American Petroleum Institute
1220 L Street, Northwest
Washington, D.C. 20005-4070
202-682-8000

Date: November 2001
To: Purchasers of API Standard 650, *Welded Steel Tanks for Oil Storage*, Tenth Edition
Re: Addendum 2

This package contains Addendum 2 of API Standard 650, *Welded Steel Tanks for Oil Storage*, Tenth Edition. This package consists of the pages that have changed since the December 2000 printing of Addendum 1.

To update your copy of API Standard 650, replace the following pages as indicated:

Part of Book Changed	Old Pages to be Replaced	New Pages
Cover	front and back covers	front and back covers
Front Matter	title page, iii–iv	title page, iii–iv
Table of Contents	v–ix (+blank)	v–ix (+blank)
Section 1	1-1–1-5 (+blank)	1-1–1-5 (+blank)
Section 2	2-3–2-10	2-3–2-10
Section 3	3-3–3-8	3-3–3-8
	3-11–3-12	3-11–3-12
	3-17–3-18	3-17–3-18
	3-21–3-32	3-21–3-32
	3-39–3-40	3-39–3-40
	3-45–3-46	3-45–3-46
	3-49–3-51(+blank)	3-49–3-51 (+blank)
Section 4	4-1 (+blank)	4-1 (+blank)
Section 5	5-1–5-4	5-1–5-4
Section 6	6-1–6-4	6-1–6-5 (+blank)
Appendix E	E-3–E-6	E-3–E-6
Appendix F	F-1–F-6	F-1–F-6
Appendix G	G-5–G-6	G-5–G-6
Appendix H	H-1–H-5 (+blank)	H-1–H-7 (+blank)
Appendix I	I-7–I-9 (+blank)	I-7–I-9 (+blank)
Appendix J	J-3 (+blank)	J-3 (+blank)
Appendix L	L-7 (+blank)	L-7 (+blank)
Appendix M	M-3–M-4	M-3–M-4
Appendix P	P-1–P-4	P-1–P-4
	P-9–P-17 (+blank)	P-9–P-17 (+blank)
Appendix S	S-3–S-4	S-3–S-4
Appendix T	none	new pages T-1–T-2
Appendix TI	none	new pages TI-1–TI-8

The parts of the text, tables, and figures that contain changes are indicated by a vertical bar and a small “01” in the margin.

Welded Steel Tanks for Oil Storage

API STANDARD 650
TENTH EDITION, NOVEMBER 1998

ADDENDUM 1, JANUARY 2000
ADDENDUM 2, NOVEMBER 2001

American Petroleum Institute

Helping You
Get The Job
Done Right.SM

Welded Steel Tanks for Oil Storage

Downstream Segment

API STANDARD 650
TENTH EDITION, NOVEMBER 1998

ADDENDUM 1, JANUARY 2000
ADDENDUM 2, NOVEMBER 2001

American
Petroleum
Institute

**Helping You
Get The Job
Done Right.** SM

SPECIAL NOTES

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

API is not undertaking to meet the duties of employers, manufacturers, or suppliers to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions, nor undertaking their obligations under local, state, or federal laws.

Information concerning safety and health risks and proper precautions with respect to particular materials and conditions should be obtained from the employer, the manufacturer or supplier of that material, or the material safety data sheet.

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. Sometimes a one-time extension of up to two years will be added to this review cycle. This publication will no longer be in effect five years after its publication date as an operative API standard or, where an extension has been granted, upon republication. Status of the publication can be ascertained from the API Standards Departmment [telephone (202) 682-8000]. A catalog of API publications and materials is published annually and updated quarterly by API, 1220 L Street, N.W., Washington, D.C. 20005.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this standard or comments and questions concerning the procedures under which this standard was developed should be directed in writing to the director, Standards Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005, standards@api.org. Requests for permission to reproduce or translate all or any part of the material published herein should be addressed to the publications manager at publications@api.org.

API standards are published to facilitate the broad availability of proven, sound engineering and operating practices. These standards are not intended to obviate the need for applying sound engineering judgment regarding when and where these standards should be utilized. The formulation and publication of API standards is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

FOREWORD

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 $2^1/_2$ 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. 00

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.

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.

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 rerated, reconstructed, relocated, repaired, modified (altered), inspected, 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 manufacturer shall specify to which edition, revision, or addenda the equipment is to be rerated, reconstructed, relocated, repaired, modified (altered), inspected, and tested.

The purchaser shall specify whether tanks supplied to this standard will have SI dimensions and comply with applicable ISO standards, or have U.S. Customary dimensions and comply with applicable U.S. standards. Where conflicts arise between SI and U.S. Customary units, the U.S. Customary units will govern.

Suggested revisions are invited and should be submitted to the American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005, standards@api.org.

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.

CONTENTS

Page

Tables

Welded Steel Tanks for Oil Storage

1 Scope

1.1 GENERAL

1.1.1 This standard covers material, design, fabrication, erection, and testing requirements for vertical, cylindrical, aboveground, closed- and open-top, welded 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 1.1.10). This standard applies only to tanks whose entire bottom is uniformly supported and to tanks in nonrefrigerated service that have a maximum operating temperature of 90°C (200°F) (see 1.1.17).

1.1.2 This standard is designed to provide the petroleum industry with tanks of adequate safety and reasonable economy for use in the storage of petroleum, petroleum products, and other liquid products commonly handled and stored by the various branches of the industry. 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 The purchaser will specify whether tanks constructed to this standard shall have SI dimensions and comply with applicable SI unit standards or have US Customary dimensions and comply with applicable US Customary unit
98 standards.

1.1.4 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. An appendix becomes a requirement only when the purchaser specifies an option covered by that appendix. See Table 1-1 for the status of each appendix.

1.1.5 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 to the minimum design metal temperatures stated in the appendix.

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

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

1.1.8 Appendix D provides requirements for submission of technical inquiries on this standard. 00

● **1.1.9** 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 purchaser.

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

1.1.11 Appendix G provides requirements for an optional aluminum dome roof.

1.1.12 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. 98

● **1.1.13** 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.

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

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

1.1.16 Appendix L provides data sheets listing required information to be used by the purchaser in ordering a storage tank and by the manufacturer upon completion of construction of the tank.

1.1.17 Appendix M provides requirements for tanks specified and designed to operate at temperatures exceeding 90°C (200°F) but not exceeding 260°C (500°F).

1.1.18 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.

Table 1-1—Status of Appendixes to API Standard 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	Purchaser's Option
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	Purchaser's Option
H	Internal floating roofs	Purchaser's Option
● 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 Standard 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
S	Austenitic stainless steel storage tanks	Requirements

Definitions:

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.

Requirement: The outlined design criteria must be used unless the purchaser and manufacturer agree upon a more stringent alternative design.

Recommendation: The outlined criteria provides a good acceptable design and may be used at the option of the purchaser and manufacturer.

● Purchaser's Option: When the purchaser specifies an option covered by an appendix, the appendix then becomes a requirement.

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

● **1.1.20** Appendix P provides minimum recommendations for design of shell openings that conform to Table 3-6 that are subject to external piping loads. An alternative or supplemental design may be agreed upon by the purchaser or manufacturer.

1.1.21 Appendix S provides requirements for stainless steel tanks.

1.1.22 Appendix T summarizes the requirements for inspection by method of examination and the reference sections within the standard. The acceptance standards, examiner 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.

1.2 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 wall.
d. The first circumferential joint in welding-end pipe connections if not welded to a flange.

● 1.3 COMPLIANCE

The manufacturer is responsible for complying with all provisions of this standard. Inspection by the purchaser's inspector (the term inspector as used herein) does not negate the manufacturer's obligation to provide quality control and inspection necessary to ensure such compliance.

1.4 REFERENCED PUBLICATIONS

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

API

Spec 5L *Specification for Line Pipe*

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 (Nonrefrigerated 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*

01 RP 2350 *Overfill Protection for Storage Tanks in Petroleum Facilities*

AA[1]

Aluminum Design Manual

00 *Aluminum Standards and Data*

Specifications for Aluminum Sheet Metal Work in Building Construction

ACI[2]

318 *Building Code Requirements for Reinforced Concrete* (ANSI/ACI 318)

350 *Environmental Engineering Concrete Structures*

AISC[3]

Manual of Steel Construction, Allowable Stress Design

AISI[4]

E-1 *Steel Plate Engineering Data Series: Useful Information—Design of Plate Structures,* Volume II

ASCE[5]

00 ASCE Std. 7-93 *Minimum Design Loads for Buildings and other Structures*

[1]The Aluminum Association Inc., 900 19th Street, N.W., Washington, D.C. 20006, www.aluminum.org.
[2]American Concrete Institute, P.O. Box 19150, Detroit, Michigan 48219-0150, www.aci-int.org.
[3]American Institute of Steel Construction, One East Wacker Drive, Suite 3100, Chicago, Illinois 60601-2001, www.aisc.org.
[4]American Iron and Steel Institute, 1101 17th Street, N.W., Suite 1300, Washington, D.C. 20036-4700, www.steel.org.
[5]American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, VA 20191-4400, www.asce.org.

ASME[6]

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)

B16.47 *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 & Pressure Vessel Code, Section V, “Nondestructive Examination”; Section VIII, “Pressure Vessels,” Division 1; and Section IX, “Welding and Brazing Qualifications”

ASNT[7]

RP SNT-TC-1A *Personnel Qualification and Certification in Nondestructive Testing*

ASTM[8]

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*

[6]ASME International, 3 Park Avenue, New York, New York 10016-5990, www.asme.org.
[7]American Society for Nondestructive Testing, 1711 Arlingate Lane, Columbus, Ohio 43228-0518, www.asnt.org.
[8]ASTM, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959, www.astm.org.

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 psi 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* 98

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 570M/A 570 *Hot-Rolled Carbon Steel Sheet and Strip, Structural Quality*

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*

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* 01

C 273 *Method for Shear Test in Flatwise Plane of Flat Sandwich Constructions or Sandwich Cores*

C 509 *Cellular Elastomeric Preformed Gasket and Sealing Material*

D 1621 *Test Method for Compressive Properties of Rigid Cellular Plastics*

D 1622 *Test Method for Apparent Density of Rigid Cellular Plastics* (ANSI/ASTM D1622)

D 2341 *Rigid Urethane Foam*

D 2856	*Test Method for Open Cell Content of Rigid Cellular Plastics by the Air Pycnometer*
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*
E 96	*Test Methods for Water Vapor Transmission of Materials*

AWS[9]

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

CSA[10]

G40.21-M	*Structural Quality Steels*

[9]American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33135, www.aws.org.
[10]Canadian Standards Association, 178 Rexdale Boulevard, Rexdale, Ontario M9W 1R3, www.csa.ca.

Supplement to National Building Code of Canada

Federal Specifications[11]

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

ISO[12]

630	*Structural Steels*

NFPA[13]

11	Standard for Low-Expansion Foam
30	Flammable and Combustible Liquids Code

01

[11]Specifications Unit (WFSIS), 7th and D Streets, N.W., Washington, D.C. 20407.
[12]International 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.
[13]NFPA International, 1 Batterymarch Park, Quincy, MA 02269-9101, www.nfpa.org.

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 for plates to a maximum thickness of 40 mm (1.5 in.) [insert plates to a maximum thickness of 65 mm (2.5 in.)].

2.2.3 CSA Specifications

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

a. The W grades may be semikilled or fully killed.

b. Fully killed steel made to fine-grain practice must be specified when required.

c. Elements added for grain refining or strengthening shall be restricted in accordance with Table 2-1.

d. Plates shall have tensile strengths that are not more than 140 MPa (20 ksi) above the minimum specified for the grade.

e. Grades 260W and 300W are acceptable for plate to a maximum thickness of 25 mm (1 in.) if semikilled and to a maximum thickness of 40 mm (1.5 in.) if fully killed and made to fine-grain practice.

f. Grade 350W 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.

2.2.4 ISO Specifications

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

98 a. 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).

98 b. 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.)].

98 2.2.5 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 2-2 are acceptable when approved by the purchaser. The requirements of this group do not apply to the ASTM, CSA, and ISO specifications listed in 2.2.2, 2.2.3, and 2.2.4. 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 2-1—Maximum Permissible Alloy Content

Alloy	Heat Analysis (percent)	Notes
Columbium	0.05	1, 2, 3
Vanadium	0.10	1, 2, 4
Columbium (≤ 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

1. 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. 98
2. On product analysis, the material shall conform to these requirements, subject to the product analysis tolerances of the specification.
3. 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.
4. When nitrogen (≤ 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.

2.2.6 General Requirements for Delivery

2.2.6.1 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.

2.2.6.2 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.

2.2.6.3 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.

2.2.6.4 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

Table 2-2—Acceptable Grades of Plate Material Produced to National Standards (See 2.2.5)

		Mechanical Properties								Chemical Composition			
00		Tensile Strength[a]				Minimum Yield Strength[c]		Maximum Thickness		Maximum Percent Carbon		Maximum Percent Phosphorus and Sulfur	
		Minimum[c]		Maximum									
	Grade[b]	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
00	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

[a]The 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.
[b]Semikilled or fully killed quality; as rolled, controlled-rolled or TMCP [20 mm (0.75 in.) maximum when controlled-rolled steel
00 or TMCP is used in place of normalized steel], or normalized.
[c]Yield strength ÷ tensile strength ≤ 0.75, based on the minimum specified yield and tensile strength unless actual test values are required by the purchaser.
[d]Nonrimming only.

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.

2.2.6.5 The use or presence of columbium, vanadium, nitrogen, copper, nickel, chromium, or molybdenum shall not exceed the limitations of Table 2-1 for all Group VI materials
01 (see Table 2-3) and ISO 630, Grade E 355.

2.2.7 Heat Treatment of Plates

2.2.7.1 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 2.2.7.2.

2.2.7.2 When a plate purchaser elects to perform the required normalizing or fabricates by hot forming (see 2.2.7.1), 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 purchase order, 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.

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

2.2.7.4 Subject to the purchaser’s approval, controlled-rolled plates (plates produced by a mechanical-thermal rolling process designed to enhance notch toughness) may be used where normalized plates are required. Each controlled-rolled plate shall receive Charpy V-notch impact energy testing in accordance with 2.2.8, 2.2.9, and 2.2.10. When controlled-rolled steels are used, consideration should be given to the service conditions outlined in 3.3.3.

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

2.2.8 Impact Testing of Plates

2.2.8.1 When required by the purchaser or by 2.2.7.4 and 2.2.9, 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.

2.2.8.2 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.

2.2.8.3 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.

2.2.8.4 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.

2.2.8.5 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.

2.2.8.6 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.

2.2.8.7 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.

2.2.9 Toughness Requirements

2.2.9.1 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 2-1. Notch toughness evaluation of plate-ring flanges, blind flanges, and manhole cover plates shall be based on "governing thickness" as defined in 2.5.5.3. 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 2.2.10.2. Each TMCP A 841 plate shall be impact tested according to 2.2.10.2 when used at design metal temperatures lower than the minimum temperatures indicated in Figure 2-1.

● **2.2.9.2** Plates less than or equal to 40 mm (1.5 in.) thick, except controlled-rolled plates (see 2.2.7.4), may be used at or above the design metal temperatures indicated in Figure 2-1 without being impact tested. To be used at design metal temperatures lower than the minimum temperatures indicated in Figure 2-1, plates shall demonstrate adequate notch toughness in accordance with 2.2.10.3 unless 2.2.10.2 or 2.2.10.4 has been specified by the purchaser. For heat-treated material, notch toughness shall be demonstrated on each plate as heat treated when 2.2.10.2 requirements are specified.

2.2.9.3 Unless experience or special local conditions justify another assumption, the design metal temperature 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 temperatures are shown in Figure 2-2. The temperatures are not related to refrigerated-tank temperatures (see 1.1.1).

2.2.9.4 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 2-3 and Figure 2-1. 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 2.2.9.1 and 3.7.2.2, item e).

2.2.9.5 The requirements in 2.2.9.4 apply only to shell nozzles and manholes. Materials for roof nozzles and manholes do not require special toughness.

2.2.10 Toughness Procedure

2.2.10.1 When a material's toughness must be determined, it shall be done by one of the procedures described in 2.2.10.2 through 2.2.10.4, as specified in 2.2.9.

2.2.10.2 Each plate as rolled or heat treated shall be impact tested in accordance with 2.2.8 at or below the design metal temperature to show Charpy V-notch longitudinal (or transverse) values that fulfill the minimum requirements of Table 2-4 (see 2.2.8 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.

2.2.10.3 The thickest plate from each heat shall be impact tested in accordance with 2.2.8 and shall fulfill the impact requirements of 2.2.10.2 at the design metal temperature.

● **2.2.10.4** 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.

● 2.3 SHEETS

Sheets for fixed and floating roofs shall conform to ASTM A 570M/A 570, 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.

2.4 STRUCTURAL SHAPES

2.4.1 Structural steel shall conform to one of the following:

a. ASTM A 36M/A 36.
b. ASTM A 131M/A 131.

Table 2-3a—Material Groups, SI Units (See Figure 2-1 and Note 1 Below)

	Group I As Rolled, Semikilled		Group II As Rolled, Killed or Semikilled		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	G40.21M-260W		A 516M-415		A 516M-380	10
	A 36M	2, 3	Grade 250	5, 8	G40.21M-260W	9	A 516M-415	10
00	Grade 235	3, 5			Grade 250	5, 9	G40.21M-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		G40.21M-300W	9, 11	A 516M-485	10	A 633M D	
00	A 516M-485		G40.21M-350W	9, 11	G40.21M-300W	9, 10	A 537M Class 1	
	A 662M B				G40.21M-350W	9, 10	A 537M Class 2	13
	G40.21M-300W	9					A 678M A	
	G40.21M-350W	9					A 678M B	13
98	E 275	4, 9					A 737M B	
	E 355	9					A 841	12, 13
00	Grade 275	5, 9						

Notes:

1. Most of the listed material specification numbers refer to ASTM specifications (including Grade or Class); there are, how-
98 ever, some exceptions: G40.21M (including Grade) is a CSA specification; Grades E 275 and E 355 (including Quality) are
01 contained in ISO 630; and Grade 235, Grade 250, and Grade 275 are related to national standards (see 2.2.5).
2. Must be semikilled or killed.
00 3. Thickness ≤ 20 mm.
4. Maximum manganese content of 1.5%.
5. Thickness 20 mm maximum when controlled-rolled steel is used in place of normalized steel.
6. 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 per-
00 mitted up to the maximum of 1.35%. Thicknesses ≤ 20 mm shall have a manganese content of 0.8–1.2% by heat analysis.
7. Thickness ≤ 25 mm.
8. Must be killed.
9. Must be killed and made to fine-grain practice.
10. Must be normalized.
11. Must have chemistry (heat) modified to a maximum carbon content of 0.20% and a maximum manganese content of 1.60% (see 2.2.6.4).
12. Produced by the thermo-mechanical control process (TMCP).
13. See 3.7.4.6 for tests on simulated test coupons for material used in stress-relieved assemblies.

Table 2-3b—Material Groups, US Customary Units (See Figure 2-1 and Note 1 Below)

Group I As Rolled, Semikilled		Group II As Rolled, Killed or Semikilled		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	G40.21M-260W		A 516-60		A 516-55	10
A 36	2, 3	Grade 250	5, 8	G40.21M-260W	9	A 516-60	10
Grade 235	3, 5			Grade 250	5, 9	G40.21M-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 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		G40.21M-300W	9, 11	A 516-70	10	A 633 D	
A 516-70		G40.21M-350W	9, 11	G40.21M-300W	9, 10	A 537 Class 1	
A 662 B				G40.21M-350W	9, 10	A 537 Class 2	13
G40.21M-300W	9					A 678 A	
G40.21M-350W	9					A 678 B	13
E 275	4, 9					A 737 B	
E 355	9					A 841	12, 13
Grade 275	5, 9						

Notes:

1. Most of the listed material specification numbers refer to ASTM specifications (including Grade or Class); there are, however, some exceptions: G40.21M (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 2.2.5).
2. Must be semikilled or killed.
3. Thickness ≤ 0.75 in.
4. Maximum manganese content of 1.5%.
5. Thickness 0.75 in. maximum when controlled-rolled steel is used in place of normalized steel.
6. Manganese content shall be 0.80–1.2% by heat analysis for thicknesses greater than 0.75 inch, 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 0.8–1.2% by heat analysis.
7. Thickness ≤ 1 inch.
8. Must be killed.
9. Must be killed and made to fine-grain practice.
10. Must be normalized.
11. Must have chemistry (heat) modified to a maximum carbon content of 0.20% and a maximum manganese content of 1.60% (see 2.2.6.4).
12. Produced by the thermo-mechanical control process (TMCP).
13. See 3.7.4.6 for tests on simulated test coupons for material used in stress-relieved assemblies.

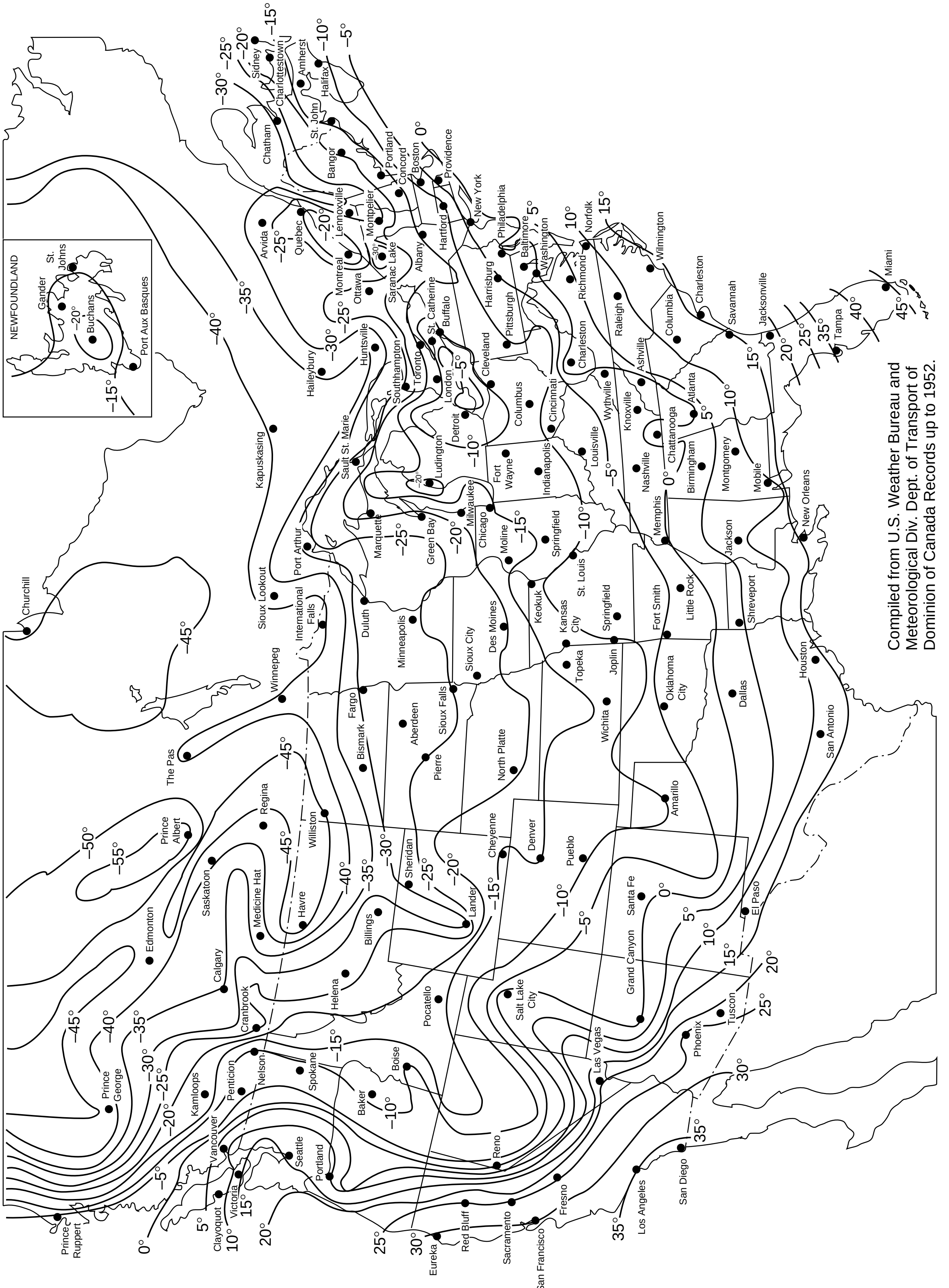


Figure 2-2—Isothermal Lines of Lowest One-Day Mean Temperatures (°F)

°C = (°F – 32)/1.8

Table 2-4—Minimum Impact Test Requirements for Plates (See Note)

Plate Material[a] and Thickness (t) in mm (in.)	Thickness mm	Thickness in.	Average Impact Value of Three Specimens[b] Longitudinal J	Longitudinal ft-lbf	Transverse J	Transverse ft-lbf
Groups I, II, III, and IIIA $t \le$ maximum thicknesses in 2.2.2 through 2.2.5			20	15	18	13
Groups IV, IVA, V, and VI (except quenched and tempered and TMCP)	$t \le 40$	$t \le 1.5$	41	30	27	20
	$40 < t \le 45$	$1.5 < t \le 1.75$	48	35	34	25
	$45 < t \le 50$	$1.75 < t \le 2$	54	40	41	30
	$50 < t \le 100$	$2 < t \le 4$	68	50	54	40
Group VI (quenched and tempered and TMCP)	$t \le 40$	$t \le 1.5$	48	35	34	25
	$40 < t \le 45$	$1.5 < t \le 1.75$	54	40	41	30
	$45 < t \le 50$	$1.75 < t \le 2$	61	45	48	35
	$50 < t \le 100$	$2 < t \le 4$	68	50	54	40

[a]See Table 2-3.
[b]Interpolation 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 $t \le 40$ mm (1.5 in.).

01 c. ASTM A 992M/A 992.

d. Structural Steels listed in AISC *Specification for Structural Steel Buildings, Allowable Stress Design*.

e. CSA G40.21-M, Grades 260W, 300W, 350W, 260WT, 300WT, and 350WT. Imperial unit equivalent grades of CSA Specification G40.21 are also acceptable.

01 f. 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 2-2 is acceptable when approved by the purchaser.

● **2.4.2** 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.

2.5 PIPING AND FORGINGS

2.5.1 Unless otherwise specified in this standard, pipe and pipe couplings and forgings shall conform to the specifications listed in 2.5.1.1 and 2.5.1.2 or to national standards equivalent to the specifications listed.

2.5.1.1 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 2.5.3).

2.5.1.2 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.

2.5.2 Unless ASTM A 671 pipe is used (electric-fusion-welded pipe) (see 2.5.3), material for shell nozzles and shell manhole necks shall be seamless pipe, seamless forging, or plate material as specified in 2.2.9.1. 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.

2.5.3 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 2.2.7, 2.2.8, and 2.2.9 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 7.2.2.

2.5.4 Weldable-quality pipe that conforms to the physical properties specified in any of the standards listed in 2.5.1 may be used for structural purposes with the allowable stresses stated in 3.10.3.

2.5.5 Except as covered in 2.5.3, the toughness requirements of pipe and forgings to be used for shell nozzles and manholes shall be established as described in 2.5.5.1 through 2.5.5.4.

2.5.5.1 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 design metal temperatures no lower than the impact test temperature required by the ASTM specification for the applicable material grade without additional impact tests (see 2.5.5.4).

2.5.5.2 Other pipe and forging materials shall be classified under the material groups shown in Figure 2-1 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.

2.5.5.3 The materials in the groups listed in 2.5.5.2 may be used at nominal thicknesses, including corrosion allowance, at design metal temperatures no lower than those shown in Figure 2-1 without impact testing (see 2.5.5.4 and Figure 2-3). The governing thicknesses to be used in Figure 2-1 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, $^1/_4$ of their nominal thickness.

2.5.5.4 When impact tests are required by 2.5.5.1 or 2.5.5.3, 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 2.2.9.2, the materials specified in 2.5.1 and 2.5.2 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.

2.6 FLANGES

2.6.1 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 2.2.9.1.

● **2.6.2** 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.

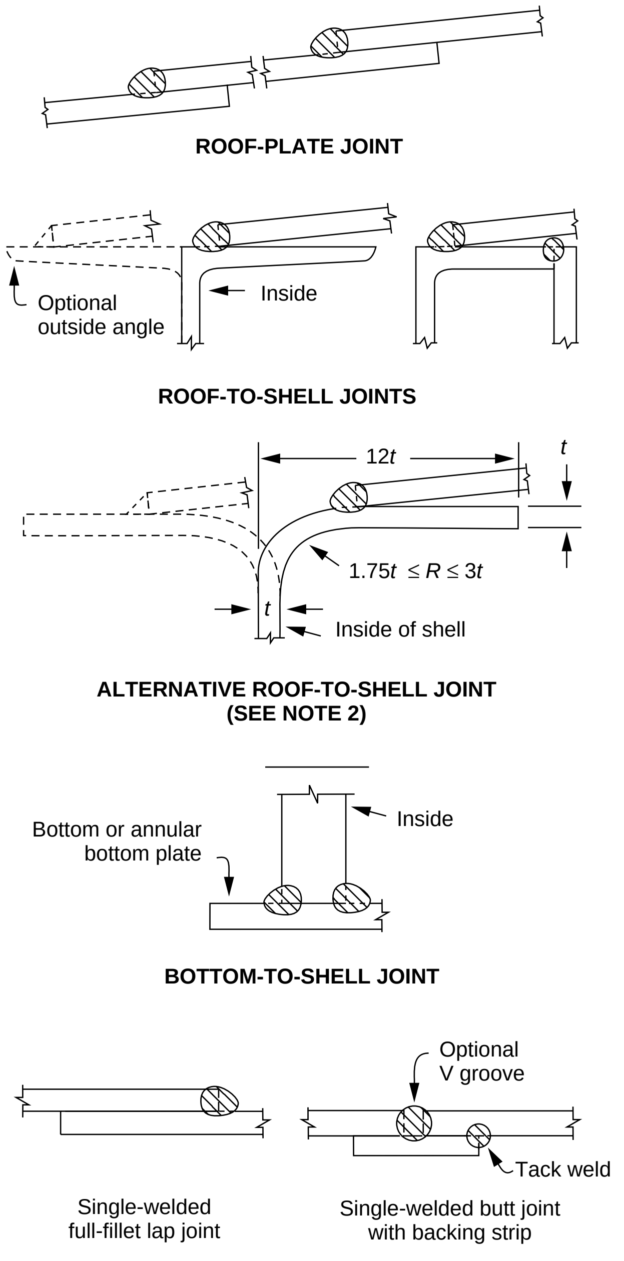
● 2.7 BOLTING

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.

