Welded Steel Tanks for Oil Storage

API STANDARD 650
NINTH EDITION, JULY 1993
ADDENDUM 1, DECEMBER 1994
ADDENDUM 2, DECEMBER 1995
ADDENDUM 3, DECEMBER 1996

American National Standards Institute ANSI/API Std 650

STEP
Strategies for Today's
Environmental Partnership

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STEP

Strategies for Today's
Environmental Partnership

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- To recognize and to respond to community concerns about our raw materials, products and operations.
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- To make safety, health and environmental considerations a priority in our planning, and our development of new products and processes.
- To advise promptly appropriate officials, employees, customers and the public of information on significant industry-related safety, health and environmental hazards, and to recommend protective measures.
- To counsel customers, transporters and others in the safe use, transportation and disposal of our raw materials, products and waste materials.
- To economically develop and produce natural resources and to conserve those resources by using energy efficiently.
- To extend knowledge by conducting or supporting research on the safety, health and environmental effects of our raw materials, products, processes and waste materials.
- To commit to reduce overall emissions and waste generation.
- To work with others to resolve problems created by handling and disposal of hazardous substances from our operations.
- To participate with government and others in creating responsible laws, regulations and standards to safeguard the community, workplace and environment.
- To promote these principles and practices by sharing experiences and offering assistance to others who produce, handle, use, transport or dispose of similar raw materials, petroleum products and wastes.

Welded Steel Tanks for Oil Storage

Manufacturing, Distribution and Marketing Department

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

Date: December 1996
To: Purchasers of API Standard 650, *Welded Steel Tanks for Oil Storage*, Ninth Edition
Re: Addendum 3

This package contains the entire Addendum 3 of API Standard 650, *Welded Steel Tanks for Oil Storage,* Ninth Edition. This package consists of the pages that have changed since the December 1995 printing of Addendum 2.

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 to Addendum 2	title page to Addendum 3
	v–vi	v–vi
	ix–xi	ix–xi (+blank)
Section 1	1-1–1-3	1-1–1-4
Section 2	2-1–2-8	2-1–2-8
Section 3	3-3–3-12	3-3–3-12
	3-19–3-20	3-19–3-20
	3-39–3-40	3-39–3-40
	3-45–3-46	3-45–3-46
Section 5	5-1–5-4	5-1–5-4
Section 6	6-1–6-4	6-1–6-4
Section 7	7-1–7-2	7-1–7-2
Appendix A	A-3–A-4	A-3–A-4
Appendix B	B-1–B-2	B-1–B-2
Appendix C	C-1–C-2	C-1–C-2
Appendix E	E-7	E-7 (+blank)
Appendix G	G-1–G-4	G-1–G-4
Appendix H	H-3–H-5	H-3–H-5 (+blank)
Appendix I	I-1–I-2	I-1–I-2
	I-5–I-6	I-5–I-6
	new	I-7–I-9 (+blank)
Appendix L	L-1	L-1 (+blank)
Appendix M	M-1–M-3	M-1–M-3 (+blank)

The parts of the text, tables, and figures that contain changes are indicated by a vertical bar and a small "96" in the margin.

NOTE: Please be aware that if you received an earlier Addendum 3 package, you should replace the pages received with the enclosed pages.

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 2½ 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 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.

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 issuancce 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. 95

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any federal, state, or municipal regulation with which this publication may conflict.

Suggested revisions are invited and should be submitted to the director of the Manufacturing, Distribution and Marketing Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

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, published at 54 *Federal Register* 29460 (July 12, 1989). The most recent edition of the *Federal Register* with regulations pertaining to asbestos should be consulted. 95

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

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

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INFORMATION REQUIRED FOR ORDERING TANKS

The purchaser shall state the following in the inquiry or purchase order:

- Specification
- Number of tanks
- Nominal capacity, in barrels
- Specific gravity of contents
- Appurtenances (type, size, and location)
- Design metal temperature
- Design pressure
- Painting requirements
- Time of completion
- Erection location and facilities
- Tank grade details
- Special provisions (permits, fees)
- Wind velocity
- Maximum operating temperature
- Foundation type
- Earthquake provisions

The purchaser may exercise an option with respect to the following requirements:

- Diameter, in feet
- Height, in feet
- Plate specifications (bottom, shell, and roof)
- Mill test reports
- Shop inspection
- Bottom test
- Shell test
- Roof test
- Magnetic particle examination
- Ultrasonic examination
- Liquid penetrant examination
- Radiographic examination
- Film ownership
- Bolting
- Bottom plates
  - Thickness
  - Size and arrangement
  - Joint design and welding procedure
- Shell plates
  - Thickness
  - Width and number of courses
  - Alignment
  - Top-angle orientation
  - Wind girders
- Corrosion allowance
  - Bottom
  - Shell
  - Roof
  - Structural members
- Roof plates
  - Thickness
  - Slope
  - Frangible roof
- Roof supports
- Roof live load and its distribution
- Appurtenances
  - Shell manhole design
  - Shell nozzle design
  - Cleanout fitting support
  - Nozzle external load
  - Drawoff sump design
  - Roof nozzle flange design
- Stairways, platforms, and walkways
- Freight and hauling
- Continuous welding of external attachments including wind girders

Note: See also Appendix L.

Welded Steel Tanks for Oil Storage

SECTION 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 1.1.8). 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 200°F (see 1.1.15).

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.

1.1.3 The appendixes of this standard contain requirements, alternative requirements, purchaser requirements (when so specified), nonmandatory recommendations and information. See Table 1-1 for the status of each appendix.

1.1.4 Appendix A provides for an alternative (and simplified) tank in which the stressed components, such as shell plates and reinforcing plates, are limited to a maximum nominal thickness of ½ inch, including any corrosion allowance, and to the minimum design metal temperatures stated in the appendix. 96

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

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

1.1.7 Appendix D explains how technical inquiries regarding this standard shall be prepared for submission to the director of the Manufacturing, Distribution and Marketing Department.

1.1.8 Appendix E provides recommended minimum basic requirements that may be specified by the purchaser for the design of storage tanks subject to seismic load.

1.1.9 Appendix F covers the additional requirements for the design of tanks subject to a small internal pressure.

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

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

1.1.12 Appendix I provides basic recommendations, which 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. 96

1.1.13 Appendix J presents requirements covering the complete shop assembly of tanks that do not exceed 20 feet in diameter.

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

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

1.1.16 Appendix M provides additional requirements for tanks with maximum operating temperatures from 200°F to 500°F.

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

1.1.18 Appendix O contains basic recommendations for the design and construction of under-bottom connections for storage tanks.

1.1.19 Appendix P presents recommended minimum requirement, which may be specified by the purchaser, for the design of storage-tank openings that conform to Table 3-8 and will be subjected to external piping loads.

1.1.20 Appendix S provides additional requirements for stainless steel tanks.

(text continued on page 1-3)

Table 1-1—Status of Appendixes to API Standard 650

Appendix	Title	Status
A	Optional design basis for small tanks	Alternative requirements
B	Recommendations for design and construction of foundations for aboveground oil storage tanks	Recommendations
C	External floating roofs	Requirements
D	Technical inquiries	Requirements
E	Seismic design of storage tanks	Purchaser's option
F	Design of tanks for small internal pressures	Requirements
G	Structurally supported aluminum dome roofs	Requirements
H	Internal floating roofs	Requirements
I	Undertank leak detection and subgrade protection	Purchaser's option
J	Shop-assembled storage tanks	Requirements
K	Sample application of the variable-design-point method to determine shell-plate thickness	Information
L	API 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	Recommendations
P	Allowable external load on tank shell openings	Purchaser's option
S	Austenitic stainless steel storage tanks	Requirements

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1.2 Compliance

96 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.

1.3 Referenced Publications

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

AA[1]

ASD-1	*Aluminum Standards and Data*
SAS-30	*Specifications for Aluminum Structures*
ASM-35	*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

API

Spec 5L	*Specification for Line Pipe*
Std 620	*Design and Construction of Large, Welded, Low-Pressure Storage Tanks* (ANSI/API 620)
RP 651	*Cathodic Protection of Aboveground Petroleum Storage Tanks* (ANSI/API 651)
RP 652	*Lining of Aboveground Petroleum Storage Tank Bottoms* (ANSI/API 652)
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*

ASME[5]

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[6]

Recommended Practice No. SNT-TC-1A

ASTM[7]

A 6	*General Requirements for Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use*
A 20	*General Requirements for Steel Plates for Pressure Vessels*
A 27	*Steel Castings, Carbon, for General Application*
A 36	*Structural Steel*
A 53	*Pipe, Steel, Black and Hot-Dipped, Zinc-Coated Welded and Seamless*
A 105	*Forgings, Carbon Steel, for Piping Components*
A 106	*Seamless Carbon Steel Pipe for High-Temperature Service*
A 131	*Structural Steel for Ships*
A 181	*Forgings, Carbon Steel, for General-Purpose Piping*
A 193	*Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service*
A 240	*Heat-Resisting Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels*
A 283	*Low and Intermediate Tensile Strength Carbon Steel Plates*
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 333	*Seamless and Welded Steel Pipe for Low-Temperature Service*
A 334	*Seamless and Welded Carbon and Alloy-Steel Tubes for Low-Temperature Service*
A 350	*Forgings, Carbon and Low-Alloy Steel, Requiring Notch Toughness Testing for*

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[1] The Aluminum Association Inc., 900 19th Street, N.W., Washington, D.C. 20006.

[2] American Concrete Institute, P.O. Box 19150, Detroit, Michigan 48219-0150.

[3] American Institute of Steel Construction, One East Wacker Drive, Suite 3100, Chicago, Illinois 60601-2001.

[4] American Iron and Steel Institute, 1101 17th Street, N.W., Suite 1300, Washington, D.C. 20036-4700.

[5] American Society of Mechanical Engineers, 345 East 47th Street, New York, New York 10017.

[6] American Society for Nondestructive Testing, 1711 Arlingate Lane, Columbus, Ohio 43228-0518.

[7] ASTM, 100 Bar Harbor Drive, West Conshohocken, Pennsyslvania 19428-2959. 96

	Piping Components
A 370	*Test Methods and Definitions for Mechanical Testing of Steel Products*
96 A 442	*Pressure Vessel Plates, Carbon Steel, Improved Transition Properties (out-of-print)*
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 525	*General Requirements for Steel Sheet, Zinc-Coated (Galvanized) by the Hot-Dip Process*
A 537	*Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel*
A 570	*Hot-Rolled Carbon Steel Sheet and Strip, Structural Quality*
A 573	*Structural Carbon Steel Plates of Improved Toughness*
A 633	*Normalized High-Strength Low-Alloy Structural Steel*
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 678	*Quenched and Tempered Carbon-Steel and High-Strength Low-Alloy Steel Plates for Structural Applications*
A 737	*Pressure Vessel Plates, High-Strength, Low-Alloy Steel*
96 A 841	*Standard Specification for Steel Plates for Pressure Vessels, Produced by the Thermo-Mechanical Control Process (TMCP)*
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* (ANSI/ASTM D2856)
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[8]

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

CSA[9]

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

Federal Specifications[10]

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

ISO[11]

630	*Structural Steels*

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[8] American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33135.

[9] Canadian Standards Association, 178 Rexdale Boulevard, Rexdale, Ontario M9W 1R3.

[10] Specifications Unit (WFSIS), 7th and D Streets, N.W., Washington, D.C. 20407.

[11] 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)].

SECTION 2—MATERIALS

2.1 General

2.1.1 Materials used in the construction of tanks shall conform to the specifications listed in this section, subject to the modifications and limitations indicated in this standard. Material produced to specifications other than those listed in this section may be employed, provided that the material is certified to meet all of the requirements of a material specification listed in this standard and the material's use is approved by the purchaser. The manufacturer's proposal shall identify the material specifications to be used.

2.1.2 When any new or unused plate and pipe material cannot be completely identified by records that are satisfactory to the purchaser as material conforming to a specification listed in this standard, the material or product may be used in the construction of tanks covered by this standard only if the material passes the tests prescribed in Appendix N.

2.2 Plates

2.2.1 GENERAL

2.2.1.1 Except as otherwise provided for in 2.1, plates shall conform to one of the specifications listed in 2.2.2 through 2.2.5, subject to the modifications and limitations indicated in this standard, including the limitations in Figure 2-1.

2.2.1.2 Plate for shells, roofs, and bottoms may be ordered on an edge-thickness basis or on a weight (pounds-per-square-foot) basis, as specified in 2.2.1.2.1 through 2.2.1.2.3.

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

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

2.2.1.2.3 Whether an edge-thickness or a weight basis is used, an underrun not more than 0.01 inch from the computed design thickness or the minimum permitted thickness is acceptable.

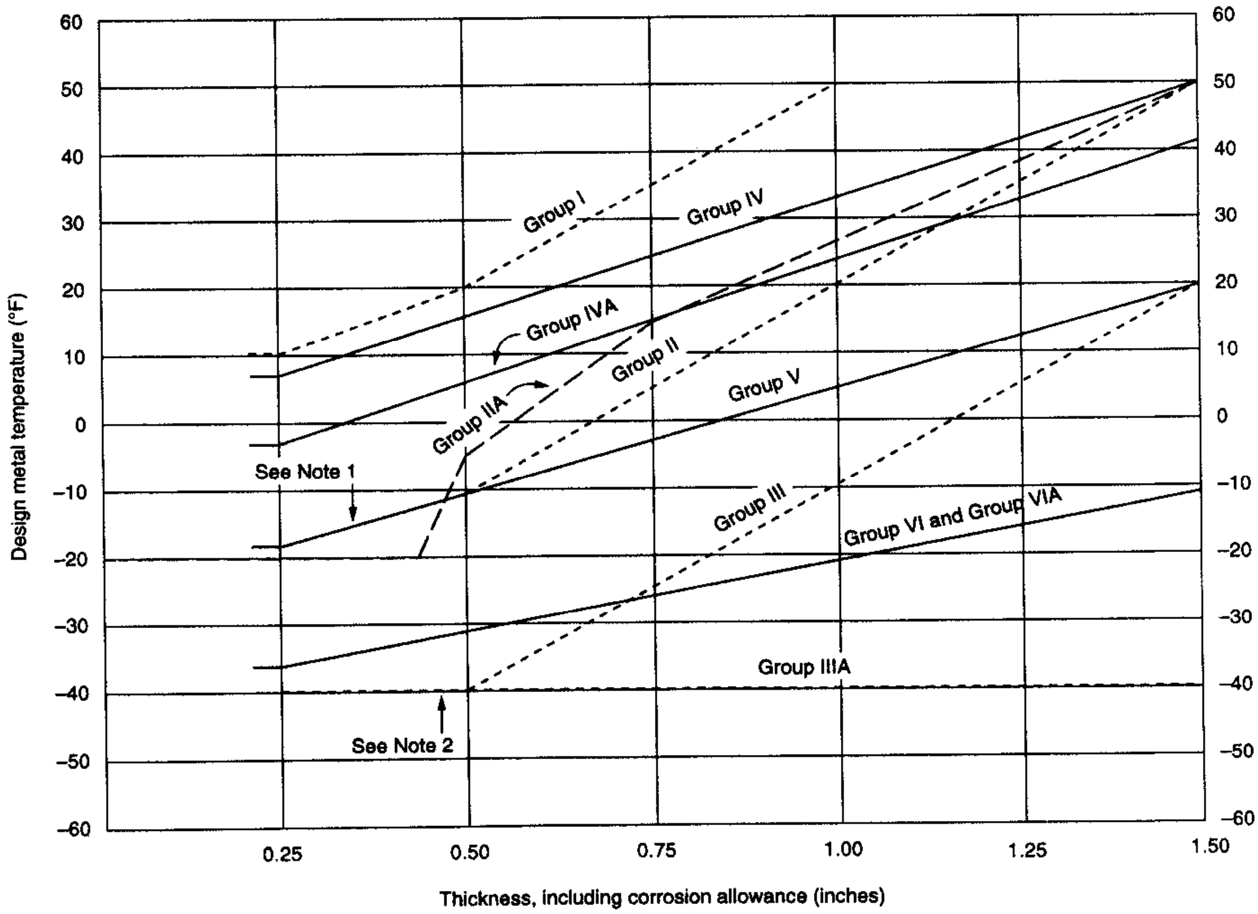
2.2.1.3 All plates shall be manufactured by the open-hearth, electric-furnace, or basic oxygen process. Steels produced by the thermo-mechanical control process (TMCP) may be used, provided that the combination of chemical composition and integrated controls of the steel manufacturing is mutually acceptable to the purchaser and the manufacturer, and provided that the specified mechanical properties in the required plate thicknesses are achieved. Copper-bearing steel shall be used if specified by the purchaser. 96

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

2.2.2 ASTM SPECIFICATIONS

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

a. ASTM A 36 for plates to a maximum thickness of 1.5 inches. None of the specifications for the appurtenant materials listed in Table 1 of ASTM A 36 are considered acceptable for tanks constructed under this standard unless it is expressly stated in this standard that the specifications are acceptable.
b. ASTM A 131, Grade A, for plates to a maximum thickness of 0.5 inch; Grade B for plates to a maximum thickness of 1 inch; Grade CS for plates to a maximum thickness of 1.5 inches (insert plates and flanges to a maximum thickness of 2 inches); and Grade EH36 for plates to a maximum thickness of 1.75 inches (insert plates and flanges to a maximum thickness of 2 inches).
c. ASTM A 283, Grade C, for plates to a maximum thickness of 1 inch.
d. ASTM A 285, Grade C, for plates to a maximum thickness of 1 inch.
e. ASTM A 442, Grades 55 and 60, for plates to a maximum thickness of 1.5 inches.
f. ASTM A 516, Grades 55, 60, 65, and 70, for plates to a maximum thickness of 1.5 inches (insert plates and flanges to a maximum thickness of 4 inches).
g. ASTM A 537, Class 1 and Class 2, for plates to a maximum thickness of 1.75 inches (insert plates to a maximum thickness of 4 inches).
h. ASTM A 573, Grades 58, 65, and 70, for plates to a maximum thickness of 1.5 inches.
i. ASTM A 633, Grades C and D, for plates to a maximum thickness of 1.75 inches (insert plates to a maximum thickness of 4 inches).
j. ASTM A 662, Grades B and C, for plates to a maximum thickness of 1.5 inches.
k. ASTM A 678, Grade A, for plates to a maximum thickness of 1.5 inches (insert plates to a maximum thickness of 2.5 inches) and Grade B for plates to a maximum thickness of 1.75 inches (insert plates to a maximum thickness of 2.5 inches). Boron additions are not permitted.
l. ASTM A 737, Grade B, for plates to a maximum thickness of 1.5 inches.



Notes:

1. The Group II and Group V lines coincide at thicknesses less than ½ inch.
2. The Group III and Group IIIA lines coincide at thicknesses less than ½ inch.
3. The materials in each group are listed in Table 2-3.
4. This figure is not applicable to controlled-rolled plates (see 2.2.7.4).
5. Use the Group IIA and Group VIA curves for pipe and flanges (see 2.5.5.2 and 2.5.5.3). 95

Figure 2-1—Minimum Permissible Design Metal Temperature for Materials Used in Tank Shells Without Impact Testing

96 m. ASTM A 841 for plates to a maximum thickness of 1.5 inches (insert plates to a maximum thickness of 2.5 inches).

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. 95

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 1 inch if semikilled and to a maximum thickness of 1.5 inches if fully killed and made to fine-grain practice. 94
f. Grade 350W is acceptable for plate to a maximum thickness of 1.75 inches (insert plates to a maximum thickness of 2 inches) if fully killed and made to fine-grain practice. 94

2.2.4 ISO SPECIFICATIONS

Plate furnished to ISO 630 in Grades Fe 42, Fe 44, and Fe 52 is acceptable within the following limitations:

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 percent) 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

Notes:

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. 96

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 0.50 inch maximum thickness unless combined with 0.15 percent minimum silicon.

4. When nitrogen (≤ 0.015 percent) is added as a supplement to vanadium, it shall be reported, and the minimum ratio of vanadium to nitrogen shall be 4:1.

94 a. Grade Fe 430 in Qualities C and D for plate to a maximum thickness of 1.5 inches and with a maximum manganese content of 1.5 percent (heat).

94 b. Grade Fe 510 in Qualities C and D for plate to a maximum thickness of 1.75 inches (insert plates to a maximum thickness of 2 inches).

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.

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 percent, the limit of the manganese content may be increased to 1.60 percent (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 percent (heat) and the weldability of the plate is given consideration. The material shall be marked "Mod" following the specification listing. The material shall conform to the product analysis tolerances of Table B in ASTM A 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 (see Table 2-3) and ISO 630, Grade Fe 510. 94

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

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

	Mechanical Properties[a]				
	Tensile Strength			Minimum Yield Strength[c]	Maximum Thickness
	Minimum[c]		Maximum		
Grade[b]	kgf/mm²	ksi	(ksi)	(ksi)	(inches)
37[d]	37	52	70	30	0.5
41	41	58	74	34	1.5
44	44	62	78	36	1.5

	Chemical Composition			
	Maximum Percent Carbon		Maximum Percent Phosphorus and Sulfur	
Grade	Heat	Product	Heat	Product
37	0.20	0.24	0.05	0.06
41	0.23	0.27	0.05	0.06
44	0.25	0.29	0.05	0.06

---

[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 (0.75 inch maximum when controlled-rolled steel 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.

Table 2-3—Material Groups (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	A 442-55		A 516-60		A 516-55	10
A 36	2, 3	A 442-60		G40.21M-260W	9	A 516-60	10
		G40.21M-260W				G40.21M-260W	9, 10
Grade 37	3, 5			Grade 41	5, 9		
Grade 41	6	Grade 41	5, 8			Grade 41	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 and TMCP	
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 I	
A 662 B				G40.21M-350W	9, 10	A 537 II	13
G40.21M-300W	9					A 678 A	
G40.21M-350W	9					A 678 B	13
Fe 430 C, D	4, 9					A 737 B	
Fe 510 C, D	9					A 841	12, 13
Grade 44	5, 9						

Notes:
1. Most of the listed material specification numbers refer to ASTM specifications (including Grade or Class); there are, however, some exceptions: 94 G40.21M (including Grade) is a CSA specification; Grades Fe 430 and Fe 510 (including Quality) are contained in ISO 630; and Grade 37, Grade 41, and Grade 44 are related to national standards (see 2.2.5).
2. Must be semikilled or killed.
3. Thickness ≤ 0.75 inch. 96
4. Maximum manganese content of 1.5 percent.
5. Thickness 0.75 inch maximum when controlled-rolled steel is used in place of normalized steel.
6. Manganese content shall be 0.80–1.2 percent by heat analysis for thicknesses greater than 0.75 inch, except that for each reduction of 0.01percent below the specified carbon maximum, an increase of 0.06 percent manganese above the specified maximum will be permitted up to the maximum of 1.35 percent. Thicknesses ≤ 0.75 inch shall have a manganese content of 0.8–1.2 percent by heat analysis. 96
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 percent and a maximum manganese content of 1.60 percent (see 2.2.6.4)
12. Produced by the thermo-mechanical control process (TMCP). 96
13. See 3.7.4.6 for tests on simulated test coupons for material used in stress relieved assemblies.

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 millimeters × 10 millimeters), 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 percent 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
95 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 1.5 inches 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 96
the minimum temperatures indicated in Figure 2-1.

2.2.9.2 Plates less than or equal to 1.5 inches 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 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 96
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).

