.47 \sqrt{(75)(0.395)}$$

$$W_{\text{shell}} = 8.0 \text{ in.}$$

From V.8.2.3.2, the required moment of inertia of the bottom stiffener is calculated as follows:

$$I_{\text{reqd}} = \frac{684 V_1 D^3}{E(N^2 - 1)}$$

$$I_{\text{reqd}} = \frac{684(86.4)(75)^3}{30,000,000(99)}$$

$$I_{\text{reqd}} = 8.39 \text{ in.}^4$$

From V.8.2.3.3.1, the required area of the bottom stiffener region is calculated as follows:

$$A_{\text{reqd}} = \frac{6V_1 D}{f}$$

$$A_{\text{reqd}} = \frac{6(86.4)(75)}{21,600}$$

$$A_{\text{reqd}} = 1.80 \text{ sq. in.}$$

From V.8.2.3.3.2, the required area of the bottom stiffener section is calculated as follows:

$$A_{\text{stiff}} = A_{\text{reqd}} - JE_s t_{sn} X_{\text{shell}} - JE_b t_b X_{\text{btm}}$$

$$A_{\text{stiff}} = 1.80 - (0.85)(.395)(8.0) - (0.85)(0.375)(6.0) = -2.80 \text{ in.}$$

The contributing portion of the shell-to-bottom joint has a calculated moment of inertia of 20.2 in.^4 and will satisfy the area and inertia requirements. Thus, an additional stiffener is not necessary.

V.11 Technical Basis of This Appendix

The organization of this appendix was modeled after a proprietary DuPont Standard SG 11.4 S. API appreciates DuPont's consent to utilize their standard as a model without any restriction or reservation to develop this appendix. The equations prescribed in this appendix were generally extracted from the same proprietary standard and are based on the same fundamental equations from various public domain references used to develop the proprietary standard. However, where appropriate, the nomenclature was changed to be consistent with API Std 650. Some equations have been modified from the proprietary standard to be consistent with API Std 650 safety factors or other design considerations. For example, some equations have been modified to be consistent with Reference 2. Where necessary, equations have been added for consistency with API Std 650 design principles, such as incorporation of the transformed shell method.

V.12 References

1. DuPont Corporate Engineering Standard SG11.4S, *Field Erected Storage Tank Design Procedures*, Section 5, External Pressure Design.
2. API Publication, *Stability of API Standard 650 Tank Shells*, Raymund V. McGrath.
3. The Structural Research Council (SSRC), *Guide to Stability Design Criteria for Metal Structures*, Section 14.3.5.
4. Code Case 2286, "Alternative Rules for Determining Allowable Compressive Stresses for Cylinders, Cones, Spheres and Formed Heads," Cases of ASME *Boiler and Pressure Vessel Code*.
5. Welding Research Council Bulletin 406, "Proposed Rules for Determining Allowable Compressive Stresses for Cylinders, Cones, Spheres and Formed Heads," C. D. Miller and K. Mokhtarian.
6. American Society of Mechanical Engineers (ASME) *Boiler and Pressure Vessel Code*, Section VIII, Division 1.
7. American Iron & Steel Institute (AISI) Publication, *Steel Plate Engineering Data, Volume 2*.
8. ASME Paper 65-MET-15, "Theoretical and Experimental Study of Steel Panels in Which Membrane Tension is Developed," by J. S. McDermott.
9. Machine Design Magazine, December 9, 1976, "Stress Analysis of Pressurized Panels," by J. A. Martinelli.

APPENDIX W—COMMERCIAL AND DOCUMENTATION RECOMMENDATIONS

- The following commercial and documentation recommendations apply to all tanks when specified by the Purchaser on the Data Sheet.

- **W.1 Document Submittals and Review**

- **W.1.1 GENERAL**

1. Technical documents listed below shall be submitted by the Manufacturer for review by the Purchaser at specified times during a project. Additional documents may be required and shall be a matter of agreement between the Purchaser and the Manufacturer. Submittals and reviews shall be in accordance with contractual schedule agreements. All documents shall be in reproducible form agreeable to the Purchaser.

2. Unless specified otherwise by the Purchaser, the minimum required content of the technical documentation packages shall be as described in this appendix.

- **W.1.2 QUOTATION OR BID DOCUMENT PACKAGE**

1. All quotations shall be submitted in accordance with this Standard and Purchaser's requirements listed in the Data Sheet. In addition, a second quotation containing alternates to Purchaser's requirements may be quoted for Purchaser's consideration provided the alternates are clearly marked as such and are completely described in that bid.

2. The Manufacturer shall mark and return the Purchaser's previously prepared Data Sheet. Some entries will not be determined until completion of negotiations and/or completion of the detailed design. Such entries may remain blank for this submittal. The bid shall include the design wind speed and design snow load that will be used in the design by the Manufacturer.