2.8 WELDING ELECTRODES

2.8.1 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 5.2.1.10 as applicable.

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



Notes:
1. See 3.1.5.4 through 3.1.5.9 for specific requirements for roof and bottom joints.
2. The alternative roof-to-shell joint is subject to the limitations of 3.1.5.9, item f.

Figure 3-3A—Typical Roof and Bottom Joints

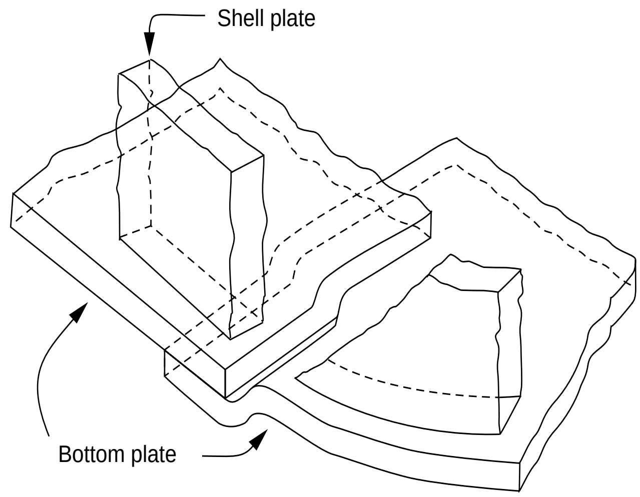


Figure 3-3B—Method for Preparing Lap-Welded Bottom Plates Under Tank Shell (See 3.1.5.4)

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 3-3C), but shall not exceed the shell plate thickness.

c. Shell-to-bottom fillet welds for shell material in Groups IV, IVA, V, or VI shall be made with a minimum of two passes.

3.1.5.8 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 if specified by the purchaser. Seal-welding should be considered to minimize the potential for entrapped moisture, which may cause corrosion.

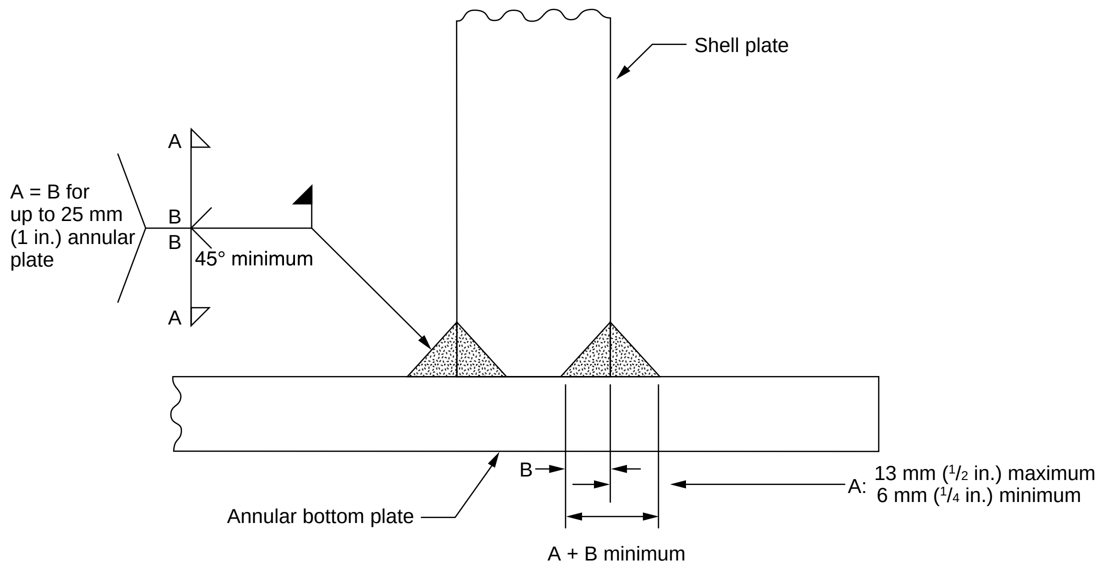
3.1.5.9 Roof and Top-Angle Joints

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. 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 3.10.2.5.

c. The top-angle sections for self-supporting roofs shall be joined by butt-welds having complete penetration and fusion. Joint efficiency factors need not be applied in conforming to the requirements of 3.10.5 and 3.10.6.

00
01



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 inch).

Figure 3-3C—Detail of Double Fillet-Groove Weld for Annular Bottom Plates With a Nominal Thickness Greater Than 13 mm ($^1/_2$ in.) (See 3.1.5.7, item b)

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 3.9, for self-supporting roofs in 3.10.5 and 3.10.6, 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: for tanks with a diameter less than or equal to 11 m (35 ft), 51 × 51 × 4.8 mm (2 × 2 × $^3/_{16}$ in.); for tanks with a diameter greater than 11 m (35 ft) but less than or equal to 18 m (60 ft), 51 × 51 × 6.4 mm (2 × 2 × $^1/_4$ in.); and for tanks with a diameter greater than 18 m (60 ft), 76 × 76 × 9.5 mm (3 × 3 × $^3/_8$ in.). At the purchaser's option, the outstanding leg of the top angle may extend inside or outside the tank shell.

f. For tanks with a diameter less than or equal to 9 m (30 ft) and a supported cone roof (see 3.10.4), 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 3-3A. This construction may be used for any tank with a self-supporting roof (see 3.10.5 and 3.10.6) 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.

3.2 DESIGN CONSIDERATIONS

3.2.1 Design Factors

The purchaser shall state the design metal temperature (based on ambient temperatures), the design specific gravity, the corrosion allowance (if any), and the design wind velocity.

3.2.2 External Loads

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.

3.2.3 Protective Measures

The purchaser should give special consideration to foundations, corrosion allowance, hardness testing, and any other protective measures deemed necessary.

3.2.4 External Pressure

This standard does not contain provisions for the design of tanks subject to partial internal vacuum; however, tanks that meet the minimum requirements of this standard may be subjected to a partial vacuum of 0.25 kPa (1 in. of water) of water pressure.

● 3.2.5 Tank Capacity

3.2.5.1 The purchaser shall specify the maximum capacity and the overfill protection level (or volume) requirement (see
01 API Recommended Practice 2350).

3.2.5.2 Maximum capacity is the volume of product in a tank when the tank is filled to its design liquid level as defined in 3.6.3.2 (see Appendix L).

3.2.5.3 The net working capacity is the volume of avail-
00 able product under normal operating conditions. The net working capacity is equal to the maximum capacity (3.2.5.2) less the minimum operating volume remaining in the tank, less the overfill protection level (or volume) requirement (see Appendix L).

3.3 SPECIAL CONSIDERATIONS

● 3.3.1 Foundation

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.

● 3.3.2 Corrosion Allowances

When necessary, the purchaser, after giving consideration to the total effect of the liquid stored, the vapor above the liquid, and the atmospheric environment, shall specify the corrosion allowance to be provided for each shell course, for the bottom, for the roof, for nozzles and manholes, and for structural members.

● 3.3.3 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.

● 3.3.4 Weld Hardness

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:

a. 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.

b. 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.

3.4 BOTTOM PLATES

● **3.4.1** All bottom plates shall have a minimum nominal thickness of 6 mm ($^{1}/_{4}$ in.) [70 kPa (10.2 lbf/in.^{2}) (see 2.2.1.2)], 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.).

3.4.2 Bottom plates of sufficient size shall be ordered so that, when trimmed, at least a 25 mm (1 in.) width will project beyond the outside edge of the weld attaching the bottom to the shell plate.

3.4.3 Bottom plates shall be welded in accordance with 3.1.5.4 or 3.1.5.5.

3.5 ANNULAR BOTTOM PLATES

3.5.1 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 3.1.5.6). When the bottom shell course is of a material in Group IV, IVA, V, or VI and the maximum product stress (see 3.6.2.1) 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 3.6.2.2) for the first shell course is less than or equal to 172 MPa (24,900 lbf/in.^{2}), lap-welded bottom plates (see 3.1.5.4) may be used in lieu of butt-welded annular bottom plates.

3.5.2 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 and at least a 50 mm (2 in.) projection outside the shell. 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 3.5.3), in mm,

H = maximum design liquid level (see 3.6.3.2), 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 3.5.3), (in.),

H = maximum design liquid level (see 3.6.3.2), (ft),

G = design specific gravity of the liquid to be stored.

3.5.3 The thickness of the annular bottom plates shall not be less than the thicknesses listed in Table 3-1 plus any specified corrosion allowance.

3.5.4 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 3.1.5.6 and 3.1.5.7, item b.

3.5.5 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 3.5.2.

Table 3-1—Annular Bottom-Plate Thicknesses

SI Units				
Nominal Plate Thickness[a] of First Shell Course (mm)	Hydrostatic Test Stress[b] in First Shell Course (MPa)			
	≤ 190	≤ 210	≤ 230	≤ 250
$t \le 19$	6	6	7	9
$19 < t \le 25$	6	7	10	11
$25 < t \le 32$	6	9	12	14
$32 < t \le 38$	8	11	14	17
$38 < t \le 45$	9	13	16	19
US Customary				
Nominal Plate Thickness[a] of First Shell Course (in.)	Hydrostatic Test Stress[c] in First Shell Course (lbf/in^2)			
	≤ 27,000	≤ 30,000	≤ 33,000	≤ 36,000
$t \le 0.75$	$^1/_4$	$^1/_4$	$^9/_{32}$	$^{11}/_{32}$
$0.75 < t \le 1.00$	$^1/_4$	$^9/_{32}$	$^3/_8$	$^7/_{16}$
$1.00 < t \le 1.25$	$^1/_4$	$^{11}/_{32}$	$^{15}/_{32}$	$^9/_{16}$
$1.25 < t \le 1.50$	$^5/_{16}$	$^7/_{16}$	$^9/_{16}$	$^{11}/_{16}$
$1.50 < t \le 1.75$	$^{11}/_{32}$	$^1/_2$	$^5/_8$	$^3/_4$

[a]Nominal plate thickness refers to the tank shell as constructed.
[b]Hydrostatic test stresses are calculated from $[4.9D(H - 0.3)]/t$ (see 3.6.3.2).
[c]Hydrostatic test stresses are calculated from $[2.6\,D(H - 1]/t$ (see 3.6.3.2).

Note: The thicknesses specified in the table, as well as the width specified in 3.5.2, 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.

3.6 SHELL DESIGN

3.6.1 General

3.6.1.1 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 (See Note 1)		Nominal Plate Thickness (See Note 2)	
(m)	(ft)	(mm)	(in.)
< 15	< 50	5	$^3/_{16}$
15 to < 36	50 to < 120	6	$^1/_4$
36 to 60	120 to 200	8	$^5/_{16}$
> 60	> 200	10	$^3/_8$

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 millimeters may be substituted for $^1/_4$-inch plate.

● **3.6.1.2** 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.

● **3.6.1.3** The design shell thickness shall be computed on the basis that the tank is filled to a level H (see 3.6.3.2) with a liquid that has a specific gravity specified by the purchaser.

3.6.1.4 The hydrostatic test shell thickness shall be computed on the basis that the tank is filled to a level H (see 3.6.3.2) with water.

3.6.1.5 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.

● **3.6.1.6** The tank shell shall be checked for stability against buckling from the design wind velocity, as specified by the purchaser, in accordance with 3.9.7. If required for stability, intermediate girders, increased shell-plate thicknesses, or both shall be used. If the design wind velocity is not specified, the maximum allowable wind velocity shall be calculated, and the result shall be reported to the purchaser at the time of the bid.

● **3.6.1.7** The manufacturer shall furnish to the purchaser a drawing that lists the following for each 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.

3.6.1.8 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.

3.6.2 Allowable Stress

3.6.2.1 The maximum allowable product design stress, S_d, shall be as shown in Table 3-2. 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.

3.6.2.2 The maximum allowable hydrostatic test stress, S_t, shall be as shown in Table 3-2. 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.

3.6.2.3 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
00 12.5 mm ($^1/_2$ in.).

3.6.2.4 Structural design stresses shall conform to the allowable working stresses given in 3.10.3.

3.6.3 Calculation of Thickness by the 1-Foot Method

3.6.3.1 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.

3.6.3.2 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 3.6.1.1, 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 3.3.2),

S_d = allowable stress for the design condition, in MPa (see 3.6.2.1),

S_t = allowable stress for the hydrostatic test condition, in MPa (see 3.6.2.2).

In US Customary units:

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

$$t_t = \frac{2.6D(H-1)}{S_t}$$ 00

where

t_d = design shell thickness (in.),

t_t = hydrostatic test shell thickness (in.),

D = nominal tank diameter, in ft (see 3.6.1.1, 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 3.3.2),

S_d = allowable stress for the design condition, (lbf/in.^{2}) (see 3.6.2.1),

S_t = allowable stress for the hydrostatic test condition, (lbf/in.^{2}) (see 3.6.2.2).

Table 3-2—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)
01	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)
			CSA Specifications			
	G40.21M	260W	260 (37,700)	410 (59,500)	164 (23,800)	176 (25,500)
	G40.21M	300W	300 (43,500)	450 (65,300)	180 (26,100)	193 (28,000)
	G40.21M	350WT	350 (50,800)	480[a] (69,600[a])	192 (27,900)	206 (29,800)
	G40.21M	350W	350 (50,800)	450 (65,300)	180 (26,100)	193 (28,000)
			National Standards			
		235	235 (34,000)	365 (52,600)	137 (20,000)	154 (22,500)
00		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			
00	E 275	C, D	265 (38,400)	425 (61,900)	170 (24,700)	182 (26,500)
	E 355	C, D	345 (50,000)	490[a] (71,000[a])	196 (28,400)	210 (30,400)

[a]By 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 3.6.2.1 and 3.6.2.2.

● **3.7.1.2** The shell opening designs described in this standard are required, except for alternative designs allowed in 3.7.1.8.

3.7.1.3 Flush-type cleanout fittings and flush-type shell connections shall conform to the designs specified in 3.7.7 and 3.7.8.

● **3.7.1.4** When a size intermediate to the sizes listed in Tables 3-3 through 3-14 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.

3.7.1.5 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 3-6.

3.7.1.6 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.

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

3.7.1.8 With the approval of the purchaser, the shape and dimensions of the shell reinforcing plates, illustrated in Figures 3-4A, 3-4B, and 3-5 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 3.7.2. Reinforcement of shell openings that comply with API Standard 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.

01 **3.7.1.9** 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.

3.7.2 Reinforcement and Welding

3.7.2.1 Openings in tank shells larger than required to accommodate a NPS 2 flanged or threaded nozzle shall be reinforced. All shell-opening connections that require reinforcement (for example, nozzles, manholes, and cleanout openings) shall be attached by welds that fully penetrate the shell; however, the partial penetration illustrated in Figure 3-4B for insert-type reinforcement is permitted. 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.

3.7.2.2 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.

c. The portion of the neck of the fitting that may be considered as reinforcement according to 3.7.2.3.

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.

3.7.2.3 The following portions of the neck of a fitting may be considered part of the area of reinforcement, except where prohibited by 3.7.2.2, item e:

a. 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.

b. The portion lying within the shell-plate thickness.

c. The portion extending inward from the inside surface of the tank shell plate to the distance specified in item a.

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

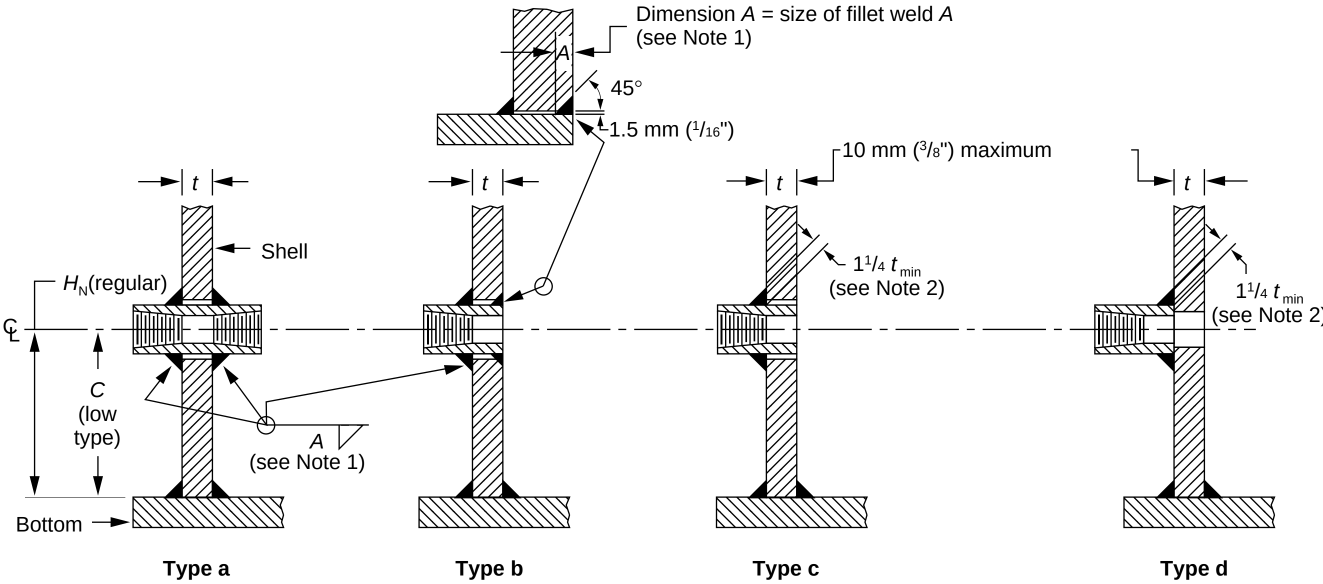
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10
Max. Design Liquid Level m (ft) *H*	Equivalent Pressure[a] kPa (psi)	Minimum Thickness of Cover Plate[b] (t_c)				Minimum Thickness of Bolting Flange After Finishing[b] (t_f)			
		500 mm (20 in.) Manhole	600 mm (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
6.4 (21)	63 (9.1)	8 (5/16)	10 (3/8)	11 (7/16)	13 (1/2)	6 (1/4)	6 (1/4)	8 (5/16)	10 (3/8)
8.2 (27)	80 (11.7)	10 (3/8)	11 (7/16)	13 (1/2)	14 (9/16)	6 (1/4)	8 (5/16)	10 (3/8)	11 (7/16)
9.8 (32)	96 (13.9)	10 (3/8)	11 (7/16)	14 (9/16)	16 (5/8)	6 (1/4)	8 (5/16)	11 (7/16)	13 (1/2)
12 (40)	118 (17.4)	11 (7/16)	13 (1/2)	16 (5/8)	18 (11/16)	8 (5/16)	10 (3/8)	13 (1/2)	14 (9/16)
14 (45)	137 (19.5)	13 (1/2)	14 (9/16)	16 (5/8)	19 (3/4)	10 (3/8)	11 (7/16)	13 (1/2)	16 (5/8)
16 (54)	157 (23.4)	13 (1/2)	14 (9/16)	18 (11/16)	21 (13/16)	10 (3/8)	11 (7/16)	14 (9/16)	18 (11/16)
20 (65)	196 (28.2)	14 (9/16)	16 (5/8)	19 (3/4)	22 (7/8)	11 (7/16)	13 (1/2)	16 (5/8)	19 (3/4)
23 (75)	226 (32.5)	16 (5/8)	18 (11/16)	21 (13/16)	24 (15/16)	12.5 (1/2)	14 (9/16)	18 (11/16)	21 (13/16)

[a]Equivalent pressure is based on water loading.
[b]For addition of corrosion allowance, see 3.7.5.2.
Note: See Figure 3-4A.

Table 3-4—Dimensions for Shell Manhole Neck Thickness

Thickness of Shell and Manhole Reinforcing Plate[a] *t* and *T*	Minimum Neck Thickness[b,c] t_n 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 (1 1/16)	11 (7/16)	11 (7/16)	11 (7/16)	11 (7/16)
28 (1 1/8)	13 (1/2)	13 (1/2)	13 (1/2)	13 (1/2)
30 (1 3/16)	14 (9/16)	14 (9/16)	14 (9/16)	14 (9/16)
32 (1 1/4)	16 (5/8)	14 (9/16)	14 (9/16)	14 (9/16)
33 (1 5/16)	16 (5/8)	16 (5/8)	16 (5/8)	16 (5/8)
34 (1 3/8)	17 (11/16)	16 (5/8)	16 (5/8)	16 (5/8)
36 (1 7/16)	17 (11/16)	17 (11/16)	17 (11/16)	17 (11/16)
40 (1 1/2)	19 (3/4)	19 (3/4)	19 (3/4)	19 (3/4)

[a]If a shell plate thicker than required is used for the product and hydrostatic loading (see 3.6), 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 3.7.2.
[b]Reinforcement 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 3-3), 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 3.7.2.
[c]For addition of corrosion allowance, see 3.7.5.2.



THREADED-TYPE SHELL NOZZLES, NPS 3/4 THROUGH NPS 2

Notes:
1. See Table 3-7, Column 6.
2. t_{min} shall be 19 mm (3/4 in.) or the thickness of either part joined by the fillet weld, whichever is less.

Figure 3-5—Shell Nozzles (continued)

3.7.3.3 The rules in 3.7.3.1 and 3.7.3.2 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 3.7.2.1) and the toe of the shell-to-bottom weld.

● **3.7.3.4** By agreement between the purchaser and the manufacturer, circular shell openings and reinforcing plates (if used) may be located in a horizontal or vertical butt-welded shell joint provided that minimum spacing dimensions are met and a radiographic examination of the welded shell joint is conducted (see Figure 3-6, Details a, c, and e). The welded shell joint shall be 100% radiographed for a length equal to three times the diameter of the opening, but weld seam being removed need not be radiographed. Radiographic examination shall be in accordance with 6.1.3 through 6.1.8.

3.7.4 Thermal Stress Relief

3.7.4.1 All flush-type cleanout fittings and flush-type shell connections shall be thermally stress-relieved after 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 to 650°C (1100°F to 1200°F) (see 3.7.4.3 for
00 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.

3.7.4.2 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 to 650°C (1100°F to 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 3.7.2.3).

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.

3.7.4.3 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 to 650°C (1100°F to 1200°F) for 1 hour per 25 mm (1 in.) of thickness prior to installation.

Table 3-6—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]
							Minimum Distance from Bottom of Tank to Center of Nozzle	
NPS (Size of Nozzle)	Outside Diameter of Pipe	Nominal Thickness of Flanged Nozzle Pipe Wall[a,b] t_n	Diameter of Hole in Reinforcing Plate D_R	Length of Side of Reinforcing Plate[b] or Diameter $L = D_o$	Width of Reinforcing Plate W	Minimum Distance from Shell to Flange Face J	Regular Type[d] H_N	Low Type C
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)	i
$1^{1}/_{2}$[f]	48.3 (1.90)	5.08 (0.200)	51 (2)	—	—	150 (6)	150 (6)	i
Threaded Fittings								
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)	i
$31^{1}/_{2}$[f]	63.5 (2.500)	Coupling	66.7 ($2^{5}/_{8}$)	—	—	—	150 (6)	i
1[f]	44.5 (1.750)	Coupling	47.6 ($1^{7}/_{8}$)	—	—	—	125 (5)	i
$^{3}/_{4}$[f]	35.0 (1.375)	Coupling	38.1 ($1^{1}/_{2}$)	—	—	—	100 (4)	i

[a]For extra-strong pipe, refer to ASTM A 53 or A 106 for other wall thicknesses; however, piping material must conform to 2.5.
[b]The 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.
● [c]Unless otherwise specified by the purchaser, the nozzle shall be located at the minimum distance but shall also meet the weld spacing requirements of 3.7.3.
[d]The H_N dimensions given in this table are for Appendix A tank designs only; refer to 3.7.3 to determine minimum H_N for basic tank designs.
[e]See Table 3-7, Column 2.
[f]Flanged nozzles and threaded nozzles 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 3-7, Column 6. Reinforcing plates may be used if desired.
[g]A threaded nozzle in an NPS 3 requires reinforcement.
● [h]Any specified corrosion allowance shall, by agreement between the purchaser and the manufacturer, be added to either the nominal thickness shown or the minimum calculated thickness required for pressure head and mechanical strength. In no case shall the thickness provided be less than the nominal thickness shown.
[i]Refer to 3.7.3.
Note: See Figure 3-5.

Table 3-9—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 h	Width of Opening b	Arc Width of Shell Reinforcing Plate W	Upper Corner Radius of Opening r_1	Upper Corner Radius of Shell Reinforcing Plate r_2	Edge Distance of Bolts e	Flange Width[a] (Except at Bottom) f_3	Bottom Flange Width f_2	Special Bolt Spacing[b] g	Number of Bolts	Diameter of Bolts
200 (8)	400 (16)	1170 (46)	100 (4)	360 (14)	32 ($1\frac{1}{4}$)	100 (4)	90 ($3\frac{1}{2}$)	80 ($3\frac{1}{4}$)	22	20 ($\frac{3}{4}$)
600 (24)	600 (24)	1830 (72)	300 (12)	740 (29)	40 ($1\frac{1}{2}$)	100 (4)	95 ($3\frac{3}{4}$)	90 ($3\frac{1}{2}$)	36	20 ($\frac{3}{4}$)
900 (36)	1200 (48)	2700 (106)	450[c] (18)	1040 (41)	40 ($1\frac{1}{2}$)	115 ($4\frac{1}{2}$)	120 ($4\frac{3}{4}$)	110 ($4\frac{1}{4}$)	46	24 (1)
1200[d] (48)	1200 (48)	3200 (125)	600 (24)	1310 ($51\frac{1}{2}$)	40 ($1\frac{1}{2}$)	115 ($4\frac{1}{2}$)	125 (5)	115 ($4\frac{1}{2}$)	52	24 (1)

[a]For neck thicknesses greater than 40 mm ($1\frac{9}{16}$ in.), increase f_3 as necessary to provide a 1.5 mm ($\frac{1}{16}$ in.) clearance between the required neck-to-flange weld and the head of the bolt.
[b]Refers to spacing at the lower corners of the cleanout-fitting flange.
[c]For Groups IV, IVA, V, and VI, 600 mm (24 in.).
[d]Only for Group I, II, III, or IIIA shell materials (see 3.7.7.2).
Note: See Figure 3-9.

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 3.7.4.2 are fulfilled.

3.7.4.4 Inspection after stress relief shall be in accordance with 5.2.3.6.

3.7.4.5 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 following tabulation:

Minimum Stress-Relieving Temperature (°C)	Minimum Stress-Relieving Temperature (°F)	Holding Time [hours per 25 mm (1 in.) of thickness]	See Note
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.

3.7.4.6 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.

3.7.5 Shell Manholes

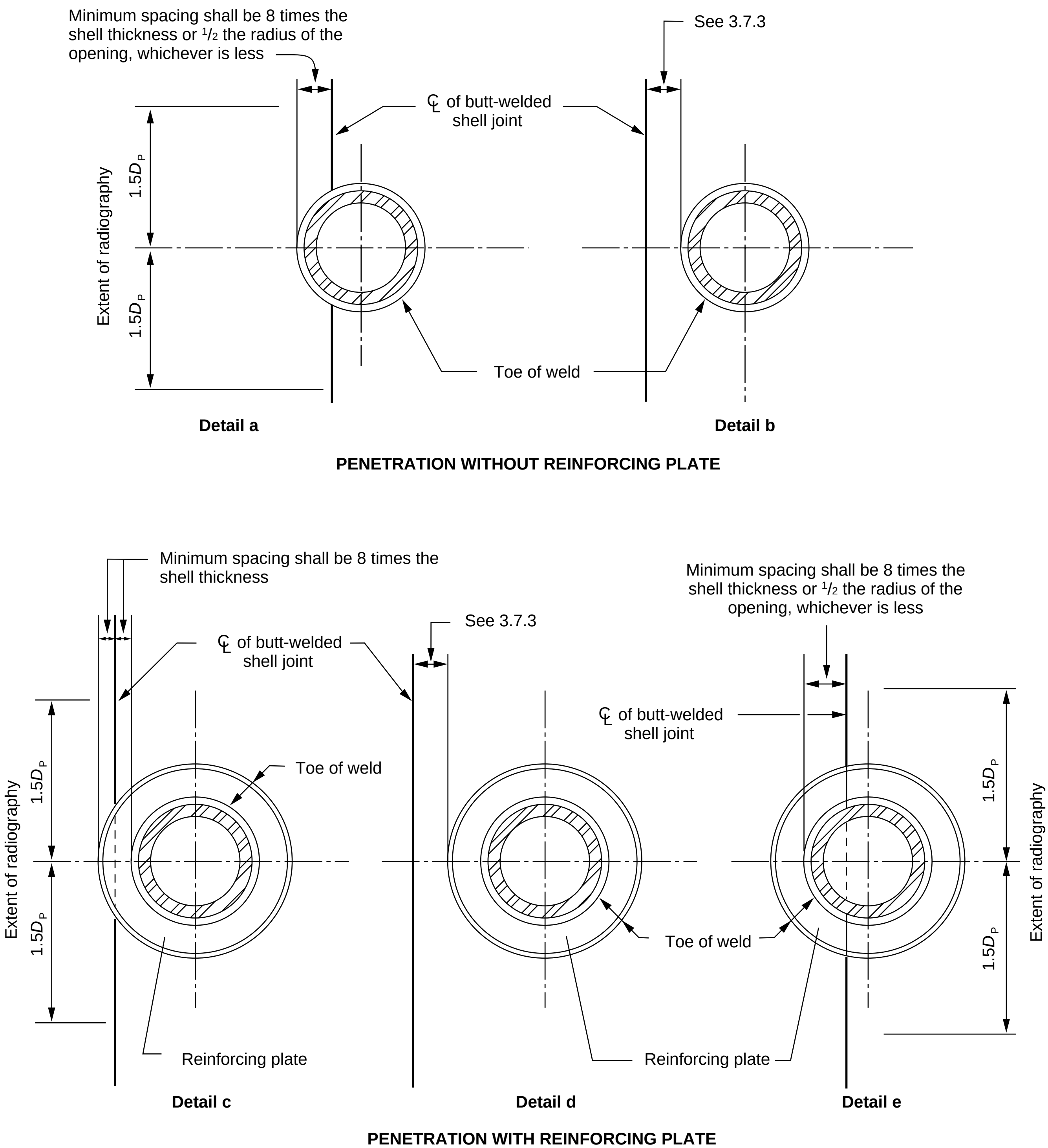
3.7.5.1 Shell manholes shall conform to Figures 3-4A and 3-4B and Tables 3-3 through 3-5 (or Tables 3-6 through 3-8), but other shapes are permitted by 3.7.1.8. Manhole reinforcing plates or each segment of the plates if they are not made in one piece shall be provided with a 6 mm ($\frac{1}{4}$ in.) diameter tell-tale 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.