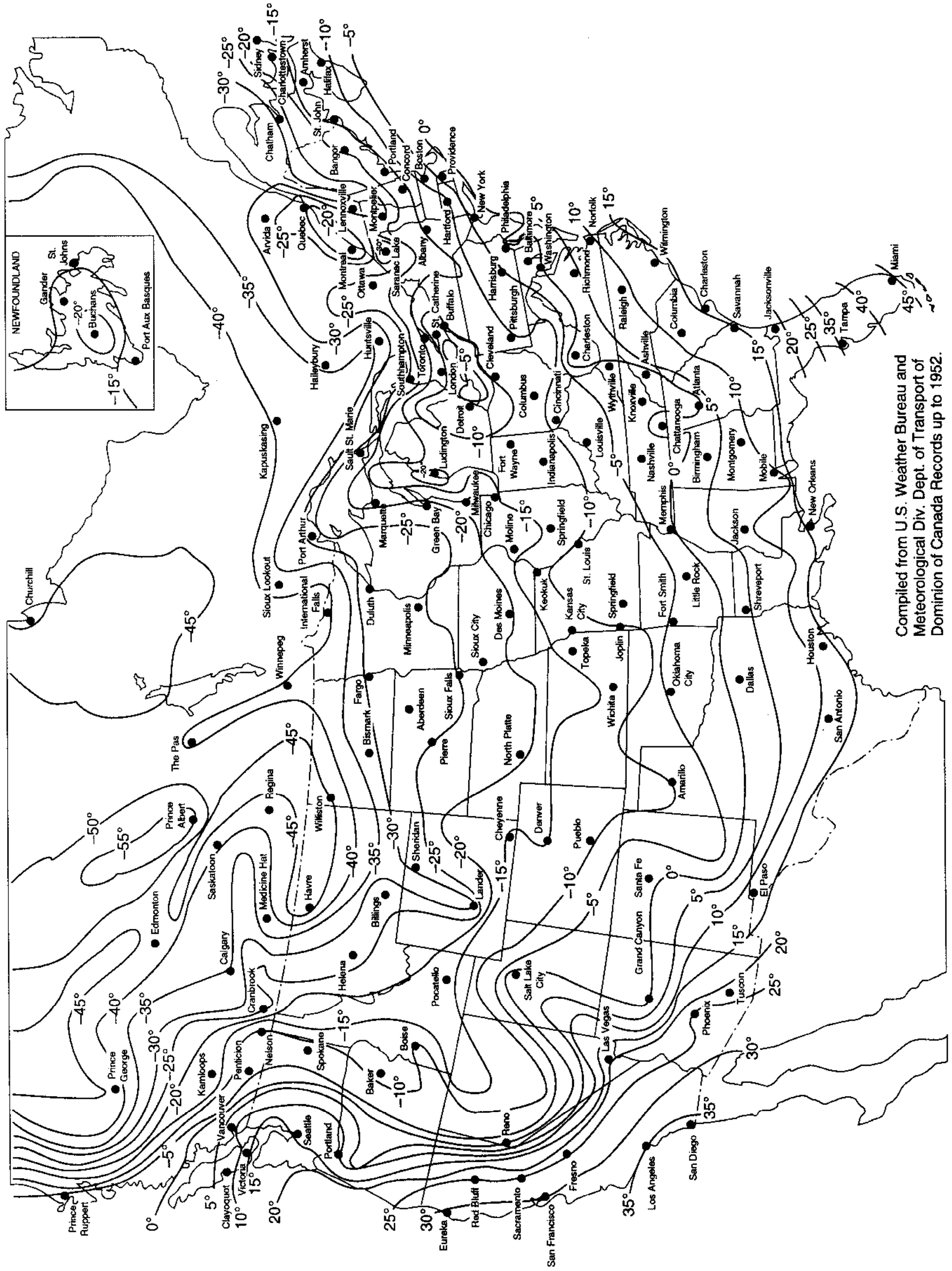
2.2.9.5 The requirements in 2.2.9.4 apply only to shell nozzles and manholes. Materials for roof nozzles and manholes do not require special toughness.

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.



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

Figure 2-2—Isothermal Lines of Lowest One-Day Mean Temperatures

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

Plate Material[a] and Thickness (t) in Inches	Average Impact Value of Three Specimens[b] (foot-pounds) Longitudinal	Average Impact Value of Three Specimens[b] (foot-pounds) Transverse
Groups I, II, III, and IIIA		
$t \leq$ maximum thicknesses in 2.2.2 through 2.2.5	15	13
96 Groups IV, IVA, V, and VI (except quenched and tempered and TMCP)		
$t \leq 1.5$	30	20
$1.5 < t \leq 1.75$	35	25
$1.75 < t \leq 2$	40	30
$2 < t \leq 4$	50	40
96 Group VI (quenched and tempered and TMCP)		
$t \leq 1.5$	35	25
$1.5 < t \leq 1.75$	40	30
$1.75 < t \leq 2$	45	35
$2 < t \leq 4$	50	40

Note: For plate ring flanges, the minimum impact test requirements for all thicknesses shall be those for $t \leq 1.5$ inches.

[a] See Table 2-3.

[b] Interpolation is permitted to the nearest foot-pound.

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.

2.2.10.5 Group-IV through -VI steels may be substituted for Group-I through -IIIA steels; however, the steel must comply with the appropriate Group (I through IIIA) requirements for impact tests (see Table 2-4 and Figure 2-1) and allowable stress (see 3.6.2) and with the following requirements:

a. The Group-IV through -VI material must be recertified by the mill or fabricator to the appropriate ASTM material specification within Groups I through IIIA. This recertification may be accomplished by the use of the material test report of the Group-IV through -VI steel being used for the substitution. The Group-IV through -VI steel must meet all of the maximum and minimum specification requirements (for example, chemistry, *YS*, and *UTS*) of the Group-I through -IIIA material.
b. The purchaser must approve the material recertification and the use of the substituted material.

2.3 Sheets

Sheets for fixed and floating roofs shall conform to ASTM 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 36.
b. ASTM A 131.
c. CSA G40.21-M, Grades 260W, 300W, 350W, 260WT, 300WT, and 350WT. Imperial unit equivalent grades of CSA Specification G40.21 are also acceptable. 95
d. ISO 630, Grades Fe 42 and Fe 44, Qualities B, C, and D.
e. 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 333, Grades 1 and 6.
e. ASTM A 334, Grades 1 and 6.
f. ASTM A 524, Grades I and II.
g. ASTM A 671 (see 2.5.3).

2.5.1.2 The following specifications are acceptable for forgings:

a. ASTM A 105.
b. ASTM A 181.
c. ASTM 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 or shall be 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 333, Grade 6; or ASTM 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 333, A 334, and A 350 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 181; and ASTM A 105.
95 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, ¼ of their nominal thickness. 95

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 333, Grade 6, for pipe or ASTM 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 13 foot-pounds (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 24 inches, 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.

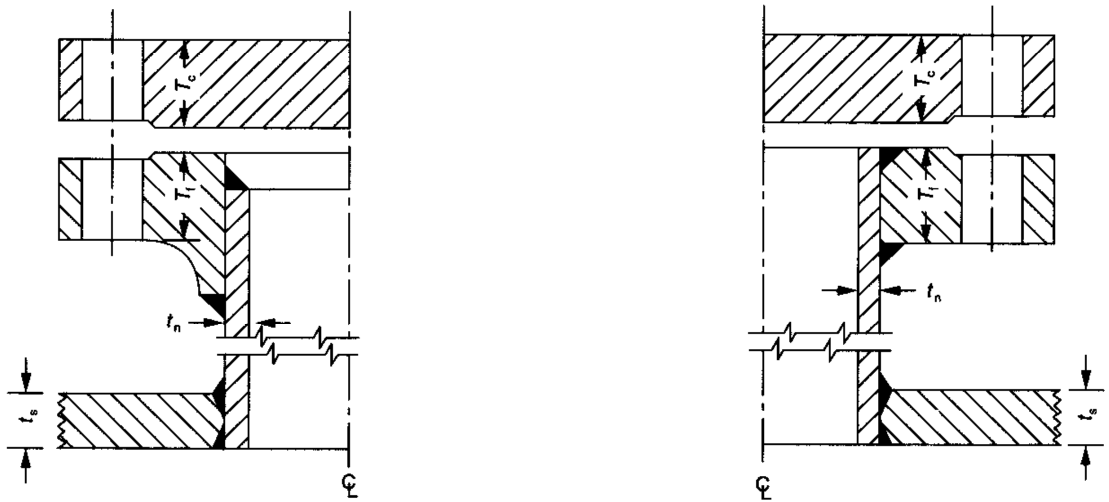
2.7 Bolting

Bolting shall conform to ASTM A 307 or A 193. 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. 96

2.8 Welding Electrodes

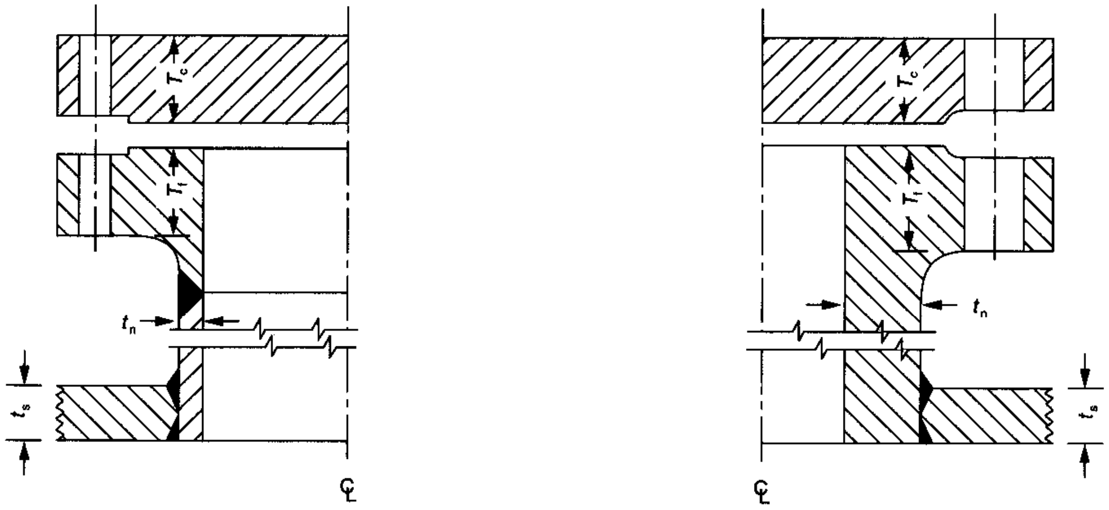
2.8.1 For the welding of materials with a minimum tensile strength less than 80 kips per square inch, the manual arc-welding electrodes shall conform to the E60 and E70 classification series (suitable for the electric current characteristics, the position of welding, and other conditions of intended use) in AWS A5.1 and shall conform to 5.2.1.10 as applicable. 94

2.8.2 For the welding of materials with a minimum tensile strength of 80–85 kips per square inch, the manual arc-welding electrodes shall conform to the E80XX-CX classification series in AWS A5.5.



SLIP–ON FLANGE

RING-TYPE FLANGE



WELDING–NECK FLANGE

LONG WELDING–NECK FLANGE

Notes:

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

Components	Governing Thickness (whichever is less)
Nozzle neck	t_n or t_s
Slip-on flange	t_n or T_f
Ring-type flange	t_n or T_f
Welding-neck flange	t_n or T_f
Long welding-neck flange	t_n or t_s
Bolted cover	t_n or T_f

Figure 2-3—Governing Thickness for Impact Test Determination of Shell Nozzle and Manhole Materials (see 2.5.5.3)

SECTION 3—DESIGN

3.1 Joints

3.1.1 DEFINITIONS

The definitions in 3.1.1.1 through 3.1.1.8 apply to tank joint designs (see 7.1 for definitions that apply to welders and welding procedures).

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

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

3.1.1.3 A *double-welded lap joint* is a joint between two overlapping members in which the overlapped edges of both members are welded with fillet welds.

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

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

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

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

3.1.1.8 A *tack weld* is a weld made to hold the parts of a weldment in proper alignment until the final welds are made.

3.1.2 WELD SIZE

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

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

3.1.3 RESTRICTIONS ON JOINTS

3.1.3.1 Restrictions on the type and size of welded joints are given in 3.1.3.2 through 3.1.3.5.

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

3.1.3.3 The minimum size of fillet welds shall be as follows: On plates $\frac{3}{16}$ inch thick, the weld shall be a full-fillet weld, and on plates more than $\frac{3}{16}$ inch thick, the weld thickness shall not be less than one-third the thickness of the thinner plate at the joint and shall be at least $\frac{3}{16}$ inch.

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

3.1.3.5 Lap-welded joints, as tack-welded, shall be lapped at least five times the nominal thickness of the thinner plate joined; however, with double-welded lap joints, the lap need not exceed 2 inches, and with single-welded lap joints, the lap need not exceed 1 inch.

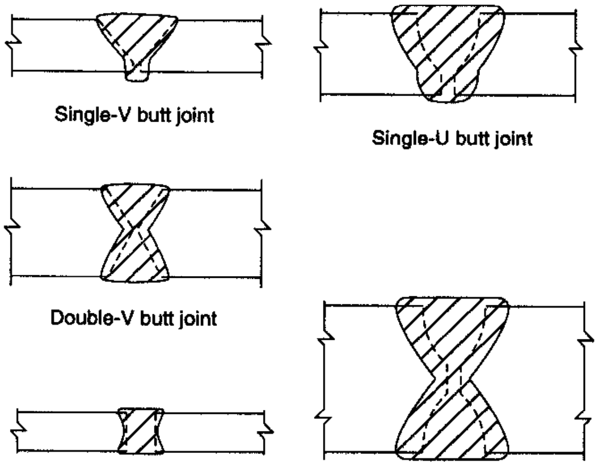
3.1.4 WELDING SYMBOLS

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

3.1.5 TYPICAL JOINTS

3.1.5.1 General

Typical tank joints are shown in Figures 3-1, 3-2, 3-3A, 3-3B, and 3-3C. The wide faces of nonsymmetrical V- or U-butt joints may be on the outside or the inside of the tank shell at the option of the manufacturer. The tank shell shall be designed so that all courses are truly vertical.


Single-V butt joint

Single-U butt joint

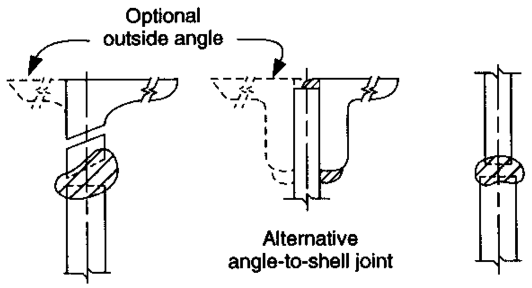
Double-V butt joint

Square-groove butt joint

Double-U butt joint

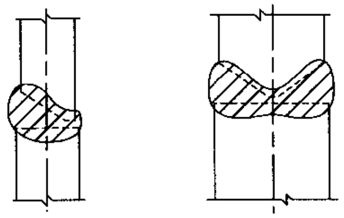
Note: See 3.1.5.2 for specific requirements for vertical shell joints.

Figure 3-1—Typical Vertical Shell Joints



Angle-to-shell
butt joint—
complete penetration

Square-groove
butt joint—
complete penetration



Single-bevel
butt joint—
complete penetration

Double-bevel
butt joint—
complete penetration

Note: See 3.1.5.3 for specific requirements for horizontal shell joints.

Figure 3-2—Typical Horizontal Shell Joints

3.1.5.2 Vertical Shell Joints

a. Vertical shell joints shall be butt joints with complete penetration and complete fusion attained by double welding or other means that will obtain the same quality of deposited weld metal on the inside and outside weld surfaces to meet the requirements of 5.2.1 and 5.2.3. The suitability of the plate preparation and welding procedure shall be determined in accordance with 7.2.
b. Vertical joints in adjacent shell courses shall not be aligned but shall be offset from each other a minimum distance of 5*t*, where *t* is the plate thickness of the thicker course at the point of offset.

3.1.5.3 Horizontal Shell Joints

a. Horizontal shell joints shall have complete penetration and complete fusion; however, as an alternative, top angles may be attached to the shell by a double-welded lap joint. The suitability of the plate preparation and welding procedure shall be determined in accordance with 7.2.
b. Unless otherwise specified, abutting shell plates at horizontal joints shall have a common vertical centerline.

3.1.5.4 Lap-Welded Bottom Joints

Lap-welded bottom plates shall be reasonably rectangular and square edged. Three-plate laps in tank bottoms shall be at least 12 inches from each other, from the tank shell, from butt-welded annular-plate joints, and from joints between annular plates and the bottom. Lapping of two bottom plates on the butt-welded annular plates does not constitute a three-plate lap weld. 95 When annular plates are used or are required by 3.5.1, they shall be butt welded and shall have a radial width that provides at least 24 inches between the inside of the shell and any lap-welded joint in the remainder of the bottom. Bottom plates need to be welded on the top side only with a continuous full-fillet weld on all seams. Unless annular bottom plates are used, the bottom plates under the bottom shell ring shall have the outer ends of the joints fitted and lap welded to form a smooth bearing for the shell plates, as shown in Figure 3-3B.

3.1.5.5 Butt-Welded Bottom Joints

Butt-welded bottom plates shall have their parallel edges prepared for butt welding with either square or V grooves. If square grooves are employed, the root openings shall not be less than ¼ inch. The butt welds shall be made by tack welding a backing strip at least ⅛ inch thick to the underside of the plate. A metal spacer shall be used to maintain the root opening between the adjoining plate edges unless the manufacturer submits another method of butt welding the bottom for the purchaser's approval. Three-plate joints in the tank bottom shall be at least 12 inches from each other and from the tank shell.

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 ⅛ inch.

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). Inspection by radiographic methods is not required for roof-plate or bottom-plate welds or for welds joining roof plates to the top angle, the top angle to the shell plate, shell plates to bottom plates, or appurtenances 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 ⅜ inch thick, one spot radiograph shall be taken in the first 10 feet 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 100 feet (approximately) and any remaining major fraction of vertical joint of the same type and thickness. At least 25 percent 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 ⅜ inch but less than or equal to 1 inch 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 2 inches 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 1 inch thick shall be fully radiographed. All junctions of vertical and horizontal joints in this thickness range shall be radiographed; each film shall clearly show not less than 2 inches of weld length 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 10 feet 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 200 feet (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 footage of welds of the same type and thickness in each group of tanks rather than the footage in each individual 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 6 inches 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 a thickness gauge or penetrometer. 96

6.1.2.9 When bottom annular plates are required by 3.5.1, the radial joints shall be radiographed as follows: (a) For 96

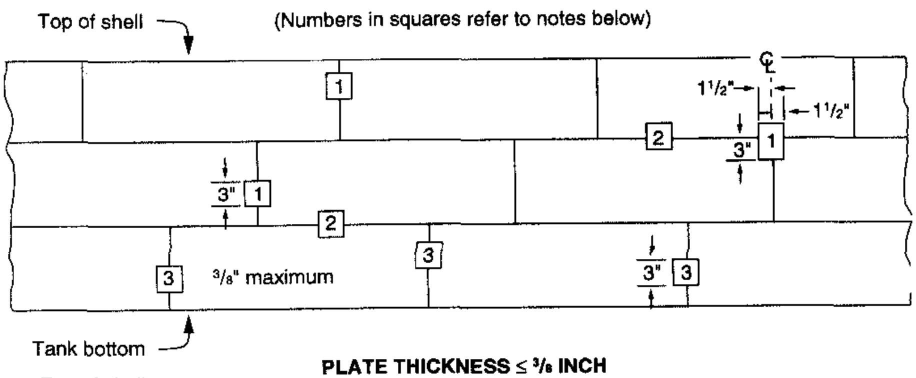
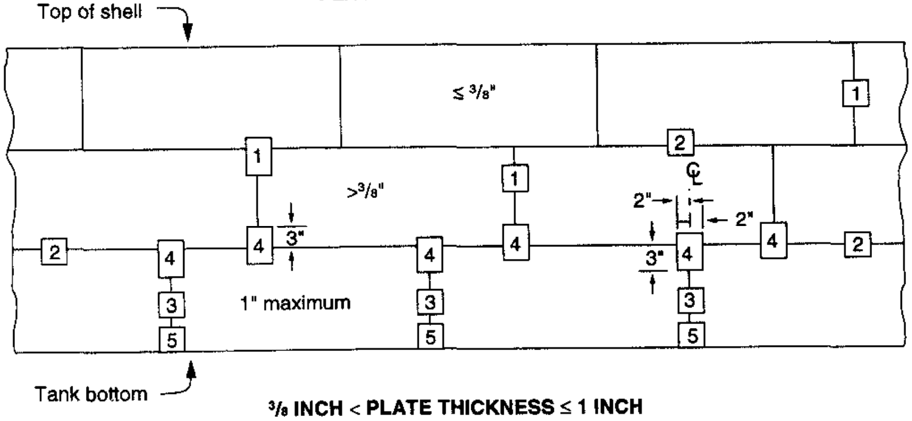


PLATE THICKNESS ≤ ⅜ INCH



⅜ INCH < PLATE THICKNESS ≤ 1 INCH

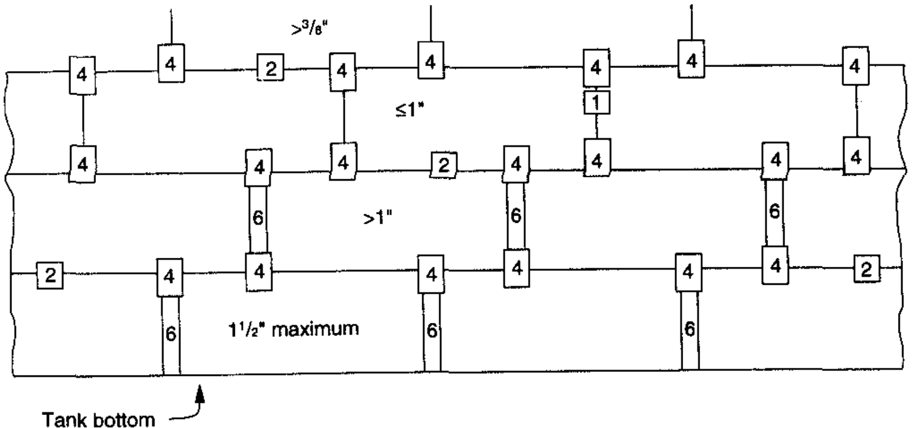


PLATE THICKNESS > 1 INCH

Notes:
1. Vertical spot radiograph in accordance with 6.1.2.2, Item a: one in the first 10 feet and one in each 100 feet thereafter, 25 percent of which shall be at intersections.
2. Horizontal spot radiograph in accordance with 6.1.2.3: one in the first 10 feet and one in each 200 feet thereafter.
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 ⅜ inch (see 6.1.2.2, Item b).
5. Spot radiograph of bottom of each vertical seam in lowest shell course over ⅜ inch (see 6.1.2.2, Item b).
6. Complete radiograph of each vertical seam over 1 inch. The complete radiograph may include the spot radiographs of the intersections if the film has a minimum width of 4 inches (see 6.1.2.2, Item c).

Figure 6-1—Radiographic Requirements for Tank Shells

96 double-welded butt joints, one spot radiograph shall be taken on 10 percent of the radial joints; (b) For single-welded butt joints with permanent or removable backup bar, one spot radiograph shall be taken on 50 percent 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 6 inches. 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 -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 -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 whether the prescribed penetrometer image and the specified hole can be seen.