3. The Manufacturer shall provide a list of all engineered accessories being purchased from suppliers, indicating the Manufacturer, and model or part number. Alternatively, when a specific Manufacturer is not known at the time of bidding, a list of Manufacturer-approved suppliers may be submitted. Excluded from the list requirement are commodities such as plate, pipe, flanges, and bolts. Included in the list are items such as floating roofs, dome roofs, roof seals, pressure vents, gauges, and instrumentation. Also, see C.1.1.

- **W.1.3 DESIGN REVIEW DOCUMENT PACKAGES**

Unless specified otherwise, a Purchaser's review of Manufacturer's design calculations and general arrangement drawings is required before the order of materials. Unless specified otherwise, the Purchaser's review of the documents listed in Items 3 through 7 below is required prior to the start of fabrication. Work may begin following conclusion of any negotiations generated by the review process. A copy of the review packages with any annotations including nozzle size, orientations, projections, placement and elevations of ladders, platforms, stairs, and attachments, etc., shall be returned to the Manufacturer. The Manufacturer shall promptly revise/update the drawings, calculations, and information on the **Data Sheet** showing all review-generated changes and shall submit copies to the Purchaser. The Design Review Document shall consist of at least the following:

1. Manufacturer's design calculations as described in W.2 and structural loads for foundation design.
2. General arrangement drawings with complete material specification.
3. Detailed fabrication drawings.
4. Welding procedure specifications (WPSs) and procedure qualification records (PQRs). This shall include weld hardness criteria when required by the Purchaser. Review of duplicate weld procedures for multiple tanks is not required when written permission is received from the Purchaser.
5. Heat treatment procedures (if required).
6. Nondestructive examination procedures and testing procedures.
7. Description of proposed test gaskets (see 4.9), including material properties, dimensions, and design characteristics.

W.1.4 INTERIM DOCUMENTS DURING CONSTRUCTION

The Manufacturer shall promptly submit revised documents describing any design or construction changes to the Purchaser. Copies of Material Test Reports applicable to components listed in 4.2.9.1 shall be forwarded to the Purchaser upon receipt of the reports.

• W.1.5 POST-CONSTRUCTION DOCUMENT PACKAGE

Upon completion of construction and testing, copies of a Manufacturer's data book shall be supplied in the quantities specified in the contract. Each copy shall contain at least the documents listed below:

1. Final general arrangement and detail fabrication drawings, marked "as-built" by the Manufacturer, complete with dimensions and data, with complete materials specification and parts list.
2. Design calculations described in W.2.
3. Copies of Material Test Reports applicable to shell plates and annular plates.
4. Reports of the results of all tests including weld hardness (when weld hardness criteria are specified), and reports of all nondestructive examinations. Radiographic films shall also be included. For tank pressure test data, include results and duration of pressure test(s), test water level, fill rate, imposed pneumatic pressure, hold times, drain rate, etc.
5. Shell and bottom elevation measurements for hydro-test.
6. Nameplate facsimile.
7. Manufacturer's certification per Figure 10-2.
8. The **Data Sheet** reflecting as-built conditions.
9. A drawing that lists the following for each shell course:
 - a. The required shell thicknesses for both the design condition (including corrosion allowance) and the hydrostatic test condition.
 - b. The nominal thickness used.
 - c. The material specification.
 - d. The allowable stresses.
10. Nominal thicknesses used for materials other than shell plates.
11. Handling criteria and rigging instructions (for shop-built tanks only).

W.2 Manufacturer's Calculations

All manual calculations shall include relevant formulas and source paragraphs in this Standard or in other specifications or engineering practices, values used in the formulas, calculated results, and acceptance criteria used. Where a computer program performs design calculations, a program description shall be given, including name and version of the program, program limitations and assumptions used, and a brief description of what the program does. These calculations and/or computer programs shall address at least the following:

1. Determination of design thicknesses for all pressure boundary elements to satisfy all specified loading conditions, which may include contents, pressure, partial vacuum, dead loads, live loads, snow loads, rain loads, roof flotation, dike or flood plain partial submergence, wind, and seismic activity.
2. Overturning check and anchorage due to wind forces, seismic forces, and internal pressure, if applicable.
3. Seismic design requirements (e.g., base shear, longitudinal compression, sliding friction resistance checks, overturning moment checks, and anchorage), if applicable.
4. Shell stability checks to determine whether shell stiffeners or increased shell course thicknesses will be required.
- 5. Unless specified otherwise by the Purchaser, whenever the tank diameter exceeds 36 m (120 ft), shell stiffness coefficients, maximum unrestrained radial deflection, angle of rotation of bottom course shell nozzles, and the nomographs for moments and forces that these nozzles can safely sustain from connected piping shall be provided in accordance with pro-

visions of Appendix P. Alternate analysis techniques, such as the finite element method, may also be used to satisfy this requirement.

- 6. Any additional calculations specified by the Purchaser to show compliance with this Standard and any appendices invoked.