3.7.5.2 Manholes shall be of built-up welded construction. The dimensions are listed in Tables 3-3 through 3-5. The dimensions are based on the minimum neck thicknesses listed in Table 3-4. 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 3-3 and 3-4.

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

3.7.5.4 The gasket materials shall meet service requirements based on the product stored, temperature, and fire resistance. Gasket dimensions, when used in conjunction with thin-plate flanges described in Figure 3-4A, 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 01
manhole cover shall be designed per API Standard 620, Sections 3.20 and 3.21.

3.7.5.5 In lieu of using Figure 3-4A or design per API Standard 620, forged flanges and forged blind flanges may be furnished per 2.6.



Note: D_p = diameter of opening.

Figure 3-6—Minimum Spacing of Welds and Extent of Related Radiographic Examination

Table 3-10—Minimum Thickness of Cover Plate, Bolting Flange, and Bottom Reinforcing Plate 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
		Size of Opening $h \times b$ (Height × Width)							
		200 × 400 (8 × 16)		600 × 600 (24 × 24)		900 × 1200 (36 × 48)		1200 × 1200 (48 × 48)	
Maximum Design LiquidLevel m (ft) H	Equivalent Pressure[a] kPa (psi)	Thickness of Bolting Flange and Cover Plate t_c	Thickness of Bottom Reinforcing Plate[b] t_b	Thickness of Bolting Flange and Cover Plate t_c	Thickness of Bottom Reinforcing Plate[c] t_b	Thickness of Bolting Flange and Cover Plate t_c	Thickness of Bottom Reinforcing Plate[d] t_b	Thickness of Bolting Flange and Cover Plate t_c	Thickness of Bottom Reinforcing Plate[e] t_b 00
6.1 (20)	60 (8.7)	10 (3/8)	13 (1/2)	10 (3/8)	13 (1/2)	16 (5/8)	21 (13/16)	16 (5/8)	22 (7/8)
10 (34)	98 (14.7)	10 (3/8)	13 (1/2)	13 (1/2)	13 (1/2)	19 (3/4)	25 (1)	21 (13/16)	28 (1 1/8)
12 (41)	118 (17.8)	10 (3/8)	13 (1/2)	13 (1/2)	14 (9/16)	22 (7/8)	28 (1 1/8)	22 (7/8)	30 (1 3/16)
16 (53)	157 (23)	10 (3/8)	13 (1/2)	14 (9/16)	16 (5/8)	24 (15/16)	32 (1 1/4)	25 (1)	33 (1 5/16)
18 (60)	177 (26)	11 (7/16)	13 (1/2)	16 (5/8)	18 (11/16)	25 (1)	33 (1 5/16)	28 (1 1/8)	35 (1 3/8)
20 (64)	196 (27.8)	11 (7/16)	13 (1/2)	16 (5/8)	18 (11/16)	27 (1 1/16)	35 (1 3/8)	28 (1 1/8)	36 (1 7/16)
22 (72)	216 (31.2)	11 (7/16)	13 (1/2)	18 (11/16)	19 (3/4)	28 (1 1/8)	36 (1 7/16)	30 (1 3/16)	38 (1 1/2)

[a]Equivalent pressure is based on water loading.
[b]Maximum of 25 mm (1 in.).
[c]Maximum of 28 mm (1 1/8 in.).
[d]Maximum of 38 mm (1 1/2 in.).
[e]Maximum of 45 mm (1 3/4 in.).
Note: See Figure 3-9.

3.7.6 Shell Nozzles and Flanges

3.7.6.1 Shell nozzles and flanges shall conform to Figures 3-4B, 3-5, and 3-7 and Tables 3-6 through 3-8, but other shapes are permitted by 3.7.1.8. Nozzle reinforcing plates 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 tell-tale hole. Such holes shall be located substantially on the horizontal centerline and shall be open to the atmosphere.

3.7.6.2 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 3-5 and Table 3-6) is increased by the amount that the horizontal chord of the opening cut in the shell plate (D_p in Figure 3-5 and Table 3-7) increases as the opening is changed from circular to elliptical for the angular installation. In addition, nozzles not larger than
00 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.

3.7.6.3 The minimum thickness of nozzle neck to be used shall be equal to the required thickness as identified by the
01 term t_n in Table 3-6, Column 3.

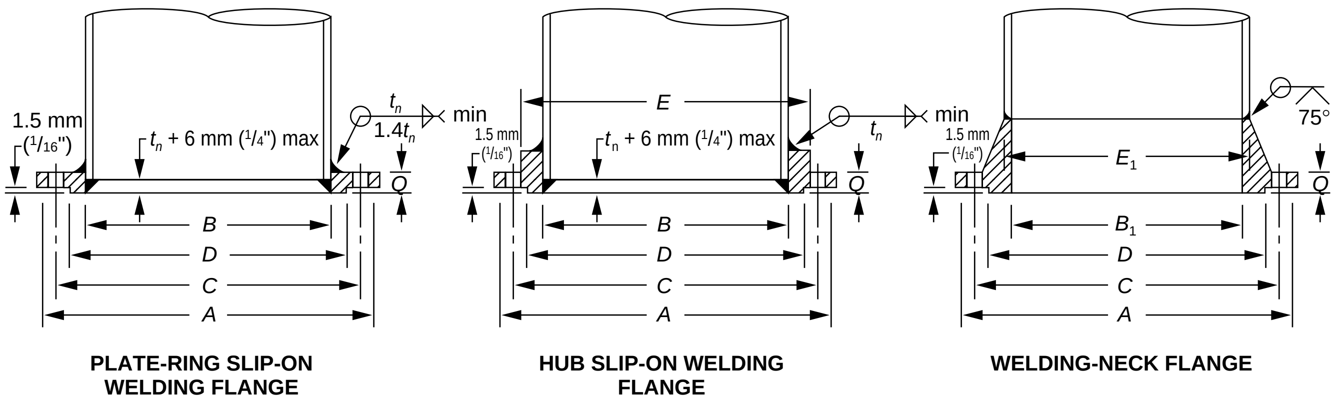
3.7.7 Flush-Type Cleanout Fittings

● **3.7.7.1** Flush-type cleanout fittings shall conform to the requirements of 3.7.7.2 through 3.7.7.12 and to the details and dimensions shown in Figures 3-9 and 3-10 and Tables 3-9 through 3-11. When a size intermediate to the sizes given in Tables 3-9 through 3-11 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.

3.7.7.2 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.).

3.7.7.3 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 3.7.4 (regardless of the thickness or strength of the material).

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



Note: The t_n designated for weld thickness is the nominal pipe wall thickness (see Tables 3-6 and 3-7).

Figure 3-7—Shell Nozzle Flanges (See Table 3-8)

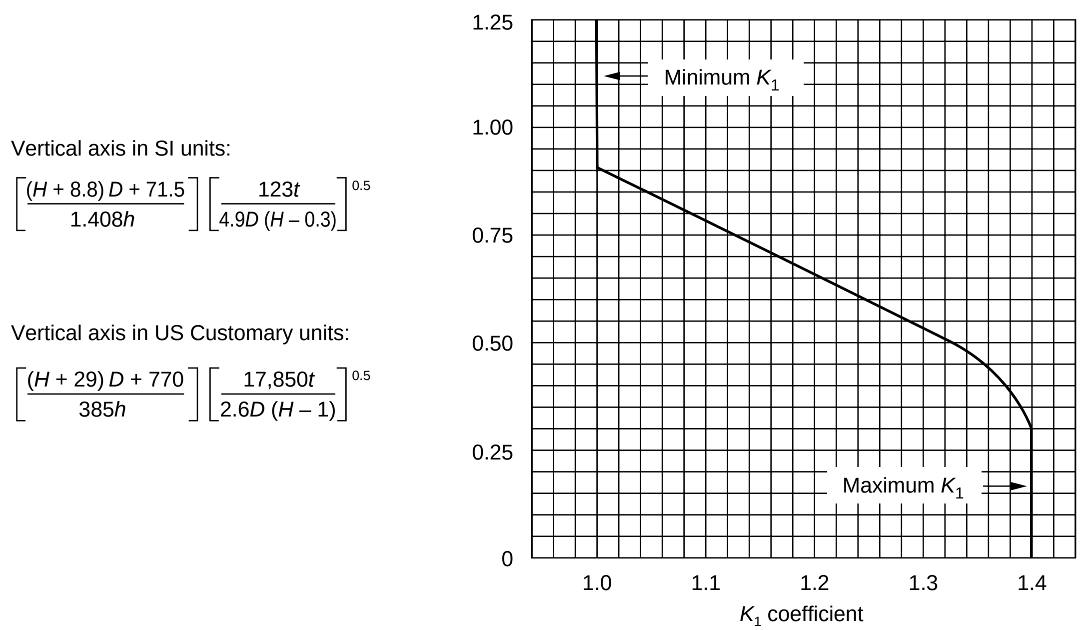


Figure 3-8—Area Coefficient for Determining Minimum Reinforcement of Flush-Type Cleanout Fittings

$$A_{cs} \geq \frac{K_1 ht}{2}$$

where

A_{cs} = cross-sectional area of the reinforcement over the top of the opening, in mm^2 (in.^{2}),

K_1 = area coefficient from Figure 3-8,

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 3.6.3, 3.6.4, or A.4.1 but exclusive of any corrosion allowance.

3.7.7.5 The thickness of the shell plate in the cleanout-opening 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. 00 01

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 cleanout-door 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.

3.7.7.6 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:

98 $$t_b = \frac{h^2}{360{,}000} + \frac{b}{170}\sqrt{HG}$$

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 3.6.3.2), in m.

98 G = specific gravity, not less than 1.0.

In US Customary units:

98 $$t_b = \frac{h^2}{14{,}000} + \frac{b}{310}\sqrt{HG}$$

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 3.6.3.2), (ft),

98 G = specific gravity, not less than 1.0.

3.7.7.7 The dimensions of the cover plate, bolting flange, bolting, and bottom-reinforcing plate shall conform to Tables 3-9 and 3-10.

3.7.7.8 All materials in the flush-type cleanout fitting assembly shall conform to the requirements in Section 2. The shell plate containing the cleanout assembly, the shell rein-
01 forcing plate, the neck plate, and the bottom reinforcing plate shall meet the impact test requirements of 2.2.9 and Figure 2-1 for the respective thickness involved at the stated 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 2.5.5.3 using Table 2-3(a), Table 2-3(b), and Figure 2-1. 01 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.

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

3.7.7.10 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 3-10, 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 3-10, Method B.

3.7.7.11 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 3-10, Method C, shall be provided to accommodate the cleanout fitting.

3.7.7.12 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 3-10, Method D.

3.7.8 Flush-Type Shell Connections

● **3.7.8.1** 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 3-11):

a. 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.

b. 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.

c. The maximum width, b, of the flush-type connection opening in the cylindrical shell shall not exceed 900 mm (36 in.).

d. The maximum height, h, of the opening in the cylindrical shell shall not exceed 300 mm (12 in.).

e. 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.

Table 3-11—Thicknesses and Heights of Shell Reinforcing Plates for Flush-Type Cleanout Fittings [mm (in.)]

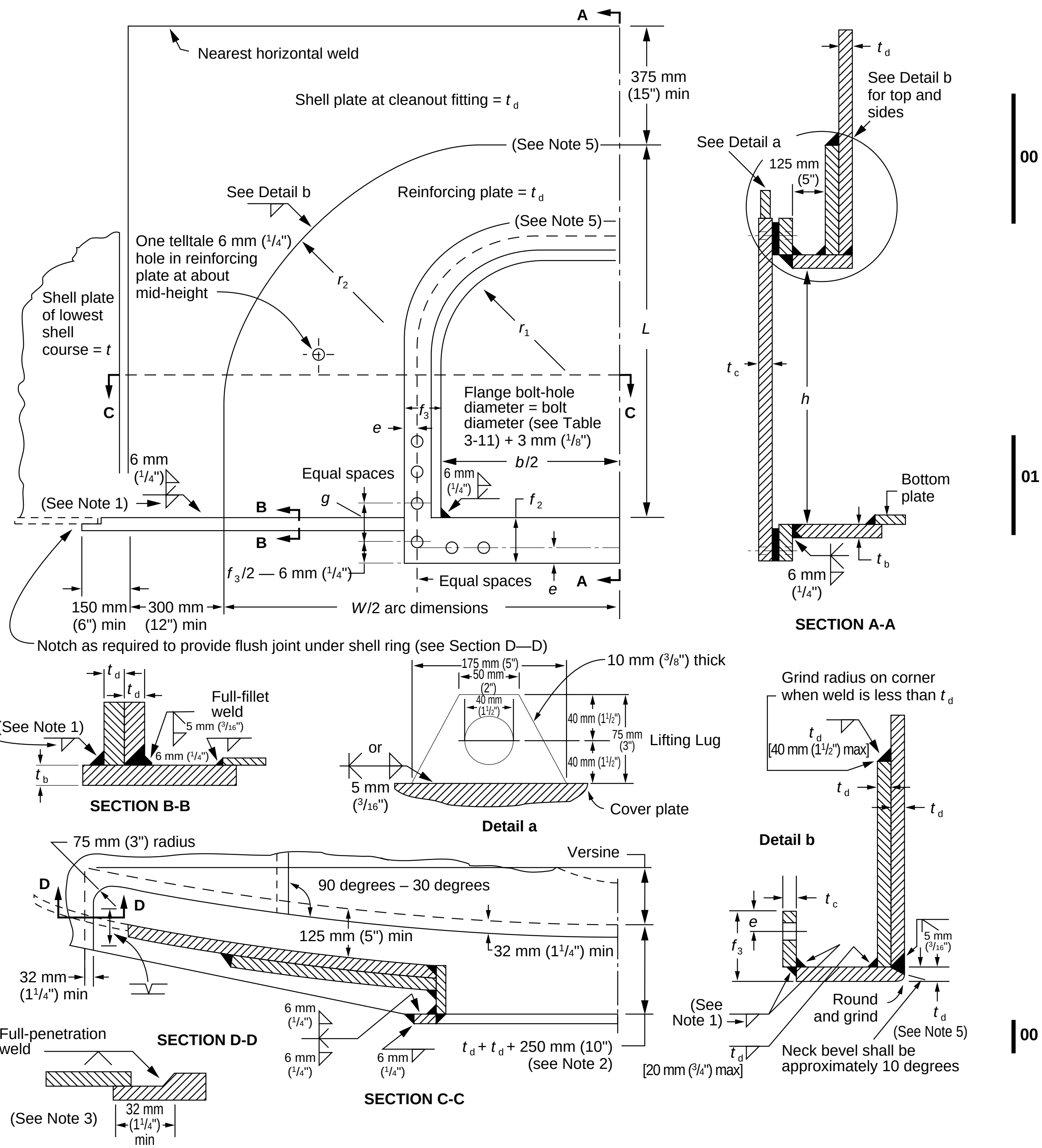
	Thickness of Lowest Shell Course t, t_d[a] mm (ft)	Maximum Design Liquid Level[c] H m (ft)	Height of Shell Reinforcing Plate for Size of Opening $h \times b$ (Height × Width) mm (ft)			
			200 × 400 (8 × 16)	600 × 600 (24 × 24)	900 × 1200 (36 × 48)	1200 × 1200 (48 × 48)
00	All	< 22 (72)	350 (14)	915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

Notes:

[a]Dimensions t_d and L may be varied within the limits defined in 3.7.7.

01 [b]1200 x 1200 (48 x 48) flush-type cleanout fittings are not permitted for tanks with greater than 38 mm ($1^1/_2$ in.) lowest shell course thickness.

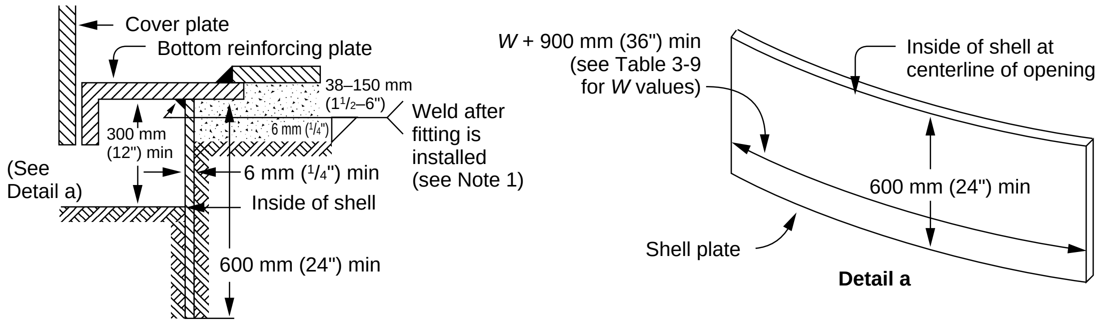
[c]See 3.6.3.2.



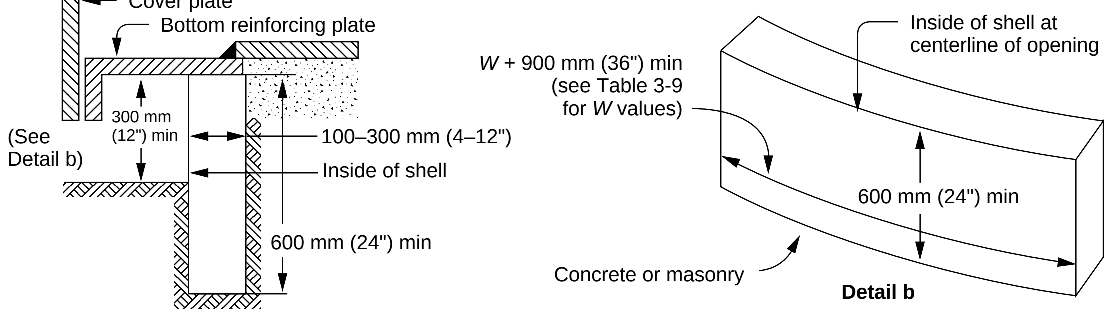
Notes:

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, 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. 00

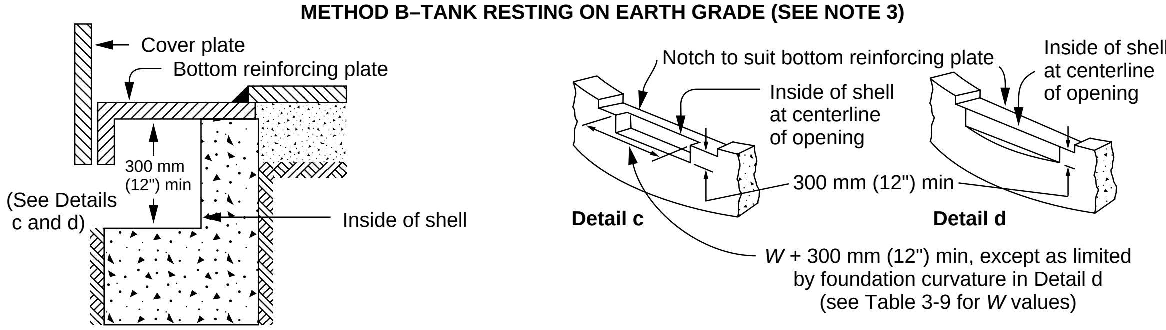
Figure 3-9—Flush-Type Cleanout Fittings (See Tables 3-9, 3-10, and 3-11)



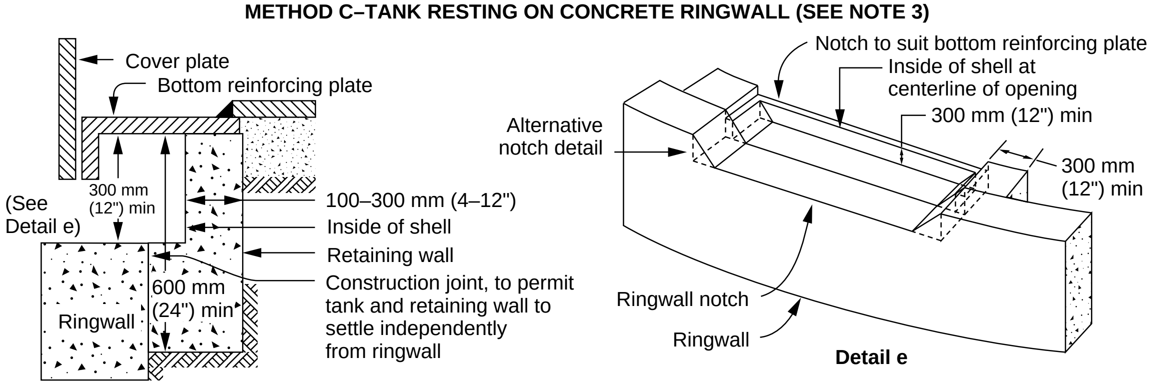
METHOD A–TANK RESTING ON EARTH GRADE (SEE NOTE 2)



METHOD B–TANK RESTING ON EARTH GRADE (SEE NOTE 3)



METHOD C–TANK RESTING ON CONCRETE RINGWALL (SEE NOTE 3)



METHOD D–TANK RESTING ON EARTH GRADE INSIDE CONCRETE RINGWALL (SEE NOTE 3)

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 3-10—Flush-Type Cleanout-Fitting Supports (See 3.7.7)

Table 3-12—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[a]	350 (14)
12	300 ($12^3/_4$)	300 ($12^3/_4$)	1300 (52)	150[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)

[a]For circular openings, this value will be $^1/_2$ of the ID based on the nozzle neck specified.
Note: See Figure 3-11.

3.7.8.2 The details of the connection shall conform to those shown in Figure 3-11, and the dimensions of the connection shall conform to Table 3-12 and to the requirements of 3.7.8.3 through 3.7.8.11.

3.7.8.3 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 to 650°C (1100°F to 1200°F) for 1 hour per 25 mm (1 in.) of shell-plate thickness, t_d (see 3.7.4.1 and 3.7.4.2).

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

a. The cross-sectional area of the reinforcement over the top of the connection shall not be less than $K_1ht/2$ (see 3.7.7.4).
b. The thickness of the shell plate, t_d, for the flush-connection
00 tion assembly shall be at least as thick as the adjacent shell plate, t, in the lowest shell course.
c. The thickness of the shell reinforcing plate shall be the same as the thickness of the shell plate in the flush-connection assembly.
d. 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.
e. 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.
f. 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 3.7.7.6):

In SI units:

$$t_b = \frac{h^2}{360{,}000} + \frac{b}{170}\sqrt{HG}$$ 98

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 3.6.3.2), in m,

G = specific gravity, not less than 1.0.

In US Customary units:

$$t_b = \frac{h^2}{14{,}000} + \frac{b}{310}\sqrt{HG}$$ 98

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 3.6.3.2), (ft),

G = specific gravity, not less than 1.0.

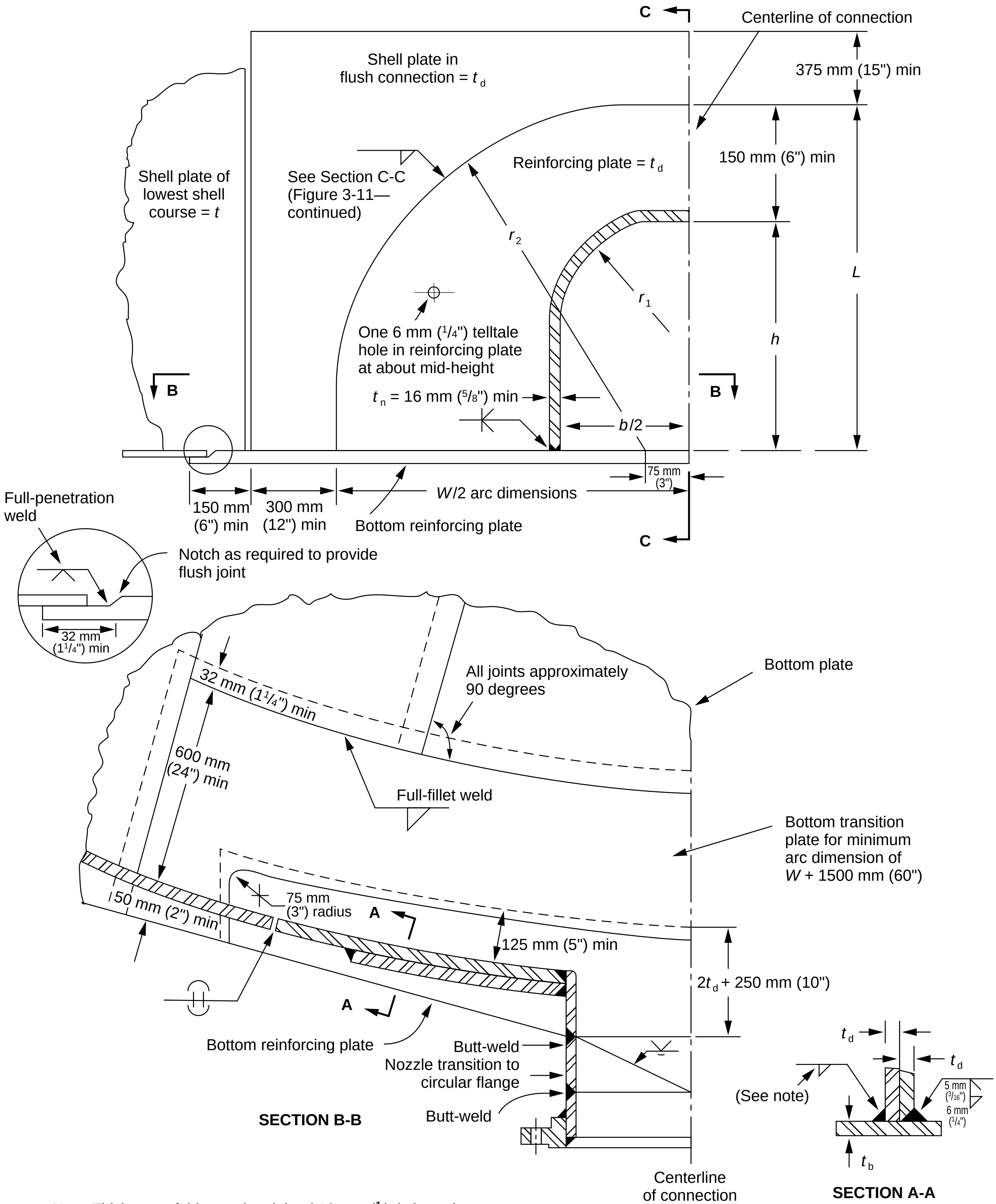
The minimum value of t_b shall be:

16 mm ($^5/_8$ in.) for $HG \le 14.4$ m (48 ft),

17 mm ($^{11}/_{16}$ in.) for 14.4 m (48 ft) < $HG \le 16.8$ m (56 ft), 98

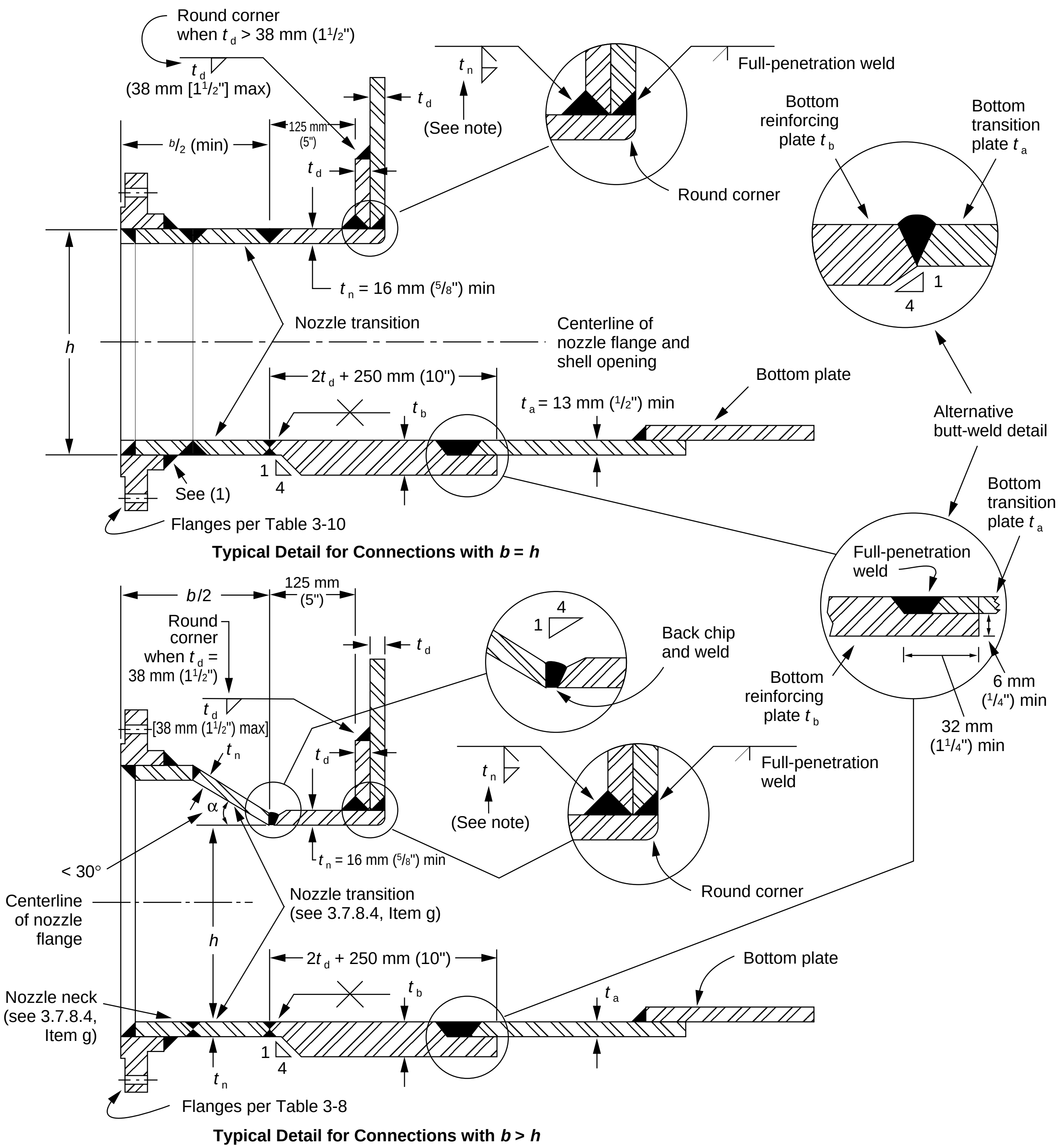
19 mm ($^3/_4$ in.) for 16.8 m (56 ft) < $HG \le 19.2$ m (64 ft).