6.1.3.4 The finished surface of the weld reinforcement may be flush with the plate or may have a reasonably uniform crown not to exceed the following values:

Plate Thickness (inches)	Maximum Thickness of Reinforcement (inches)
≤ ½	1/16
> ½ to 1	3/32
> 1	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 3 inches 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. 95

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:

96 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 12 inches 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 -III personnel. In addition, all Level-I personnel shall be under the direct supervision of Level-II or -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 12 inches 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. 96

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 $\frac{1}{64}$ inch.

c. The frequency of surface porosity in the weld does not exceed one cluster (one or more pores) in any 4 inches of length, and the diameter of each cluster does not exceed $\frac{3}{32}$ inch.

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. 96

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. 96

c. The repair weld shall be visually examined for defects.

SECTION 7—WELDING PROCEDURE AND WELDER QUALIFICATIONS

7.1 Definitions

In this standard, terms relating to welding shall be interpreted as defined in Section IX of the ASME Code. Additional terms are defined in 7.1.1 and 7.1.2.

7.1.1 An *angle joint* is a joint between two members that intersect at an angle between 0 degrees (a butt joint) and 90 degrees (a corner joint).

7.1.2 *Porosity* refers to gas pockets or voids in metal.

7.2 Qualification of Welding Procedures

7.2.1 GENERAL REQUIREMENTS

7.2.1.1 The erection manufacturer and the fabrication manufacturer, if other than the erection manufacturer, shall prepare welding procedure specifications and shall perform tests documented by procedure qualification records to support the specifications, as required by Section IX of the ASME Code and any additional provisions of this standard. If the manufacturer is part of an organization that has, to the purchaser's satisfaction, established effective operational control of the qualification of welding procedures and of welder performance for two or more companies of different names, then separate welding procedure qualifications are not required, provided all other requirements of 7.2, 7.3, and Section IX of the ASME Code are met.

7.2.1.2 The welding procedures used shall produce weldments with the mechanical properties required by the design.

7.2.1.3 Material specifications listed in Section 2 of this standard but not included in Table QW-422 of Section IX of the ASME Code shall be considered as P1 material with group numbers assigned as follows according to the minimum tensile strength specified:

a. Less than or equal to 60 kips per square inch—Group 1.
b. Greater than 60 kips per square inch but less than or equal to 75 kips per square inch—Group 2.
c. Greater than 75 kips per square inch—Group 3.

96 | Separate welding procedures and performance qualifications shall be conducted for A 841 material.

7.2.1.4 Welding variables (including supplementary essential variables when impact tests are required by 7.2.2), as defined by QW-250 of Section IX of the ASME Code, shall be used to determine the welding procedure specifications and the procedure qualification records to be instituted. In addition, when impact tests of the heat-affected zone are required, the heat-treated condition of the base material shall be a supplementary essential variable. If a protective coating has been applied to weld edge preparations, the coating shall be included as an essential variable of the welding procedure specification, as required by 5.2.1.9.

7.2.2 IMPACT TESTS

7.2.2.1 Impact tests for the qualification of welding procedures shall comply with the applicable provisions of 2.2.8 and shall be made at or below the design metal temperature.

7.2.2.2 When impact testing of a material is required by 2.2.8 or 2.2.9, impact tests of the heat-affected zone shall be made for all automatic and semiautomatic procedures.

7.2.2.3 For all materials to be used at a design metal temperature below 50°F, the qualification of the welding procedure for vertical joints shall include impact tests of the weld metal. If vertical joints are to be made by an automatic or semiautomatic process, impact tests of the heat-affected zone shall also be made.

7.2.2.4 Impact tests of the weld metal shall be made for all procedures used for welding the components listed in 2.2.9.1 and attachments to these components when the design metal temperature is below 20°F.

7.2.2.5 Impact tests shall show minimum values for acceptance in accordance with 2.2.8.3 and the following:

a. For P1, Group 1, materials—15 foot-pounds, average of three specimens.
b. For P1, Group 2, materials—20 foot-pounds, average of three specimens.
c. For P1, Group 3, materials—25 foot-pounds, average of three specimens.

For shell plates thicker than 1½ inches, these values shall be increased by 5 foot-pounds for each ½ inch over 1½ inches. Interpolation to the nearest foot-pound is permitted.

7.2.2.6 Weld-metal impact specimens shall be taken across the weld with one face substantially parallel to and within 1/16 inch of the surface of the material. The notch shall be cut normal to the original material surface and with the weld metal entirely within the fracture zone.

7.2.2.7 Heat-affected-zone impact specimens shall be taken across the weld and as near the surface of the material as is practicable. Each specimen shall be etched to locate the heat-affected zone, and the notch shall be cut approximately normal to the original material surface and with as much heat-affected-zone material as possible included in the fracture zone.

7.2.2.8 Production welding shall conform to the qualified welding procedure, but production-weld test plates need not be made.

7.3 Qualification of Welders

7.3.1 The erection manufacturer and the fabrication manufacturer, if other than the erection manufacturer, shall conduct tests for all welders assigned to manual and semiautomatic welding and all operators assigned to automatic welding to demonstrate the welders' and operators' ability to make acceptable welds. Tests conducted by one manufacturer shall not qualify a welder or welding operator to do work for another manufacturer.

7.3.2 The welders and welding operators who weld pressure parts and join nonpressure parts, such as all permanent and temporary clips and lugs, to pressure parts shall be qualified in accordance with Section IX of the ASME Code.

7.3.3 The records of the tests for qualifying welders and welding operators shall include the following:

a. Each welder or welding operator shall be assigned an identifying number, letter, or symbol by the fabrication or erection manufacturer.
b. The fabrication or erection manufacturer shall maintain a record of the welders or welding operators employed that shows the date and results of the tests for each welder or operator and the identifying mark assigned to each welder or operator. This record shall be certified by the fabrication or erection manufacturer and shall be accessible to the inspector.

7.4 Identification of Welded Joints

The welder or welding operator's identification mark shall be hand- or machine-stamped adjacent to and at intervals not exceeding 3 feet along the completed welds. In lieu of stamping, a record may be kept that identifies the welder or welding operator employed for each welded joint; these records shall be accessible to the inspector. Roof plate welds and flange-to-nozzle-neck welds do not require welder identification. 95

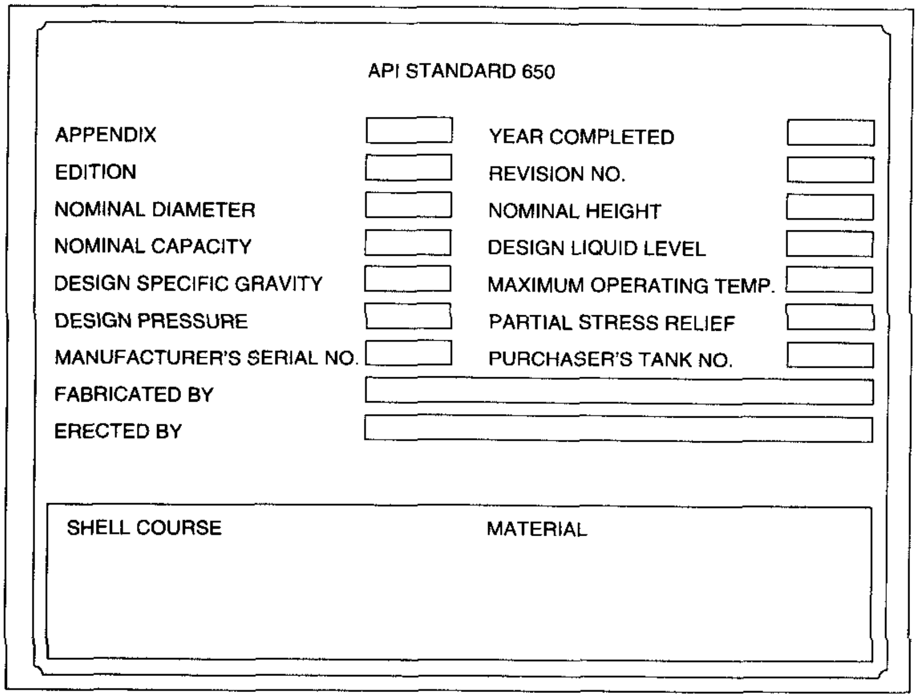
SECTION 8—MARKING

8.1 Nameplates

8.1.1 A tank made in accordance with this standard shall be identified by a nameplate similar to that shown in Figure 8-1. The nameplate shall indicate, by means of letters and numerals not less than 3/32 inch high, the following information:

a. API Standard 650.
b. The applicable appendix to API Standard 650.
c. The year the tank was completed.
d. The date of the edition and the revision number of API Standard 650.
e. The nominal diameter and nominal height, in feet and inches (unless other units are specified by the purchaser).
f. The nominal capacity, in 42-gallon barrels (unless other units are specified by the purchaser).
g. The design liquid level, in feet and inches (unless other units are specified by the purchaser).
h. The design specific gravity of the liquid.
i. The design pressure, which shall be shown as atmospheric unless Appendix F applies.
j. The maximum operating temperature, in degrees Fahrenheit (unless other units are specified by the purchaser), which shall not exceed 200°F except in cases where Appendix M applies.
k. The name of the fabrication manufacturer if other than the erection manufacturer. The manufacturer's serial number or contract number shall be from the erection manufacturer.
l. The material specification number for each shell course.
m. When stress relief is applied to a part in accordance with the requirements of 3.7.4, the letters "SR."
n. The purchaser's tank number.

8.1.2 The nameplate shall be attached to the tank shell adjacent to a manhole or to a manhole reinforcing plate immediately above a manhole. A nameplate that is placed directly on the shell plate or reinforcing plate shall be attached by continuous welding or brazing all around the nameplate. A nameplate that is riveted or otherwise permanently attached to an auxiliary plate of ferrous material shall be attached to the tank shell plate or reinforcing plate by continuous welding. The nameplate shall be of corrosion-resistant metal.



Note: At the purchaser's request or at the erection manufacturer's discretion, additional pertinent information may be shown on the nameplate, and the size of the nameplate may be increased proportionately.

Figure 8-1—Nameplate

MANUFACTURER'S CERTIFICATION FOR A TANK BUILT TO API STANDARD 650

To ____
(name and address of purchaser)

____

____

We hereby certify that the tank constructed for you at ______________________________
(location)

____

____

and described as follows: ______________________________
(serial or contract number, diameter, height, capacity, floating or fixed roof)

____

meets all applicable requirements of API Standard 650, __________ Edition, __________ Revision, Appendix

________, dated ______________, including the requirements for design, materials, fabrication, and erection.

The tank is further described on the attached as-built data sheet dated __________________.

____
Manufacturer

____
Authorized Representative

____
Date

Figure 8-2—Manufacturer's Certification Letter

8.1.3 When a tank is fabricated and erected by a single organization, that organization's name shall appear on the nameplate as both fabricator and erector.

8.1.4 When a tank is fabricated by one organization and erected by another, the names of both organizations shall appear on the nameplate, or separate nameplates shall be applied by each.

8.2 Division of Responsibility

Unless otherwise agreed upon, when a tank is fabricated by one manufacturer and erected by another, the erection manufacturer shall be considered as having the primary responsibility. The erection manufacturer shall make certain that the materials used in the fabrication of the components and in the construction of the tank are in accordance with all applicable requirements.

8.3 Certification

The manufacturer shall certify to the purchaser, by a letter such as that shown in Figure 8-2, that the tank has been constructed in accordance with the applicable requirements of this standard. An as-built data sheet in accordance with Appendix L shall be attached to the certification letter.

APPENDIX A—OPTIONAL DESIGN BASIS FOR SMALL TANKS

A.1 Scope

A.1.1 This appendix provides requirements for field-erected tanks of relatively small capacity in which the stressed components have a maximum nominal thickness of ½ inch, including any corrosion allowance specified by the purchaser. The stressed components include the shell and reinforcing plates, bottom and shell reinforcing plates for flush-type cleanout fittings and flush-type connections, and bottom plates that are welded to the shell, but the stressed components do not include other bottom plates, covers, and nozzle and manhole necks and their flanges.

A.1.2 This appendix is applicable only when specified by the purchaser and is limited to design metal temperatures above –20°F (above –40°F when killed, fine-grain material is used).

A.1.3 This appendix is applicable to any of the Section 2 materials, although the single allowable stress does not provide any advantage to higher strength steels.

A.1.4 This appendix states only the requirements that differ from the basic rules in this standard. When differing requirements are not stated, the basic rules must be followed; however, the overturning effect of a wind load should be considered.

A.1.5 Typical sizes, capacities, and shell-plate thicknesses are listed in Tables A-1 through A-4 for a design in accordance with A.4 (joint efficiency = 0.85; specific gravity = 1.0; and corrosion allowance = 0).

A.2 Materials

A.2.1 Shell-plate materials shall not be more than ½ inch thick, as stated in A.1.1.

95 **A.2.2** For stressed components, the Group-I and -II materials listed in Table 2-3 may be used above a design metal temperature of –20°F but need not conform to the toughness requirements of 2.2.9, Figure 2-1, and 7.2.2. Group-III and -IIIA materials may be used above a design metal temperature of –40°F and shall conform to impact requirements of 7.2.2.

A.2.3 Material used for shell nozzle and manhole necks and flanges shall conform to 2.5, 2.6, and Table 2-3 but need not conform to the toughness requirements of 2.2.9, 2.5.5, and Figure 2-1.

A.3 Design

A.3.1 The maximum tensile stress before the joint efficiency factor is applied shall be 21,000 pounds per square inch.

A.3.2 Stresses shall be computed on the assumption that the tank is filled with water (specific gravity = 1.0) or with the liquid to be stored if it is heavier than water.

A.3.3 The tension in each ring shall be computed 12 inches above the centerline of the lower horizontal joint of the course in question. When these stresses are computed, the tank diameter shall be taken as the nominal diameter of the bottom course.

A.3.4 The joint efficiency factor shall be 0.85 with the spot radiography required by A.5.3. By agreement between the purchaser and the manufacturer, the spot radiography may be omitted, and a joint efficiency factor of 0.70 shall be used.

A.4 Thickness of Shell Plates

A.4.1 The minimum thicknesses of shell plates shall be computed from the stress on the vertical joints, using the following formula:

$$t = \frac{2.6D(H-1)G}{(E)(21,000)} + CA$$

Where:

t = minimum thickness, in inches (see 3.6.1.1).
D = nominal diameter of the tank, in feet (see 3.6.1.1, Note 1).
H = design liquid level, in feet (see 3.6.3.2).
G = specific gravity of the liquid to be stored, as specified by the purchaser. The specific gravity shall not be less than 1.0.
E = joint efficiency, which is either 0.85 or 0.70 (see A.3.4).
CA = corrosion allowance, in inches, as specified by the purchaser (see 3.3.2).

A.4.2 The nominal thickness of shell plates (including shell extensions for floating roofs) shall not be less than that listed in 3.6.1.1. The nominal thickness of shell plates refers to the tank shell as constructed. The nominal thicknesses given in 3.6.1.1 are based on erection requirements.

A.5 Tank Joints

A.5.1 Vertical and horizontal joints in the shell, bottom joints, shell-to-bottom joints, wind-girder joints, and roof and top-angle joints shall conform to 3.1.5.

A.5.2 The requirements of 3.7.3 for the spacing of welds do not apply except for the requirement that the spacing between the toes of welds around a connection shall not be less than 2½ times the shell thickness at the connection.

A.5.3 When radiographic inspection is required (joint efficiency = 0.85), the spot radiographs of vertical joints shall conform to 6.1.2.2, Item a, excluding the ⅜-inch shell-thickness limitation in Item a and excluding the additional ran-

Table A-1—Typical Sizes and Corresponding Nominal Capacities (in Barrels) for Tanks With 72-Inch Courses

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11
Tank Diameter (feet)	Capacity per Foot of Height (barrels)	Tank Height (feet)/Number of Courses in Completed Tank								
		12/2	18/3	24/4	30/5	36/6	42/7	48/8	54/9	60/10
10	14.0	170	250	335	420	505	—	—	—	—
15	31.5	380	565	755	945	1,130	—	—	—	—
20	56.0	670	1,010	1,340	1,680	2,010	2,350	2,690	—	—
25	87.4	1,050	1,570	2,100	2,620	3,150	3,670	4,200	4,720	5,250
30	126	1,510	2,270	3,020	3,780	4,530	5,290	6,040	6,800	7,550
35	171	2,060	3,080	4,110	5,140	6,170	7,200	8,230	9,250	10,280
40	224	2,690	4,030	5,370	6,710	8,060	9,400	10,740	12,100	13,430
45	283	3,400	5,100	6,800	8,500	10,200	11,900	13,600	15,300	17,000
50	350	4,200	6,300	8,400	10,500	12,600	14,700	16,800	18,900	21,000
60	504	6,040	9,060	12,100	15,110	18,130	21,150	24,190	37,220	*28,260* *D = 58*
70	685	8,230	12,340	16,450	20,580	24,700	28,800	32,930	*30,970*	—
80	895	10,740	16,120	21,500	26,880	32,260	37,600	*35,810*	*D = 64*	—
90	1,133	13,600	20,400	27,220	34,030	40,820	*40,510*	*D = 73*	—	—
100	1,399	16,800	25,200	33,600	42,000	*48,400*	*D = 83*	—	—	—
120	2,014	24,190	36,290	48,380	*58,480* *D = 118*	*D = 98*	—	—	—	—
140	2,742	32,930	49,350	65,860	—	—	—	—	—	—
160	3,581	43,000	64,510	*74,600*	—	—	—	—	—	—
180	4,532	54,430	81,650	*D = 149*	—	—	—	—	—	—
200	5,595	67,200	100,800	—	—	—	—	—	—	—
220	6,770	81,310	*102,830* *D = 202*	—	—	—	—	—	—	—

Note: The nominal capacities given in this table were calculated using the following formula:

$$C = 0.14D^2H$$

Where:

C = capacity of tank, in 42-gallon barrels.
D = diameter of tank, in feet (see A.4.1).
H = height of tank, in feet (see A.4.1).

The capacities and diameters in italics (Columns 4–11) are the maximums for the tank heights given in the column heads, based on a maximum permissible shell-plate thickness of ½ inch, a maximum allowable design stress of 21,000 pounds per square inch, a joint efficiency of 0.85, and no corrosion allowance (see A.4.1).

dom spot radiograph required by Item a. The spot radiographs of horizontal joints shall conform to 6.1.2.3.

A.6 Intermediate Wind Girders

Calculations for and installation of intermediate wind girders are not required unless specified by the purchaser.

A.7 Shell Manholes and Nozzles

A.7.1 Except for other designs and shapes permitted by 3.7.1.2, shell manholes shall conform to 3.7.5, Figures 3-4A and 3-4B, and Tables 3-3 through 3-7.

A.7.2 Shell nozzles and flanges shall conform to 3.7.6; Figures 3-4B, 3-5, and 3-7; and Tables 3-8 through 3-10.

A.7.3 The radiographic requirements of 3.7.3.4 do not apply.

A.8 Flush–Type Cleanout Fittings

A.8.1 The details and dimensions of flush-type cleanout fittings shall conform to 3.7.7, Figures 3-9 and 3-10, and Tables 3-11 through 3-13; however, the increased shell-plate thickness given in 3.7.7.5 is not required unless needed to satisfy the minimum requirements of 3.7.7.4.

A.8.2 The provisions for stress relief specified in 3.7.4 and 3.7.7.3 are not required unless they are specified by the purchaser or unless any plate in the unit has a thickness greater than ⅝ inch.

A.9 Flush–Type Shell Connections

The details and dimensions of flush-type shell connections shall conform to 3.7.8, Figure 3-11, and Table 3-14.

A.10 Flush–Type Bolted Door Sheets

A.10.1 Flush-type bolted door sheets shall conform to Figure A-1 and Table A-5.

A.10.2 Bolted door sheets shall be based on the specific design requirements in A.10.2.1 through A.10.2.7.

Table A-2—Shell-Plate Thicknesses (in Inches) for Typical Sizes of Tanks With 72-Inch Courses

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12
Tank Diameter (feet)	Tank Height (feet)/Number of Courses in Completed Tank										Maximum Allowable Height for Diameter[a] (feet)
	6/1	12/2	18/3	24/4	30/5	36/6	42/7	48/8	54/9	60/10	
10	3/16	3/16	3/16	3/16	3/16	3/16	—	—	—	—	—
15	3/16	3/16	3/16	3/16	3/16	3/16	—	—	—	—	—
20	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16	—	—	—
25	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16	0.20	0.22	—
30	3/16	3/16	3/16	3/16	3/16	3/16	3/16	0.21	0.24	0.26	—
35	3/16	3/16	3/16	3/16	3/16	3/16	0.21	0.24	0.27	0.30	—
40	3/16	3/16	3/16	3/16	3/16	0.21	0.24	0.28	0.31	0.35	—
45	3/16	3/16	3/16	3/16	3/16	0.23	0.27	0.31	0.35	0.38	—
50	1/4	1/4	1/4	1/4	1/4	0.26	0.30	0.35	0.39	0.43	—
60	1/4	1/4	1/4	1/4	0.26	0.31	0.36	0.41	0.47	—	58.2
70	1/4	1/4	1/4	1/4	0.30	0.36	0.42	0.48	—	—	50.0
80	1/4	1/4	1/4	0.27	0.34	0.41	0.48	—	—	—	43.9
90	1/4	1/4	1/4	0.31	0.38	0.46	—	—	—	—	39.1
100	1/4	1/4	1/4	0.34	0.43	—	—	—	—	—	35.3
120	5/16	5/16	5/16	0.41	—	—	—	—	—	—	29.6
140	5/16	5/16	0.35	0.47	—	—	—	—	—	—	25.5
160	5/16	5/16	0.40	—	—	—	—	—	—	—	22.5
180	5/16	5/16	0.45	—	—	—	—	—	—	—	20.1
200	5/16	0.32	0.50	—	—	—	—	—	—	—	18.2
220	3/8	3/8	—	—	—	—	—	—	—	—	16.6

Note: The plate thicknesses shown in this table are based on a maximum allowable design stress of 21,000 pounds per square inch, a joint efficiency of 0.85, and no corrosion allowance (see A.4.1). The plate thicknesses given as fractions are thicker than required for hydrostatic loading but, for practical reasons, have been fixed at the values given; plates for these courses may therefore be ordered on a weight basis. The plate thicknesses given as decimals are based on the maximum allowable stress; plates for these courses must therefore be ordered on a thickness basis. (See 2.2.1.2 and A.4 for thickness requirements and methods of ordering.) When the plate thicknesses shown were derived, it was assumed, on the basis of average mill practice, that the edge thickness of plates 72 inches wide, ordered on a weight basis, would underrun the nominal thickness by 0.03 inch. In 2.2.1.2.3, an actual thickness is permitted to underrun a calculated or specified thickness by 0.01 inch; consequently, plate thicknesses are given as fractions only when the fractional value exceeds the calculated thickness of the course by more than 0.02 inch.

[a] Based on a maximum permissible shell-plate thickness of 1/2 inch, a maximum allowable design stress of 21,000 pounds per square inch, a joint efficiency of 0.85, and no corrosion allowance.

A.10.2.1 The minimum net cross-sectional area of the door plate, excluding the tapered ends, shall not be less than the product of the shell-plate thickness and the vertical height of the cutout in the shell plus twice the diameter of the bolt hole:

$$t_D(h_D - N_1 d) = t_s(h_c + 2d)$$

Where:

t_D = thickness of the door plate, in inches.
h_D = height of the door plate, in inches.
N_1 = number of bolts in the first row of bolts next to the shell cutout.
d = diameter of bolts and bolt holes, in inches.
t_s = thickness of the shell plate, in inches.
h_c = height of the shell cutout, in inches.

A.10.2.2 The shear stress in the cross-section of the bolts shall not exceed 16,000 pounds per square inch.

A.10.2.3 The bearing stress on the bolts and bolt holes shall not exceed 32,000 pounds per square inch, and the fit of the turned bolt in the reamed hole shall conform to the standards of AISC.