W.3 Manufacturer's Drawing Contents

All Manufacturer's drawings shall be thoroughly checked for accuracy and completeness before sending for Purchaser review. Manufacturer's drawing(s) shall show, as a minimum, the following information:

- 1. An updated list of drawings for each tank shall be resubmitted each time drawings are revised and reissued.
- 2. Identification of the storage tank as designated by the Purchaser.
- 3. Reference to applicable practices, standards, specifications, details, and associated drawings and sketches.
- 4. Materials of construction, designated corrosion allowance(s), and gasket specifications.
- 5. Extent of postweld heat treatments.
- 6. Extent of radiography to be applied to bottom, shell, and roof butt-welds.
- 7. Shell design joint efficiencies, for Appendices A, J, and S.
- 8. Complete details and dimensions of the tank, including external and internal attachments and appurtenances supplied by Manufacturer and sub-contractors.
- 9. Bottom slope.
- 10. Nominal plate thicknesses for shell, roof, reinforcement, and bottom.
- 11. Location of all welded seams. All welds shall be either pictorially detailed or identified by use of the standard welding symbols of ANSI/AWS A2.4. Welding procedures shall be listed for each weld. A "weld map" may be used if it clearly indicates the weld procedure specification used for every joint.
- 12. For flanges other than those conforming to ASME B16.5 or ASME B16.47, and marked accordingly, show all dimensions and finish of flange face.
- 13. Facsimile of nameplate with data to be stamped thereon with location and details of fabrication of nameplate bracket.
- 14. Empty, operating, and test weight of tank.
- 15. Loads on foundation as also shown on the **Data Sheet**, Line 13.
- 16. Foundation plans and construction details (if supplied by the Manufacturer or the sub-contractor).

W.4 Bids for Floating Roofs

- **W.4.1** Bids for tanks having floating roofs shall contain sufficient engineering data, including material specifications for both metallic and non-metallic components, nominal thicknesses, and sufficient information (see C.3.4.1 and C.3.4.2 or H.2.1, as applicable) to enable the Purchaser to verify that the bidder has considered all specified design requirements.
- W.4.2** Manufacturer shall list in the quotation all roof accessories furnished and included in the base price of the roof. If any accessories are purchased from other suppliers, the Manufacturer shall provide that supplier's name and the model or part number.
- W.4.3** Manufacturer shall state the lowest and highest operating level of roof in the quotation.
- W.4.4** Manufacturer shall clearly describe the extent of electrical grounding and shunts included as a part of the floating roof design.
- W.4.5** Manufacturer shall provide a cross-section of all seals showing materials and complete details of construction with the bid.
- W.4.6** The Manufacturer shall submit with the bid the minimum and the maximum allowable annular space between the roof and shell, as well as the maximum and minimum annular space the proposed roof seal system can accommodate.
- W.4.7** Manufacturer shall specify size, number, and type of drains with the quotation (external roof only).

W.4.8 The bid shall state if a wind skirt, a top-shell extension, or overflows will be required for proper functioning of the roof seal (external roof only).

W.4.9 The Manufacturer of the external floating roof shall prepare and submit to the Purchaser the following calculations:

- **W.4.9.1** Calculations showing that the roof design complies with the buoyancy requirements of C.3.4.1a, for both single-deck and double-deck roofs using the smaller of the specific gravity in C.3.4.1 (0.7), or the minimum specific gravity of the product specified on the Data Sheet, Line 5.

W.4.9.2 Calculations showing that the roof design complies with the punctured compartment loading condition for single-deck pontoon roofs and for double deck roofs as specified in C.3.4.1b.

W.4.9.3 Calculations showing that the design of the roof and roof supports satisfies C.3.10.2.

W.4.10 The Manufacturer of the internal floating roof shall prepare and submit to the Purchaser the following calculations, considering internal floating roof deflections and stresses for each of the load conditions required by Appendix H. All calculations for the floating condition shall be based upon the design specific gravity (per H.4.2.1.1).

W.4.10.1 Calculations showing that the roof design complies with the buoyancy requirements of H.4.2.1.

W.4.10.2 Calculations showing that the roof design complies with the punctured compartment loading condition for single-deck pontoon roofs and for double deck roofs as specified in H.4.2.3.

W.4.10.3 Calculations showing that the design of the roof and roof supports in the landed condition satisfies H.4.2.2.2.

W.4.11 The internal floating roof Manufacturer shall specify the internal floating roof weight and total flotation displacement provided based on a flotation level for design specific gravity per H.4.2.1.

• **W.5 Jobsite Responsibilities**

Unless otherwise specified by the Purchaser, the Manufacturer shall furnish all labor, tools, equipment, supplies, materials, utilities (including power for welding), storage, and personnel services necessary for, and reasonably incidental to, the delivery of materials to the site, the construction of the tank(s), and the removal of surplus and scrap materials from the job site. See the Data Sheet (see Line 14) for the Manufacturer's additional post-hydro-test responsibilities. The Purchaser shall furnish and dispose of the water for hydro-testing the tank from the tie-in points as designated on the Data Sheet, Line 14.



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