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.).



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

Figure 3-11—Flush-Type Shell Connection



SECTION C-C

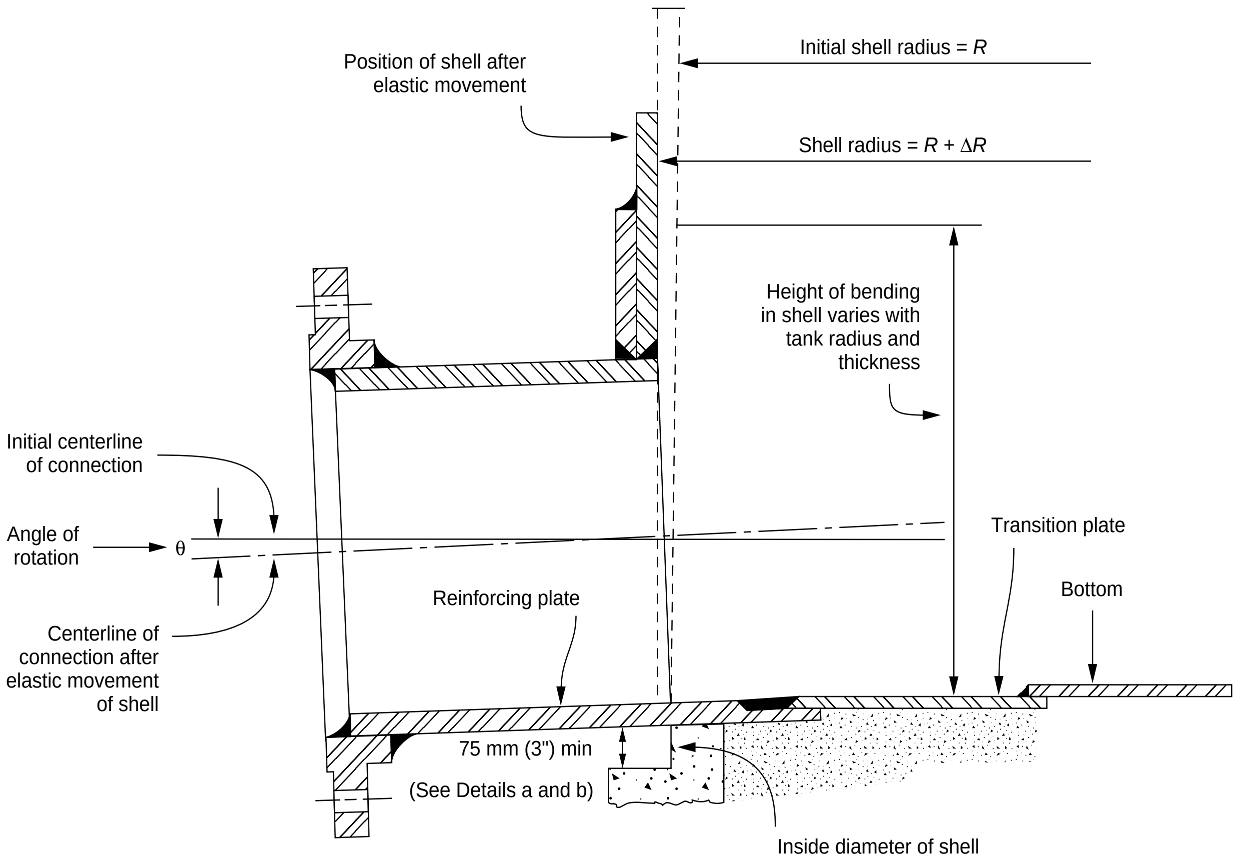
Notes:
Thickness of thinner plate joined 13 mm ($^1/_2$ in.) maximum.
(1) Flange weld sizes shall be the smaller of available hub material or t_n.

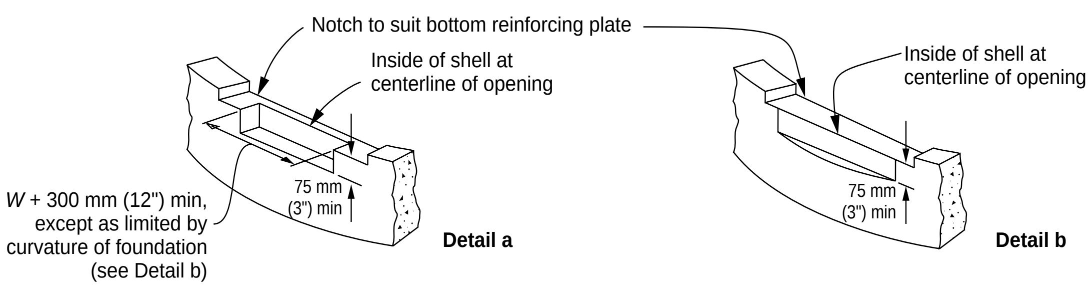
Figure 3-11—Flush-Type Shell Connection (continued)

3.7.8.5 All materials in the flush-type shell connection assembly shall conform to the requirements in Section 2. 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
01 conform to 2.2.9 and Figure 2-1 for the respective thickness involved at the stated 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 2.5.5.3 and used in Figure 2-1. 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. 01

3.7.8.6 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.

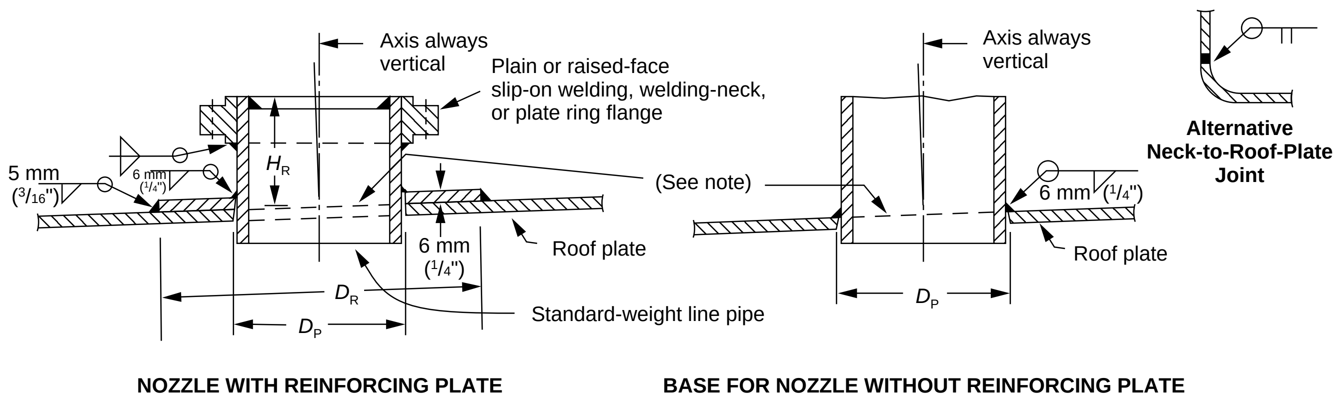
3.7.8.7 Where anchoring devices are required by Appendixes E and F to resist shell uplift, the devices shall be spaced so that they will be located immediately adjacent to each side of the reinforcing plates around the opening.





DETAILS OF NOTCH IN RINGWALL

Figure 3-12—Rotation of Shell Connection



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

Figure 3-16—Flanged Roof Nozzles (See Table 3-14)

3.9.3.2 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 × 64 × 4.8 mm ($2^1/_2 \times 2^1/_2 \times {}^3/_{16}$ in.) top curb angle for shells 5 mm ($^3/_{16}$ in.) thick, with a 76 × 76 × 6.4 mm (3 × 3 × $^1/_4$ in.) angle for shells more than 5 mm ($^3/_{16}$ in.) thick, or with other members of equivalent section modulus.

3.9.3.3 Rings that may trap liquid shall be provided with adequate drain holes.

3.9.3.4 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.

3.9.4 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 600 mm (24 in.) clear of the projecting curb angle on the top of the tank shell. It shall preferably 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.

3.9.5 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.

3.9.6 Top Wind Girder

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

In SI units:

$$Z = \frac{D^2 H_2}{17}$$

where

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

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.

In US Customary units:

$$Z = 0.0001\, D^2 H_2$$

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.

● Note: This equation is based on a wind velocity of 160 km/h (100 mph). If specified by the purchaser, other wind velocities may be used by multiplying the right side of the equation by $(V/160\text{ km/h})^2$, where V equals the wind velocity in km/h [$(V/100\text{ mph})^2$ where V equals the wind velocity in mph]. If the design wind velocity has not been specified and if the maximum allowable wind velocity calculated for the tank shell is less than 160 km/h (100 mph), the calculated velocity may be used provided it is reported to the purchaser. 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 160 km/h (100 mph) design wind velocity can be found in item a of the note to 3.9.7.1.)

Table 3-16—Dimensions for Drawoff Sumps

NPS	Diameter of Sump mm (in.) *A*	Depth of Sump mm (in.) *B*	Distance from Center Pipe to Shell m (ft) *C*	Thickness of Plates in Sump mm (in.) *t*	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 3-16.

3.9.6.2 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 3-20
01 and Table 3-20).

3.9.6.3 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 3.9.6.1. 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 toeboard 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 3-21 shows the opening described above. Alternative details that provide a load-carrying capacity equal to that of the girder cross section away from the opening may be provided.

3.9.7 Intermediate Wind Girders

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

In SI units:

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

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),

D = nominal tank diameter (m). 00

In US Customary units:

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

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,

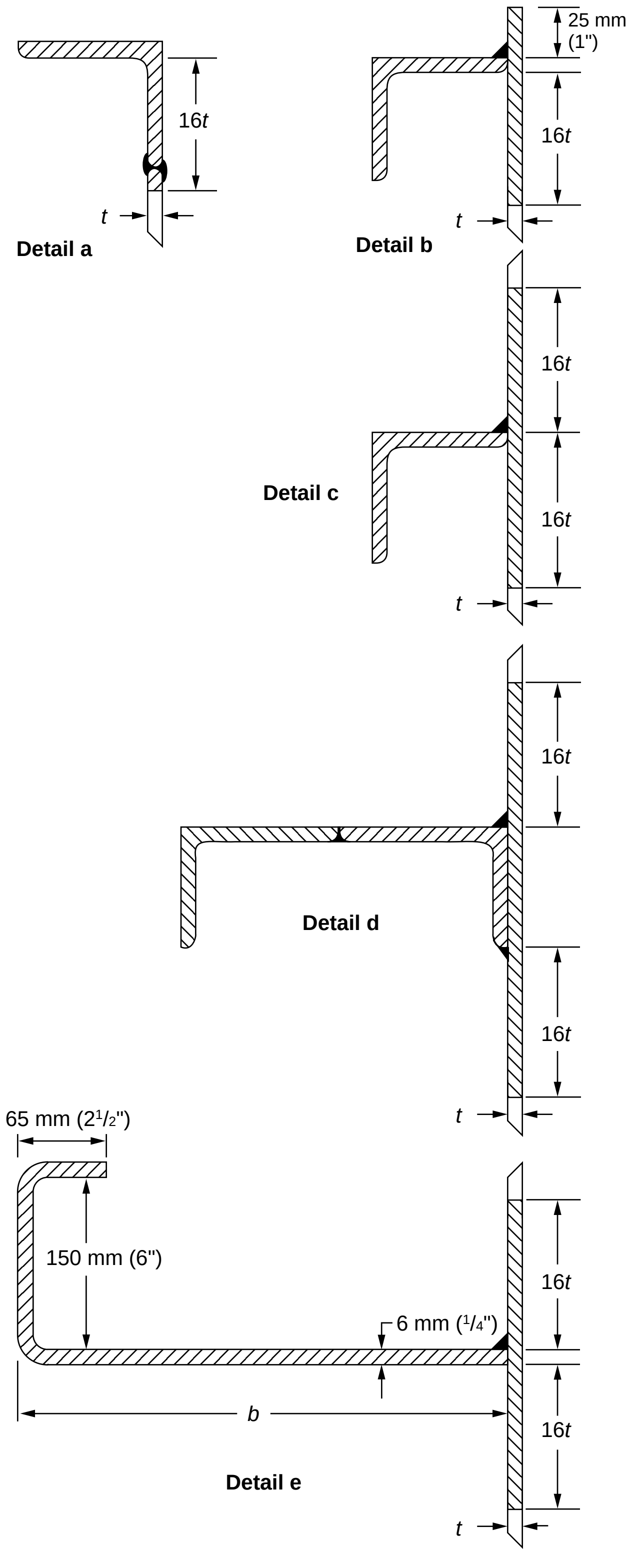
t = as ordered thickness, unless otherwise specified, of the top shell course (in.),

D = nominal tank diameter (ft).

Note: 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 R. V. McGrath's "Stability of API Standard 650 Tank Shells"):[13]

● a. A design wind velocity (V) of 160 km/h (100 mph), which imposes a dynamic pressure of 1.23 kPa (25.6 lbf/ft^2). The velocity is increased by 10% for either a height above ground or a gust factor; thus the pressure is increased to 1.48 kPa (31 lbf/ft^2). An additional 0.24 kPa (5 lbf/ft^2) is added to account for inward drag associated with open-top tanks or for internal vacuum associated with closed-top tanks. A total of 1.72 kPa (36 lbf/ft^2) is obtained. For the purposes of this standard, this pressure is intended to be the result of a 160 km/h (100 mph) fastest mile velocity at approximately 9 m (30 ft) above ground. H_1 may be modified for other wind velocities, as specified by the purchaser, by multiplying the.

[13] R. 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.



Note: The section moduli given in Table 3-20 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 3-20—Typical Stiffening-Ring Sections for Tank Shells (See Table 3-20) 01

3.10.2.5.2 Deleted 01

● **3.10.2.5.3** When a frangible joint is specified by the purchaser, the cross-sectional area of the roof-to-shell junction, A, shall not exceed the following:

In SI units:

$$A = \frac{W}{1390 \tan\theta}$$

In US Customary units:

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

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

All members in the region of the roof-to-shell junction, including insulation rings, shall be considered as contributing to the cross-sectional area. When a frangible joint is specified, the top angle may be smaller than that required by item e of 3.1.5.9.

3.10.2.6 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.

● **3.10.2.7** These rules cannot cover all details of tank roof design and construction. With the approval of the purchaser, the roof need not comply with 3.10.4, 3.10.5, 3.10.6, and 3.10.7. 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.

● **3.10.2.8** 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 3.10.3.

3.10.3 Allowable Stresses

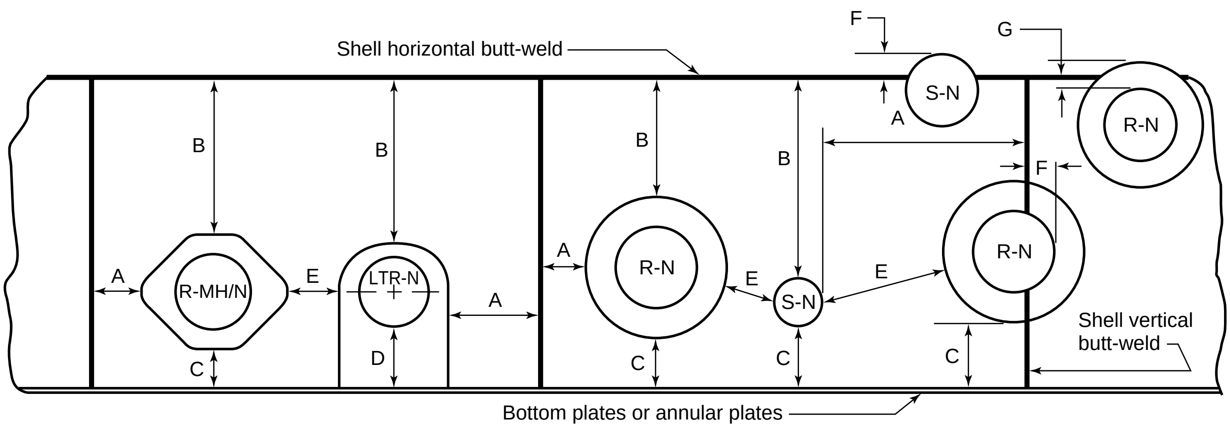
● 3.10.3.1 General

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.

Table 3-20—Section Moduli [cm^3 (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)
01 Top Angle: Figure 3-20, 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)	—	—	—
01 Curb Angle: Figure 3-20, 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 × /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)	—	—	—
01 One Angle: Figure 3-20, 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)
01 Two Angles: Figure 3-20, 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)
01 Formed Plate: Figure 3-20, 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)
01 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.



Note:
R-MH/N = Reinforced Opening (manhole or nozzle with diamond shape reinforcing plate, see Figure 3-4A and 3-5).
LTR-N = Low Type Reinforced Opening (nozzle with tombstone shape reinforcing plate, see Figure 3-5, Detail a and b).
R-N = Reinforced Opening (manhole or nozzle with circular reinforcing plate or thickened insert plate, see Figure 3-5).
S-N = Non-Reinforced Opening (manhole or nozzle inserted into the shell per the alternate neck detail of Figure 3-4B).

Variables		Reference	Minimum Dimension Between Weld Toes or Weld Centerline (1)(3)						
Shell t	Condition	Paragraph Number	A (2)	B (2)	C (2)	D (4)	E (2)	F (5)	G (5)
$t \leq 12.5$ mm ($t \leq {}^1/_2$ in.)	As welded or PWHT	3.7.3.2	150 mm (6 in.)	75 mm (3 in.) or $2^1/_2 t$			75 mm (3 in.) or $2^1/_2 t$		
		3.7.3.3			75 mm (3 in.) or $2^1/_2 t$				
		3.7.3.3			75 mm (3 in.) for S-N				
		3.7.3.3				Table 3-6			
		• 3.7.3.4						$8t$ or ${}^1/_2\ r$	
		• 3.7.3.4							$8t$
$t > 12.5$ mm ($t > {}^1/_2$ in.)	As Welded	3.7.3.1.a	$8W$ or 250 mm (10 in.)	$8W$ or 250 mm (10 in.)					
		3.7.3.1.b					$8W$ or 150 mm (6 in.)		
		3.7.3.3			$8W$ or 250 mm (10 in.)				
		3.7.3.3			75 mm (3 in.) for S-N				
		3.7.3.3				Table 3-6		$8t$ or ${}^1/_2\ r$	
		• 3.7.3.4							$8t$
		• 3.7.3.4							
$t > 12.5$ mm ($t > {}^1/_2$ in.)	PWHT	3.7.3.2	150 mm (6 in.)	75 mm (3 in.) or $2^1/_2 t$			75 mm (3 in.) or $2^1/_2 t$		
		3.7.3.3			75 mm (3 in.) or $2^1/_2 t$				
		3.7.3.3			75 mm (3 in.) for S-N				
		3.7.3.3				Table 3-6			
		• 3.7.3.4						$8t$ or ${}^1/_2\ r$	
		• 3.7.3.4							$8t$

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 3-6, column 9.
5. Purchaser option to allow shell openings to be located in horizontal or vertical shell butt-welds. See Figure 3-6.
t = shell thickness, r = radius of opening. Minimum spacing for dimension F is the lessor of $8t$ or ${}^1/_2\ r$.

Figure 3-22—Minimum Weld Requirements for Openings in Shells According to Section 3.7.3

01

00

3.10.5.2 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:

$$\frac{D^2}{0.432\ \sin\theta}$$

where

θ = angle of the cone elements to the horizontal, in degrees,

D = nominal diameter of the tank shell in m.

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

Note: When the sum of the live and dead loads exceeds 2.2 kPa, the maximum cross-sectional area of the top angle shall be increased by the following ratio:

$$\frac{\textit{live load} + \textit{dead load}}{2.2\ \text{kPa}}$$

In US Customary units:

$$\frac{D^2}{3000\ \sin\theta}$$

where

θ = angle of the cone elements to the horizontal, in degrees,

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

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

Note: When the sum of the live and dead loads exceeds 45 lbf/ft^2, the maximum cross-sectional area of the top angle shall be increased by the following ratio:

$$\frac{\textit{live load} + \textit{dead load}}{45\ \text{lbf/ft}^2}$$

● 3.10.6 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.

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

Minimum radius = 0.8*D* (unless otherwise specified by the purchaser)

Maximum radius = 1.2*D*

In SI units:

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

Maximum thickness = 12.5 mm, exclusive of corrosion allowance 98

where

D = nominal diameter of the tank shell,

r_r = roof radius, in m.

Note: When the sum of the live and dead loads exceeds 2.2 kPa, the minimum thickness shall be increased by the following ratio:

$$\sqrt{\frac{\textit{live load} + \textit{dead load}}{2.2\ \text{kPa}}}$$

In US Customary units:

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

Maximum thickness = $^1/_2$ in., exclusive of corrosion allowance. 98

where

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

r_r = roof radius, (ft).

Note: When the sum of the live and dead loads exceeds 45 lb/ft^2, the minimum thickness shall be increased by the following ratio:

$$\sqrt{\frac{\textit{live load} + \textit{dead load}}{45\ \text{lbf/ft}^2}}$$

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

In SI units:

$$\frac{Dr_r}{0.216}$$

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

Note: When the sum of the live and dead loads exceeds 2.2 kPa, the maximum cross-sectional area of the top angle shall be increased by the following ratio:

$$\frac{\textit{live load} + \textit{dead load}}{2.2\ \text{kPa}}$$

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:

$$\frac{Dr_r}{1500}$$

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

Note: When the sum of the live and dead loads exceeds 45 lbf/ft^2, the maximum cross-sectional area of the top angle shall be increased by the following ratio:

$$\frac{\textit{live load} + \textit{dead load}}{45\ \text{lbf/ft}^2}$$

3.10.7 Top-Angle Attachment for Self-Supporting Roofs

3.10.7.1 Information and certain restrictions on types of top-angle joints are provided in item c of 3.1.5.9. Details of welding are provided in 5.2.

3.10.7.2 At the option of the manufacturer, the edges of the roof plates for self-supporting roofs, including the cone, dome, and umbrella types, may be flanged horizontally to rest flat against the top angle to improve welding conditions.

3.10.8 Tank Venting

3.10.8.1 Tanks designed in accordance with this standard and having a fixed roof shall be vented for both normal conditions (resulting from operational requirements and atmospheric 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 3.10.8.2 and 3.10.8.3.

01 **3.10.8.2** 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 Standard 2000 for normal venting.

3.10.8.3 Emergency venting requirements are satisfied if the tank is equipped with a weak roof-to-shell attachment (frangible joint) in accordance with 3.10.2.5, or if the tank is equipped with pressure relief devices adequate to prevent internal pressure from exceeding the tank design pressure and meeting the requirements specified in API Standard 2000 for emergency venting.

3.11 WIND LOAD ON TANKS (OVERTURNING STABILITY)

● **3.11.1** When specified by the purchaser, overturning stability shall be calculated using the following procedure: The wind load or pressure shall be assumed to be 1.4 kPa (30 lbf/ft^2) on vertical plane surfaces, 0.86 kPa (18 lbf/ft^2) on projected areas of cylindrical surfaces, and 0.72 kPa (15 lbf/ft^2) on projected areas of conical and double-curved surfaces. These wind pressures are based on a wind velocity 160 km/h (100 mph). For structures designed for wind velocities other than 160 km/h (100 mph), the wind loads specified above shall be adjusted in proportion to the following ratio:

In SI units:

$$(V / 160)^2$$

where

V = wind velocity, in km/h, as specified by the purchaser.

In US Customary units:

$$(V / 100)^2$$

where

V = wind velocity, in mph, as specified by the purchaser.

Note: When the wind velocity is not specified, the maximum wind velocity to avoid overturning instability shall be calculated and reported to the purchaser.

3.11.2 For an unanchored tank, the overturning moment from wind pressure shall not exceed two-thirds of the dead-load resisting moment, excluding any tank contents, and shall be calculated as follows:

$$M \le \frac{2}{3}\left(\frac{WD}{2}\right)$$

where

M = overturning moment from wind pressure, in N-m (ft-lbf),

W = shell weight available to resist uplift, less any corrosion allowance, plus dead weight supported by the shell minus simultaneous uplift from operating conditions such as internal pressure on the roof, in N (lbf),

D = tank diameter, in m (ft).

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

$$t_B = \frac{4M}{dN} - \frac{W}{N}$$

where

t_B = design tension load per anchor, in N (lbf),

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

N = number of anchors.

Anchors shall be spaced a maximum of 3 m (10 ft). The allowable tensile stress for anchors shall be in accordance with Appendix F.

3.11.4 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. 98

SECTION 4—FABRICATION

4.1 GENERAL

4.1.1 Workmanship

● **4.1.1.1** All work of fabricating API Standard 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.

4.1.1.2 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.

● 4.1.2 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.

4.1.3 Shaping of Shell Plates

Shell plates shall be shaped to suit the curvature of the tank and the erection procedure according to the following schedule:

	Nominal Plate Thickness mm (in.)	Nominal Tank Diameter m (ft)
	≥ 16 ($^5/_8$)	All
00	From 13 ($^1/_2$) to < 16 ($^5/_8$)	≤ 36 (120)
	From 10 ($^3/_8$) to < 13 ($^1/_2$)	≤ 18 (60)
	From 5 ($^3/_{16}$) to < 10 ($^3/_8$)	≤ 12 (40)

4.1.4 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.

4.1.5 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.

4.2 SHOP INSPECTION

● **4.2.1** 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 01
inspector that the material is being furnished in accordance with this standard. Also, the manufacturer shall furnish, sam- 01
ples or specimens of materials for the purpose of qualifying welders in accordance with 7.3.

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 4.2.2). 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 purchase order that they be provided.

4.2.2 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.

4.2.3 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.

SECTION 5—ERECTION

5.1 GENERAL

5.1.1 The subgrade for receiving the tank bottom shall be provided by the purchaser, unless otherwise specified on the purchase order, and shall be uniform and level.

5.1.2 The manufacturer shall furnish all labor, tools, welding equipment and cables, falsework, scaffolding, and other equipment necessary for erecting tanks that are complete and ready for use. Power for welding shall be supplied by the manufacturer unless other arrangements are stated in the purchase order.

5.1.3 Paint or foreign material shall not be used between surfaces in contact in the construction of the tank proper, except as permitted by 5.2.1.9.

5.1.4 Paint or other protection for structural work inside and outside of the tank shall be as specified on the purchase order and shall be applied by competent workers.

5.1.5 Lugs attached by welding to the exterior of the tank for the purpose of erection only shall be removed, and any noticeable projections of weld metal shall be chipped from the plate. The plate shall not be gouged or torn in the process of removing the lugs.

5.2 DETAILS OF WELDING

5.2.1 General

5.2.1.1 Tanks and their structural attachments shall be welded by the shielded metal-arc, gas metal-arc, gas tungsten-arc, oxyfuel, 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
01 accordance with the requirements of Section 7 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.

5.2.1.2 No welding of any kind shall be performed when the surfaces of the parts to be welded are wet from rain, snow, or ice; when rain or snow is falling on such surfaces; or during periods of high winds unless the welder and the work are properly shielded. Also, no welding of any kind shall be performed when the temperature of the base metal is less than –20°C (0°F). When the temperature of the base metal is –20°C to 0°C (0°F to 32°F) or the thickness of the base metal is in excess of 32 mm (1$^{1}/_{4}$ in.), the base metal within 75 mm (3 in.) of the place where welding is to be started shall be heated to a temperature warm to the hand (see 5.2.3.4 for preheat requirements for shell plates over 38 mm [1$^{1}/_{2}$ in.] thick).

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

5.2.1.4 The edges of all welds shall merge with the surface of the plate without a sharp angle. For vertical butt joints, the maximum acceptable undercutting is 0.4 mm ($^{1}/_{64}$ in.) of the base metal. For horizontal butt joints, undercutting not exceeding 0.8 mm ($^{1}/_{32}$ in.) in depth is acceptable.

5.2.1.5 The reinforcement of the welds on all butt joints on each side of the plate shall not exceed the following thicknesses:

Plate Thickness mm (inches)	Maximum Reinforcement Thickness mm (in.)		
	Vertical Joints	Horizontal Joints	
≤ 13 ($^{1}/_{2}$)	2.5 ($^{3}/_{32}$)	3 ($^{1}/_{8}$)	00
> 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 6.1.3.4.

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

5.2.1.7 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.

5.2.1.8 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 6.5 for criteria for visual examination).

5.2.1.9 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.