A.10.2.4 The shear strength of the bolted door sheet connection shall be at least 90 percent of the design tensile strength of the undisturbed shell plate as illustrated in the equations below. For shear loading on a flush-type door sheet: 96

$$(N)(a)(16{,}000) = t_s(h_c + 2.5d + f)(21{,}000)(0.90)$$

For shear loading on a raised-type door sheet:

$$(N)(a)(16{,}000) = t_s(h_c + 4d)(21{,}000)(0.90)$$

Where:

N = number of bolts required in each end section of door plate.
a = cross-sectional area of the bolts, in square inches.
f = distance from the bottom of the shell cutout to the centerline of the bottom row of bolts, in inches.

A.10.2.5 The distance between centers of bolt holes shall not be less than three times the bolt diameter, and the spacing

(text continued on page A-8)

Table A-3—Typical Sizes and Corresponding Nominal Capacities (in Barrels) for Tanks With 96-Inch Courses

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
Tank Diameter (feet)	Capacity per Foot of Height (barrels)	Tank Height (feet)/Number of Courses in Completed Tank						
		16/2	24/3	32/4	40/5	48/6	56/7	64/8
10	14.0	225	335	450	—	—	—	—
15	31.5	505	755	1,010	1,260	—	—	—
20	56.0	900	1,340	1,790	2,240	2,690	—	—
25	87.4	1,400	2,100	2,800	3,500	4,200	4,900	5,600
30	126	2,020	3,020	4,030	5,040	6,040	7,050	8,060
35	171	2,740	4,110	5,480	6,850	8,230	9,600	10,980
40	224	3,580	5,370	7,160	8,950	10,740	12,540	14,340
45	283	4,530	6,800	9,060	11,340	13,600	15,880	18,140
50	350	5,600	8,400	11,200	14,000	16,800	19,600	22,400
60	504	8,060	12,100	16,130	20,160	24,190	28,220	*26,130* *D = 54*
70	685	10,960	16,450	21,950	27,440	32,930	*30,140* *D = 62*	—
80	895	14,320	21,500	28,670	35,840	*35,810* *D = 73*		—
90	1,133	18,130	27,220	36,290	*45,360* *D = 88*		—	—
100	1,399	22,380	33,600	44,800		—	—	—
120	2,014	32,250	48,380	*54,200* *D = 110*	—	—	—	—
140	2,742	43,900	65,860	—	—	—	—	—
160	3,581	57,340	*74,600* *D = 149*	—	—	—	—	—
180	4,532	72,570		—	—	—	—	—
200	5,595	89,600	—	—	—	—	—	—
220	6,770	108,410	—	—	—	—	—	—

Note: The nominal capacities given in this table were calculated using the following formula:

$$C = 0.14D^2H$$

Where:

C = capacity of tank, in 42-gallon barrels.
D = diameter of tank, in feet (see A.4.1).
H = height of tank, in feet (see A.4.1).

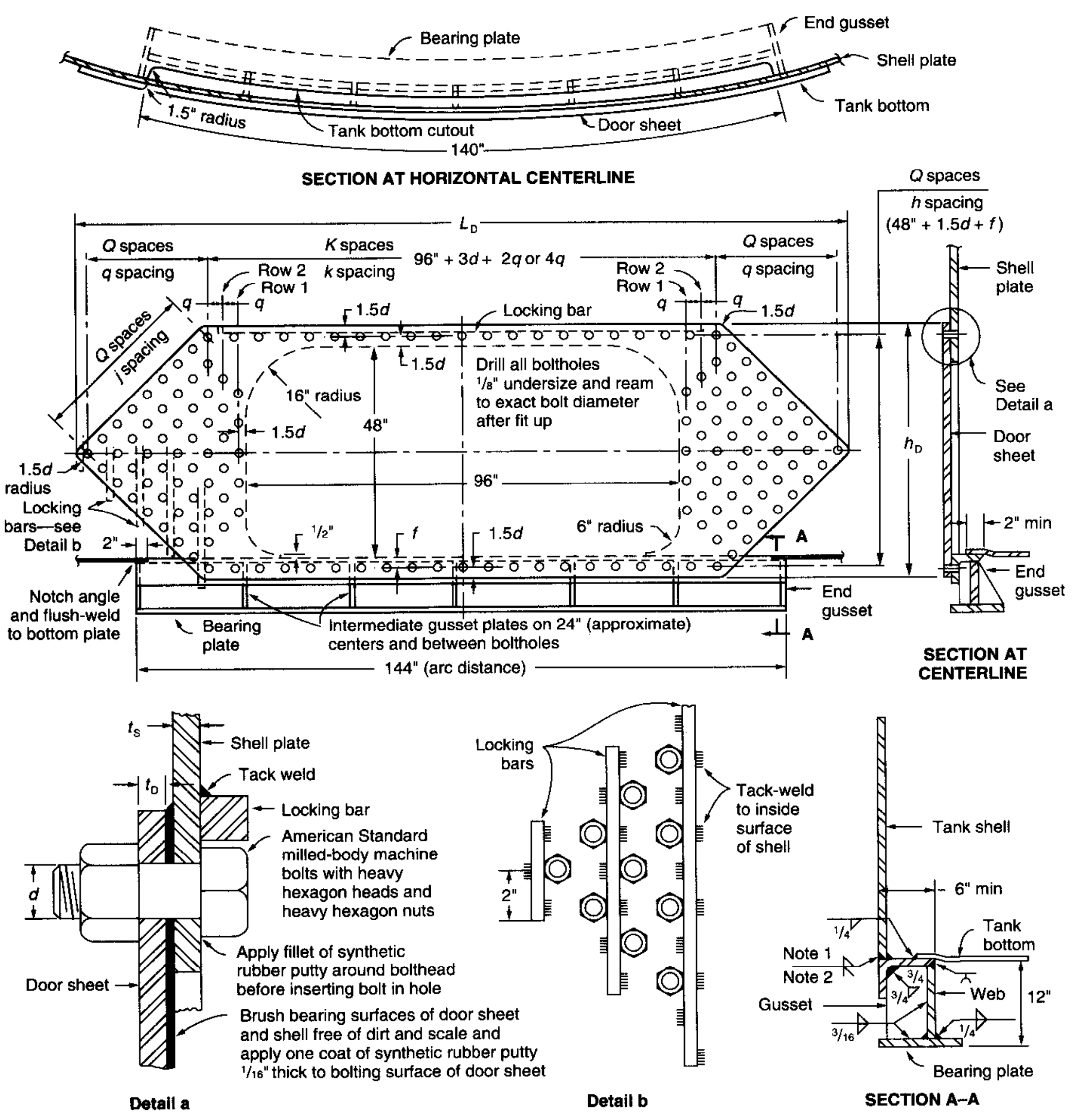
The capacities and diameters in italics (Columns 4–9) are the maximums for the tank heights given in the column heads, based on a maximum permissible shell-plate thickness of ½ inch, a maximum allowable design stress of 21,000 pounds per square inch, a joint efficiency of 0.85, and no corrosion allowance (see A.4.1).

Table A-4—Shell-Plate Thicknesses (in Inches) for Typical Sizes of Tanks With 96-Inch Courses

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10
Tank Diameter (feet)	Tank Height (feet)/Number of Courses in Completed Tank								Maximum Allowable Height for Diameter[a] (feet)
	8/1	16/2	24/3	32/4	40/5	48/6	56/7	64/8	
10	³⁄₁₆	³⁄₁₆	³⁄₁₆	³⁄₁₆	—	—	—	—	—
15	³⁄₁₆	³⁄₁₆	³⁄₁₆	³⁄₁₆	³⁄₁₆	—	—	—	—
20	³⁄₁₆	³⁄₁₆	³⁄₁₆	³⁄₁₆	³⁄₁₆	³⁄₁₆	—	—	—
25	³⁄₁₆	³⁄₁₆	³⁄₁₆	³⁄₁₆	³⁄₁₆	³⁄₁₆	0.20	0.23	—
30	³⁄₁₆	³⁄₁₆	³⁄₁₆	³⁄₁₆	³⁄₁₆	0.21	0.24	0.28	—
35	³⁄₁₆	³⁄₁₆	³⁄₁₆	³⁄₁₆	0.20	0.24	0.28	0.33	—
40	³⁄₁₆	³⁄₁₆	³⁄₁₆	³⁄₁₆	0.23	0.28	0.32	0.37	—
45	³⁄₁₆	³⁄₁₆	³⁄₁₆	0.21	0.26	0.31	0.36	0.42	—
50	¼	¼	¼	0.25	0.29	0.35	0.40	0.46	—
60	¼	¼	¼	0.27	0.34	0.41	0.48	—	58.2
70	¼	¼	¼	0.32	0.40	0.48	—	—	50.0
80	¼	¼	0.27	0.37	0.46	—	—	—	43.9
90	¼	¼	0.31	0.41	—	—	—	—	39.1
100	¼	¼	0.34	0.46	—	—	—	—	35.3
120	⁵⁄₁₆	⁵⁄₁₆	0.41	—	—	—	—	—	29.6
140	⁵⁄₁₆	⁵⁄₁₆	0.47	—	—	—	—	—	25.5
160	⁵⁄₁₆	0.35	—	—	—	—	—	—	22.5
180	⁵⁄₁₆	0.40	—	—	—	—	—	—	20.1
200	⁵⁄₁₆	0.44	—	—	—	—	—	—	18.2
220	⅜	0.48	—	—	—	—	—	—	16.6

Note: The plate thicknesses shown in this table are based on a maximum allowable design stress of 21,000 pounds per square inch, a joint efficiency of 0.85, and no corrosion allowance (see A.4.1). The plate thicknesses given as fractions are thicker than required for hydrostatic loading but, for practical reasons, have been fixed at the values given; plates for these courses may therefore be ordered on a weight basis. The plate thicknesses given as decimals are based on the maximum allowable stress; plates for these courses must therefore be ordered on a thickness basis. (See 2.2.1.2 and A.4 for thickness requirements and methods of ordering.) When the plate thicknesses shown were derived, it was assumed, on the basis of average mill practice, that the edge thickness of plates 96 inches wide, ordered on a weight basis, would underrun the nominal thickness by 0.05 inch. In 2.2.1.2.3, an actual thickness is permitted to underrun a calculated or specified thickness by 0.01 inch; consequently, plate thicknesses are given as fractions only when the fractional value exceeds the calculated thickness of the course by more than 0.04 inch.

[a] Based on a maximum permissible shell-plate thickness of ½ inch, a maximum allowable design stress of 21,000 pounds per square inch, a joint efficiency of 0.85, and no corrosion allowance.



Notes:

1. This weld shall be the same size as the size specified for the fillet weld attaching the shell to the tank bottom.
2. This weld should be the same size as the size specified for the fillet weld attaching the shell to the tank bottom. After welding, the weld shall be ground smooth to clear the door plate.

Figure A-1—Flush-Type Bolted Door Sheet (See Table A-5)

Table A-5—Flush-Type Bolted Door Sheets (See Figure A-1)

(All dimensions are in inches)

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11
Shell Thickness t_s	Q	q	h	j	K	k	t_D	h_D	f	L_D
¼	7	1 15/16	7.375	4.165	36	2.837	7/16	53⅞	2½	131½
5/16	8	1 15/16	6.453	3.766	30	3.275	7/16	53⅞	2½	131½
⅜	8	1 15/16	6.453	3.766	30	3.404	7/16	53⅞	2½	139¼
7/16	8	2¼	6.477	3.945	24	4.297	½	54 7/16	2½	141¼
½	8	2¼	6.477	3.945	22	4.892	9/16	54 7/16	2½	146¼

Column 12	Column 13	Column 14	Column 15	Column 16	Column 17	Column 18	Column 19	Column 20	Column 21	Column 22	Column 23
Number of Bolts			Bolt Diameter d	Bolt Length	Length of Bolt Thread	Square Locking Bar	Angle	Web	Intermediate Gusset	End Gusset	Bearing Plate
Row 1	Row 2	Total									
—	7	156	¾	2	1⅛	⅝	6 × 4 × ⅜	¼ × 11⅝	¼ × 5 × 11⅝	¼ × 8 × 11⅝	¼ × 9
—	—	146	¾	2	1 1/16	⅝	6 × 4 × ⅜	¼ × 11⅝	¼ × 5 × 11⅝	¼ × 8 × 11⅝	¼ × 9
3	6	164	¾	2	1	⅝	6 × 4 × ⅜	¼ × 11⅝	¼ × 5 × 11⅝	¼ × 8 × 11⅝	¼ × 9
—	2	138	⅞	2¼	1⅛	¾	6 × 4 × ½	⅜ × 11⅜	⅜ × 5 × 11⅜	⅜ × 8 × 11⅜	⅜ × 9
3	6	148	⅞	2½	1¼	¾	6 × 4 × ½	⅜ × 11⅜	⅜ × 5 × 11⅜	⅜ × 8 × 11⅜	⅜ × 9

Note: American National Standard washers shall be used on both sides of the plate for shell thicknesses of ⅜ inch or less.

Table A-6—Raised-Type Bolted Door Sheets (See Figure A-3)

(All dimensions are in inches)

Column 1 Shell Thickness t_s	Column 2 Q	Column 3 q	Column 4 h	Column 5 j	Column 6 K	Column 7 k	Column 8 t_D	Column 9 h_D	Column 10 L_D
¼	7	1¹⁵⁄₁₆	7.179	4.080	36	2.837	⁷⁄₁₆	52½	131½
⁵⁄₁₆	7	1¹⁵⁄₁₆	7.179	4.080	30	3.404	⁷⁄₁₆	52½	131½
⅜	8	1¹⁵⁄₁₆	6.281	3.691	30	3.404	⁷⁄₁₆	52½	135⅜
⁷⁄₁₆	8	2¼	6.328	3.883	24	4.109	½	53¼	137¼
½	8	2¼	6.328	3.883	22	4.688	⁹⁄₁₆	53¼	141¼

Column 11 Number of Bolts Row 1	Column 12 Row 2	Column 13 Total	Column 14 Bolt Diameter d	Column 15 Bolt Length	Column 16 Length of Bolt Thread	Column 17 Square Locking Bar
—	5	152	¾	2	1⅛	⅝
—	7	144	¾	2	1⁵⁄₁₆	⅝
—	8	164	¾	2	1	⅝
—	—	136	⅞	2¼	1⅛	¾
—	6	144	⅞	2½	1¼	¾

Note: American National Standard washers shall be used on both sides of the plate for shell thicknesses of ⅜ inch or less.

of bolt holes at the sealing edge of the plate shall not exceed seven times the sum of the minimum door-sheet thickness plus the nominal bolt diameter plus the washer thickness (if washers are used).

A.10.2.6 The tensile stress in the net section of the door plate at the first row of bolt holes next to the shell-plate cutout shall not exceed 21,000 pounds per square inch, and at the subsequent rows, the tensile stress shall not exceed 21,000 pounds per square inch after allowance is made for the total shearing value or bearing value (whichever is less) of the bolts in the preceding row or rows.

A.10.2.7 The following provisions apply to flush-type bolted door sheets:

a. The girder shall be designed to withstand the bending moment that would result if the ends of the girder were on hard ground and the center was unsupported.
b. The load on the girder shall be equal to the weight of a column of water with the following dimensions: (1) 0.03 times the tank radius, in feet; (2) the width of the shell cutout, in feet, plus 2; and (3) the tank height, in feet.
c. The design length of the girder shall be equal to the width of the shell cutout, in feet, plus 2.

Note: When, because of wear, the difference in the diameters of the bolts and bolt holes is approximately 0.020 inch, it is recommended that the holes be rereamed and fitted with oversize milled-body bolts; however, the holes shall not be reamed so much that the efficiency of the bolted connection becomes less than 0.85. This point is reached when the bolt-hole diameters become ¼ inch larger than the bolt diameters specified in Tables A-5 and A-6.

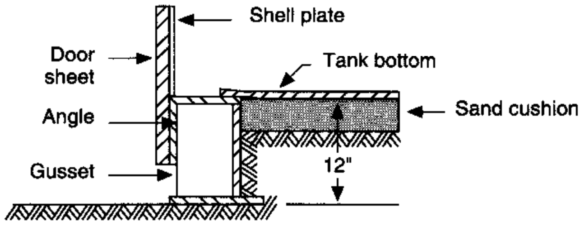
A.10.3 When a flush-type bolted door sheet is installed on a tank that is resting on an earth grade with or without a concrete retaining wall and without a concrete or masonry wall under the tank shell, provision shall be made to support the fitting and retain the grade as shown in Figure A-2, Method A.

A.10.4 When a flush-type bolted door sheet is installed on a tank resting on a ringwall, a cutout with the dimensions shown in Figure A-2, Method B, shall be provided.

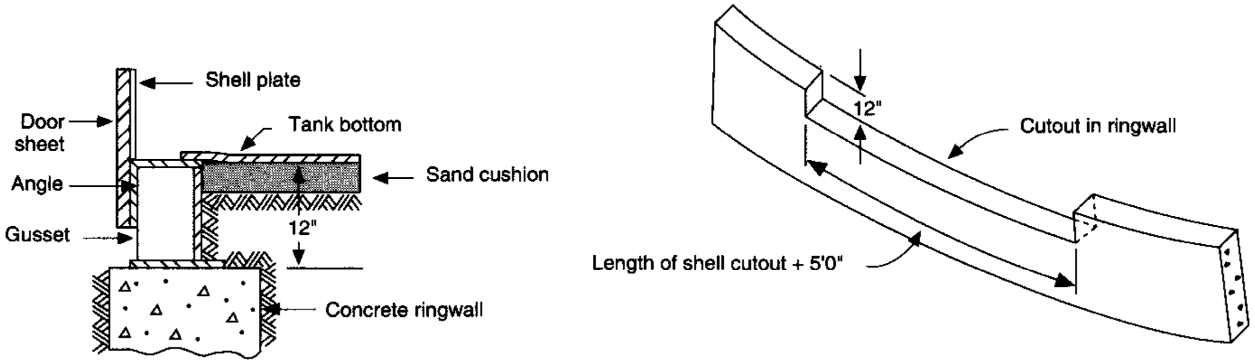
A.10.5 Openings larger than 2 inches nominal pipe size in flush-type bolted door sheets shall be reinforced in accordance with 3.7.2, and the reinforcement shall replace the cutout area of the door plate.

A.11 Raised–Type Bolted Door Sheets

Raised-type bolted door sheets shall conform to Figure A-3 and Table A-6.



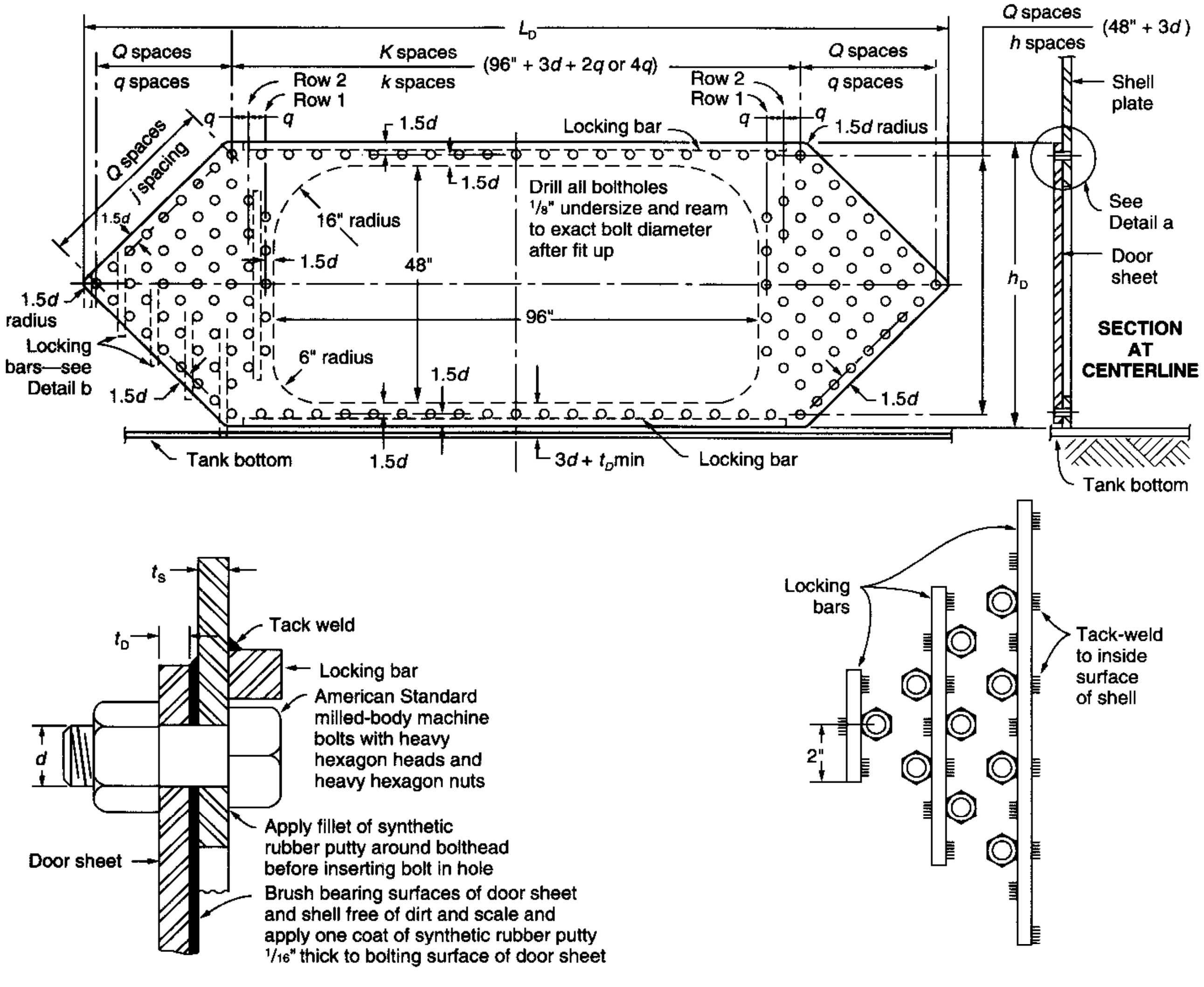
METHOD A—TANK RESTING ON EARTH GRADE, WITH OR WITHOUT RETAINING WALL



METHOD B—TANK RESTING ON CONCRETE RINGWALL

Note: Before the bottom plate is attached to the angle, (a) a sand cushion shall be placed flush with the top of the angle, and (b) the earth fill and sand cushion shall be thoroughly compacted.

Figure A-2—Supports for Flush-Type Bolted Door Sheet



Detail a

Detail b

Figure A-3—Raised-Type Bolted Door Sheet (See Table A-6)

APPENDIX B—RECOMMENDATIONS FOR DESIGN AND CONSTRUCTION OF FOUNDATIONS FOR ABOVEGROUND OIL STORAGE TANKS

B.1 Scope

96| **B.1.1** This appendix provides important considerations for the design and construction of foundations for aboveground steel oil storage tanks with flat bottoms. Recommendations are offered to outline good practice and to point out some precautions that should be considered in the design and construction of storage tank foundations.

B.1.2 Since there is a wide variety of surface, subsurface, and climatic conditions, it is not practical to establish design data to cover all situations. The allowable soil loading and the exact type of subsurface construction to be used must be decided for each individual case after careful consideration. The same rules and precautions shall be used in selecting foundation sites as would be applicable in designing and constructing foundations for other structures of comparable magnitude.