5.2.1.10 Low-hydrogen electrodes shall be used for manual metal-arc welds, including the attachment of the first shell course to bottom or annular plates, as follows:

a. For all welds in shell courses greater than 12.5 mm ($^{1}/_{2}$ in.) thick made of material from Groups I–III.
b. For all welds in all shell courses made of material from Groups IV–VI.

5.2.2 Bottoms

5.2.2.1 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.

5.2.2.2 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.

5.2.2.3 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.

5.2.3 Shells

5.2.3.1 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 ($^{5}/_{8}$ in.) thick shall not exceed 10% of the plate thickness or 3 mm ($^{1}/_{8}$ in.), whichever is less; misalignment for plates less than or equal to 16 mm ($^{5}/_{8}$ in.) thick shall not exceed 1.5 mm ($^{1}/_{16}$ in.).

5.2.3.2 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 ($^{1}/_{8}$ in.); however, for upper plates less than 8 mm ($^{5}/_{16}$ in.) thick, the maximum projection shall be limited to 1.5 mm ($^{1}/_{16}$ in.).

5.2.3.3 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.

5.2.3.4 For circumferential and vertical joints in tank shell courses constructed of material more than 38 mm (1$^{1}/_{2}$ in.) thick (based on the thickness of the thicker plate at the joint), multipass weld procedures are required, with no pass over 19 mm ($^{3}/_{4}$ in.) thick permitted. A minimum preheat of 90°C (200°F) is required for these welds.

5.2.3.5 The requirements of this section shall be followed 01 when welding to Group IV, IVA, V, and VI materials. Permanent and temporary attachments (see 5.2.1.10 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 need for preheat shall be considered when the procedure is selected either for welding thick plates or for welding during low atmospheric temperature. The welds of permanent attachments (not including 00 shell-to-bottom welds) and areas where temporary attachments are removed, shall be examined visually and by either the magnetic particle method or the liquid penetrant method 01 (see 6.2, 6.4, or 6.5 for the appropriate inspection criteria).

5.2.3.6 Completed welds of stress-relieved assemblies shall be examined by visual, as well as by magnetic particle 01 or penetrant methods, after stress relief, but before hydrostatic test.

5.2.3.7 Flush-type connections shall be inspected according to 3.7.8.11.

5.2.4 Shell-To-Bottom Welds

5.2.4.1 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 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.

5.2.4.2 As an alternative to 5.2.4.1, 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
00 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.

00 **5.2.4.3** By agreement between the purchaser and the manufacturer, the examinations of 5.2.4.1 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.

5.2.5 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.

5.3 INSPECTION, TESTING, AND REPAIRS

5.3.1 General

5.3.1.1 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 pur-
01 chaser's inspector reasonable facilities to assure the inspector that the work is being performed in accordance with this standard.

5.3.1.2 Any material or workmanship shall be subject to the replacement requirements of 4.2.3.

5.3.1.3 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.

5.3.1.4 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.

5.3.2 Inspection of Welds

5.3.2.1 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 the radiographic method specified in 6.1 and using the visual method. In addition, the purchaser's inspector may visually inspect all butt-welds for cracks, arc strikes, excessive undercuts, surface porosity, incomplete fusion, and other defects. Acceptance and repair criteria for the visual method are specified in 6.5.

5.3.2.2 Fillet Welds

Fillet welds shall be inspected by the visual method. The final weld shall be cleaned of slag and other deposits prior to 01
inspection. Visual examination acceptance and repair criteria are specified in 6.5.

5.3.2.3 Responsibility

The manufacturer shall be responsible for making radio- 01
graphs 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 01
be the responsibility of the purchaser.

5.3.3 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 accep-
tance and repair criteria are specified in 6.5. In addition, all 01
welds shall be tested by one of the following methods:

a. A vacuum box test in accordance with 6.6.

b. A tracer gas test in accordance with 6.6.11.

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 01 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.

5.3.4 Inspection of Reinforcement-Plate Welds

After fabrication is completed but before the tank is filled with test water, the reinforcement plates shall be tested 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 tell-tale hole specified in 3.7.5.1. 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.

01 ● 5.3.5 Testing of the Shell

After the entire tank is completed but before any permanent external piping is connected to the tank, the shell (except for the shell of tanks designed in accordance with Appendix F) shall be tested by one of the following methods:

a. 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; or (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. 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.

b. 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 01 internal air pressure as specified for the roof test in 5.3.6 and carefully examining the joints for leakage; or (3) using any combination of the methods stipulated in 5.3.5.b, subitems 1 and 2. 01

5.3.6 Testing of the Roof

5.3.6.1 Upon completion, the roof of a tank designed to be gastight (except for roofs designed under 5.3.6.2, 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 soap solution or other material suitable for the detection of leaks.

b. Vacuum testing the weld joints in accordance with 6.6 to detect any leaks. 01

● **5.3.6.2** Upon completion, the roof of a tank not designed to be gastight, 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.

5.4 REPAIRS TO WELDS

5.4.1 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 6.2, 6.4, and 6.5, as applicable.

5.4.2 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 6.1.7. Mechanical caulking is not permitted.

5.4.3 All defects, cracks, or leaks in shell joints or the shell-to-bottom joint shall be repaired in accordance with 6.1.7.

● **5.4.4** 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 00 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

SECTION 6—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.

6.1 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.).

6.1.1 Application

Radiographic inspection is required for shell butt-welds (see 6.1.2.2 and 6.1.2.3), annular-plate butt-welds (see 6.1.2.9), and flush-type connections with butt-welds (see 3.7.8.11). Radiographic inspection is not required for the following: roof-plate welds, bottom-plate welds, welds joining
00 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.

6.1.2 Number and Location of Radiographs

6.1.2.1 Except when omitted under the provisions of A.3.4, radiographs shall be taken as specified in 6.1.2 through 6.1.8.

6.1.2.2 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 6-1 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 6-1).

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
98 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 6-1).

c. Vertical joints in which the shell plates are greater than 25
mm (1 in.) thick shall be fully radiographed. All junctions of 00
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 98
on each side of the vertical intersection (see the bottom panel of Figure 6-1).

d. The butt-weld around the periphery of an insert manhole or nozzle shall be completely radiographed.

6.1.2.3 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 6.1.2.2 (see Figure 6-1).

6.1.2.4 When two or more tanks are erected in the same location for the same purchaser, either concurrently or serially, the number of spot radiographs to be taken may be based on the aggregate length of welds of the same type and thick-
ness in each group of tanks rather than the length in each indi- 00
vidual tank.

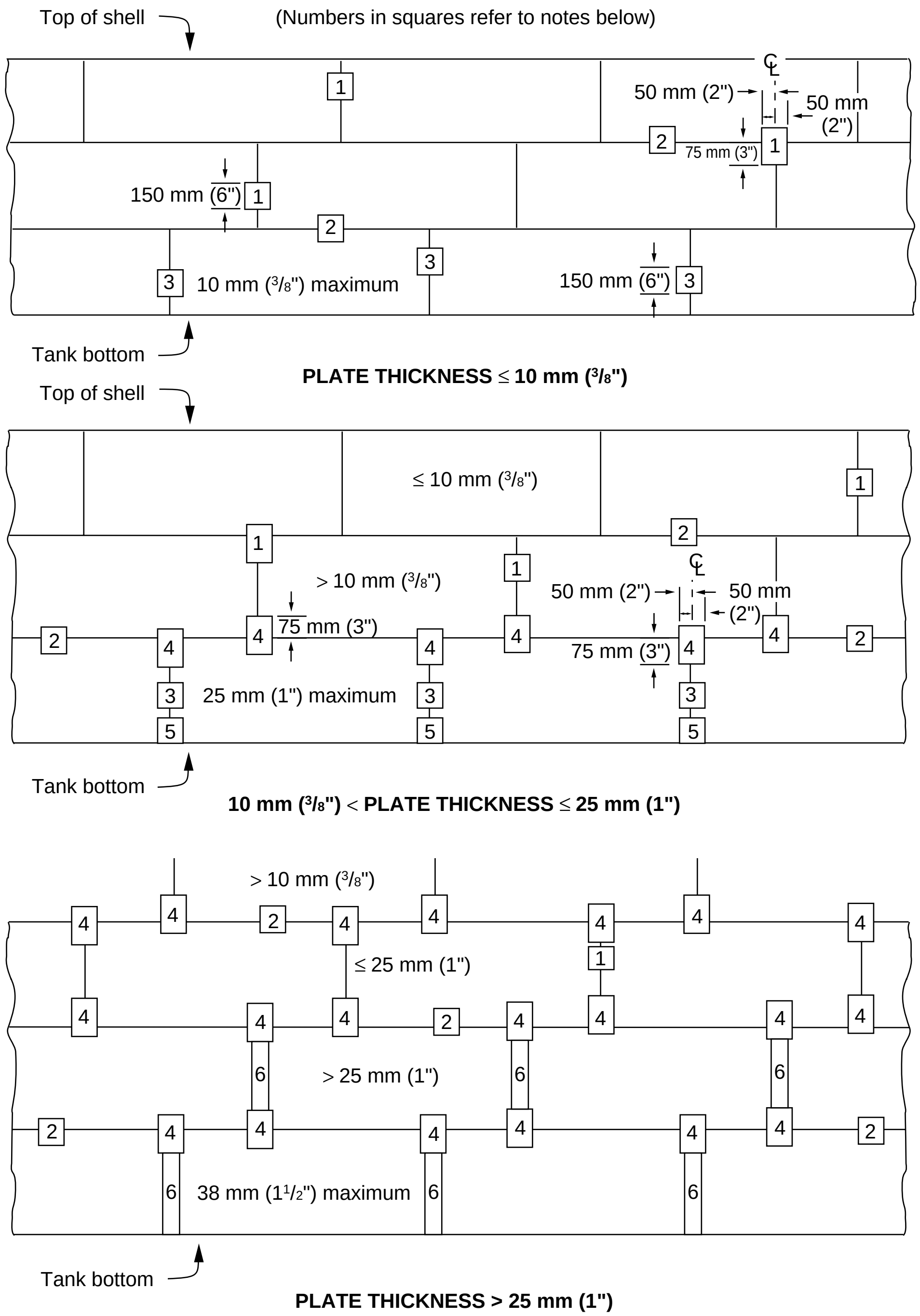
6.1.2.5 It should be recognized that the same welder or welding operator may not weld both sides of the same butt joint. If two welders or welding operators weld opposite sides of the same butt joint, it is permissible to inspect their work with one spot radiograph. If the spot radiograph is rejected, further spot radiographs shall be taken to determine whether one or both of the welders or welding operators are at fault.

6.1.2.6 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.

● **6.1.2.7** 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.

6.1.2.8 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). 01

6.1.2.9 When bottom annular plates are required by 3.5.1, or by M.4.1, the radial joints shall be radiographed as



98

98

Notes:
1. Vertical spot radiograph in accordance with 6.1.2.2, 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 6.1.2.3: one in the first 3 m (10 ft) and one in each 60 m (200 ft) thereafter. 00
3. Vertical spot radiograph in each vertical seam in the lowest course (see 6.1.2.2, 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 6.1.2.2, item b).
5. Spot radiograph of bottom of each vertical seam in lowest shell course over 10 mm ($^3/_8$ in.) (see 6.1.2.2, 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 6.1.2.2, item c).

Figure 6-1—Radiographic Requirements for Tank Shells 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 backup 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 backup 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.

6.1.3 Technique

6.1.3.1 Except as modified in this section, the radiographic examination method employed shall be in accordance with Section V, Article 2, of the ASME Code.

6.1.3.2 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.

6.1.3.3 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 the ability to see
01 the prescribed image quality indicator (penetrameter) and the specified hole or wire.

6.1.3.4 The finished surface of the weld reinforcement at
01 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.)
00	≤ 13 ($\frac{1}{2}$)	1.5 ($\frac{1}{16}$)
	> 13 ($\frac{1}{2}$) to 25 (1)	2.5 ($\frac{3}{32}$)
	> 25 (1)	3 ($\frac{1}{8}$)

6.1.4 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.

6.1.5 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.

6.1.6 Determination of Limits of Defective Welding

When a section of weld is shown by a radiograph to be unacceptable under the provisions of 6.1.5 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 6.1.5, 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 6.1.5, the limits of unacceptable welding shall be determined as specified for the initial section.

6.1.7 Repair of Defective Welds

6.1.7.1 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.

● **6.1.7.2** All repaired welds in joints shall be checked by repeating the original inspection procedure and by repeating one of the testing methods of 5.3, subject to the approval of the purchaser.

6.1.8 Record of Radiographic Examination

6.1.8.1 The manufacturer shall prepare an as-built radiograph map showing the location of all radiographs taken along with the film identification marks.

● **6.1.8.2** After the structure is completed, the films shall be the property of the purchaser unless otherwise agreed upon by the purchaser and the manufacturer.

6.2 MAGNETIC PARTICLE EXAMINATION

6.2.1 When magnetic particle examination is specified, the method of examination shall be in accordance with Section V, Article 7, of the ASME Code.

6.2.2 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.

6.2.3 The manufacturer shall determine that each magnetic particle examiner 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.) 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 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.

6.2.4 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.

6.3 ULTRASONIC EXAMINATION

6.3.1 When ultrasonic examination is specified, the method of examination shall be in accordance with Section V, Article 5, of the ASME Code.

6.3.2 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.

6.3.3 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.

● **6.3.4** Acceptance standards shall be agreed upon by the purchaser and the manufacturer.

6.4 LIQUID PENETRANT EXAMINATION

6.4.1 When liquid penetrant examination is specified, the method of examination shall be in accordance with Section V, Article 6, of the ASME Code.

6.4.2 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.

6.4.3 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.

6.4.4 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.

6.5 VISUAL EXAMINATION

6.5.1 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. Undercutting does not exceed the limits given in 5.2.1.4 for vertical and horizontal butt joints. For welds that attach nozzles, manholes, cleanout openings, and permanent attachments, undercutting shall not exceed 0.4 mm ($^1/_{64}$ in.).
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.). 00

6.5.2 A weld that fails to meet the criteria given in 6.5.1 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.

6.6 VACUUM TESTING

6.6.1 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 01 interpretation of the test. The open bottom shall be sealed against the tank surface by a suitable gasket. Connections, valves, lighting and gauges, shall be provided as required. A soap film solution or commercial leak detection solution, applicable to the conditions, shall be used.

6.6.2 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.

6.6.3 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)
01 shall be performed for the detection of very small leaks.

6.6.4 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.

6.6.5 The vacuum box test shall have at least 50 mm (2 in.) overlap of previously viewed surface on each application.

6.6.6 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.

6.6.7 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.

6.6.8 The vacuum shall be maintained for the greater of either at least 5 seconds or the time required to view the area under test.

6.6.9 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.

6.6.10 A record or report of the test including a statement addressing temperature and light intensity shall be completed and furnished to the customer upon request.

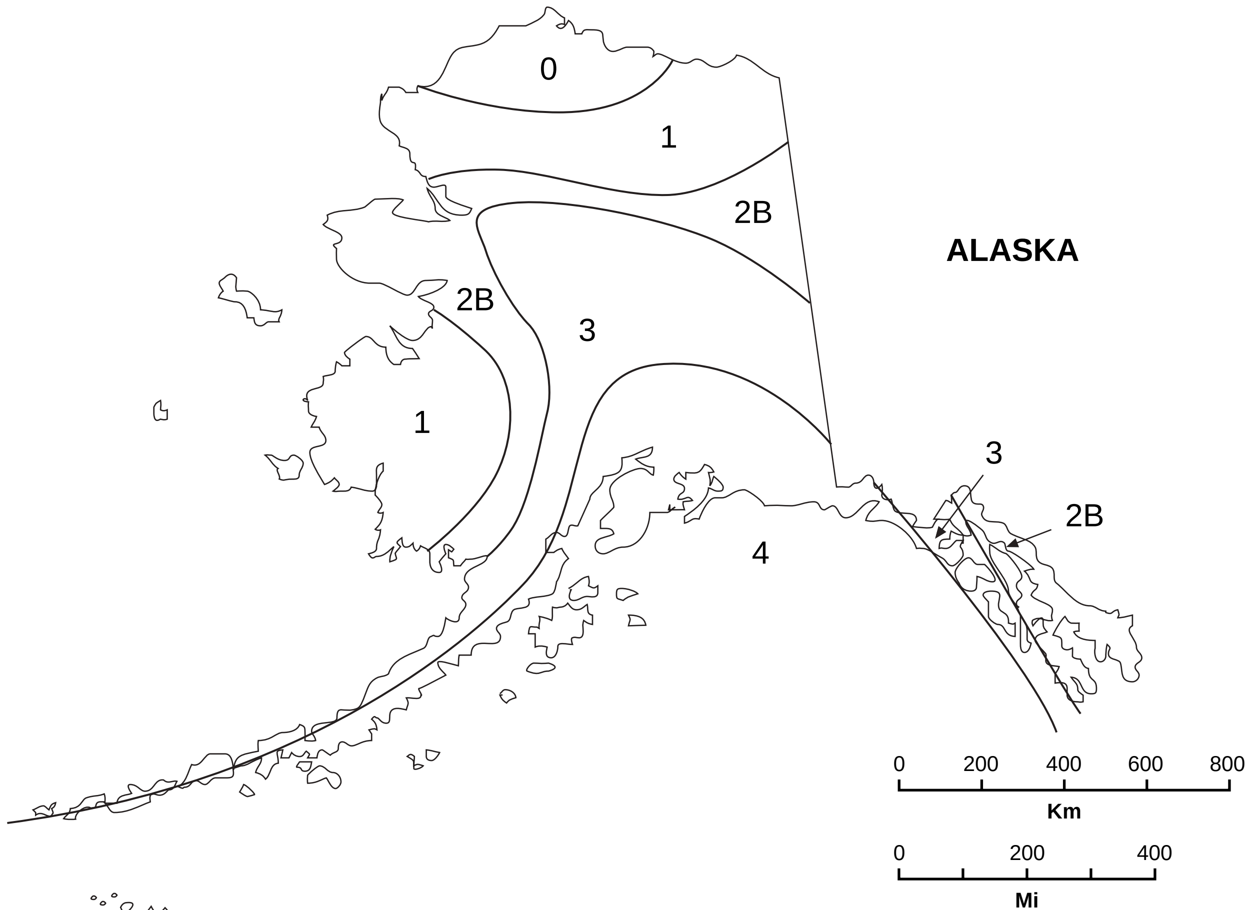
● **6.6.11** As an alternate to vacuum box testing, a suitable tracer gas and compatible detector can be used to test the integrity of welded bottom joints for their entire length. Where tracer gas testing is employed as an alternate to vacuum box testing, it shall meet the following requirements:

a. Tracer gas testing shall be performed in accordance with a 01
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 x 10^{-4} Pa m^3/s (1 x 10^{-3} std cm^3/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 purchaser and 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.



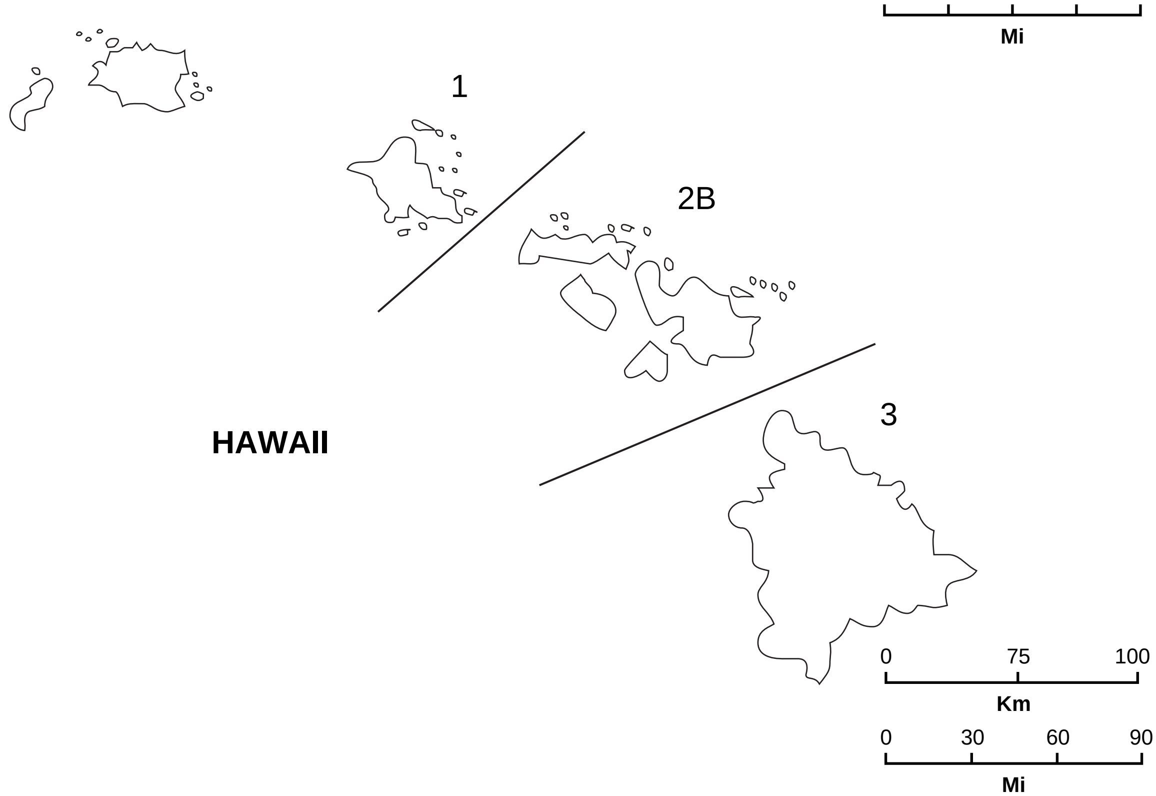


Figure E-1—Seismic Zones (continued)

Table E-1—Seismic Zone Tabulation for Areas Outside the United States

Location	Seismic Zone	Location	Seismic Zone
Asia		Pacific Ocean area	
Turkey		Caroline Islands	
Ankara	2B	Koror, Paulau	2B
Karamursel	3	Ponape	0
Atlantic Ocean area		Johnston Island	1
Azores	2B	Kwajalein	1
Bermuda	1	Mariana Island	
Caribbean		Guam	3
Bahama Islands	1	Saipan	3
Canal Zone	2B	Tinain	3
Leeward Islands	3	Marcus Island	1
Puerto Rico	3	Okinawa	3
Trinidad Island	2B	Philippine Islands	3
North America		Samoa Islands	3
Greenland	1	Wake Island	0
Iceland			
Keflavik	3		

Table E-2—Seismic Zone Factor

Seismic Factor (from Figure E-1 or other sources)	Seismic Zone Factor (horizontal acceleration)
1	0.075
2A	0.15
2B	0.20
3	0.30
4	0.40

E.3.2 EFFECTIVE MASS OF TANK CONTENTS

E.3.2.1 The effective masses W_1 and W_2 may be determined by multiplying W_T by the ratios W_1/W_T and W_2/W_T, respectively, obtained from Figure E-2 for the ratio D/H.

where

● W_T = total weight of the tank contents, in pounds. (The specific gravity of the product shall be specified by the purchaser.),

D = nominal tank diameter, in m (ft) (see 3.6.1.1, Note 1),

H = maximum design liquid level, in m (ft) (see 3.6.3.2).

E.3.2.2 The heights from the bottom of the tank shell to the centroids of the lateral seismic forces applied to W_1 and W_2, X_1 and X_2, may be determined by multiplying H by the ratios X_1/H and X_2/H, respectively, obtained from Figure E-3 for the ratio D/H.

E.3.2.3 The curves in Figures E-2 and E-3 are based on a modification of the equations presented in ERDA Technical Information Document 7024.[15] Alternatively, W_1, W_2, X_1, and X_2 may be determined by other analytical procedures based on the dynamic characteristics of the tank.

E.3.3 LATERAL FORCE COEFFICIENTS

E.3.3.1 The lateral force coefficient C_1 shall be 0.60 unless the product of ZIC_1 and the product of ZIC_2 are determined as outlined in E.3.3.3.

E.3.3.2 The lateral force coefficient C_2 shall be determined as a function of the natural period of the first sloshing mode, T, and the soil conditions at the tank site unless otherwise determined by the method given in E.3.3.3. When T is less than or equal to 4.5,

$$C_2 = \frac{0.75S}{T}$$

When T is greater than 4.5,

$$C_2 = \frac{3.375S}{T^2}$$

where

S = site coefficient from Table E-3,

T = natural period of the first sloshing mode, in seconds. T may be determined from the following equation:

In SI units:

$$T = 1.81k(D^{0.5})$$

where D = nominal tank diameter in m.

In U.S. Customary units: 01

$$T = k(D^{0.5})$$

where D = nominal tank diameter in ft.

k = factor obtained from Figure E-4 for the ratio D/H.

● **E.3.3.3** Alternatively, by agreement between the purchaser and the manufacturer, the lateral force determined by the products of ZIC_1 and ZIC_2 may be determined from response spectra established for the specific tank site and furnished by the purchaser; however, the lateral force ZIC_1 shall not be less than that determined in accordance with E.3.1 and E.3.3.1.

The response spectra for a specific site should be established considering the active faults within the region, the types of faults, the magnitude of the earthquake that could be generated by each fault, the regional seismic activity rate, the proximity of the site to the potential source faults, the attenuation of the ground motion between the faults and the site, and the soil conditions at the site. The spectrum for the factor ZIC_1 should be established for a damping coefficient of 2% of critical. Scaling of the response spectrum to account for the reserve capacity of the tank is permissible. The acceptable reserve capacity shall be specified by the purchaser and can be determined from table tests, field observations, and the ductility of the structure.

[15]ERDA Technical Information Document 7024, *Nuclear Reactors and Earthquakes* (prepared by Lockheed Aircraft Corporation and Holmes & Narver, Inc.), U.S. Atomic Energy Commission, August 1963.

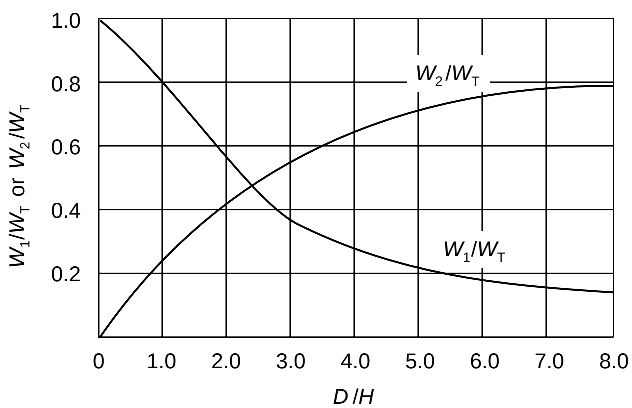


Figure E-2—Effective Masses

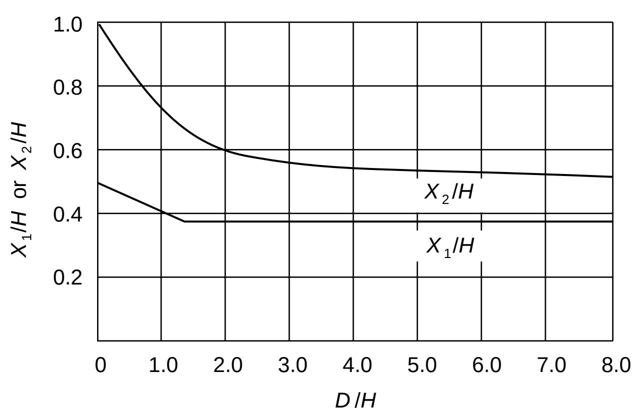


Figure E-3—Centroids of Seismic Forces

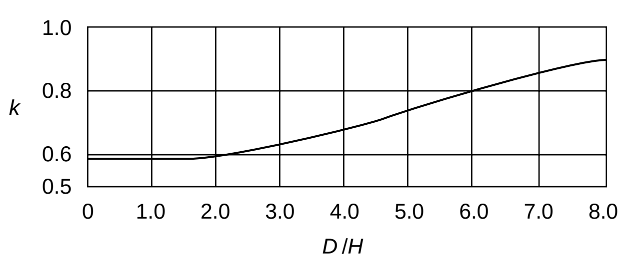


Figure E-4—Factor k

The spectrum for the factor ZIC_2 should correspond to the spectrum for ZIC_1 modified for a damping coefficient of 0.5% of critical. In determining the factor ZIC_1 from the spectrum, the fundamental period of the tank with its contents shall be taken into account unless the maximum spectral acceleration is used.

E.4 Resistance to Overturning

E.4.1 Resistance to the overturning moment at the bottom of the shell may be provided by the weight of the tank shell and by the anchorage of the tank shell or, for unanchored tanks, the weight of a portion of the tank contents adjacent to the shell. For unanchored tanks, the portion of the contents that may be used to resist overturning depends on the width of the bottom plate under the shell that lifts off the foundation and may be determined as follows:

In SI units:

$$w_L = 99 t_b \sqrt{F_{by} G H}$$

However, w_L shall not exceed 196GHD

where

w_L = maximum weight of the tank contents that may be used to resist the shell overturning moment, in N/m of shell circumference,

t_b = thickness of the bottom plate under the shell, in mm, used to calculate w_L (see E.4.2), 00

F_{by} = minimum specified yield strength of the bottom plate under the shell, MPa,

● G = design specific gravity of the liquid to be stored, as specified by the purchaser,

H = maximum design liquid level, m (see 3.6.3.2),

D = nominal tank diameter, m (see 3.6.1.1, Note 1). 98

In U.S. Customary units:

$$w_L = 7.9 t_b \sqrt{F_{by} G H}$$

However, w_L shall not exceed 1.25GHD

where

w_L = maximum weight of the tank contents that may be used to resist the shell overturning moment, in lbf/ft of shell circumference,

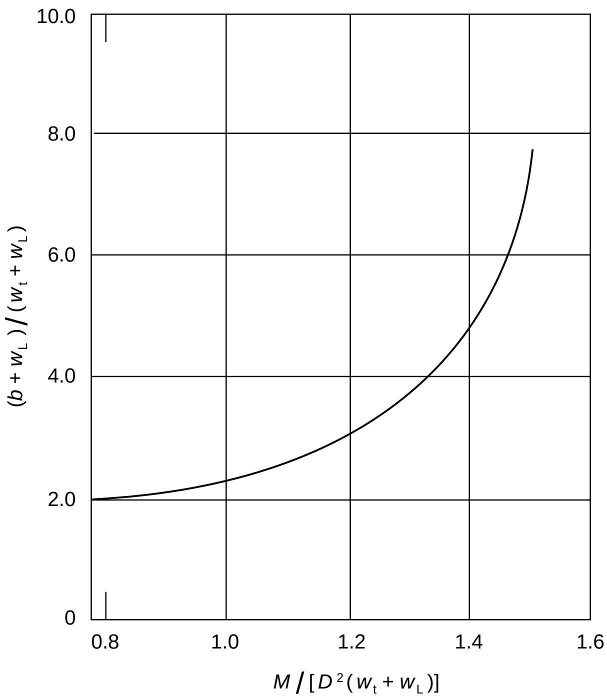
t_b = thickness of the bottom plate under the shell in inches, used to calculate w_L (see E.4.2), 00

F_{by} = minimum specified yield strength of the bottom plate under the shell (lbf/in.^{2}),

● G = design specific gravity of the liquid to be stored, as specified by the purchaser,

H = maximum design liquid level (ft) (see 3.6.3.2),

D = nominal tank diameter (ft) (see 3.6.1.1, Note 1). 98



Note: This figure may be used to compute b when M / [$D^2(w_t + w_L)$] is greater than 0.785 but less than or equal to 1.5 (see E.5.1).

Figure E-5—Compressive Force b

E.4.2 The thickness of the bottom plate under the shell may be greater than or equal to t_b, but the thickness, t_b, used to calculate w_L shall not exceed the larger of 6 mm (1/4 in.) or the first shell course thickness less the shell corrosion allowance,
00 nor shall t_b exceed the actual thickness of the bottom plate under the shell less the corrosion allowance for the bottom plate. Where the bottom plate under the shell is thicker than the remainder of the bottom, the width of the thicker plate under the shell shall be equal to or greater than:

In SI units:

$$0.1745 \times 10^{-3}\ w_L / GH \text{ (m)}$$

01 In U.S. Customary units:

$$0.0274 \times 10^{-3}\ w_L / GH \text{ (ft)}$$

E.5 Shell Compression

E.5.1 UNANCHORED TANKS

For unanchored tanks, the maximum longitudinal compressive force at the bottom of the shell may be determined as follows: When $M / [D^2(w_t + w_L)]$ is less than or equal to 0.785,

$$b = w_t + \frac{1.273M}{D^2}$$

When $M / [D^2(w_t + w_L)]$ is greater than 0.785 but less than or equal to 1.5, b may be computed from the value of the following parameter obtained from Figure E-5:

Table E-3—Site Coefficients (See Note)

Type	Description	S Factor
S_1	A soil profile with either a) a rock-like material characterized by a shear wave velocity greater than 760 m/sec (2500 ft/sec) or by other suitable means of classification or b) stiff or dense soil conditions where the soil depth is less than 60 m (200 ft).	1.0
S_2	A soil profile with stiff or dense soil conditions where the soil depth exceeds 60 m (200 ft).	1.2
S_3	A soil profile 12 m (40 ft) or more in depth containing more than 6 m (20 ft) of soft to medium stiff clay but more than 12 m (40 ft) of soft clay.	1.5
S_4	A soil profile containing more than 12 m (40 ft) of soft clay.	2.0

Note: The site factor shall be established from properly substantiated geotechnical data. In locations where the soil properties are not known in sufficient detail to determine the soil profile type, soil profile S_3 shall be used. Soil profile S_4 need not be assumed unless the building official determines that soil profile S_4 may be present at the site or in the event that soil profile S_4 is established by geotechnical data.

$$\frac{b + w_L}{w_t + w_L}$$

When $M / [D^2(w_t + w_L)]$ is greater than 1.5 but less than or equal to 1.57,

$$\frac{b + w_L}{w_t + w_L} = \frac{1.490}{\left[1 - \frac{0.637M}{D^2(w_t + w_L)}\right]^{0.5}}$$

where

b = maximum longitudinal compressive force at the bottom of the shell, in N/m (lbf/ft) of shell circumference,

w_t = weight of the tank shell and the portion of the fixed roof supported by the shell, in N/m (lbf/ft) of shell circumference.

When $M / [D^2(w_t + w_L)]$ is greater than 1.57 or when $b/1000t$
($b/12t$) is greater than F_a (see E.5.3), the tank is structurally 01
unstable. It is then necessary to take one of the following measures:

a. Increase the thickness of the bottom plate under the shell, t_b, to increase w_L without exceeding the limitations of E.4.1 and E.4.2.
b. Increase the shell thickness, t.
c. Change the proportions of the tank to increase the diameter and reduce the height.
d. Anchor the tank in accordance with E.6.

E.5.2 ANCHORED TANKS

For anchored tanks, the maximum longitudinal compressive force at the bottom of the shell may be determined as follows:

$$b = w_t + \frac{1.273M}{D^2}$$

APPENDIX F—DESIGN OF TANKS FOR SMALL INTERNAL PRESSURES

F.1 Scope

F.1.1 The maximum internal pressure for closed-top API Standard 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 Standard 620, Appendixes Q and R). For shell temperatures above 90°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.2 through F.6. Overturning stability with respect to
00 wind conditions shall be determined in accordance with 3.11 when specified by the purchaser. 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 ($2^1/_2$ 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 8-1) 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.

01 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 (mm^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 (m),

t_h = nominal roof thickness (mm).

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.).

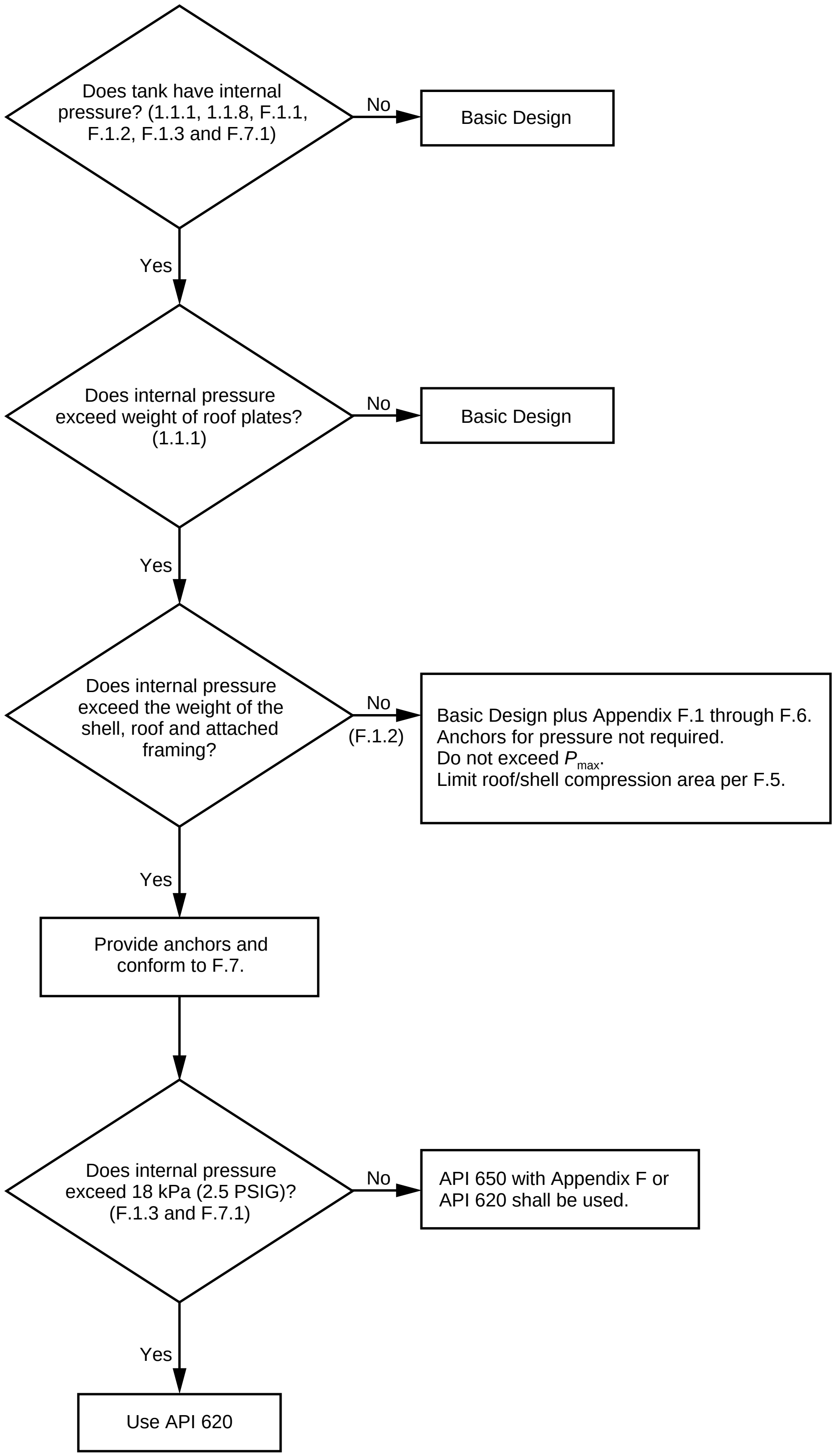
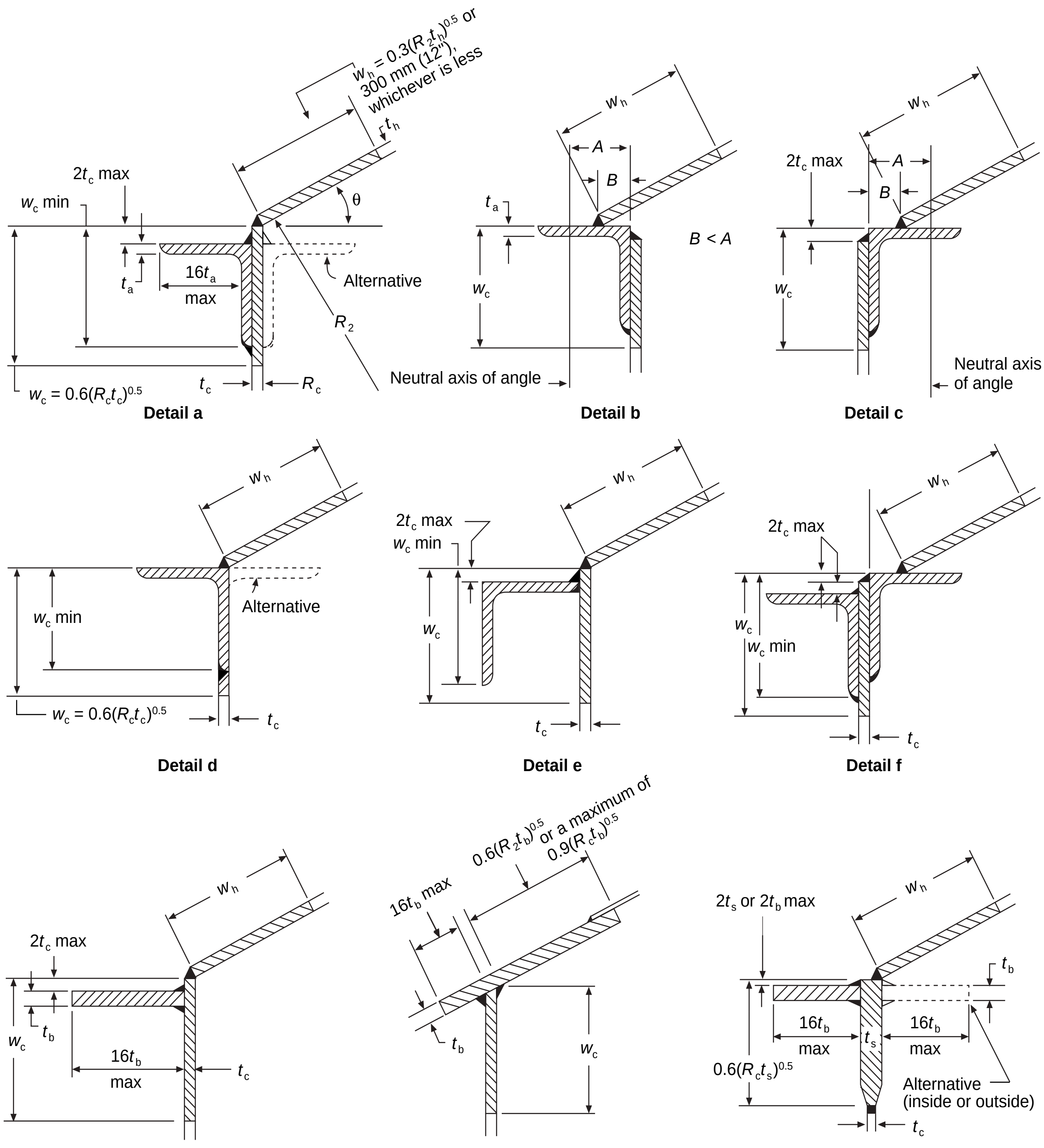


Figure F-1—Appendix F Decision Tree



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,
= $0.6\,(R_c t_s)^{0.5}$,

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,
= $R_c/(\sin\theta)$.

Note: All dimensions and thicknesses are in mm (in.)

Figure F-2—Permissible Details of Compression Rings

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:

00

$$P_{max} = \frac{0.00127W}{D^2} + 0.08t_h - \frac{0.00382M}{D^3}$$

where

P_{max} = maximum design pressure (kPa),

W = total weight of the shell and any framing (but not roof plates) supported by the shell and roof (N),

M = wind moment (N-m), when wind overturning stability has been specified by the purchaser in accordance with 3.11, otherwise $M = 0$. Anchorage may be required when the maximum design pressure is
00 combined with the specified load. If overturning stability has not been specified, the manufacturer shall report the maximum wind velocity the tank may withstand without anchorage when combined with the maximum design pressure.

In US Customary units:

00

$$P_{max} = \frac{0.245W}{D^2} + 8t_h - \frac{0.735M}{D^3}$$

where

P_{max} = maximum design pressure (in. of water),

W = total weight of the shell and any framing (but not roof plates) supported by the shell and roof (lbf),

M = wind moment (ft-lbf), when wind overturning stability has been specified by the purchaser in accordance with 3.11, otherwise $M = 0$. Anchorage may be required when the maximum design pressure is
00 combined with the specified load. If overturning stability has not been specified, the manufacturer shall report the maximum wind velocity the tank may withstand without anchorage when combined with the maximum design pressure.

F.4.3 As top angle size and roof slope decrease and tank diameter increases, the design pressure permitted by F.4.1
01 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:

$$P_{max} < 0.8P_f$$

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 may be calculated from the following equation:

In SI units:

$$A = \frac{D^2(P - 0.08t_h)}{1.1(\tan\theta)}$$

where

A = total required compression area at the roof-to-shell junction (mm^2).

In US Customary units:

$$A = \frac{D^2(P - 8t_h)}{30{,}800(\tan\theta)}$$

where

A = total required compression area at the roof-to-shell junction (in.^{2}).

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 3.10.5 and 3.10.6.

F.6 Calculated Failure Pressure

In tanks that meet the criteria of 3.10.2.5.1, 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: 01

In SI units:

$$P_f = 1.6P - 0.047\,t_h$$

where

P_f = calculated failure pressure (kPa).

In US Customary units:

$$P_f = 1.6P - 4.8\ t_h$$

where

P_f = calculated failure pressure (in. of water).

01 Note: This formula is based on failure occurring at a yield stress 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 ($2^1/_2$ lbf/in.^{2}) Gauge

01 **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 3-3 and flush-type cleanout fitting thicknessess in Table 3-10, 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 3.12.4 of API Standard 620, except the allowable compressive stress shall be increased to 140 MPa (20,000 lbf/in.^{2}).

00 **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 Standard 620. The thickness of a self-supporting roof shall not be less than that specified in 3.10.5 or 3.10.6, as applicable.

● **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 satisfy the following conditions:

a. The design stresses shall satisfy all of the conditions listed in Table F-1.

b. When corrosion is a possibility, an additional thickness should be considered for anchors and attachments. If anchor bolts are used, their nominal diameter should not be less than 25 mm (1 in.) plus a corrosion allowance of at least 6 mm ($^1/_4$ in.) on the diameter.

c. Any anchor bolts shall be uniformly tightened to a snug fit, and any anchor straps shall be welded while the tank is filled with the 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 the threads.

Table F-1—Design Stresses for Anchors of Tanks with Design Pressures up to 18 kPa ($2^1/_2$ lbf/in.^{2}) Gauge

Uplift Resulting From	Allowable Stress at Root of Anchor Bolt Threads	
	MPa	(lbf/in.^{2})
Tank design pressure	105	15,000
Tank design pressure plus wind[a]	140	20,000
Tank test pressure	140	20,000
Failure pressure (from F.6) × 1.5[b]	[c]	[c]

[a]See Appendix E for seismic design requirements.
[b]For this condition, the effective liquid weight on the tank bottom shall not be assumed to reduce the anchor load. The failure pressure shall be calculated using as-built thicknesses.
[c]Minimum specified yield strength.

d. 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 bolt 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 shell attachment is via chair-type assemblies or anchor rings of sufficient size and height.

e. Evaluate anchor attachments to the shell to ensure that localized stresses in the shell will be adequately handled. One acceptable evaluation technique is given in ASME Section VIII, Division 2, Appendix 4, using the allowable stress per API 650 substituted for S_m. The method of attachment and evaluation shall take into account the uplift conditions listed in Table F-1, and shall consider the effect of deflection and rotation of the tank shell.

f. If tanks are to be anchored, the anchors must be sized to resist the combined affects of uplift due to internal pressure and seismic loading or internal pressure and wind loading. 00

F.7.5 The counterbalancing weight, such as a concrete ringwall, 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.

F.7.7 Deleted 01

G.4.2.4 Seismic Load

If the tank is designed for seismic loads, the roof shall be designed for a horizontal seismic force determined as follows:

$$F = 0.6\ ZIW_r$$

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.4.2.5 Load Combinations

The following load combinations shall be considered:

a. Dead load.
b. Dead load plus uniform live load.
c. Dead load plus unbalanced live load.
d. Dead load plus wind load.
e. Dead load plus uniform live load plus wind load.
f. Dead load plus unbalanced live load plus wind load.
g. Dead load plus seismic load.

If an internal or external design pressure is specified by the purchaser, the loads resulting from either of these pressures shall be added to the load combinations specified in Items a–g above, and the structure shall be designed for the most severe loading.

G.4.2.6 Panel Loads

G.4.2.6.1 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/ft^2) over the full area of the panel without sustaining permanent distortion.

G.4.2.6.2 The roof shall be designed to support two concentrated loads 1100 N (250 lbf), each distributed over two separate 0.1 m^2 (1 ft^2) areas of any panel.

G.4.2.6.3 The loads specified in G.4.2.6.1 and G.4.2.6.2 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
01 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 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).

G.8.3 ROOF VENTS (Section replaced by 3.10.8) 01

G.8.4 SKYLIGHTS

G.8.4.1 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.4.2.6. The purchaser shall specify the total skylight area to be provided. 01

G.8.4.2 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 & H.5.2.2.2), the purchaser shall consider skylight material compatibility with exposure to elevated concentrations of the stored product. 01

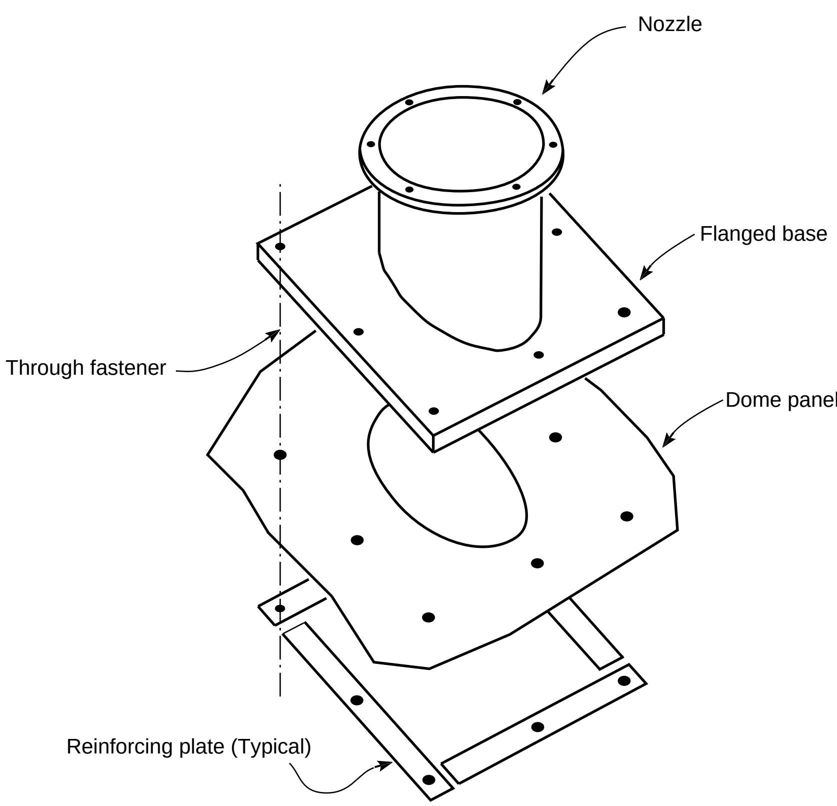


Figure G-2—Typical Roof Nozzle

APPENDIX H—INTERNAL FLOATING ROOFS

H.1 Scope

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 3.10 of this standard is applicable, except as modified in this appendix.

H.2 Types

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 require-
01 ments, regulatory compliance, service life expectancy, ambient temperature, 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 evaluated.[1]

H.2.2 The following types of internal floating roofs are described in this appendix:

a. Metallic pan internal floating roofs[2,3] 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[3] 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.

f. Metallic sandwich-panel internal floating roofs have metallic panel modules for buoyancy compartments. Panel modules may include a honeycomb 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.4.2.4)[4]. These roofs are in full contact 01
with the liquid surface and are typically constructed of aluminum alloys.

g. Hybrid internal floating roofs shall, upon agreement between the purchaser and the manufacturer, be a design combination of roof types described in H2.2.b and H2.2.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.

H.3 Material

H.3.1 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

---

[1]Internal 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 can provide guidance for this evaluation.

[2]The Purchaser should note that this design does not have multiple flotation compartments necessary to meet the requirements of H.4.2.4.

[3]These 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. These types are considered a fixed roof tank (i.e., having no internal floating roof) for the siting requirements of NFPA 30.

[4]A 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).

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 2 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
01 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 Section 5.5 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.

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 (H.2.2.e) 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 may be accomplished by electric bonding shunts in the seal area (a minimum of four, uniformly distributed) or flexible 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, considering strength, corrosion resistance, joint reliability, flexibility, and service life. 01

H.4.1.7 Each 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.2.2.c, 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 25mm (1 in.) above the top of the pontoon rim/skirt.

● **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.2.2.c, d, and g), included with seal welding the flotation compartment, the top edge of each bulkhead shall also be provided with a continuous seal weld so that the top edge is liquid and vapor tight.

H.4.1.9 For metallic sandwich-panel roofs (type H.2.2.f), 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 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.4.2.2** The internal floating roof shall be designed to safely support at least two men (2.2 kN [500 lbf] over 0.1 m^2 [1 ft^2]) 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,
01 and expected concentrated live loads.

H.4.2.3 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.4.2.4 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.2.2.b, c, and g) shall be capable of floating without additional damage after any two compartments and the center deck are punctured and flooded.

● **H.4.2.5** 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/ft^2) 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/ft^2) 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.4.2.6** Calculations for both the floating and supported condition, considering internal floating roof deflections and stresses for each of the load conditions required by this appendix, shall be performed and reported to the purchaser, when specified. All calculations for the floating condition shall be based upon the design specific gravity (per H.4.2.1).

H.4.2.7 The 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.

H.4.2.8 Aluminum load carrying members, assemblies and connections shall comply with the design requirements of the latest edition of the "Aluminum Design Manual: Specification for Aluminum Structures," as published by the Aluminum Association, Inc. (Washington, DC).

● **H.4.2.9** 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. 01

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 Section 3.1 of this standard. Welded joints between aluminum members shall conform to Section 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 Fillet welds on material less than 5 mm ($^3/_{16}$ in.) thick shall not have a thickness 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.

● **H.4.3.4** Use of any joint sealing compound, insulating material, 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.

● **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

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 01

● **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 temperature, permeability, abrasion resistance, discoloration, aging, embrittlement, flammability, and other compatibility factors. The various seal types (listed H.4.4.5) will have variable life expectancy and service limitations.

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 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.

H.4.4.5 Seal Types

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.4.4.5.a), secondary mechanical shoe type (similar in design to shoe seals per H.4.4.5.c) and flexible-wiper seals. Flexible-wiper seal means a rim seal comprised of a blade of 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). 01 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.

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 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.

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.2.2. a, 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 and approved by the purchaser. Supports fabricated from pipe shall be notched or perforated at the bottom to provide drainage.

● **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
01 include corrosive contaminant combinations not found in the normal product. The purchaser shall specify if any protective measures are required.

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 Recommended Practice 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 manway, 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 activated vents shall be adjustable as required per H.4.6.

● 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 01
the vents located within any 10 m (32 ft) interval is at least 0.2 m^2 (2.0 ft^2). The total net open area of these vents shall be greater than or equal to 0.06 m^2/m (0.2 ft^2/ft) of tank diameter. These vents 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 vent area).

H.5.2.2.2 A center circulation vent with a minimum net open area of 30,000 mm^2 (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).

● **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 3.10.8, based on information provided by the purchaser.

H.5.3 LIQUID-LEVEL INDICATION 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 overfill protection levels (see NFPA 30 and API Recommended Practice 2350). Overflow slots shall not be used as a primary means of detecting an overfill 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 overfill 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
01 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 percent 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 ANTIROTATION 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

At least one fixed roof manhole, 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 750mm (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. 01

● 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 Recommended Practice 2003. Purchaser shall provide pumping rates and any blending, pigging and recirculation data along with the inlet diameter, for manufacturers 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.

● 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.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 Section 5.5 of this standard), which would inhibit proper internal floating roof and seal operation, that are identified by the internal
01 floating roof erector shall be reported to the purchaser.

● **H.6.2** Deck seams and other joints that are required to be liquid tight or vapor tight per H.4.1.3 shall be tested by the joint assembler for leaks. 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 manufacturer.

H.6.3 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.6.4** 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.

● **H.6.4.1** Internal floating roofs in accordance with H.5.1 types H.2.2.a, b, c, d, and g. shall be given a flotation test on water. Internal floating roofs in accordance with types H.2.2.e and H.2.2.f 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 01
the upper side of the part in contact with the liquid shall be considered evidence of leakage.

● **H.6.4.2** 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.

● **H.6.4.3** 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.

I.7.2 The thickness and design metal temperature of the
00 bottom plate shall be in accordance with Figure 2-1.

I.7.3 The maximum spacing between adjacent or radial grillage members and the bottom plate thickness shall satisfy the requirements of 1.7.3.1 and 1.7.3.2.

I.7.3.1 The maximum spacing between adjacent or radial grillage members shall not exceed:

$$b = \left[\frac{1.5F_y(t_g - CA)^2}{p}\right]^{0.5}$$

I.7.3.2 The required minimum thickness of the bottom plate supported on grillage shall be determined by the following equation:

$$t_g = \left[\frac{b^2(p)}{1.5F_y}\right]^{0.5} + CA$$

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).

I.7.3.3 The maximum calculated deflection of the bottom plate at mid-span shall not exceed $(t_g - CA) / 2$:

$$d = \frac{0.0284pb^4}{E_s(t_g - CA)^3} \leq (t_g - CA) / 2$$

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).

I.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.

I.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*.[3] Concrete grillage members may also be used.

● **I.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.

I.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 lateral load, the grillage members shall 01
be anchored to the foundation.

I.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.

I.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.

I.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.

I.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

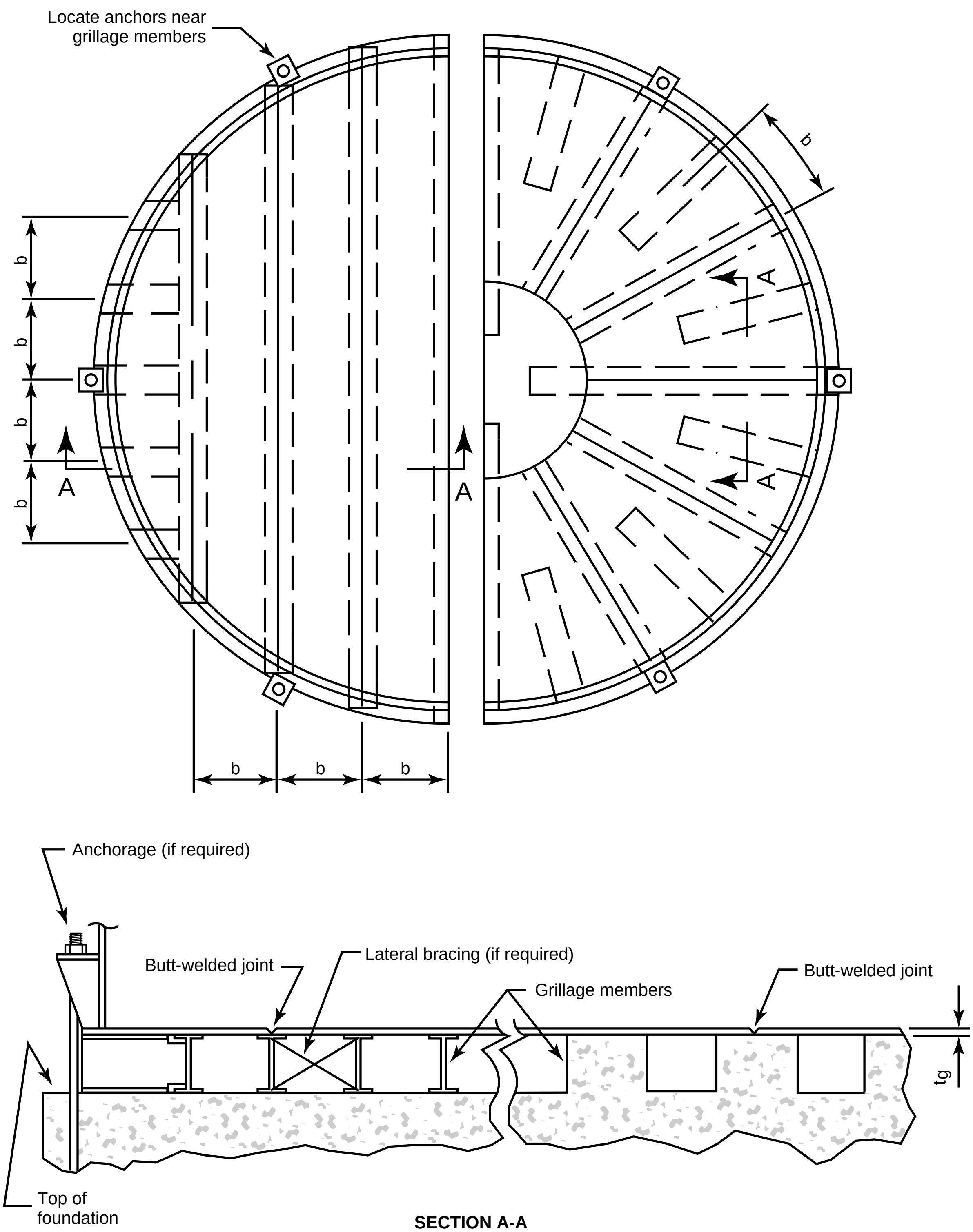


Figure I-11—Tanks Supported by Grillage Members (General Arrangement)

(minimum length and location according to Method A of
01 Figure 3-10) 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 sup-
00 port members shall not exceed 300 mm (12 in.).