B.2 Subsurface Investigation and Construction

B.2.1 At any tank site, the subsurface conditions must be known to estimate the soil bearing capacity and settlement that will be experienced. This information is generally obtained from soil borings, load tests, sampling, laboratory testing, and analysis by an experienced geotechnical engineer familiar with the history of similar structures in the vicinity. The subgrade must be capable of supporting the load of the tank and its contents. The total settlement must not strain connecting piping or produce gauging inaccuracies, and the settlement should not continue to a point at which the tank bottom is below the surrounding ground surface. The estimated settlement shall be within the acceptable tolerances for the tank shell and bottom.

B.2.2 When actual experience with similar tanks and foundations at a particular site is not available, the following ranges for factors of safety should be considered for use in the foundation design criteria for determining the allowable soil bearing pressures. (The owner or geotechnical engineer responsible for the project may use factors of safety outside these ranges.)

a. From 2.0 to 3.0 against ultimate bearing failure for normal operating conditions.
b. From 1.5 to 2.25 against ultimate bearing failure during hydrostatic testing.
c. From 1.5 to 2.25 against ultimate bearing failure for operating conditions plus the maximum effect of wind or seismic loads.

B.2.3 Some of the many conditions that require special engineering consideration are as follows:

a. Sites on hillsides, where part of a tank may be on undisturbed ground or rock and part may be on fill or another construction or where the depth of required fill is variable.
b. Sites on swampy or filled ground, where layers of muck or compressible vegetation are at or below the surface or where unstable or corrosive materials may have been deposited as fill.
c. Sites underlain by soils, such as layers of plastic clay or organic clays, that may support heavy loads temporarily but settle excessively over long periods of time.
d. Sites adjacent to water courses or deep excavations, where the lateral stability of the ground is questionable.
e. Sites immediately adjacent to heavy structures that distribute some of their load to the subsoil under the tank sites, thereby reducing the subsoil's capacity to carry additional loads without excessive settlement.
f. Sites where tanks may be exposed to flood waters, possibly resulting in uplift, displacement, or scour.
g. Sites in regions of high seismicity that may be susceptible to liquefaction.
h. Sites with thin layers of soft clay soils that are directly beneath the tank bottom and that can cause lateral ground stability problems.

B.2.4 If the subgrade is inadequate to carry the load of the filled tank without excessive settlement, shallow or superficial construction under the tank bottom will not improve the support conditions. One or more of the following general methods should be considered to improve the support conditions:

a. Removing the objectionable material and replacing it with suitable, compacted material.
b. Compacting the soft material with short piles.
c. Compacting the soft material by preloading the area with an overburden of soil. Strip or sand drains may be used in conjunction with this method.
d. Stabilizing the soft material by chemical methods or injection of cement grout.
e. Transferring the load to a more stable material underneath the subgrade by driving piles or constructing foundation piers. This involves constructing a reinforced concrete slab on the piles to distribute the load of the tank bottom.
f. Constructing a slab foundation that will distribute the load over a sufficiently large area of the soft material so that the load intensity will be within allowable limits and excessive settlement will not occur.

g. Improving soil properties by vibrocompaction, vibroreplacement, or deep dynamic compaction.
h. Slow and controlled filling of the tank during hydrostatic testing. When this method is used, the integrity of the tank may be compromised by excessive settlements of the shell or bottom. For this reason, the settlements of the tank shall be closely monitored. In the event of settlements beyond established ranges, the test may have to be stopped and the tank releveled.

B.2.5 The fill material used to replace muck or other objectionable material or to build up the grade to a suitable height shall be adequate for the support of the tank and product after the material has been compacted. The fill material shall be free of vegetation, organic matter, cinders, and any material that will cause corrosion of the tank bottom. The grade and type of fill material shall be capable of being compacted with standard industry compaction techniques to a density sufficient to provide appropriate bearing capacity and acceptable settlements. The placement of the fill material shall be in accordance with the project specifications prepared by a qualified geotechnical engineer.

B.3 Tank Grades

B.3.1 The grade or surface on which a tank bottom will rest should be constructed at least 1 foot above the surrounding ground surface. This will provide suitable drainage, help keep the tank bottom dry, and compensate for some small settlement that is likely to occur. If a large settlement is expected, the tank bottom elevation shall be raised so that the final elevation above grade will be a minimum of 6 inches after settlement.

B.3.2 There are several different materials that can be used for the grade or surface on which the tank bottom will rest. To minimize future corrosion problems and maximize the effect of corrosion prevention systems such as cathodic protection, the material in contact with the tank bottom should be fine and uniform. Gravel or large particles shall be avoided. Clean washed sand 3 to 4 inches deep is recommended as a final layer because it can be readily shaped to the bottom contour of the tank to provide maximum contact area and will protect the tank bottom from coming into contact with large particles and debris. Large foreign objects or point contact by gravel or rocks could cause corrosion cells that will cause pitting and premature tank bottom failure.

During construction, the movement of equipment and materials across the grade will mar the graded surface. These irregularities should be corrected before bottom plates are placed for welding.

Adequate provisions, such as making size gradients in sublayers progressively smaller from bottom to top, should be made to prevent the fine material from leaching down into the larger material, thus negating the effect of using the fine material as a final layer. This is particularly important for the top of a crushed rock ringwall.

Note: For more information on tank bottom corrosion and corrosion prevention that relates to the foundation of a tank, see API Recommended Practice 651.

B.3.3 Unless otherwise specified by the owner, the finished tank grade shall be crowned from its outer periphery to its center at a slope of one inch in ten feet. The crown will partly compensate for slight settlement, which is likely to be greater at the center. It will also facilitate cleaning and the removal of water and sludge through openings in the shell or from sumps situated near the shell. Because crowning will affect the lengths of roof-supporting columns, it is essential that the tank manufacturer be fully informed of this feature sufficiently in advance. (For an alternative to this paragraph, see B.3.4.)

B.3.4 As an alternative to B.3.3, the tank bottom may be sloped toward a sump. The tank manufacturer must be advised as required in B.3.3.

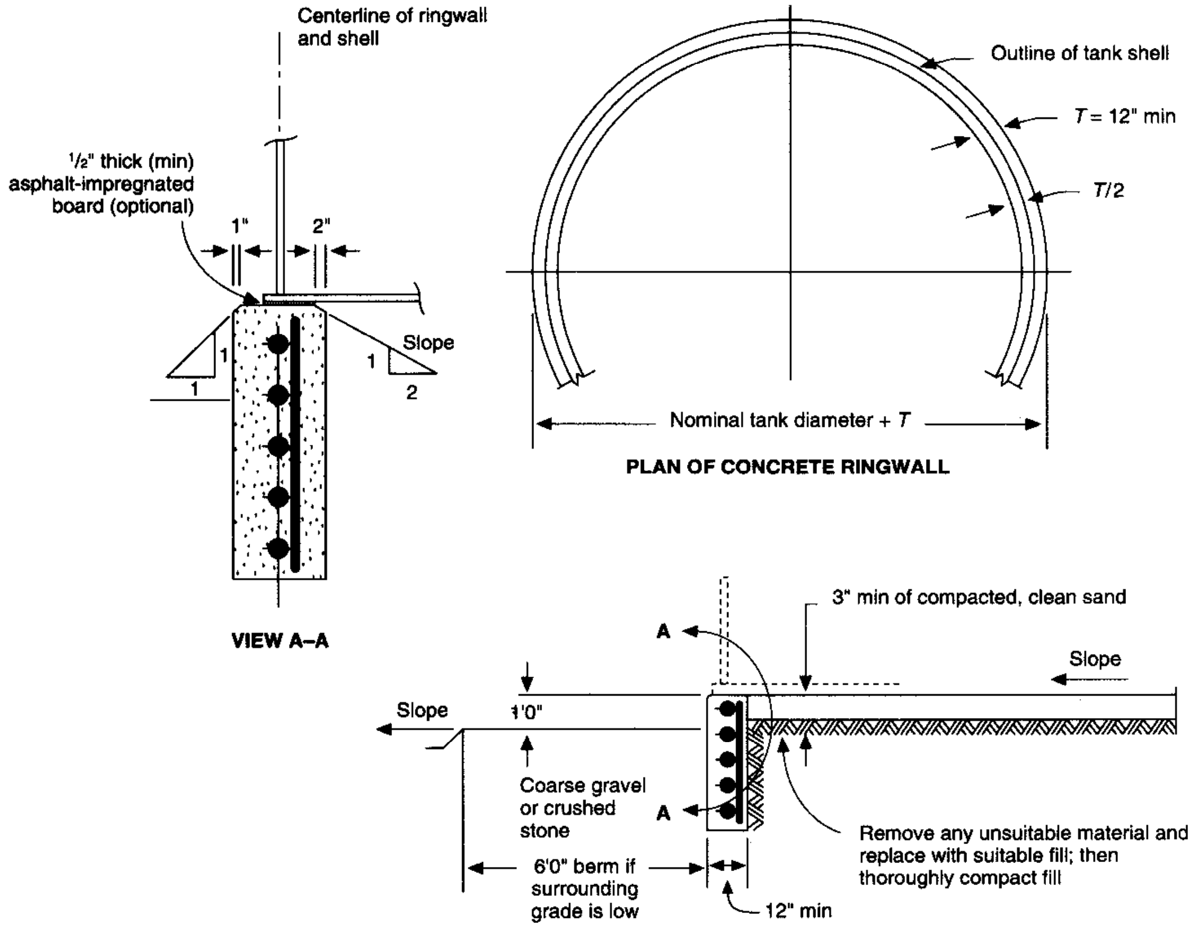
B.4 Typical Foundation Types

B.4.1 EARTH FOUNDATIONS WITHOUT A RINGWALL

B.4.1.1 When an engineering evaluation of subsurface conditions that is based on experience and/or exploratory work has shown that the subgrade has adequate bearing capacity and that settlements will be acceptable, satisfactory foundations may be constructed from earth materials. The performance requirements for earth foundations are identical to those for more extensive foundations. Specifically, an earth foundation should accomplish the following:

a. Provide a stable plane for the support of the tank.
b. Limit overall settlement of the tank grade to values compatible with the allowances used in the design of the connecting piping.
c. Provide adequate drainage.
d. Not settle excessively at the perimeter due to the weight of the shell wall.

B.4.1.2 Many satisfactory designs are possible when sound engineering judgment is used in their development. Three designs are referred to in this appendix on the basis of their satisfactory long-term performance. For smaller tanks, foundations can consist of compacted crushed stone, screenings, fine gravel, clean sand, or similar material placed directly on virgin soil. Any unstable material must be removed, and any replacement material must be thoroughly compacted. For larger tanks or tanks with heavy shells, two recommended designs that include ringwalls are illustrated in Figures B-1 and B-2 and described in B.4.2 and B.4.3.



Notes:
1. See B.4.2.3 for requirements for reinforcement.
2. The top of the concrete ringwall shall be smooth and level. The concrete strength shall be at least 3000 pounds per square inch after 28 days. Reinforcement splices must be staggered and shall be lapped to develop full strength in the bond. If staggering of laps is not possible, refer to ACI 318 for additional development requirements.
3. Ringwalls that exceed 12 inches in width shall have rebars distributed on both faces.
4. See B.4.2.2 for the position of the tank shell on the ringwall.

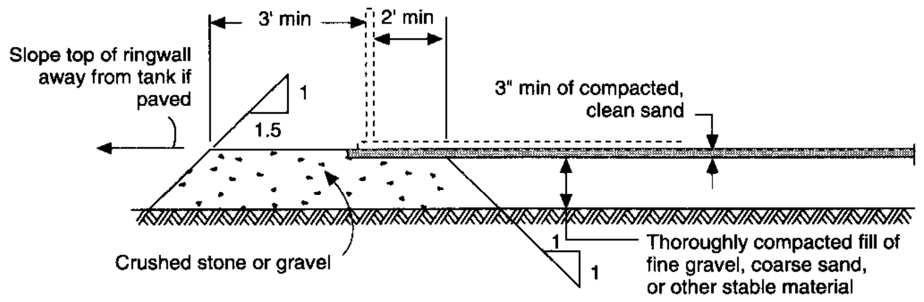
Figure B-1—Example of Foundation With Concrete Ringwall

B.4.2 EARTH FOUNDATIONS WITH A CONCRETE RINGWALL

B.4.2.1 A large tank or a tank with a high shell and/or a self-supported roof imposes a substantial load on its foundation under the shell. This is particularly important with regard to shell distortion in floating-roof tanks. When there is some doubt whether a foundation will be able to carry the shell load directly, a ringwall foundation should be used. As an alternative to the concrete ringwall noted in this section, a crushed stone ringwall (see B.4.3) may be used. A foundation with a concrete ringwall has the following advantages:

a. It provides better distribution of the concentrated load of the shell to produce a more nearly uniform soil loading under the tank.
b. It provides a level, solid starting plane for construction of the shell.
c. It provides a better means of leveling the tank grade, and it is capable of preserving its contour during construction.
d. It retains the fill under the tank bottom and prevents loss of material as a result of erosion.
e. It minimizes moisture under the tank.

A disadvantage of concrete ringwalls is that they may not smoothly conform to differential settlements. This disadvan-



Note: Any unsuitable material shall be removed and replaced with suitable fill; the fill shall then be thoroughly compacted.

Figure B-2—Example of Foundation With Crushed Stone Ringwall

tage may lead to high bending stresses in the bottom plates adjacent to the ringwall.

B.4.2.2 When a concrete ringwall is designed, it shall be proportioned so that the allowable soil bearing is not exceeded. The ringwall shall not be less than 12 inches thick. The centerline diameter of the ringwall shall equal the nominal diameter of the tank; however, the ringwall centerline may vary if required to facilitate the placement of anchor bolts or to satisfy soil bearing limits for seismic loads or excessive uplift forces. The depth of the wall will depend on local conditions, but the depth must be sufficient to place the bottom of the ringwall below the anticipated frost penetration and within the specified bearing strata. As a minimum, the bottom of the ringwall, if founded on soil, shall be located 2 feet below the lowest adjacent finish grade. Tank foundations must be constructed within the tolerances specified in 5.5.5. Recesses shall be provided in the wall for flush-type cleanouts, drawoff sumps, and any other appurtenances that require recesses.

B.4.2.3 A ringwall should be reinforced against temperature changes and shrinkage and reinforced to resist the lateral pressure of the confined fill with its surcharge from product loads. ACI 318 is recommended for design stress values, material specifications, and rebar development and cover. The following items concerning a ringwall shall be considered:

a. The ringwall shall be reinforced to resist the direct hoop tension resulting from the lateral earth pressure on the ringwall's inside face. Unless substantiated by proper geotechnical analysis, the lateral earth pressure shall be assumed to be at least 50 percent of the vertical pressure due to fluid and soil weight. If a granular backfill is used, a lateral earth pressure coefficient of 30 percent may be used.

b. The ringwall shall be reinforced to resist the bending moment resulting from the uniform moment load. The uniform moment load shall account for the eccentricities of the applied shell and pressure loads relative to the centroid of the resulting soil pressure. The pressure load is due to the fluid pressure on the horizontal projection of the ringwall inside the shell.

c. The ringwall shall be reinforced to resist the bending and torsion moments resulting from lateral, wind, or seismic loads applied eccentrically to it. A rational analysis, which includes the effect of the foundation stiffness, shall be used to determine these moments and soil pressure distributions.

d. The total hoop steel area required to resist the loads noted above shall not be less than the area required for temperature changes and shrinkage. The minimum hoop steel area required for temperature changes and shrinkage is 0.0025 times the vertical cross-sectional area of the ringwall. (For the suggested minimum reinforcing steel for walls, see ACI 318, Chapter 14.)

e. For ring foundations that are no wider than the foundation wall depth, the vertical steel area required for temperature changes and shrinkage is 0.0015 times the horizontal cross-sectional area of the ringwall. (For the suggested minimum reinforcement of walls, see ACI 318, Chapter 14.) Additional vertical steel may be required for uplift or torsional resistance.

f. When the ringwall width exceeds 18 inches, using a footing beneath the wall should be considered. Footings may also be useful for resistance to uplift forces.

g. Structural backfill within and adjacent to concrete ringwalls and around items such as vaults, undertank piping, and sumps requires close field control to maintain settlement tolerances. Backfill should be granular material compacted to the density and compacting as specified in the foundation construction specifications. For other backfill materials, sufficient tests shall be conducted to verify that the material has adequate strength and will undergo minimal settlement.

B.4.3 EARTH FOUNDATIONS WITH A CRUSHED STONE AND GRAVEL RINGWALL

B.4.3.1 A crushed stone or gravel ringwall will provide adequate support for high loads imposed by a shell. A foundation with a crushed stone or gravel ringwall has the following advantages:

a. It provides better distribution of the concentrated load of the shell to produce a more nearly uniform soil loading under the tank.
b. It provides a means of leveling the tank grade, and it is capable of preserving its contour during construction.
c. It retains the fill under the tank bottom and prevents loss of material as a result of erosion.
d. It can more smoothly accommodate differential settlement because of its flexibility.

A disadvantage of the crushed stone or gravel ringwall is that it is more difficult to construct it to close tolerances and achieve a flat, level plane for construction of the tank shell.

B.4.3.2 For crushed stone or gravel ringwalls, careful selection of design details is necessary to ensure satisfactory performance. The type of foundation suggested is shown in Figure B-2. Significant details include the following:

a. The 3-foot shoulder and berm shall be protected from erosion by being constructed of crushed stone or covered with a permanent paving material.
b. Care shall be taken during construction to prepare and maintain a smooth, level surface for the tank bottom plates.
c. The tank grade shall be constructed to provide adequate drainage away from the tank foundation.
d. The tank foundation must be true to the specified plane within the tolerances specified in 5.5.5.

B.4.4 SLAB FOUNDATIONS

B.4.4.1 When the soil bearing loads must be distributed over an area larger than the tank area or when it is specified by the owner, a reinforced concrete slab shall be used. Piles beneath the slab may be required for proper tank support.

B.4.4.2 The structural design of the slab, whether on grade or on piles, shall properly account for all loads imposed upon the slab by the tank. The reinforcement requirements and the design details of construction shall be in accordance with ACI 318.

B.5 Tank Foundations for Leak Detection

Appendix I provides recommendations on the construction of tank and foundation systems for the detection of leaks through the bottoms of storage tanks.

APPENDIX C—EXTERNAL FLOATING ROOFS

C.1 Scope

This appendix provides minimum requirements that, unless otherwise qualified in the text, apply to pan-type, pontoon-type, and double-deck-type floating roofs. This appendix is intended to limit only those factors that affect the safety and durability of the installation and that are considered to be consistent with the quality and safety requirements of this standard. Numerous alternative details and proprietary appurtenances are available; however, agreement between the purchaser and the manufacturer is required before they are used.

C.2 Material

The material requirements of Section 2 shall apply unless otherwise stated in this appendix. Castings shall conform to ASTM A 27, Grade 60-30, fully annealed.

C.3 Design

C.3.1 GENERAL

The roof and accessories shall be designed and constructed so that the roof is allowed to float to the maximum design liquid level and then return to a liquid level that floats the roof well below the top of the tank shell without damage to any part of the roof, tank, or appurtenances. During such an occurrence, no manual attention shall be required to protect the roof, tank, or appurtenances. If a windskirt or top-shell extension is used to contain the roof seals at the highest point of travel, appropriate alarm devices shall be provided to indicate that the liquid level in the tank has risen above the designed capacity height unless the tank shell has been designed for a liquid height to the top of the shell extension. The purchaser shall specify the indicator arrangement suitable for operating purposes. Emergency overflow openings may be provided to protect the tank and floating roof from damage.

C.3.2 JOINTS

Joints shall be designed as described in 3.1.

C.3.3 DECKS

C.3.3.1 Roofs in corrosive service, such as covering sour crude oil, should be the contact type designed to eliminate the presence of any air-vapor mixture under the deck.

C.3.3.2 Unless otherwise specified by the purchaser, all deck plates shall have a minimum nominal thickness of 3/16 inch (permissible ordering basis—7.65 pounds per square foot of plate, 0.180-inch plate, or 7-gauge sheet).

C.3.3.3 Deck plates shall be joined by continuous full-fillet welds on the top side. On the bottom side, where flexure can be anticipated adjacent to girders, support legs, or other relatively rigid members, full-fillet welds not less than 2 inches long on 10-inch centers shall be used on any plate laps that occur within 12 inches of any such members.

C.3.3.4 Top decks of double-deck roofs and of pontoon sections, which are designed with a permanent slope for drainage, shall have a minimum slope of 3/16 inch in 12 inches and shall preferably be lapped to provide the best drainage. Plate buckles shall be kept to a minimum.

C.3.4 PONTOON DESIGN

C.3.4.1 Floating roofs shall have sufficient buoyancy to remain afloat on liquid with a specific gravity of 0.7 and with primary drains inoperative for the following conditions:

a. Ten inches of rainfall in a 24-hour period with the roofs intact, except for double-deck roofs provided with emergency drains to keep water to a lesser volume that the roofs will safely support. Such emergency drains shall not allow the product to flow onto the roof.
b. Single-deck and any two adjacent pontoon compartments punctured in single-deck pontoon roofs and any two adjacent compartments punctured in double-deck roofs, both roof types with no water or live load.

C.3.4.2 The pontoon portions of single-deck pontoon-type roofs shall be designed to have adequate strength to prevent permanent distortion when the center deck is loaded by its design rainwater (C.3.4.1, Item a) or when the center deck and two adjacent pontoons are punctured (C.3.4.1, Item b). If calculations are required by the purchaser, the allowable stress and stability criteria shall be jointly established by the purchaser and the manufacturer as part of the inquiry. Alternatively, a proof test simulating the conditions of C.3.4.1, with the roof floating on water, may be performed on the roof or on one of similar design that is of equal or greater diameter.

C.3.4.3 Any penetration of the floating roof shall not allow product to flow onto the roof under design conditions.

C.3.5 PONTOON OPENINGS

Each compartment shall be provided with a liquid-tight manhole. Manhole covers shall be provided with suitable hold-down fixtures (which may be of the quick-opening type) or with other means of preventing wind or fire-fighting hose streams from removing the covers. The top edge of the manhole necks shall be at an elevation that prevents liquid from entering the compartments under the conditions of C.3.4.

Each compartment shall be vented to protect against internal or external pressure. Vents may be in the manhole cover or the top deck of the compartment. The vents shall be at an elevation that prevents liquid from entering the compartment under the conditions of C.3.4 and shall terminate in a manner that prevents entry of rain and fire-fighting liquids.

C.3.6 COMPARTMENTS

Compartment plates are radial or circumferential dividers forming compartments that provide flotation for the roof (see C.3.4). All internal compartment plates (or sheets) shall be single-fillet welded along all of their edges, and other welding shall be performed at junctions as required to make each compartment liquid tight. Each compartment shall be tested for tightness using internal pressure or a vacuum box and a soap solution or penetrating oil.

C.3.7 LADDERS

96 Unless otherwise specified by the purchaser, the floating roof shall be supplied with a ladder that automatically adjusts to any roof position so that access to the roof is always provided. The ladder shall be designed for full-roof travel, regardless of the normal setting of the roof-leg supports. If a rolling ladder is furnished, it shall have full-length handrails on both sides and shall be designed for a 1000-pound midpoint load with the ladder in any operating position.

C.3.8 ROOF DRAINS

Primary roof drains shall be of the hose, jointed, or siphon type, as specified on the purchase order. A check valve shall be provided near the roof end of the hose and on jointed pipe drains on single-deck and pan-type roofs to prevent backflow of stored product if leakage occurs. Provisions shall be made to prevent kinking of the hose or pinching of the hose under the deck support legs. Hose drains shall be designed to permit their replacement without personnel entering the tank. The swing joints of pipe drains shall be packed to prevent leakage. The installation of either the hose or the pipe drain shall include the installation of the proper shell fittings for its operation and, if necessary, removal. The minimum-size drain shall be capable of preventing the roof from accumulating a water level greater than design at the maximum rainfall rate specified by the purchaser for the roof when the roof is floating at the minimum operating level; however, the drain shall not be smaller than 3 inches for roofs with a diameter less than or equal to 120 feet or smaller than 4 inches for roofs with a diameter greater than 120 feet.