I.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 underside 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.

d. A 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 6.

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
01 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 4.2.3.

J.5 Inspection of Shell Joints

The methods of inspecting shell joints described in Section 6 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 7 apply to shop-assembled tanks.

J.7 Marking

Shop-assembled tanks shall be marked in accordance with Section 8, except that 8.1.4 and 8.2 are not applicable. The nameplate (see Figure 8-1) shall indicate that the tank has been designed in accordance with this appendix.

TABLE L-1—INDEX OF DECISIONS OR ACTIONS WHICH MAY BE REQUIRED OF THE PURCHASER

1.1.9
1.1.13
1.1.19
1.1.20
Table 1-1 App. E, I, O, & P
1.3
2.1.1
2.1.2
2.1.3.b & c
2.2.1.3
Table 2-1, Note 1
2.2.5
Table 2-2, Note C
2.2.6.3
2.2.7.1
2.2.7.2
2.2.7.3
2.2.7.4
2.2.8.1
2.2.9.2
2.2.10.4
2.3
2.4.1.f
2.4.2
2.6.2
2.7
01 3.1.5.8.b
3.1.5.9.e
3.2.1
3.2.2
3.2.3
3.2.5
3.3.1
3.3.2
3.3.3
3.3.4
3.4.1
3.6.1.1 Notes 1 & 3
3.6.1.2
3.6.1.3
3.6.1.6
3.6.1.7
Table 3-2, Note A
3.6.3.2 G & CA
3.6.4.1
3.7.1.2
3.7.1.4
3.7.3.4
3.7.4.5
3.7.5.2
3.7.7.1
Figure 3-4A, Note 1
Figure 3-4B, Note 6
Table 3-8, Notes C & H
Table 3-9, Note C
Figure 3-5, Note 4
Figure 3-9, Note 4
3.7.8.1
3.8.2
3.8.7
3.9.6.1 Note
3.9.7.1 Notes A & D
3.9.7.6
3.9.7.7
3.10.2.2
3.10.2.4
3.10.2.5.3
3.10.2.7
3.10.2.8
3.10.3.1
3.10.4.1
3.10.4.4
3.10.4.5
3.10.5
3.10.6
3.11.1
4.1.1.1
4.1.2
4.2.1
5.1.1
5.1.4
5.2.1.1
5.2.1.7
5.2.3.3
5.2.4.1
5.2.4.2
5.3.2.3
5.3.5
5.3.6.2
5.4.4
5.5.1
6.1.2.7
6.1.7.2
6.1.8.2
6.3.4
6.6.11
7.2.1.1
8.1.1.e, f, g, j & n
Figure 8-1, Note
A.1.1
A.1.2
A.3.4
A.4.1 CA
A.6
A.8.2
B.2.2
B.3.3
B.3.4
B.4.4.1
C.1
C.3.1
C.3.3.2
C.3.4.2
C.3.7
C.3.8
C.3.9
C.3.10.1
C.3.11
C.3.13
C.3.14
E.1
E.3.1 Z, I, W_r
E.3.2.1 W_t
E.3.3.3
E.4.1 G
E.5.3 G
E.6.2.6
E.6.2.7
E.8.1
E.8.2
F.1.2
F.7.4
G.1.3.1
G.1.3.2
G.1.3.3
G.1.4.1
G.1.4.2
G.2.1
G.2.4
G.4.2.2.1
G.4.2.3.1
G.4.2.3.2
G.4.2.5
G.4.3
G.5.3
G.6.2
G.7
G.8.1
G.8.4.1
G.8.4.2
G.9
G.10.1.1
G.10.1.2
G.11.3
H.1
H.2.1
H.3.1
H.4.1.6
H.4.1.8
H.4.1.10
H.4.2.2
H.4.2.5
H.4.2.6
H.4.2.9
H.4.3.1
H.4.3.3
H.4.3.3.1
H.4.3.4
H.4.3.5
H.4.4.2
H.4.6.1
H.4.6.2
H.4.6.3
H.4.6.5
H.4.6.6
H.4.6.7
H.4.6.8
H.5.1.1
H.5.1.4
H.5.2.1
H.5.2.2
H.5.2.2.3
H.5.3.1
H.5.3.2
H.5.3.3
H.5.5.3
H.5.6
H.5.7
H.5.8
H.6.1
H.6.2
H.6.4
H.6.4.1
H.6.4.2
H.6.4.3
I.1.2
I.1.3
I.5.5
I.6.2
I.6.3
I.6.4
I.7.1
I.7.3.2
I.7.6
J.1.2
J.3.2.1
J.3.6.2
J.3.7.1
J.3.7.2
J.3.8.2
J.4.2.2
Appendix L
M.2
M.4.2
N.2.1
N.2.2.b
N.2.4
N.2.5
N.2.6
O.2.2
O.2.6
O.3.1.4
P.1
P.8.1
P.8.2
S.1.2
S.2.1.2
S.2.2
Table S-1, Notes 1–3 and 5
S.3.2 G & CA
S.4.3.2
S.4.4.3
S.4.5.1
S.4.9.2
S.4.10.1.1
S.4.10.1.2
S.4.13
S.6.a

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 6.2). 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,

01
$$S = \frac{0.028 D^2 t_b^{0.25}}{t} \times \left[\frac{58HG}{(Dt)^{0.5}} + \frac{26.2CTt^{0.5}}{D^{1.5}} - \frac{4.8BS_y t_b^2}{(Dt)^{1.5}} - G\right]$$

= 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 tank's maximum operating temperature (°C),

S_y = specified minimum yield strength of the bottom plate at the tank's maximum operating 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 subgrade (see footnote 16),

= 0.85 if no C factor is specified by the purchaser,

B = foundation factor (see footnote 16),

= 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 6.2). This magnetic particle examination shall be performed on the root pass at every $^1/_2$ inch of deposited weld metal while the weld is being made and on the completed weld. The examination shall be performed before hydrostatic testing,

$$S = \frac{0.033 D^2 t_b^{0.25}}{t} \times \left[\frac{6.3HG}{(Dt)^{0.5}} + \frac{436CTt^{0.5}}{D^{1.5}} - \frac{BS_y t_b^2}{(Dt)^{1.5}} - G\right]$$ 01

= 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 tank's maximum operating temperature (°F),

S_y = specified minimum yield strength of the bottom plate at the tank's maximum operating temperature (lbf/in.^{2}),

D = nominal tank diameter (ft),

H = difference in filling height between the full level and the low level (ft),

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 subgrade (see footnote 16),

= 0.85 if no C factor is specified by the purchaser,

B = foundation factor (see footnote 16),

= 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 3.10.5 and 3.10.6, which are applicable to self-supporting roofs, shall be modified. For operating temperatures above 90°C (200°F), the calculated minimum thickness of roof plates, as defined in 3.10.5 and 3.10.6, shall be increased by the ratio of 199,000 MPa (28,800,000 psi) to the material's modulus of elasticity at the maximum operating 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 operating temperature to 199,000 MPa (28,800,000 psi) 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 Operating Temperature

Maximum Operating Temperature		Modulus of Elasticity	
°C	°F	MPa	lbf/in.^{2}
90	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 P—ALLOWABLE EXTERNAL LOADS ON TANK SHELL OPENINGS

Note: This appendix is based on H. D. Billimoria and J. Hagstrom's "Stiffness Coefficients and Allowable Loads for Nozzles in Flat Bottom Storage Tanks"[17] 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."[18]

● P.1 Scope

This appendix establishes minimum recommendations for
00 the design of storage-tank openings that conform to Table 3-6
and will be subjected to external piping loads. This appendix
shall be used only when specified by the purchaser and is recommended only for tanks larger than 36 m (120 ft) in diameter. The recommendations 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
00 the tank bottom and meet the requirements of Table 3-6. It is
recognized that the purchaser may specify other procedures, special factors, and additional requirements. When the use of this appendix is specified, any deviation from its requirements shall be mutually agreed upon by the purchaser and the manufacturer. It is not intended that this appendix necessarily be applied to piping connections similar in size and configuration to those on tanks of similar size and thickness for which satisfactory service experience is available.

P.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.3 for a description of the nomenclature).

---

[17] H. D. Billimoria and J. Hagstrom, "Stiffness Coefficients and Allowable Loads for Nozzles in Flat Bottom Storage Tanks," Paper 77-PVP-19, American Society of Mechanical Engineers, New York, 1977.

[18] H. D. Billimoria and K. K. Tam, "Experimental Investigation of Stiffness Coefficients and Allowable Loads for a Nozzle in a Flat Bottom Storage Tank," Paper 80-C2/PVP-59, American Society of Mechanical Engineers, New York, 1980.

P.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),

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 operating 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.),

λ = $a / (Rt)^{0.5}$,

Table P-1—Modulus of Elasticity and Thermal Expansion Coefficient at the Design Temperature

Design Temperature °C	Design Temperature °F	Modulus of Elasticity MPa (psi) E	Thermal Expansion Coefficient[a] [mm × 10^{-6}/(mm-°C)] (inches × 10^{-6} per inch-°F)
20	70	203,000 (29,500,000)	—
90	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)

[a]Mean coefficient of thermal expansion, going from 20°C (70°F) to the temperature indicated.

Note: Linear interpolation may be applied for intermediate values.

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.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.5 Shell Deflection and Rotation

P.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:

01 $$W = \frac{9.8 \times 10^{-6} GHR^2}{Et} \times \left[1 - e^{-\beta L} \cos(\beta L) - \frac{L}{H}\right] + \alpha R \Delta T$$

In US Customary units:

01 $$W = \frac{0.036 GHR^2}{Et} \times \left[1 - e^{-\beta L} \cos(\beta L) - \frac{L}{H}\right] + \alpha R \Delta T$$

P.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.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.5, and the rigidity and restraint of the connected piping system.

P.7 Determination of Allowable Loads for the Shell Opening

P.7.1 CONSTRUCTION OF NOMOGRAMS

P.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.

P.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 YC, YF, and YL are coefficients determined from Figures P-4A and P-4B. 01

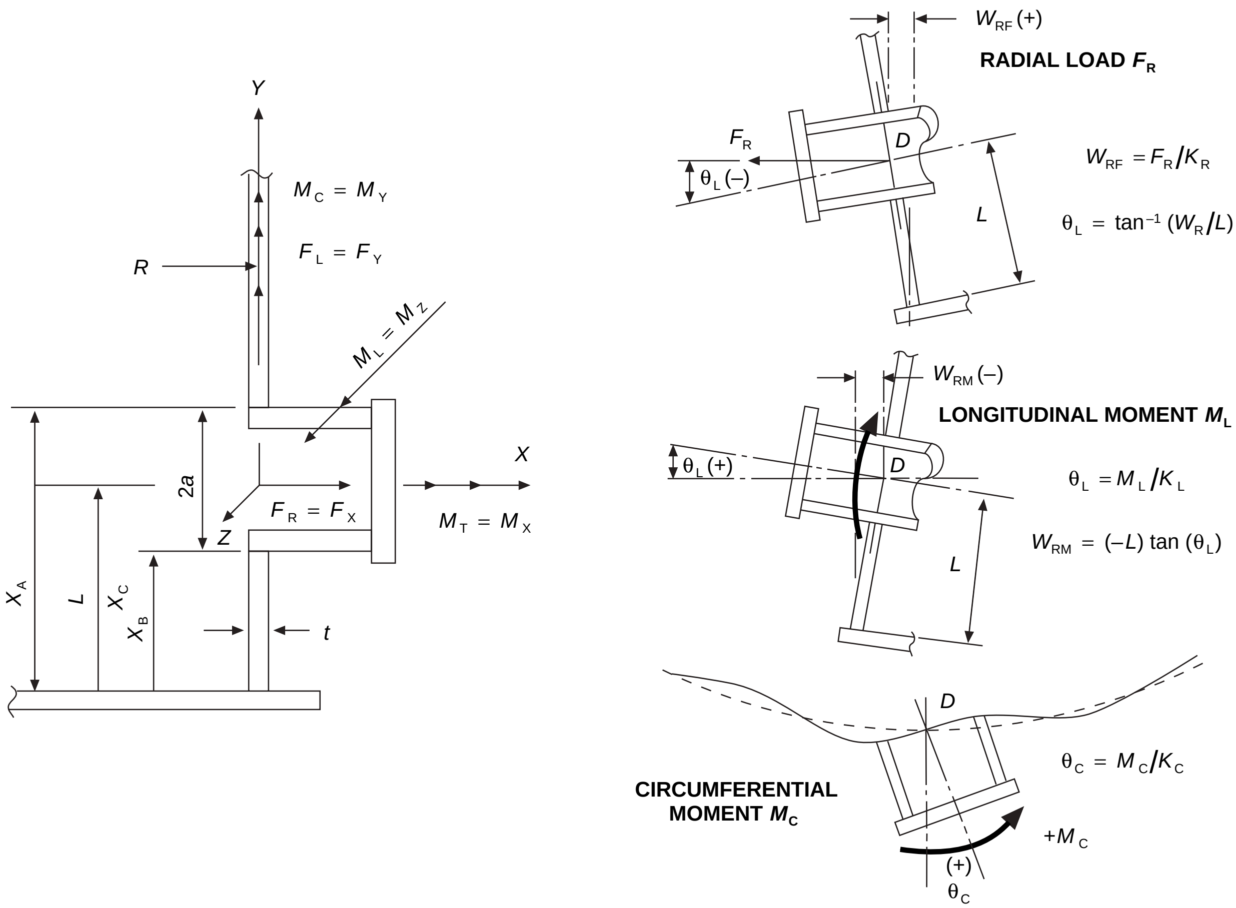


Figure P-1—Nomenclature for Piping Loads and Deformation

P.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.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.7.2 DETERMINATION OF ALLOWABLE LOADS

P.7.2.1 Use the values for F_R, M_L, and M_C obtained from the piping analyses to determine the quantities $(\lambda / 2Y_F)(F_R/F_P)$, $(\lambda / aY_L)(M_L/F_P)$, and $(\lambda / aY_C)(M_C/F_P)$.

P.7.2.2 Plot the point $(\lambda / 2Y_F)(F_R/F_P)$, $(\lambda / aY_L)(M_L/F_P)$ on the nomogram constructed as shown in Figure P-5A.

P.7.2.3 Plot the point $(\lambda / 2Y_F)(F_R/F_P)$, $(\lambda / aY_C)(M_C/F_P)$ on the nomogram constructed as shown in Figure P-5B.

P.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.7.2.2 and P.7.2.3 lie within the boundaries of the nomograms constructed for the particular opening-tank configuration.

P.8 Manufacturer and Purchaser Responsibility

● **P.8.1** The manufacturer is responsible for furnishing to the purchaser the shell stiffness coefficients (see P.4) and the unrestrained shell deflection and rotation (see P.5). The purchaser is responsible for furnishing to the manufacturer the magnitude of the shell-opening loads (see P.6). The manufacturer shall determine, in accordance with P.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.7.1.

● **P.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.

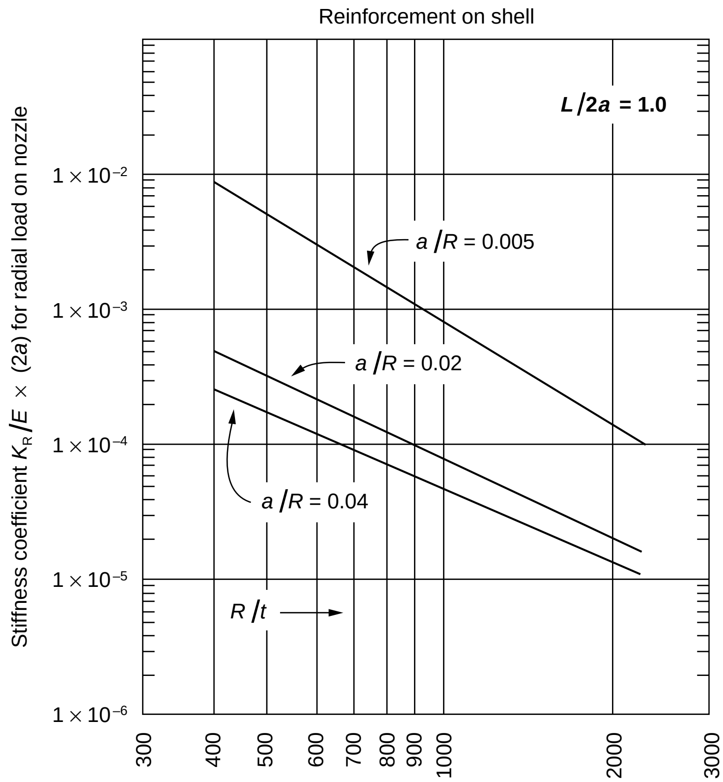
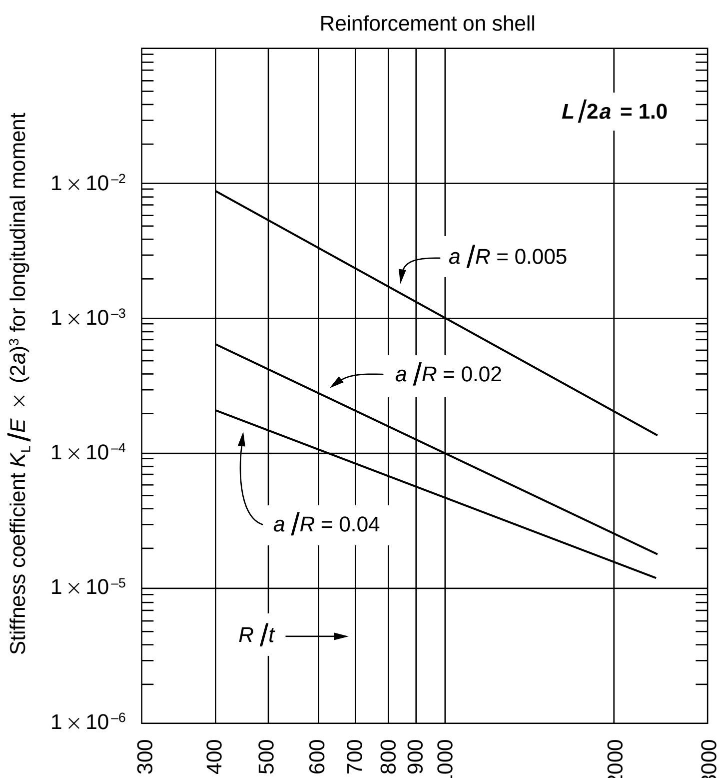


Figure P-2A—Stiffness Coefficient for Radial Load: Reinforcement on Shell (L / 2a = 1.0)



01

Figure P-2B—Stiffness Coefficient for Longitudinal Moment: Reinforcement on Shell (L / 2a = 1.0)

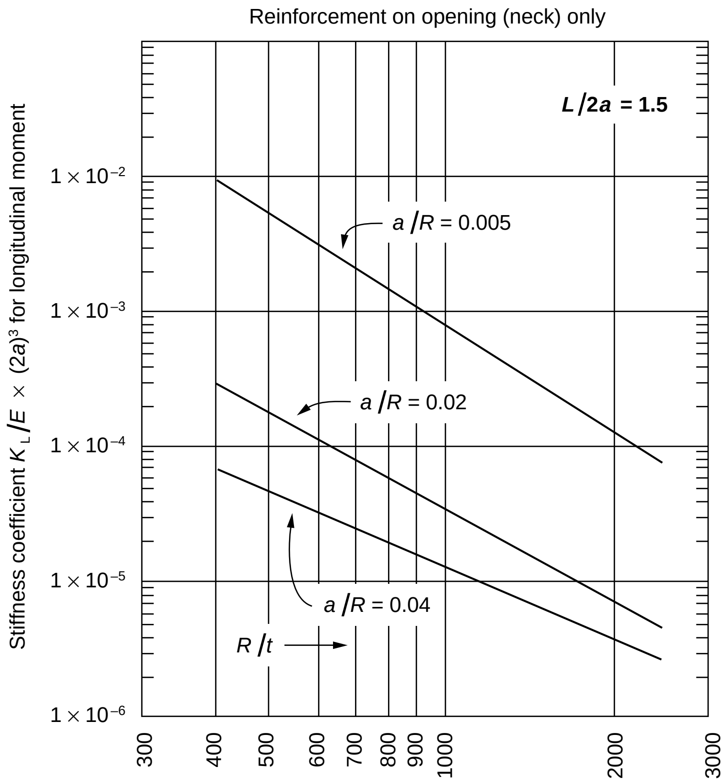


Figure P-2K—Stiffness Coefficient for Longitudinal Moment: Reinforcement in Nozzle Neck Only (L / 2a = 1.5)

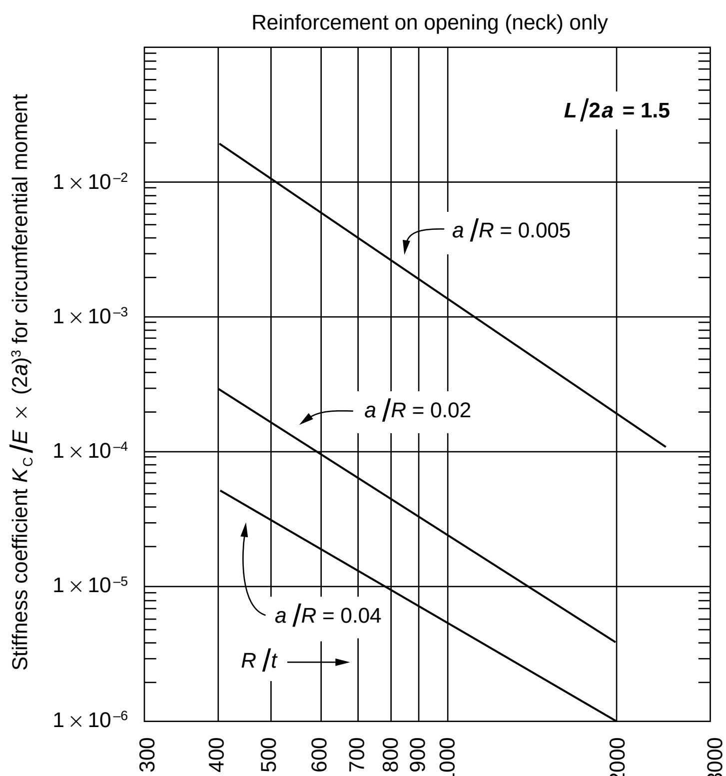


Figure P-2L—Stiffness Coefficient for Circumferential Moment: Reinforcement in Nozzle Neck Only (L / 2a = 1.5)

P.9 Sample Problem

P.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 Standard 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?

$$
\begin{aligned}
a &= 305 \text{ mm (12 in.)},\\
L &= 630 \text{ mm (24.75 in.)},\\
H &= 19{,}200 \text{ mm } (64 \times 12 = 768 \text{ in.}),\\
\Delta T &= 90 - 20 = 70°\text{C } (200 - 70 = 130°\text{F}),\\
R &= 80{,}000/2 = 40{,}000 \text{ mm } ((260 \times 12)/2 = 1560 \text{ in.}),\\
t &= 34 \text{ mm (1.33 in.)}.
\end{aligned}
$$

P.9.2 SOLUTION

P.9.2.1 Calculate the stiffness coefficients for the nozzle-tank connection:

$$
\begin{aligned}
R/t &= 40{,}000/34 = 1176 \quad (1560/1.33 = 1173)\\
a/R &= 305/40{,}000 = 0.008 \quad (12/1560 = 0.008)\\
L/2a &= 630/610 \cong 1.0 \quad (24.75/24 \cong 1.0)
\end{aligned}
$$

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:

$$\frac{K_L}{E(2a)^3} = 3.0 \times 10^{-4}$$

$$K_L = (3.0 \times 10^{-4})(199{,}000 \text{ N/mm}^2)(610 \text{ mm})$$

$$= 13.6 \times 10^9 \text{ N-mm/rad}$$

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:

$$\frac{K_C}{E(2a)^3} = 5.0 \times 10^{-4}$$

$$K_C = (5.0 \times 10^{-4})(28.8 \times 10^6)(24)^3$$

$$= 199 \times 10^6 \text{ in.-lb/rad}$$

P.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:

$$\beta = \frac{1.285}{(Rt)^{0.5}} = \frac{1.285}{(40{,}000 \times 34)^{0.5}} = 0.00110 \text{ mm}$$

$$\beta L = (0.00110)(630) = 0.7 \text{ rad}$$

$$W = \frac{9.8 \times 10^{-6} GHR^2}{Et}\left[1 - e^{-\beta L}\cos(\beta L) - \frac{L}{H}\right] + \alpha R \Delta T$$ 00

$$= \frac{(9.8 \times 10^{-6})(1)(19{,}200)(40{,}000)^2}{(199{,}000)(34)}$$

$$\left[1 - e^{-0.7}\cos(0.7) - \frac{630}{19{,}200}\right] + (12.0 \times 10^{-6})(40{,}000)(70)$$

$$= 59.77 \text{ mm}$$

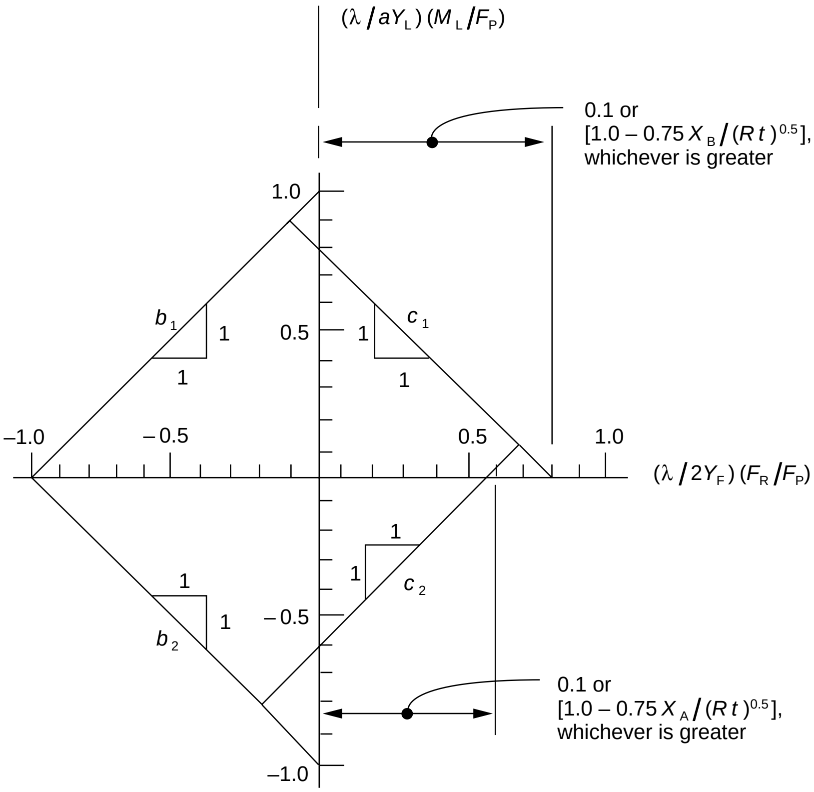


Figure P-3A—Construction of Nomogram for b_1, b_2, c_1, c_2 Boundary

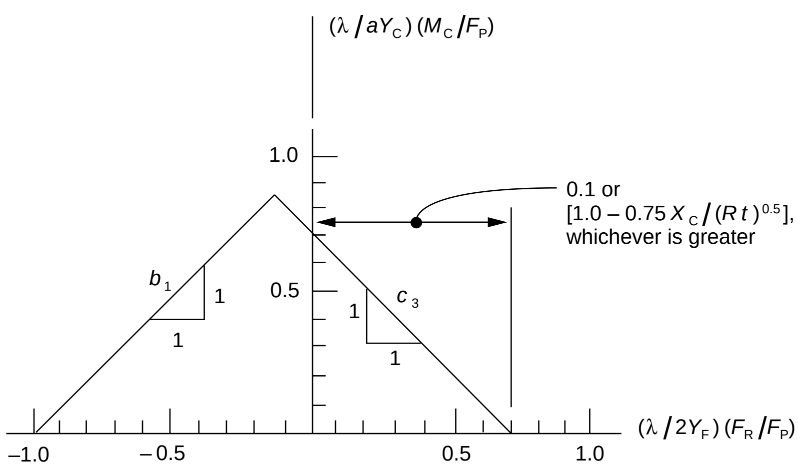


Figure P-3B—Construction of Nomogram for b_1, c_3 Boundary

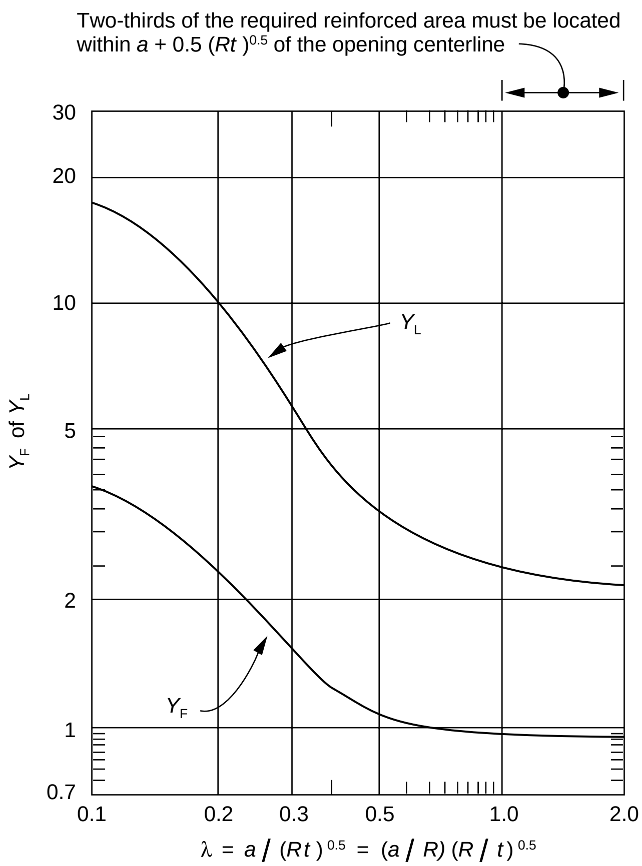


Figure P-4A—Obtaining Coefficients Y_F and Y_L

00 $$\theta = \frac{9.8 \times 10^{-6} GHR^2}{Et}\left\{\frac{1}{H} - \beta e^{-\beta L}[\cos(\beta L) + \sin(\beta L)]\right\}$$

$$= \frac{(9.8 \times 10^{-6})(1)(19{,}200)(40{,}000)^2}{(199{,}000)(34)}$$

$$\left\{\frac{1}{19{,}200} - 0.0011 e^{-0.7}[\cos(0.7) + \sin(0.7)]\right\}$$

$$= -0.032 \text{ rad}$$

In US Customary units:

$$\beta = \frac{1.285}{(Rt)^{0.5}} = \frac{1.285}{(1560 \times 1.33)^{0.5}} = 0.0282 \text{ in.}$$

$$\beta L = (0.0282)(24.75) = 0.7$$

$$W = \frac{0.036 GHR^2}{Et}\left[1 - e^{-\beta L}\cos(\beta L) - \frac{L}{H}\right] + \alpha R \Delta T$$

$$= \frac{0.036(1)(768)(1560)^2}{(28.8 \times 10^6)(1.33)}\left[1 - e^{-0.7}\cos(0.7) - \frac{24.75}{768}\right]$$

$$+ (6.67 \times 10–6)(1560)(130)$$

$$= 2.39 \text{ inches}$$

$$\theta = \frac{0.036 GHR^2}{Et}\left\{\frac{1}{H} - \beta e^{-\beta L}[\cos(\beta L) + \sin(\beta L)]\right\}$$

$$= \frac{0.036(1)(768)(1560)^2}{(28.8 \times 10^6)(1.33)}\left\{\frac{1}{768} - \beta e^{-0.7}[\cos(0.7) + \sin(0.7)]\right\}$$

$$= -0.032 \text{ rad}$$

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 mm (36.75 in.)

X_B = 325 mm (12.75 in.)

X_C = 630 mm (24.75 in.)

Determine the allowable loads for the shell opening, as in P.9.2.3.

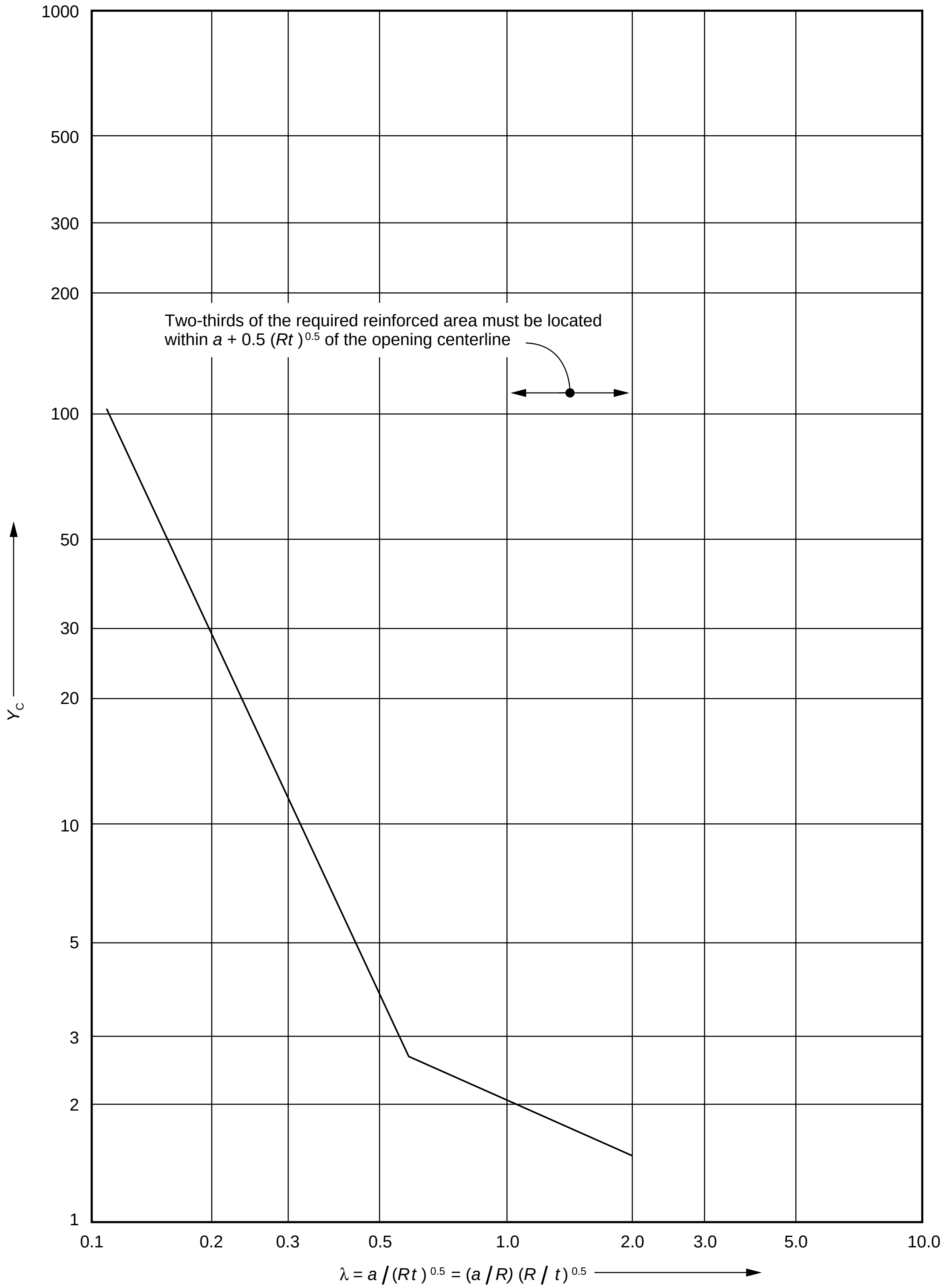


Figure P-4B—Obtaining Coefficient Y_C

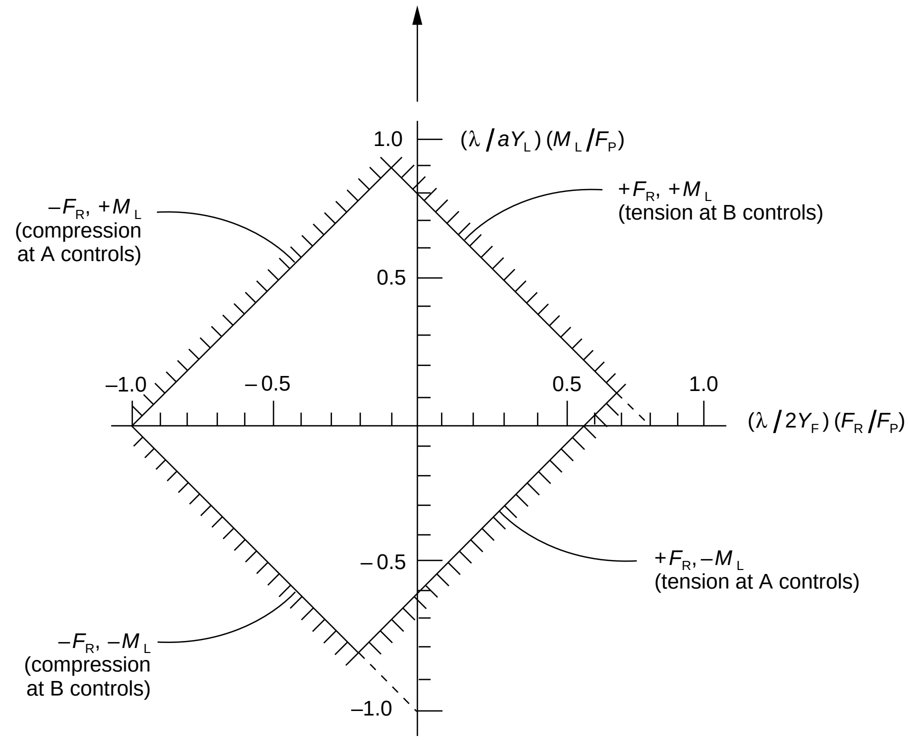


Figure P-5A—Determination of Allowable Loads from Nomogram: F_R and M_L

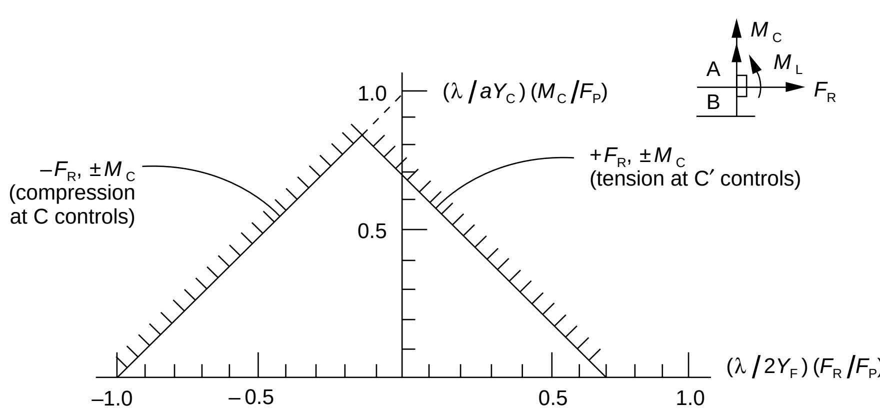


Figure P-5B—Determination of Allowable Loads from Nomogram: F_R and M_C

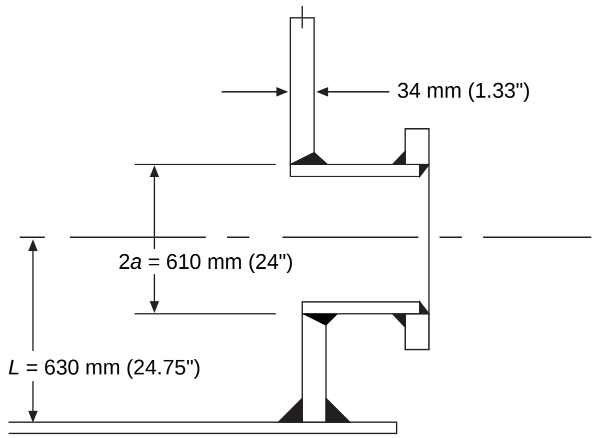


Figure P-6—Low-Type Nozzle with Reinforcement in Nozzle Neck Only (for Sample Problem)

P.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.9.2.4 Construct the load nomograms (see Figure P-7):

In SI units:

$$1.0 - 0.75\frac{X_B}{(Rt)^{0.5}} = 1.0 - 0.75\left(\frac{325}{1166}\right) = 0.79$$

$$1.0 - 0.75\frac{X_A}{(Rt)^{0.5}} = 1.0 - 0.75\left(\frac{935}{1166}\right) = 0.40$$

$$1.0 - 0.75\frac{X_C}{(Rt)^{0.5}} = 1.0 - 0.75\left(\frac{630}{1166}\right) = 0.59$$

$$F_P = P\pi a^2 = (9800)(1.0)(19.2 - 0.630)\pi(0.305)^2$$

$$= 53{,}200 \text{ N}$$

$$\frac{\lambda}{2Y_F}\left(\frac{F_R}{F_P}\right) = \frac{0.26}{(2)(2.0)}\left(\frac{F_R}{53{,}200}\right) = 1.22 \times 10^{-6} F_R$$

$$\frac{\lambda}{aY_L}\left(\frac{M_L}{F_P}\right) = \frac{0.26}{(305)(7.8)}\left(\frac{M_L}{53{,}200}\right) = 2.05 \times 10^{-9} M_L$$

$$\frac{\lambda}{aY_C}\left(\frac{M_C}{F_P}\right) = \frac{0.26}{(305)(15)}\left(\frac{M_C}{53{,}200}\right) = 1.07 \times 10^{-9} M_C$$

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.9.2.5 Determine the limit piping loads.

For $M_L = 0$ and $M_C = 0$,

$$\frac{\lambda}{2Y_F}\left(\frac{F_R}{F_P}\right) = 5.35 \times 10^{-6} F_R \le 0.4$$

$$\frac{\lambda}{2Y_F}\left(\frac{F_R}{F_P}\right) = 1.22 \times 10^{-6} F_R \le 0.4$$

Therefore,

$$F_{Rmax} = \frac{0.4}{1.22 \times 10^{-6}} = 328{,}000 \text{ N (tension at A controls)}$$

$$F_{Rmax} = \frac{0.4}{5.35 \times 10^{-6}} = 74{,}800 \text{ pounds (tension at A controls)}$$

For $M_L = 0$ and $F_R = 0$,

$$\frac{\lambda}{aY_C}\left(\frac{M_C}{F_P}\right) = 1.07 \times 10^{-9} M_C \le 0.59$$

$$\frac{\lambda}{aY_C}\left(\frac{M_C}{F_P}\right) = 119 \times 10^{-9} M_C \le 0.59$$

Therefore,

$$M_{Cmax} = \frac{0.59}{1.07 \times 10^{-9}} = 550 \times 10^6 \text{ N-mm (tension at C}' \text{ controls)}$$

$$M_{Cmax} = \frac{0.59}{1.19 \times 10^{-7}} = 4.95 \times 10^6 \text{ in./lbs (tension at C}' \text{ controls)}$$

For $F_R = 0$ and $M_C = 0$,

$$\frac{\lambda}{aY_L}\left(\frac{M_L}{F_P}\right) = 2.05 \times 10^{-9} M_L \le 0.4$$

$$\frac{\lambda}{aY_L}\left(\frac{M_L}{F_P}\right) = 229 \times 10^{-9} M_L \le 0.4$$

Therefore,

$$M_{Lmax} = \frac{0.4}{2.05 \times 10^{-9}} = 195 \times 10^6 \text{ N-mm (tension at A controls)}$$

$$M_{Lmax} = \frac{0.4}{2.3 \times 10^{-7}} = 1.74 \times 10^6 \text{ in./lbs (tension at A controls)}$$

P.9.3 SUMMARY

The limit piping loads are as follows:

In SI units:

$$F_{Rmax} = 328{,}000 \text{ N (tension at A controls)}$$

$$M_{Cmax} = 550 \times 10^6 \text{ N-mm (tension at C}' \text{ controls)}$$

$$M_{Lmax} = 195 \times 10^6 \text{ N-mm (tension at A controls)}$$

In US Customary units:

$$F_{Rmax} = 74{,}800 \text{ pounds (tension at A controls)}$$

$$M_{Cmax} = 4.95 \times 10^6 \text{ in.-lbs (tension at C}' \text{ controls)}$$

$$M_{Lmax} = 1.74 \times 10^6 \text{ in.-lbs (tension at A controls)}$$

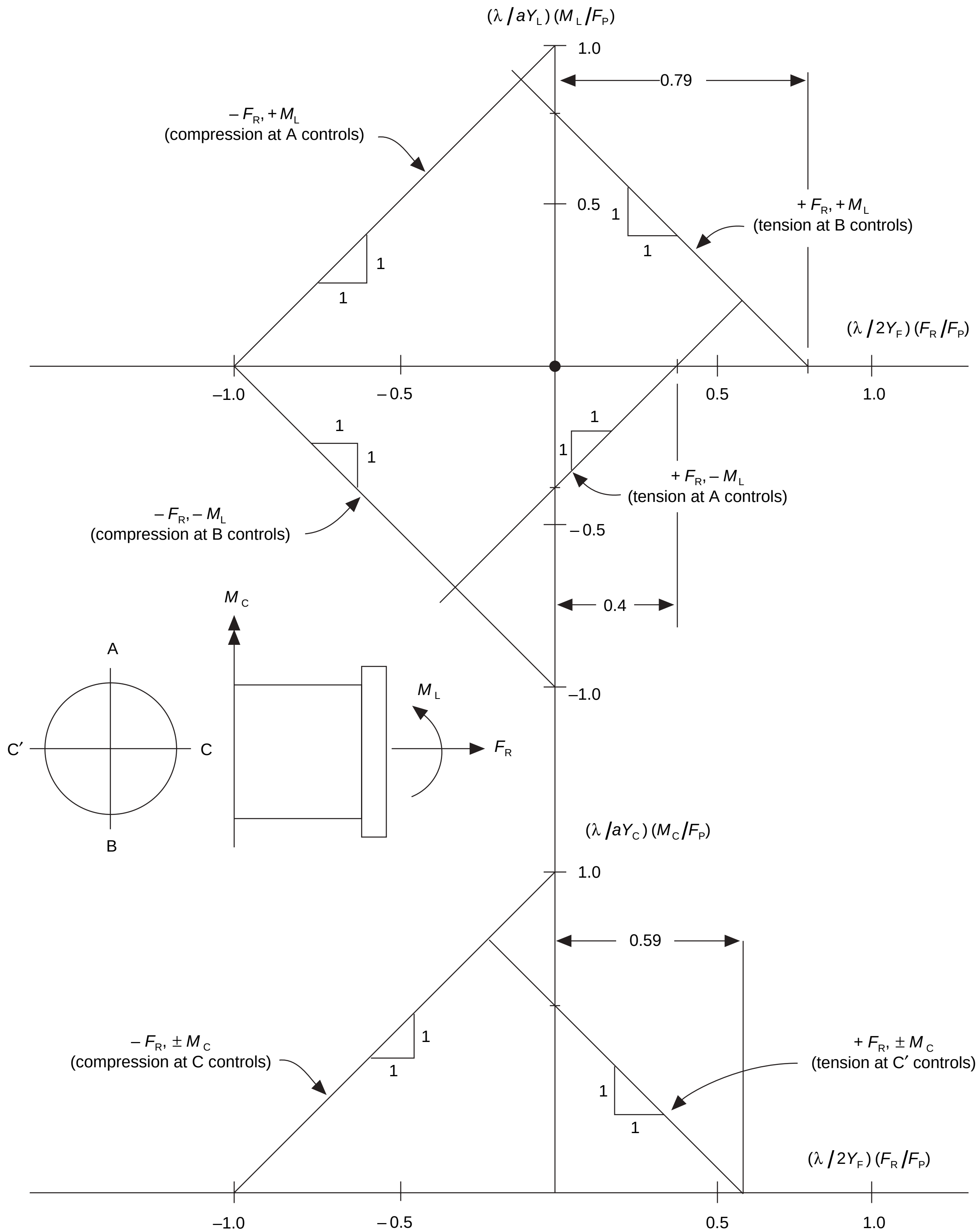


Figure P-7—Allowable-Load Nomograms for Sample Problem

S.3.2 SHELL DESIGN

The required minimum thickness of shell plates shall be the greater of the values computed by the following formulas
00 and the shell thickness shall not be less than the nominal plate thickness listed in 3.6.1.1:

In SI units:

00

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

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

where

- t_d = design shell thickness (mm),
- t_t = hydrostatic test shell thickness (mm),
- D = nominal diameter of tank (m) (see 3.6.1.1),
- H = design liquid level (m) (see 3.6.3.2),
- ● 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 3.3.2),
- 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-2).

In US Customary units:

00

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

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

where

- t_d = design shell thickness (in.),
- t_t = hydrostatic test shell thickness (in.),
- D = nominal diameter of tank (ft) (see 3.6.1.1),
- H = design liquid level (ft) (see 3.6.3.2),
- ● 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 3.3.2),
- 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 3.7 must be maintained.

S.3.3.2 Thermal stress relief requirements of 3.7.4 are not applicable.

S.3.3.3 Shell manholes shall be in conformance with 3.7.5 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 design temperature, or (b) the ratio of 205 MPa (30,000 psi) to the material yield strength at the design temperature.

S.3.3.4 As an alternative to S.3.3.3, plate ring flanges may be designed in accordance with API Standard 620 rules using the allowable stresses given in Table S-3.

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 value of 212 MPa (30,800 psi) shall be multiplied by the ratio of the material yield strength at the 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 9.8G (12G) shall be added to the design liquid height in meters (ft). The maximum joint efficiency shall be 0.85. 01

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 design temperature to 220 MPa (32,000 psi). (See Table S-5 for yield strengths.)

S.3.6 APPENDIX M—MODIFICATIONS

S.3.6.1 Appendix M requirements shall be met for stainless steel tanks with design temperatures 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 3.7.7 for flush-type cleanout fittings and of 3.7.8 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 00 40°C (100°F) to the material yield strength at the design temperature, or (b) the ratio of 205 MPa (30,000 psi) to the material yield strength at the 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 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 3.10.5 and 3.10.6 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 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 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) to 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) to 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 A380, 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 residues 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).

APPENDIX T—NDE REQUIREMENTS SUMMARY

Process	Welds Requiring Inspection	Reference Section
Air Test	Reinforcement plate welds inside and outside to 100 kPa (15 lbf/in.^{2}).	5.3.5
Air Test	Roofs designed to be airtight if roof seams are not vacuum box tested.	5.3.7.1.a
Air Test	Drain pipe and hose systems of primary drains of external floating roofs.	C.4.5
Air Test	Appendix F tanks with anchors.	F.7.6
Air Test	Aluminum dome roofs if required to be gastight.	G.10.1.2
Air Test	Shop built tanks	J.4.2.2
Hydro	Tank shell.	5.3.6.a
MT	Flush-type shell connections: nozzle-to-tank shell, repad welds, shell-to-bottom reinforcing pad welds on the root pass, each $^1/_2$ inch of weld, and completed weld. After stress relieving before hydro test.	3.7.8.11
MT	Permanent attachment welds and temporary weld removal areas.	5.2.3.5
MT	Welds attaching nozzles, manways, and clean out openings.	5.2.3.6
MT	First pass of the internal shell-to-bottom weld.	5.2.4.1.a
MT	Final shell-to-bottom welds, inside and outside instead of MT, PT, pen. oil, or VB of the initial inside pass.	5.2.4.2.c
Pen. Oil	All seams of internal floating roofs exposed to liquid or vapors.	H.4.3.4
Pen. Oil	First pass of the internal shell-to-bottom weld if approved instead of MT or PT.	5.2.4.1.d
Pen. Oil	Tank shell if no water for hydrostatic test.	5.3.6.b
Pen. Oil	Deck seams of external floating roofs.	C.4.2
PT	Permanent attachment welds and temporary weld removal areas instead of MT if approved.	5.2.3.5
PT	Welds attaching nozzles, manways, and clean out openings instead of MT if approved.	5.2.3.6
PT	First pass of the internal shell-to-bottom weld if approved instead of MT.	5.2.4.1.b or c
PT	Final shell-to-bottom welds, inside and outside instead of MT, PT, pen. oil, or VB of the initial inside pass.	5.2.4.2.c
PT	All aluminum structural welds and components joined by welding.	G.11.3
PT	Shell-to-bottom welds, opening connections not radiographed all welds of attachments to shells, and all butt welds of shell plates and annular plates of stainless steel tanks.	S.4.14.2
RT	Shell plate butt welds.	5.3.2.1
RT	Butt welds of annular plates that are required by 3.5.1 or M.4.1.	6.1.2.9
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.	3.7.8.11
Tracer Gas	Entire length of bottom weld joints as an alternative to vacuum box testing.	5.3.3.5
UT	When specified for weld examination.	6.3.1
VB	First pass of the internal shell-to-bottom weld if approved instead of MT, PT, or pen. oil.	5.2.4.1.e
VB	Final shell-to-bottom welds, inside and outside instead of MT, PT, pen. oil, or VB of the initial inside pass.	5.2.4.2.c
VB	Bottom welds.	5.3.4.a
VB	Welds of roofs designed to be gastight if not air tested.	5.3.7.1.b
VB	All seams of internal floating roofs exposed to liquid or vapors.	H.4.3.4
VB	Flexible membrane liners.	I.6.2
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.	3.7.8.11
VE	Tack of shell butt welds left in place.	5.2.1.8
VE	Permanent attachment welds and temporary weld removal areas.	5.2.3.5
VE	Welds attaching nozzles, manways, and clean out openings.	5.2.3.6
VE	First pass of the internal shell-to-bottom weld.	5.2.4.1
VE	Final shell-to-bottom welds, inside and outside instead of MT, PT, pen. oil, or VB of the initial inside pass.	5.2.4.2.b
VE	Shell plate butt welds.	5.3.2.1

01

Process	Welds Requiring Inspection	Reference Section
VE	Fillet welds.	5.3.2.2
VE	Welds on roofs not designed to be gas tight.	5.3.7.2
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
Water	Bottom welds if not vacuum box tested.	5.3.4.b
Water	External floating roofs—floating test.	C.4.3
Water	Aluminum dome roofs after completion.	G.10.1.1
Water	Internal floating roofs	H.7.3

Definitions:

MT= Magnetic Particle Examination
Pen Oil = Penetrating Oil Test
01 PT = Liquid Penetrant Examination
RT = Radiographic Testing
VB = Vacuum Box Testing
VE = Visual Examination

Acceptance Standards:

MT: ASME Section V, Article 7
PT: ASME Section V, Article 6, excluding aluminum dome parts—see AWS D1.2.
RT: ASME Section VIII, Paragraph UW-51(b)
Tracer Gas: None
UT: As agreed upon by purchaser and manufacturer.
VB: None
VE: API-650 6.5

Examiner Qualifications:

MT: API 650, Section 6.2.3
PT: API 650, Section 6.2.3
RT: ASNT Level II or III
Tracer Gas: None
UT: ASNT Level II or III. A Level I may be used with restrictions—see API 650, Section 6.3.3.
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: ASME Section V, Article 5
VB: None
VE: None

APPENDIX TI—TECHNICAL INQUIRY RESPONSES

Following are selected responses to requests for interpretation API Standard 650 requirements. A more extensive listing of interpretations can be found on the API website at http://api-ep.api.org under the “Standards” section. Additional information on technical inquiries can be found in Appendix D.

SECTION 1.1 SCOPE

650-I-03/00

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? 01

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

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 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.

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 3.5 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.

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?

01 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 3-11, does API 650 cover flush shell connections to be installed non-radially?

Reply 1: No.

Question 2: Referencing Figure 3-12, are flush-type shell connections smaller than 8 in. covered in API 650?

Reply 2: No.

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.

SECTION 3.8 SHELL ATTACHMENTS AND TANK APPURTENANCES

650-I-51/00 01

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.

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?

Reply1: 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.

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/ft^2?

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.

01
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?

Reply 2: Yes.

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.

SECTION 5.3 INSPECTING, TESTING, AND REPAIRS

650-I-16/00

Question: Regarding the hydrotesting 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 5.3.6 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-33/00

Question: Does API 650, Section 5.3.6, prohibit starting the water filling for hydrostatic testing while completing some welded attachments on the last shell ring above the water level?

Reply: No. 01

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.

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 +/- 3mm ($^1/_8$ 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 hydrotesting, can the manufacturer insist that the purchaser accept the tank?

01

Reply 1: No. Agreement by both parties is required.

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?

Reply: No.

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.

Reply 2: This is a contractual matter not covered by API 650.

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).

APPENDIX E SEISMIC DESIGN OF STORAGE TANKS

650-I-44/99

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?

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. 01

650-I-45/99

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)?

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.

650-I-25/00

Question 1: Should the metric formula for calculating the natural period of the first sloshing mode in Section E.3.3.2 read:

$$T = k(D^{0.5})\left(\frac{1}{0.5521}\right)$$

Reply 1: Yes. This correction will appear in Addendum 2 of API 650.

Question 2: Should the metric formula for calculating the width of the thicker plate under the shell in Section E.4.2 read:

$$0.1745 \times 10^{-3} w_L / GH (\mathrm{m})$$

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.

APPENDIX H INTERNAL FLOATING ROOFS

650-I-50/99

Question 1: Does API 650 require that floating roof seals be installed prior to hydrotesting the tank?

Reply 1: No.

Question 2: Is a roof seal considered a major component of the tank?

01 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 Publication 937 *Evaluation of Design Criteria for Storage Tanks with Frangible Roof Joints*.

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 $S_d \times E$.

Reply: Yes, you are correct. This typographical error was corrected in Addendum 1 to API 650, 10th Edition.

Additional copies are available through Global Engineering Documents at (800) 854-7179 or (303) 397-7956

Information about API Publications, Programs and Services is available on the World Wide Web at: http://www.api.org

American Petroleum Institute

1220 L Street, Northwest
Washington, D.C. 20005-4070
202-682-8000

Product No. C650A2