C.3.9 VENTS

Suitable vents shall be provided to prevent overstressing of the roof deck or seal membrane. The purchaser should specify liquid withdrawal rates so that the fabricator may size the vacuum vents. Vents, bleeder valves, or other suitable means shall be adequate to evacuate air and gases from underneath the roof during initial filling.

C.3.10 SUPPORTING LEGS

C.3.10.1 The floating roof shall be provided with supporting legs. Legs fabricated from pipe shall be notched or perforated at the bottom to provide drainage. The length of the legs shall be adjustable from the top side of the roof. The operating- and cleaning-position levels of the supporting legs shall be as specified on the purchase order. The manufacturer shall make certain that all tank appurtenances, such as mixers, interior piping, and the fill nozzle, are cleared by the roof in its lowest position.

C.3.10.2 The legs and attachments shall be designed to support the roof and a uniform live load of at least 25 pounds per square foot. Where possible, the roof load shall be transmitted to the legs through bulkheads or diaphragms. Leg attachments to single decks shall be given particular attention to prevent failures at the points of attachment. Steel pads or other means shall be used to distribute the leg loads on the bottom of the tank. If pads are used, they shall be continuously welded to the bottom.

C.3.11 ROOF MANHOLES

At least one roof manhole shall be provided for access to the tank interior and for ventilation when the tank is empty. The number of roof manholes shall be as specified by the purchaser. Each manhole shall have a minimum nominal diameter of 24 inches and shall have a tight-gasketed, bolted cover equivalent to the cover shown in Figure 3-13. 94

C.3.12 CENTERING AND ANTIROTATION DEVICES

Suitable devices shall be provided to maintain the roof in a centered position and to prevent it from rotating. These devices shall be capable of resisting the lateral forces imposed by the roof ladder, unequal snow loads, and wind loads.

C.3.13 SEALS

The space between the outer periphery of the roof and the tank shell shall be sealed by a flexible device that provides a reasonably close fit to the shell surfaces. If the sealing device employs steel shoes in contact with the shell, such shoes shall be made from galvanized sheet conforming to

ASTM A 525 with a minimum nominal thickness of 16 gauge and a G90 coating. If uncoated shoes are specified, they shall be made from sheet steel with the thickness and quality specified on the purchase order. An adequate but minimum number of expansion joints shall be provided. Any fabric or nonmetallic material used as a seal or seal component shall be durable in its environment and shall not discolor or contaminate the product stored.

API Recommended Practice 2003 should be consulted regarding the possible need for bonding shunts between the roof and the metallic shoes. Provision for such shunts shall be a subject for agreement between the purchaser and the manufacturer.

C.3.14 GAUGING DEVICE

Each roof shall be provided with a gauge hatch or gauge well with a tight cap that complies with the design specified in the purchase order.

C.4 Fabrication, Erection, Welding, Inspection, and Testing

C.4.1 The applicable fabrication, erection, welding, inspection, and testing requirements of this standard shall apply.

C.4.2 Deck seams and other joints that are required to be liquid or vapor tight shall be tested for leaks by means of penetrating oil or any other method consistent with the methods described in this standard for testing cone-roof seams and tank-bottom seams.

C.4.3 The roof shall be given a flotation test while the tank is being filled with water and emptied. During this test, the upper side of the lower deck shall be examined for leaks. The appearance of a damp spot on the upper side of the lower deck shall be considered evidence of leakage.

C.4.4 The upper side of the upper decks of pontoon and double-deck roofs shall be visually inspected for pinholes and defective welding.

C.4.5 Drainpipe and hose systems of primary drains shall be tested with water at a pressure of 50 pounds per square inch gauge. During the flotation test, the roof drain valves shall be kept open and observed for leakage of the tank contents into the drain lines.

APPENDIX D—TECHNICAL INQUIRIES

D.1 Introduction

API will consider written requests for interpretations of API Standard 650. API staff will make such interpretations in writing after consulting, if necessary, with the appropriate committee officers and committee members. The API committee responsible for maintaining API Standard 650 meets regularly to consider written requests for interpretations and revisions and to develop new criteria dictated by technological development. The committee's activities in this regard are limited strictly to interpretations of the standard and to the consideration of revisions to the present standard on the basis of new data or technology. As a matter of policy, API does not approve, certify, rate, or endorse any item, construction, proprietary device, or activity, and accordingly, inquiries that require such consideration will be returned. Moreover, API does not act as a consultant on specific engineering problems or on the general understanding or application of the standard. If, based on the inquiry information submitted, it is the opinion of the committee that the inquirer should seek other assistance, the inquiry will be returned with the recommendation that such assistance be obtained. All inquiries that cannot be understood because they lack information will be returned.

D.2 Inquiry Format

D.2.1 Inquiries shall be limited strictly to requests for interpretation of the standard or to the consideration of revisions to the standard on the basis of new data or technology. Inquiries shall be submitted in the format described in D.2.2 through D.2.5.

D.2.2 The scope of an inquiry shall be limited to a single subject or a group of closely related subjects. An inquiry concerning two or more unrelated subjects will be returned.

D.2.3 An inquiry shall start with a background section that states the purpose of the inquiry, which would be either to obtain an interpretation of the standard or to propose a revision to the standard. The background section shall concisely provide the information needed for the committee's understanding of the inquiry (with sketches as necessary) and shall cite the applicable edition, revision, paragraphs, figures, and tables.

D.2.4 After the background section, an inquiry's main section shall state the inquiry as a condensed, precise question, omitting superfluous background information and, where appropriate, posing the question so that the reply could take the form of "yes" or "no" (perhaps with provisos). This inquiry statement should be technically and editorially correct. The inquirer shall state what he or she believes the standard requires. If the inquirer believes a revision to the standard is needed, he or she shall provide recommended wording.

D.2.5 The inquirer shall include his or her name and mailing address. The inquiry should be typed; however, legible handwritten inquiries will be considered. Inquiries should be submitted to the director of the Manufacturing, Distribution and Marketing Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

APPENDIX E—SEISMIC DESIGN OF STORAGE TANKS

E.1 Scope

This appendix provides recommended minimum basic requirements that may be specified by the purchaser for the design of storage tanks subject to seismic load. These requirements represent accepted practice for application to flat-bottom tanks; however, other procedures and applicable factors or additional requirements may be specified by the purchaser or jurisdictional authorities. Any deviation from the requirements of this appendix must be by agreement between the purchaser and the manufacturer.

Note: The basis for these requirements, together with the formulas for the design curves in Figures E-2 through E-5 and information for calculating other seismic effects, is included in a paper by R. S. Wozniak and W. W. Mitchell, "Basis of Seismic Design Provisions for Welded Steel Oil Storage Tanks."[14]

E.2 General

The design procedure considers two response modes of the tank and its contents:

a. The relatively high-frequency amplified response to lateral ground motion of the tank shell and roof, together with the portion of the liquid contents that moves in unison with the shell.
b. The relatively low-frequency amplified response of the portion of the liquid contents that moves in the fundamental sloshing mode.

The design requires the determination of the hydrodynamic mass associated with each mode and the lateral force and overturning moment applied to the shell as a result of the response of the masses to lateral ground motion. Provisions are included to assure stability of the tank shell with respect to overturning and to preclude buckling of the tank shell as a result of longitudinal compression.

This appendix has no provisions for determining the increased hoop tension that would result from earthquake motion. The increased hoop tension, correctly calculated from the lateral force coefficients specified in this appendix, would not increase the hoop stresses above a generally acceptable stress level that could be used for seismic design of the tank shell.

E.3 Design Loading

E.3.1 OVERTURNING MOMENT

Note: The overturning moment determined in E.3.1 is the moment applied to the bottom of the shell only. The tank foundation is subjected to an additional overturning moment as a result of lateral displacement of the tank contents; this additional moment may need to be considered in the design of some foundations, such as pile-supported concrete mats.

The overturning moment due to seismic forces applied to the bottom of the shell shall be determined as follows:

$$M = ZI(C_1W_sX_s + C_1W_rH_t + C_1W_1X_1 + C_2W_2X_2)$$

Where:

M = overturning moment applied to the bottom of the tank shell, in foot-pounds.
Z = seismic zone factor (horizontal seismic acceleration) as determined by the purchaser or the appropriate government authority that has jurisdiction. The seismic zone maps of Figure E-1, the seismic zone tabulation for areas outside the United States (see Table E-1), or the *Supplement to National Building Code of Canada* may be used as an aid to determine the seismic zone. Table E-2 can be used to determine the seismic zone factor, Z.
I = importance factor.
= 1.0 for all tanks unless a larger importance factor is specified by the purchaser. The I factor should not exceed 1.25, and this maximum value should be applied only to tanks that must provide emergency post-earthquake service or to tanks that store toxic or explosive substances in areas where an accidental release of product would be considered to be dangerous to the safety of the general public.
C_1, C_2 = lateral earthquake force coefficients determined according to E.3.3.
W_s = total weight of the tank shell, in pounds.
X_s = height from the bottom of the tank shell to the shell's center of gravity, in feet.
W_r = total weight of the tank roof (fixed or floating) plus a portion of the snow load, if any, specified by the purchaser, in pounds.
H_t = total height of the tank shell, in feet.
W_1 = weight of the effective mass of the tank contents that move in unison with the tank shell, as determined according to E.3.2.1, in pounds.
X_1 = height from the bottom of the tank shell to the centroid of lateral seismic force applied to W_1, as determined according to E.3.2.2, in feet.
W_2 = weight of the effective mass of the tank contents that move in the first sloshing mode, as determined according to E.3.2.1, in pounds.
X_2 = height from the bottom of the tank shell to the centroid of lateral seismic force applied to W_2, as determined according to E.3.2.2, in feet.

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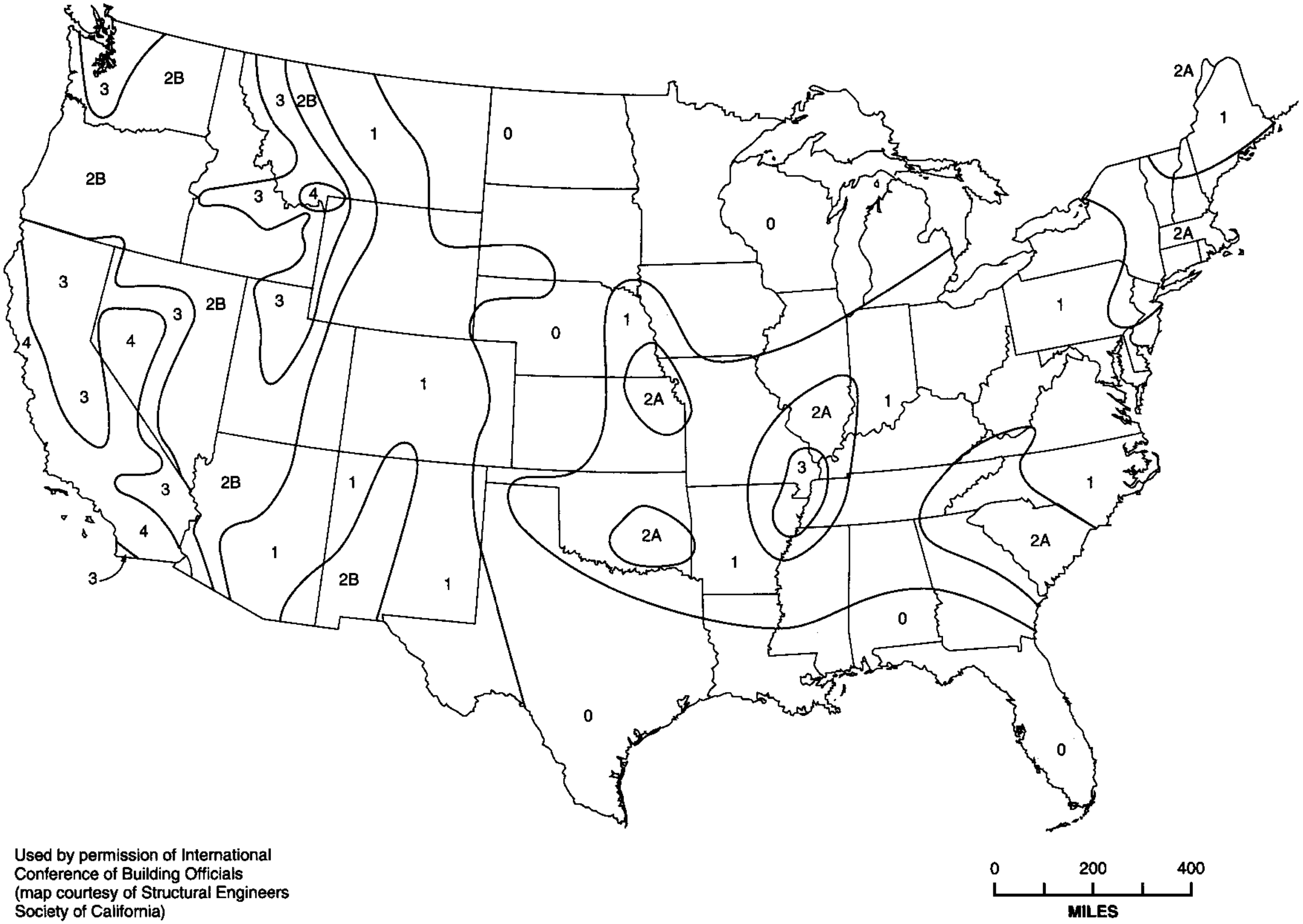
[14] R. S. Wozniak and W. W. Mitchell, "Basis of Seismic Design Provisions for Welded Steel Oil Storage Tanks," *1978 Proceedings—Refining Department*, Volume 57, American Petroleum Institute, Washington, D.C., 1978, pp. 485–501.



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(map courtesy of Structural Engineers
Society of California)

Figure E-1—Seismic Zones

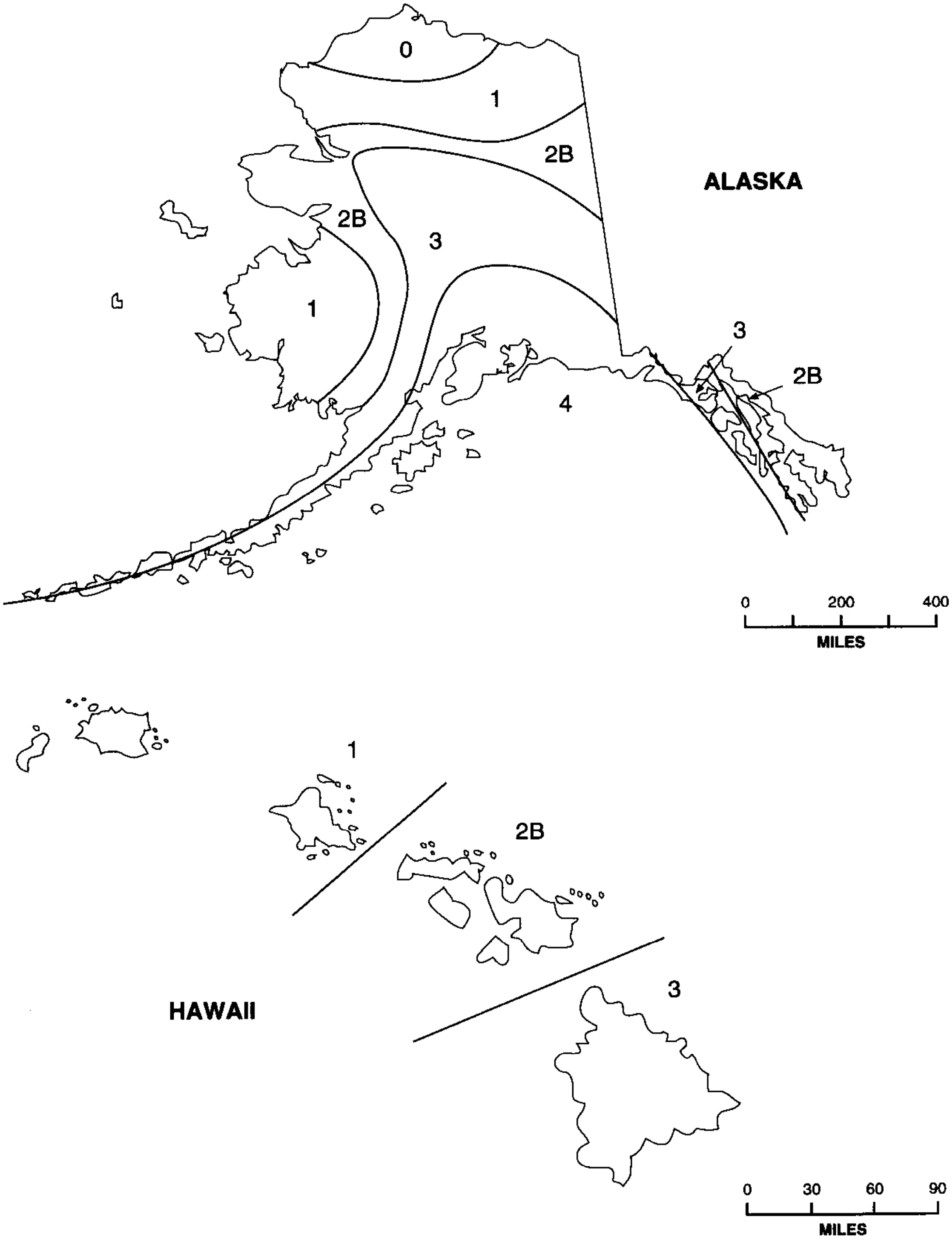

Figure E-1—Continued

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		

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 feet (see 3.6.1.1, Note 1).

H = maximum design liquid level, in feet (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.

Table E-2—Seismic Zone Factor (Horizontal Acceleration)

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.3.3 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:

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

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

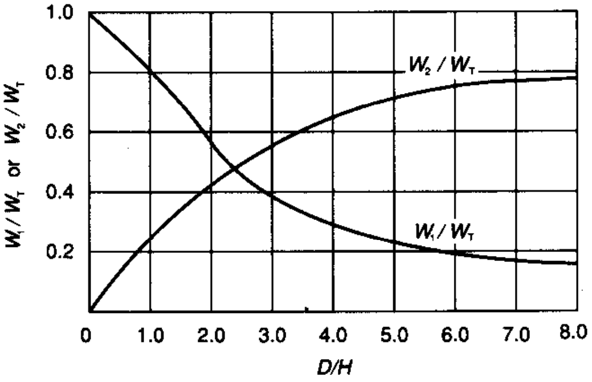

Figure E-2—Effective Masses

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[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.

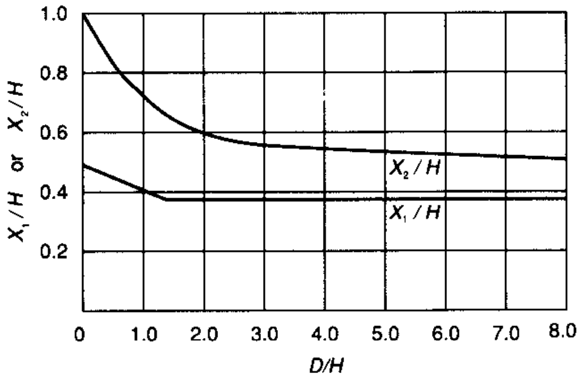


Figure E-3—Centroids of Seismic Forces

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 percent 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.

The spectrum for the factor ZIC_2 should correspond to the spectrum for ZIC_1 modified for a damping coefficient of 0.5 percent 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.

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 2500 feet per second or by other suitable means of classification or b) stiff or dense soil conditions where the soil depth is less than 200 feet	1.0
S_2	A soil profile with stiff or dense soil conditions where the soil depth exceeds 200 feet	1.2
S_3	A soil profile 40 feet or more in depth containing more than 20 feet of soft to medium stiff clay but more than 40 feet of soft clay	1.5
S_4	A soil profile containing more than 40 feet 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.

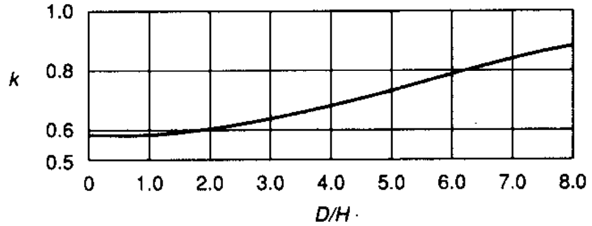


Figure E-4—Factor k

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:

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

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 pounds per foot of shell circumference.

t_b = thickness of the bottom plate under the shell, in inches.

F_{by} = minimum specified yield strength of the bottom plate under the shell, in pounds per square inch.

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

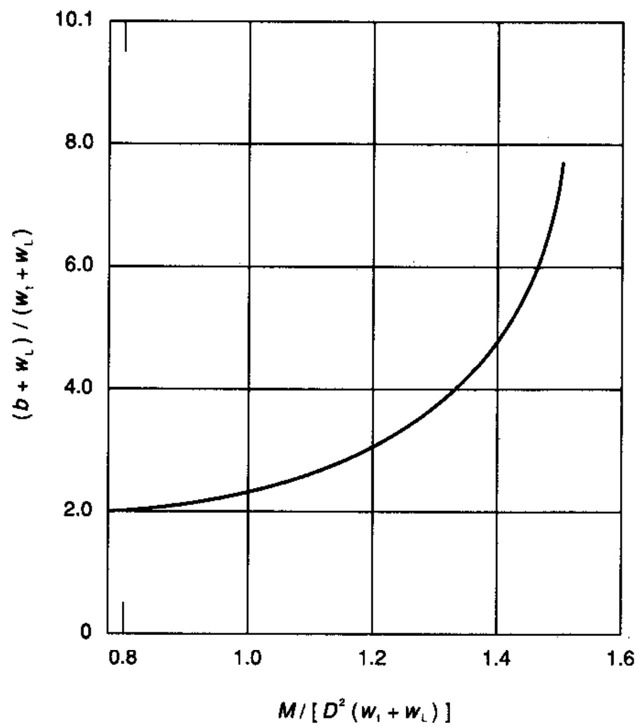
E.4.2 The thickness of the bottom plate under the shell, t_b, shall not exceed the thickness of the bottom shell course or ¼ inch, whichever is greater. Where the bottom plate under the shell is thicker than the remainder of the bottom, the width of the thicker plate under the shell, in feet, measured radially inward from the shell shall be greater than or equal to $0.0274 w_L / GH$.

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,

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



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*

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:

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

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

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

Where:

b = maximum longitudinal compressive force at the bottom of the shell, in pounds per foot of shell circumference.

w_t = weight of the tank shell and the portion of the fixed roof supported by the shell, in pounds per foot of shell circumference.

When $M/[D^2(w_t + w_L)]$ is greater than 1.57 or when $b/12t$ is greater than F_a (see E.5.3), the tank is structurally 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:

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

E.5.3 MAXIMUM ALLOWABLE SHELL COMPRESSION

The maximum longitudinal compressive stress in the shell, $b/12t$, shall not exceed the maximum allowable stress, F_a, determined by the following formulas for F_a, which take into account the effect of internal pressure due to the liquid contents. When GHD^2/t^2 is greater than or equal to 10^6,

$$F_a = \frac{10^6 t}{D}$$

When GHD^2/t^2 is less than 10^6,

$$F_a = \frac{10^6 t}{2.5D} + 600\sqrt{GH}$$

However, F_a shall not be greater than $0.5F_{ty}$.

Where:

t = thickness of the bottom shell course, excluding any corrosion allowance, in inches.

F_a = maximum allowable longitudinal compressive stress in the shell, in pounds per square inch.

F_{ty} = minimum specified yield strength of the bottom shell course, in pounds per square inch.

E.5.4 UPPER SHELL COURSES

If the thickness of the lower shell course calculated to resist the seismic overturning moment is greater than the thickness required for hydrostatic pressure, both excluding any corrosion allowance, then the calculated thickness of each upper shell course for hydrostatic pressure shall be increased in the same proportion, unless a special analysis is made to determine the seismic overturning moment and corresponding stresses at the bottom of each upper shell course.

E.6 Anchorage of Tanks

E.6.1 MINIMUM ANCHORAGE

When anchorage is provided, it shall be designed to provide the following minimum anchorage resistance, in pounds per foot of shell circumference:

$$\frac{1.273M}{D^2} - w_t$$

The stresses due to anchor forces in the tank shell at the points where the anchors are attached shall be investigated. (For a design procedure, see AISI E-1, Volume II, Part VII, "Anchor Bolt Chairs.")

E.6.2 DESIGN CONSIDERATIONS

E.6.2.1 If an anchored tank is not properly designed, its shell can be susceptible to tearing. Care should be taken to ensure that the strength of the anchorage attachments is greater than the specified minimum yield strength of the anchors so that the anchors yield before the attachments fail. Experience has shown that properly designed anchored tanks retain greater reserve strength with respect to seismic overload than unanchored tanks retain. In addition to the requirements of E.6.1, anchor design shall take into account the requirements of E.6.2.2 through E.6.2.7.

E.6.2.2 The spacing between anchors shall not exceed 10 feet. On tanks less than 50 feet in diameter, the spacing between anchors shall not exceed 6 feet. When anchor bolts are used, they shall have a minimum diameter of 1 inch, excluding any corrosion allowance.

E 6.2.3 The maximum allowable stress for the anchorage parts shall not exceed the following values:

a. For anchors designed for seismic loading alone or in combination with other loading, an allowable tensile stress equal to 0.80 yield stress (0.60 of yield stress multiplied by 1.33).
b. For other parts, 133 percent of the allowable stress in accordance with 3.10.3.
c. The maximum allowable design stress in the shell at the
96 anchor attachment shall be limited to 25,000 pounds per
square inch with no increase for seismic loading.

These stresses can be used in conjunction with other loads for seismic loading when the combined loading governs.

E.6.2.4 The anchor attachment assembly and the attachment to the shell shall be designed for a load equal to the minimum specified yield strength multiplied by the as-built minimum cross-sectional area of the anchor.

E.6.2.5 The embedment strength of the anchor in the foundation shall be sufficient to develop the specified minimum yield strength of the anchor. Hooked anchors or end plates may be used to resist pullout.

E.6.2.6 The purchaser should specify any corrosion allowance that is to be added to the anchor dimensions. The furnished anchors, including their corrosion allowance, shall be used to determine the design loads for the shell attachment and embedment requirements.

E.6.2.7 When specified by the purchaser, the anchors shall be designed to allow for thermal expansion of the tank resulting from a shell temperature greater than 200°F

E.7 Piping

Suitable flexibility shall be provided in the vertical direction for all piping attached to the shell or to the bottom of the tank. On unanchored tanks subject to bottom uplift, piping connected to the bottom shall be free to lift with the bottom or shall be located so that the horizontal distance measured from the shell to the edge of the connecting reinforcement is equal to the width of the bottom hold-down, as calculated in E.4.2, plus 12 inches.

E.8 Additional Considerations

E.8.1 The purchaser shall specify any freeboard desired to minimize or prevent overflow and damage to the roof and upper shell that may be caused by sloshing of the liquid contents.

E.8.2 The base of the roof-supporting columns shall be restrained to prevent lateral movement during earthquakes. When specified by the purchaser, the columns shall be designed to resist the forces caused by sloshing of the liquid contents.

E.8.3 The additional vertical forces at the shell caused by the seismic overturning moment shall be considered in the design of the tank foundation.

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 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 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 2½ pounds per square inch 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.2 Venting

F.2.1 OPERATING CONDITIONS

Vents shall be sized and set so that at their rated capacity, the internal pressure under any normal operating conditions exceeds neither the internal design pressure, P, nor the maximum design pressure, P_{max} (see F.4 and note to F.6).

F.2.2 EMERGENCY CONDITIONS

F.2.2.1 Where the construction of the compression ring conforms to but does not exceed the minimum requirements of Item e of 3.1.5.9, 3.10.2, and 3.10.4, the frangible characteristic of the ring is retained, and additional emergency venting devices are not required.

F.2.2.2 Where the weld size exceeds $\frac{3}{16}$ inch, where the slope of the roof at the top-angle attachment is greater than 2 inches in 12 inches, where the cross-sectional area of the roof-to-shell junction, A, exceeds the value calculated in 3.10.2.5.3, or where fillet welding from both sides is specified, emergency venting devices conforming to the requirements of API Standard 2000 shall be provided by the purchaser. The manufacturer shall provide suitable tank connections for the devices.

F.3 Roof Details

The details of the roof-to-shell junction shall be in accordance with Figure F-1, 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):

$$P = \frac{(30{,}800)(A)(\tan\theta)}{D^2} + 8t_{\text{h}}$$

Where:

P = internal design pressure, in inches of water.
A = area resisting the compressive force, as illustrated in Figure F-1, in square inches.
θ = angle between the roof and a horizontal plane at the roof-to-shell junction, in degrees.
$\tan\theta$ = slope of the roof, expressed as a decimal quantity.
D = tank diameter, in feet.
t_{h} = nominal roof thickness, in inches.

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:

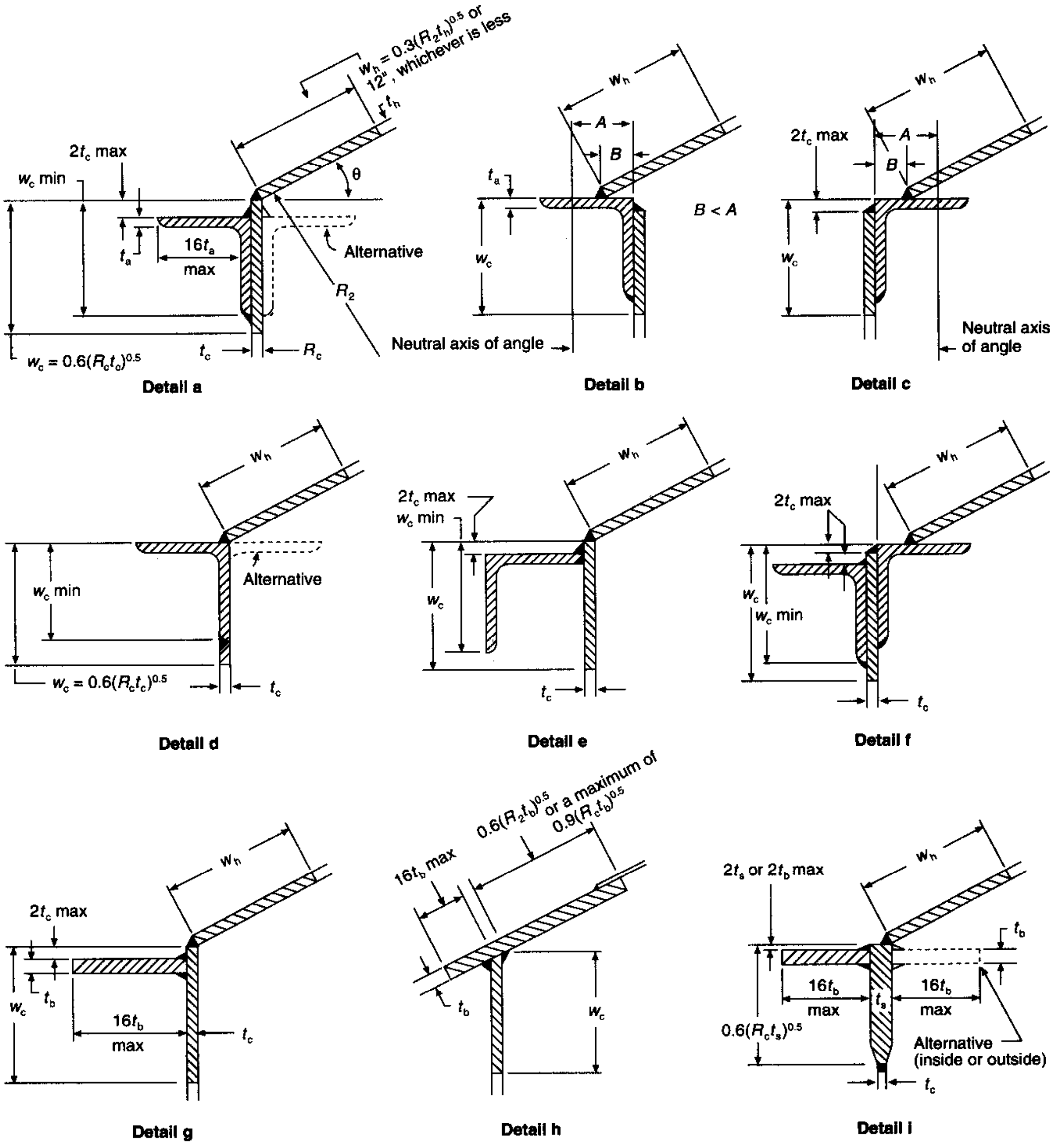
$$P_{\text{max}} = \frac{0.245W}{D^2} + 8t_{\text{h}} - \frac{0.735M}{D^3}$$

Where:

P_{max} = maximum design pressure, in inches of water.
W = total weight of the shell and any framing (but not roof plates) supported by the shell and roof, in pounds.
M = wind moment, in foot-pounds.

F.4.3 For large tanks that have the minimum top angle and a roof of small slope, the vent setting should be less than P_{max} (see note to F.6).

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 pres-



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.
= $0.6\,(R_ct_s)^{0.5}$

w_h = maximum width of participating roof.
= $0.3(R_2t_h)^{0.5}$ or 12 inches, 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 shown are in inches.

Figure F-1—Permissible Details of Compression Rings sure, 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:

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

Where:

A = total required compression area at the roof-to-shell junction, in square inches.

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 maximum design pressure permitted by F.4.1, as follows:

$$P_f = 1.6P - 4.8t_h$$

Where:

P_f = calculated failure pressure, in inches of water.

Note: This formula is based on failure occurring at a yield stress of 32,000 pounds per square inch. 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. Overpressure in a low-pitched roof usually results in a failure of the frangible joint at the roof-to-shell junction. The application of this formula to large tanks that have the minimum top angle and a roof of small slope will result in the calculation of a failure pressure that exceeds the maximum design pressure by only a small amount. In such unusual cases, a vent setting should be specified that will provide a safe margin, depending on the characteristics of the vent, between the maximum operating pressure and the calculated failure pressure. A suggested limitation is that P_{max} not exceed $0.8P_f$.

F.7 Anchored Tanks With Design Pressures up to 2½ Pounds per Square Inch Gauge

F.7.1 For tanks that meet the requirements of this standard but have design pressures up to 2½ pounds per square inch gauge, shell thicknesses shall be as specified in A.4.1, except that the pressure, P (in inches of water), divided by $12G$ shall be added to the design liquid height, in feet. The shell thickness is limited to 0.50 inch including any corrosion allowance.

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-1. 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 20,000 pounds per square inch.

F.7.3 The design and welding of roofs and the 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. 94

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 1 inch plus a corrosion allowance of at least ¼ inch 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.

d. The attachment of anchors to the shell shall not add significant localized stresses to the shell. The method of attachment shall take into account the effect of deflection and

Table F-1—Design Stresses for Anchors of Tanks With Design Pressures up to 2½ Pounds per Square Inch Gauge

Uplift Resulting From	Allowable Stress at Root of Anchor Bolt Threads (pounds per square inch)
Tank design pressure	15,000
Tank design pressure plus wind[a]	20,000
Tank test pressure	20,000
Failure pressure (from F.6) × 1.5[b]	[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.

rotation of the tank shell. Attachment of the anchor bolts to the shell shall be through stiffened chair-type assemblies or anchor rings of sufficient size and height.

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 Venting shall be provided by the purchaser in accordance with API Standard 2000. The manufacturer shall provide a suitable tank connection. The vents shall be checked during or after the testing of the tank.

APPENDIX G—STRUCTURALLY SUPPORTED ALUMINUM DOME ROOFS

G.1 General

G.1.1 PURPOSE

This appendix establishes minimum criteria for the design, fabrication, and erection of structurally supported aluminum dome roofs. When this appendix is applicable, the requirements of 3.10 and the paragraphs in Appendix F that deal with roof design are superseded. All other requirements of API Standard 650 shall apply, except that the operating temperature shall not exceed 200°F.

G.1.2 DEFINITION

A *structurally supported aluminum dome roof* is a fully triangulated aluminum space truss with the struts joined at points arrayed on the surface of a sphere. Aluminum closure panels are firmly attached to the frame members. The roof is attached to and supported by the tank at mounting points equally spaced around the perimeter of the tank.

G.1.3 GENERAL APPLICATION

G.1.3.1 New Tanks

When this appendix is specified for a new tank, the tank shall be designed to support the aluminum dome roof. The roof manufacturer shall supply the magnitude and direction of all the forces acting on the tank as a result of the roof loads, together with details of the roof-to-shell attachment. The tank shall be designed as an open-top tank, and its wind girder shall meet the requirements of 3.9. The top of the tank shell shall be structurally suitable for attachment of the dome roof structure.

G.1.3.2 Existing Tanks

When this appendix is specified for an aluminum dome roof to be added to an existing tank (with or without an existing roof), the roof manufacturer shall verify that the tank has sufficient strength to support a new roof. Information on the existing tank shall be provided by the purchaser. The purchaser shall specify the existing or new appurtenances to be accommodated by the roof manufacturer. The roof manufacturer shall supply the values of the forces acting on the tank as a result of the roof loads. The purchaser shall verify the adequacy of the foundations. Unless otherwise specified, any reinforcement required to enable the tank to support the roof shall be the responsibility of the purchaser. The design and erection of the roof shall accommodate the actual tank shape. The existing tank shall be equipped with a wind girder that meets the requirements of 3.9 for an open-top tank.

G.1.3.3 Existing Tank Data Sheet

When an aluminum dome is ordered for an existing tank, a data sheet shall be completed by the purchaser (see Figure G-1).

G.1.4 SPECIAL FEATURES

G.1.4.1 Self-Supporting Structure

The aluminum dome roof shall be supported only from the rim of the tank; primary horizontal thrust shall be contained by an integral tension ring. The design of the connection between the roof and the tank rim shall allow for thermal expansion. A minimum temperature range of ±120°F shall be used for design unless a wider range is specified by the purchaser.

G.1.4.2 Finish

Unless otherwise specified, the aluminum dome roof materials shall have a mill finish.

G.1.4.3 Maintenance and Inspection

The roof manufacturer shall provide a maintenance and inspection manual for roof items that may require maintenance, periodic inspection, or both.

G.2 Materials

G.2.1 GENERAL

Materials furnished to meet the requirements of this appendix shall be new. A complete material specification shall be submitted by the roof manufacturer for approval by the purchaser. The materials shall be compatible with the product specified to be stored in the tank and the surrounding environment. No aluminum alloy with a magnesium content greater than 3 percent shall be used when the design temperature of the roof exceeds 150°F. Properties and tolerances of aluminum alloys shall conform to AA ASD-1.

G.2.2 STRUCTURAL FRAME

Structural frame members shall be fabricated from 6061-T6 or a recognized alloy with properties established by the Aluminum Association, Inc.

G.2.3 ROOF PANELS

Roof panels shall be fabricated from Series 3000 or 5000 aluminum with a minimum nominal thickness of 0.050 inch.

DATA SHEET FOR A STRUCTURALLY SUPPORTED ALUMINUM DOME ADDED TO AN EXISTING TANK

JOB NO. ____________ ITEM NO. ____________
PURCHASE ORDER NO. ____________
REQUISITION NO. ____________
INQUIRY NO. ____________
PAGE 1 OF 1 BY ____________

(INFORMATION TO BE COMPLETED BY THE PURCHASER)

1. PURCHASER/AGENT ____________
ADDRESS ____________
CITY ____________ STATE ____________ ZIP ____________
PHONE ____________ FAX ____________
2. USER ____________
3. ERECTION SITE: NAME OF PLANT ____________
LOCATION ____________
4. TANK NO. ____________
5. PUMPING RATES: IN ______ BARRELS PER HOUR OUT ______ BARRELS PER HOUR
6. MAXIMUM DESIGN ROOF TEMPERATURE ____________ (NOT TO EXCEED 200°F)
7. DESIGN PRESSURE: ○ ATMOSPHERIC OR ______ INCHES OF WATER (INDICATE WHETHER POSITIVE OR NEGATIVE)
8. ROOF LOADS: UNIFORM LIVE ____________ POUNDS PER SQUARE FOOT
SPECIAL (PROVIDE SKETCH) ____________ POUNDS PER SQUARE FOOT
9. EARTHQUAKE DESIGN: ○ YES ○ NO
SEISMIC ZONE ____________
ZONE FACTOR (SEE TABLE E-2) ____________
IMPORTANCE FACTOR ____________
96 SNOW LOAD, IF ANY, TO BE COMBINED WITH SEISMIC ____________ POUNDS PER SQUARE FOOT
10. WIND LOAD: VELOCITY ____________ MILES PER HOUR
11. MAXIMUM HEIGHT FROM TOP OF SHELL TO TOP OF DOME ____________ FEET
12. TANK SHELL THICKNESS (ACTUAL)

COURSE NUMBER	MINIMUM THICKNESS	TYPICAL THICKNESS	PLATE WIDTH

13. ACTUAL TANK STIFFENER DETAILS, POSITION AND DIMENSIONS (PROVIDE SKETCH)
14. GASES EXPECTED IN THE VAPOR SPACE ____________
15. REQUIRED FREEBOARD ABOVE TOP OF TANK ____________ INCHES
16. ACTUAL MINIMUM TANK DIAMETER AT THE TOP OF THE TANK ____________ FEET
ACTUAL MAXIMUM TANK DIAMETER AT THE TOP OF THE TANK ____________ FEET
17. ELEVATION OF TOP OF TANK: MAXIMUM ____________ MINIMUM ____________
18. LIST ALL APPURTENANCES, OTHER THAN THOSE TO BE REMOVED BY THE PURCHASER, AND INDICATE ACTION REQUIRED OF CONTRACTOR

APPURTENANCE	CONTRACTOR ACTION REMOVE	ACCOMMODATE
	○	○
	○	○
	○	○
	○	○
	○	○
	○	○
	○	○
	○	○

Figure G-1—Data Sheet for a Structurally Supported Aluminum Dome Added to an Existing Tank

G.2.4 BOLTS AND FASTENERS

Fasteners shall be of 7075-T73 aluminum, 2024-T4 aluminum, austenitic stainless steel, or other materials as agreed to by the purchaser. Only stainless steel fasteners shall be used to attach aluminum to steel.

G.2.5 SEALANT AND GASKET MATERIAL

G.2.5.1 Sealants shall be silicone or urea urethane compounds that conform to Federal Spec TT-S-00230C unless another material is required for compatibility with stored materials. Sealants shall remain flexible over a temperature range of –80 to +300°F without tearing, cracking, or becoming brittle. Elongation, tensile strength, hardness, and adhesion shall not change significantly with aging or exposure to ozone, ultraviolet light, or vapors from the product stored in the tank.

G.2.5.2 Preformed gasket material shall be Neoprene, silicone, Buna-N, urea urethane, or EPDM elastomer meeting ASTM C 509 or Federal Spec ZZ-R-765C unless another material is required for compatibility with stored materials.

G.2.6 SKYLIGHT PANELS

Skylight panels shall be clear acrylic or polycarbonate with a minimum nominal thickness of 0.25 inch.

G.3 Allowable Stresses

G.3.1 ALUMINUM STRUCTURAL MEMBERS

Aluminum structural members and connections shall be designed in accordance with AA SAS-30 except as modified by this appendix.

G.3.2 ALUMINUM PANELS

Aluminum panels shall be designed in accordance with AA ASM-35 and this appendix. Attachment fasteners shall not penetrate both the panel and the flange of the structural member.

G.3.3 BOLTS AND FASTENERS

G.3.3.1 The maximum stress in bolts and fasteners for any design condition shall not exceed the allowable stress given in Table G-1.

G.3.3.2 The hole diameter for a fastener shall not exceed the diameter of the fastener plus 1/16 inch.

G.4 Design

G.4.1 DESIGN PRINCIPLES

G.4.1.1 The roof framing system shall be designed as a three-dimensional space frame or truss with membrane covering (roof panels) providing loads along the length of the individual members. The design must consider the increased compression induced in the framing members due to the tension in the roof panels. Local and general shell buckling must also be considered.

Table G-1—Bolts and Fasteners

Materials	Allowable Tensile Stress[a,b] (ksi)	Allowable Shear Stress[a,b,c] (ksi)
Austenitic stainless steel[d]	25.0	18.0
Austenitic stainless steel[e]	34.0	25.0
2024-T4 aluminum	26.0	16.0
7075-T73 aluminum	28.0	17.0

[a] The root-of-thread area shall be used to calculate the strength of threaded parts.

[b] For wind and seismic loads, these values may be increased by one-third.

[c] If the thread area is completely out of the shear area, the cross-sectional area of the shank may be used to determine the allowable shear load.

[d] For bolts with a minimum tensile strength of 90 ksi.

[e] For bolts with a minimum tensile strength of 125 ksi.

G.4.1.2 The actual stresses in the framing members and panels under all design load conditions shall be less than or equal to the allowable stresses.

G.4.2 DESIGN LOADS

G.4.2.1 Dead Load

The dead load shall be the weight of the roof and all accessories permanently attached to it, including any insulation.

G.4.2.2 Live Load

G.4.2.2.1 Uniform Live Load

The minimum live load shall be a uniform load of 25 pounds per square foot of projected area. 96

G.4.2.2.2 Unbalanced Live Load

The design shall consider one-half of the uniform load required per square foot applied to one-half of the dome with no live load on the other half.

G.4.2.3 Wind Load

The minimum wind load shall be the load resulting from a wind velocity of 100 miles per hour unless a different wind velocity is specified by the purchaser. Wind loading shall be determined in accordance with 3.11.

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:

95 $$F = 0.6\,ZIW_r$$

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 60 pounds per square foot 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 of 250 pounds, each distributed over two separate 1-square-foot 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 9 inches water column. When the design pressure, P_{max}, for a tank with an aluminum dome roof is being calculated, the weight of the roof, including structure, shall be added to the weight of the shell in the W term in F.4.2, and t_h shall be taken as zero. Vents shall be sized so that the venting requirements can be handled without exceeding the internal design pressure.

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 ⅛ inch 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.

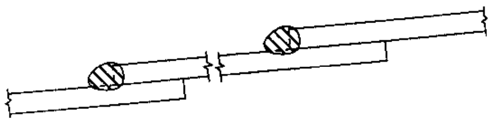
G.6 Physical Characteristics

G.6.1 SIZES

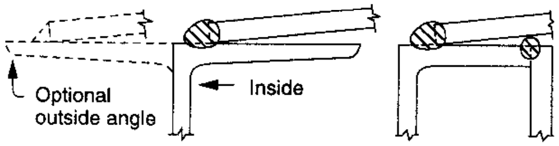
An aluminum dome roof may be used on any size tank erected in accordance with this standard.

G.6.2 DOME RADIUS

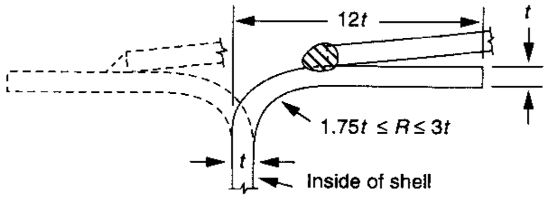
The maximum dome radius shall be 1.2 times the diameter of the tank. The minimum dome radius shall be 0.7 times the diameter of the tank unless otherwise specified by the purchaser.



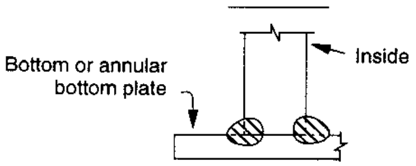
ROOF–PLATE JOINT



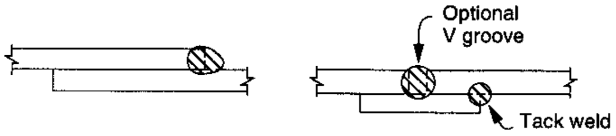
ROOF–TO–SHELL JOINTS



ALTERNATIVE ROOF–TO–SHELL JOINT (SEE NOTE 2)



BOTTOM–TO–SHELL JOINT



Single-welded full-fillet lap joint

Single-welded butt joint with backing strip

BOTTOM–PLATE JOINTS

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

3.1.5.6 Bottom Annular–Plate Joints

Bottom annular-plate radial joints shall be butt welded in accordance with 3.1.5.5 and shall have complete penetration and complete fusion. The backup bar shall be compatible for welding the annular plates together.

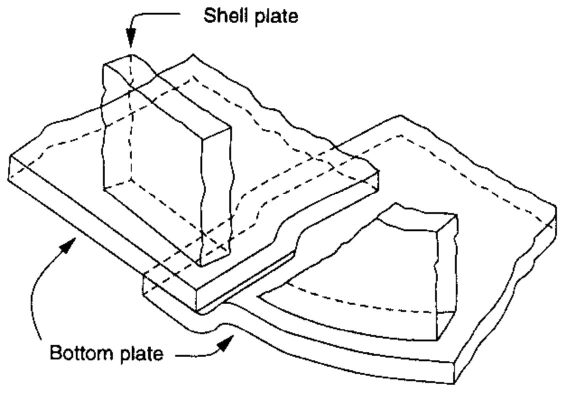


Figure 3-3B—Method for Preparing Lap-Welded Bottom Plates Under Tank Shell (See 3.1.5.4)

3.1.5.7 Shell–to–Bottom Fillet Welds

a. For bottom and annular plates with a nominal thickness ½ inch and less, the attachment between the bottom edge of the lowest course shell plate and the bottom plate shall be a continuous fillet weld laid on each side of the shell plate. The size of each weld shall not be more than ½ inch and shall not be less than the nominal thickness of the thinner of the two plates joined (that is, the shell plate or the bottom plate immediately under the shell) or less than the following values:

Nominal Thickness of Shell Plate (inches)	Minimum Size of Fillet Weld (inches)
0.1875	3/16
> 0.1875 to 0.75	1/4
> 0.75 to 1.25	5/16
> 1.25 to 1.75	3/8

b. For annular plates with a nominal thickness greater than ½ inch, 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).

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 mini-

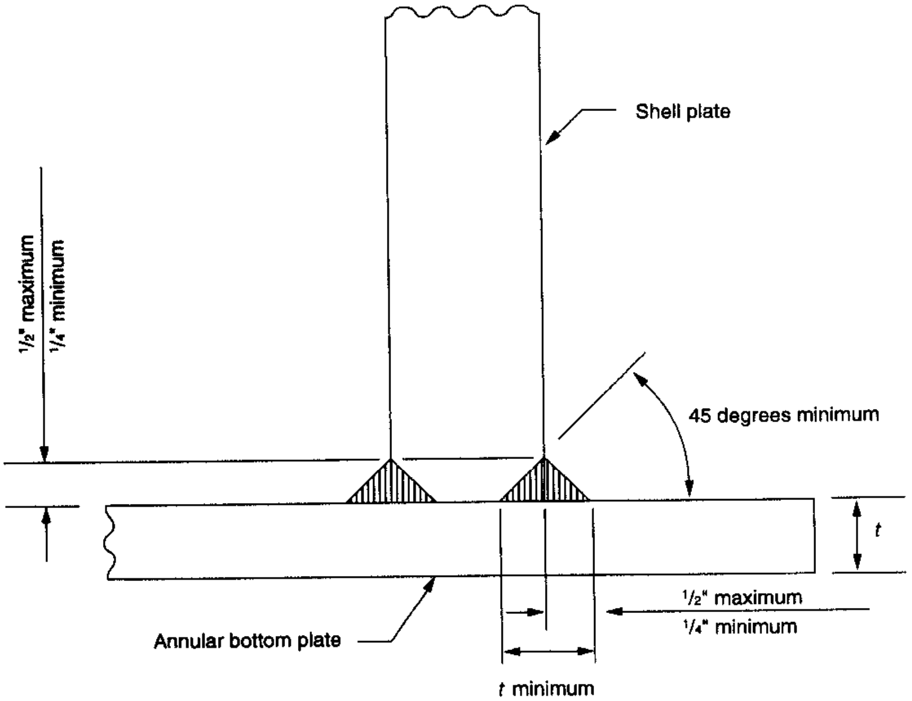


Figure 3-3C—Detail of Double Fillet-Groove Weld for Annular Bottom Plates With a Nominal Thickness Greater Than ½ Inch (See 3.1.5.7, Item b)

mize 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. 96

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.

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 35 feet, 2 × 2 × 3/16 inches; for tanks with a diameter greater than 35 feet but less than or equal to 60 feet, 2 × 2 × ¼ inches; and for tanks with a diameter greater than 60 feet, 3 × 3 × ⅜ inches. 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 30 feet 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 1 inch of water pressure.

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
94 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 100 feet 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 ¼ inch [10.2 pounds per square foot (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 72 inches.

Note: When specified by the purchaser, a minimum nominal thickness of 6 millimeters for all bottom plates is acceptable.

3.4.2 Bottom plates of sufficient size shall be ordered so that, when trimmed, at least a 1-inch 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 23,200 pounds per square inch or the maximum hydrostatic test stress (see 3.6.2.2) for the first shell course is less than or equal to 24,900 pounds per square inch, 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 24 inches between the inside of the shell and any lap-welded joint in the remainder of the bottom and at least a 2-inch projection outside the shell. A greater radial width of annular plate is required when calculated as follows:

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

Where:

t_b = thickness of the annular plate (see 3.5.3), in inches.
H = maximum design liquid level (see 3.6.3.2), in feet.
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.

96 **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.

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 (feet) (See Note 1)	Nominal Plate Thickness (inches) (See Note 2)
< 50	3/16
50 to < 120	¼
120 to 200	5/16
> 200	⅜

Note 1: Unless otherwise specified by the purchaser, the nominal tank diameter shall be the centerline diameter of the bottom shell-course plates.
Note 2: Nominal plate thickness refers to the tank shell as constructed. The thicknesses specified are based on erection requirements.
Note 3: When specified by the purchaser, plate with a minimum nominal thickness of 6 millimeters may be substituted for ¼-inch plate.

3.6.1.2 Unless otherwise agreed to by the purchaser, the shell plates shall have a minimum nominal width of 72 inches. 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.

Table 3-1—Annular Bottom-Plate Thicknesses (Inches)

Nominal Plate Thickness[a] of First Shell Course (inches)	Hydrostatic Test Stress[b] in First Shell Course (pounds per square inch)			
	≤ 27,000	≤ 30,000	≤ 33,000	≤ 36,000
$t \le 0.75$	¼	¼	9/32	11/32
$0.75 < t \le 1.00$	¼	9/32	⅜	7/16
$1.00 < t \le 1.25$	¼	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	½	⅝	¾

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

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.

Table 3-2—Permissible Plate Materials and Allowable Stresses (Pounds per Square Inch)

Plate Specification	Grade	Minimum Yield Strength	Minimum Tensile Strength	Product Design Stress S_d	Hydrostatic Test Stress S_t
ASTM Specifications					
A 283	C	30,000	55,000	20,000	22,500
A 285	C	30,000	55,000	20,000	22,500
A 131	A, B, CS	34,000	58,000	22,700	24,900
A 36	—	36,000	58,000	23,200	24,900
A 131	EH 36	51,000	71,000[a]	28,400	30,400
A 442	55	30,000	55,000	20,000	22,500
A 442	60	32,000	60,000	21,300	24,000
A 573	58	32,000	58,000	21,300	24,000
A 573	65	35,000	65,000	23,300	26,300
A 573	70	42,000	70,000[a]	28,000	30,000
A 516	55	30,000	55,000	20,000	22,500
A 516	60	32,000	60,000	21,300	24,000
A 516	65	35,000	65,000	23,300	26,300
A 516	70	38,000	70,000	25,300	28,500
A 662	B	40,000	65,000	26,000	27,900
A 662	C	43,000	70,000[a]	28,000	30,000
A 537	1	50,000	70,000[a]	28,000	30,000
A 537	2	60,000	80,000[a]	32,000	34,300
A 633	C, D	50,000	70,000[a]	28,000	30,000
A 678	A	50,000	70,000[a]	28,000	30,000
A 678	B	60,000	80,000[a]	32,000	34,300
A 737	B	50,000	70,000[a]	28,000	30,000
A 841		50,000	70,000[a]	28,000	30,000
CSA Specifications					
G40.21M	260W	37,700	59,500	23,800	25,500
G40.21M	300W	43,500	65,300	26,100	28,000
G40.21M	350WT	50,800	69,600[a]	27,900	29,800
G40.21M	350W	50,800	65,300	26,100	28,000
National Standards					
	37	30,000	52,600	20,000	22,500
	41	34,000	58,300	22,700	25,000
	44	36,000	62,600	24,000	26,800
ISO 630					
Fe 430	C, D	38,400	61,900	24,700	26,500
Fe 510	C, D	50,000	71,000[a]	28,400	30,400

[a] By agreement between the purchaser and the manufacturer, the tensile strength of these materials may be increased to 75,000 pounds per square inch minimum and 90,000 pounds per square inch maximum (and to 85,000 pounds per square inch minimum and 100,000 pounds per square inch maximum for ASTM A 537, Class 2, and A 678, Grade B). When this is done, the allowable stresses shall be determined as stated in 3.6.2.1 and 3.6.2.2.

3.6.2.2 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 21,000 pounds per square inch 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 ½ inch.

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 1 foot above the bottom of each shell course. Appendix A permits only this design method. This method shall not be used for tanks larger than 200 feet 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:

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

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

Where:

t_d = design shell thickness, in inches.
t_t = hydrostatic test shell thickness, in inches.
D = nominal tank diameter, in feet (see 3.6.1.1, Note 1).
H = design liquid level, in feet.
= 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 inches, as specified by the purchaser (see 3.3.2).
S_d = allowable stress for the design condition, in pounds per square inch (see 3.6.2.1).
S_t = allowable stress for the hydrostatic test condition, in pounds per square inch (see 3.6.2.2).

3.6.4 CALCULATION OF THICKNESS BY THE VARIABLE–DESIGN–POINT METHOD

Note: This procedure normally provides a reduction in shell-course thicknesses and total material weight, but more important is its potential to permit construction of larger diameter tanks within the maximum plate thickness limitation. For background information, see L. P. Zick and R. V. McGrath, "Design of Large Diameter Cylindrical Shells."[12]

96 **3.6.4.1** Design by the variable-design-point method gives shell thicknesses at design points that result in the calculated stresses being relatively close to the actual circumferential shell stresses. This method may only be used when the purchaser has not specified that the 1-foot method be used and when the following is true:

$$L/H \leq 2$$

Where:

L = $(6Dt)^{0.5}$, in inches.
D = tank diameter, in feet.
t = bottom-course shell thickness, in inches.
H = maximum design liquid level (see 3.6.3.2), in feet.

3.6.4.2 The minimum plate thicknesses for both the design condition and the hydrostatic test condition shall be determined as outlined. Complete, independent calculations shall be made for all of the courses for the design condition, exclusive of any corrosion allowance, and for the hydrostatic test condition. The required shell thickness for each course shall be the greater of the design shell thickness plus any corrosion allowance or the hydrostatic test shell thickness, but the total shell thickness shall not be less than the shell thickness required by 3.6.1.1, 3.6.1.5, and 3.6.1.6. When a greater thickness is used for a shell course, the greater thickness may be used for subsequent calculations of the thicknesses of the shell courses above the course that has the greater thickness, provided the greater thickness is shown as the required design thickness on the manufacturer's drawing (see 3.6.1.7).

3.6.4.3 To calculate the bottom-course thicknesses, preliminary values t_{pd} and t_{pt} for the design and hydrostatic test conditions shall first be calculated from the formulas in 3.6.3.2.

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

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

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

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

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

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

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

Where:

h_1 = height of the bottom shell course, in inches.
r = nominal tank radius, in inches.
t_1 = actual thickness of the bottom shell course, less any thickness added for corrosion allowance, in inches, used to calculate t_2 (design). The total thickness of the bottom shell course shall be used to calculate t_2 (hydrostatic test).

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

$$t_2 = t_1$$

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

$$t_2 - t_{2a}$$

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

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

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

Where:

t_2 = minimum design thickness of the second shell course excluding any corrosion allowance, in inches.
t_{2a} = thickness of the second shell course, in inches, as calculated for an upper shell course as described in 3.6.4.6.

The preceding formula for t_2 is based on the same allowable stress being used for the design of the bottom and second courses. For tanks where the value of the ratio is greater than or equal to 2.625, the allowable stress for the second course may be lower than the allowable stress for the bottom course when the methods described in 3.6.4.6 through 3.6.4.8 are used.

3.6.4.6 To calculate the upper-course thicknesses for both the design condition and the hydrostatic test condition, a preliminary value t_u for the upper-course thickness shall be calculated using the formulas in 3.6.3.2, and then the distance x of the variable design point from the bottom of the course shall be calculated using the lowest value obtained from the following:

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

$$x_2 = 12CH$$

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

Where:

t_u = thickness of the upper course at the girth joint, in inches.
$C = [K^{0.5}(K - 1)]/(1 + K^{1.5})$
$K = t_L / t_u$
t_L = thickness of the lower course at the girth joint, in inches.
H = design liquid level (see 3.6.3.2), in feet.

3.6.4.7 The minimum thickness t_x for the upper shell courses shall be calculated for both the design condition (t_{dx}) and the hydrostatic test condition (t_{tx}) using the minimum value of x obtained from 3.6.4.6:

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

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

3.6.4.8 The steps described in 3.6.4.6 and 3.6.4.7 shall be repeated using the calculated value of t_x as t_u until there is little difference between the calculated values of t_x in succession (repeating the steps twice is normally sufficient). Repeating the steps provides a more exact location of the design point for the course under consideration and, consequently, a more accurate shell thickness.

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

3.6.5 CALCULATION OF THICKNESS BY ELASTIC ANALYSIS

For tanks where L/H is greater than 2, the selection of shell thicknesses shall be based on an elastic analysis that shows the calculated circumferential shell stresses to be below the allowable stresses given in Table 3-2. The boundary conditions for the analysis shall assume a fully plastic moment caused by yielding of the plate beneath the shell and zero radial growth.

3.7 Shell Openings

3.7.1 GENERAL

3.7.1.1 The following requirements for shell openings are intended to restrict the use of appurtenances to those providing for attachment to the shell by welding.

3.7.1.2 The shell opening designs described in this standard are required, except for alternative designs allowed in 3.7.1.8. 96

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 3-8.

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.

3.7.2 REINFORCEMENT AND WELDING

3.7.2.1 Openings in tank shells larger than required to accommodate a 2-inch 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 percent, 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-percent 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-percent 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.

3.7.2.4 The aggregate strength of the weld attaching a fitting to the shell plate, an intervening reinforcing plate, or both shall at least equal the proportion of the forces passing through the entire reinforcement that is calculated to pass through the fitting.

3.7.2.5 The aggregate strength of the welds attaching any intervening reinforcing plate to the shell plate shall at least equal the proportion of the forces passing through the entire reinforcement that is calculated to pass through the reinforcing plate.

3.7.2.6 The attachment weld to the shell along the outer periphery of a flanged fitting or reinforcing plate shall be considered effective only for the parts lying outside the area bounded by vertical lines drawn tangent to the shell opening; however, the outer peripheral weld shall be applied completely around the reinforcement. All of the inner peripheral weld shall be considered effective. The strength of the effective attachment weld shall be considered as the weld's shear resistance at the stress value given for fillet welds in 3.10.3.5. The size of the outer peripheral weld shall be equal to the thickness of the shell plate or reinforcing plate, whichever is whichever is thinner, but shall not be greater than 1½ inches. When low-type nozzles are used with a reinforcing plate that extends to the tank bottom (see Figure 3-5), the size of the portion of the peripheral weld that attaches the reinforcing plate to the bottom plate shall conform to 3.1.5.7. The inner peripheral weld shall be large enough to sustain the remainder of the loading.

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

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

3.7.3 SPACING OF WELDS AROUND CONNECTIONS

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

3.7.3.1 For non-stress-relieved welds on shell plates over ½ inch thick, the minimum spacing between penetration connections and adjacent shell-plate joints shall be governed by the following:

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

3.7.3.2 Where stress relieving of the periphery weld has been performed prior to welding of the adjacent shell joint or where a non-stress-relieved weld is on a shell plate less than or equal to ½ inch thick, the spacing may be reduced to 6 inches from vertical joints or to the greater of 3 inches or 2½ times the shell thickness from horizontal joints. The spacing between the welds around the periphery of a thickened insert plate or around a reinforcing plate shall be the greater of 3 inches or 2½ times the shell thickness.

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 3 inches 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-percent 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 1100°F–1200°F (see 3.7.4.3 for quenched and tempered materials) for 1 hour per inch of shell thickness. The assembly shall include the bottom reinforcing plate (or annular plate) and the flange-to-neck weld. 95

[Old Paragraph 3.7.4.2 was deleted and subsequent paragraphs renumbered.] 95

95 **3.7.4.2** When the shell material is Group I, II, III, or IIIA, all opening connections 12 inches or larger in nominal diameter in a shell plate or thickened insert plate more than 1 inch 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 1100°F–1200°F for 1 hour per inch 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 ⅝ inch, or the butt joint of a welding-neck flange does not exceed ¾ inch. If the material is preheated to a minimum temperature of 200°F during welding, the weld limits of ⅝ inch and ¾ inch may be increased to 1¼ and 1½ inches, respectively.

95 **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 ½ inch 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 1100°F–1200°F for 1 hour per inch of thickness prior to installation.

95 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.

95 **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 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:

95

Minimum Stress-Relieving Temperature (°F)	Holding Time (hours per inch) of thickness)	See Note
1100	1	1
1050	2	1
1000	4	1
950	10	1, 2
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 II 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. 96

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 3-8 through 3-10), 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 ¼-inch-diameter telltale hole (for detection of leakage through the interior welds). Each hole shall be located on the horizontal centerline and shall be open to the atmosphere. 94

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. 94

3.7.5.3 The maximum diameter D_p of a shell cutout shall be as listed in Column 3 of Table 3-9. Dimensions for required reinforcing plates are listed in Table 3-8. 94

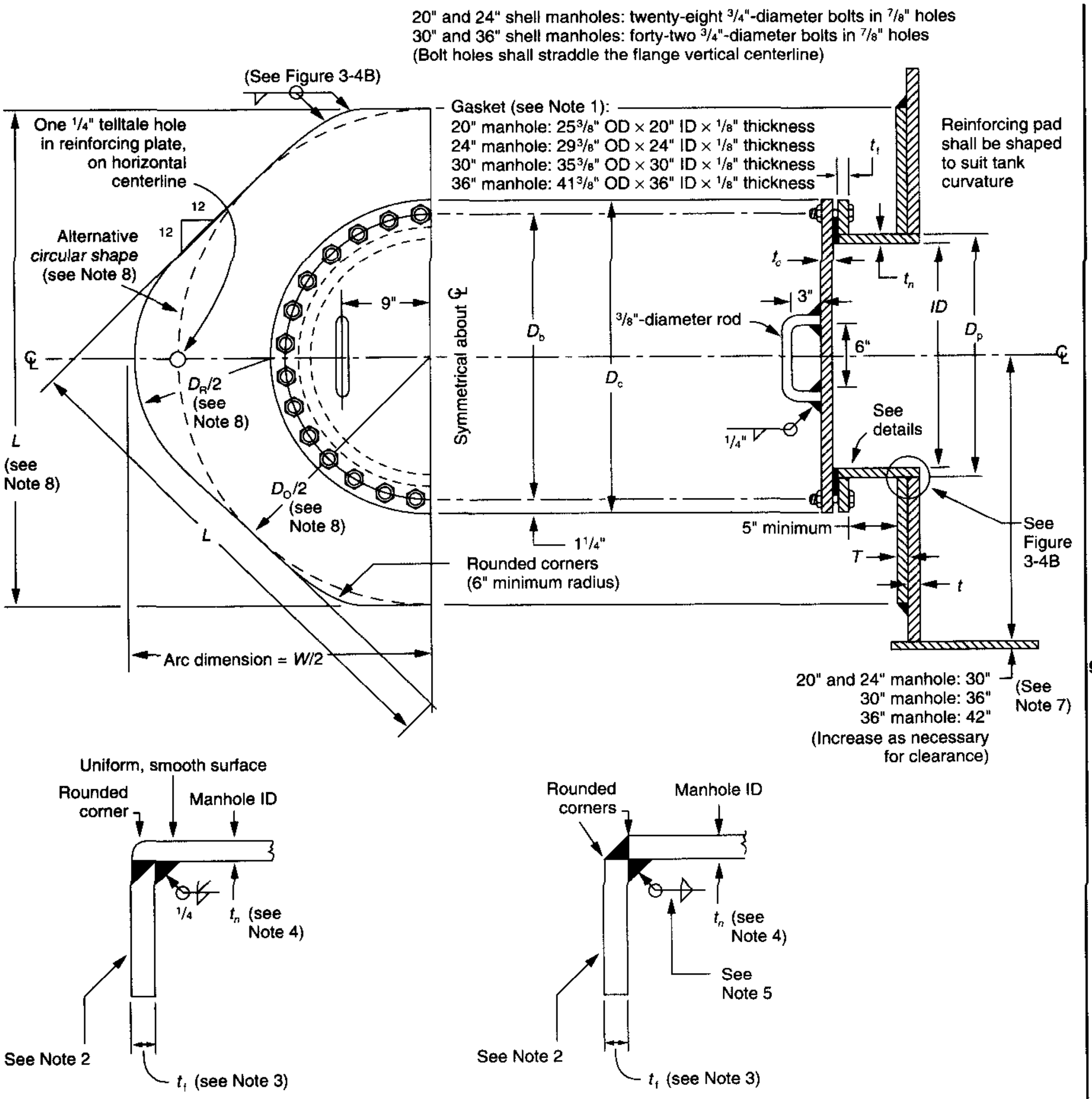
3.7.6 SHELL NOZZLES AND FLANGES

3.7.6.1 Shell nozzles and flanges shall conform to Figures 3-4B, 3-5, and 3-7 and Tables 3-8 through 3-10, 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 ¼-inch-diameter telltale 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 3-8) 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 3-9) increases as the opening is changed from circular to elliptical for the angular installation. In addition, nozzles not larger than 3 inches nominal pipe size—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 term t_n in Table 3-8, Column 3. 94

(text continued on page 3-20)



Detail a

Detail b

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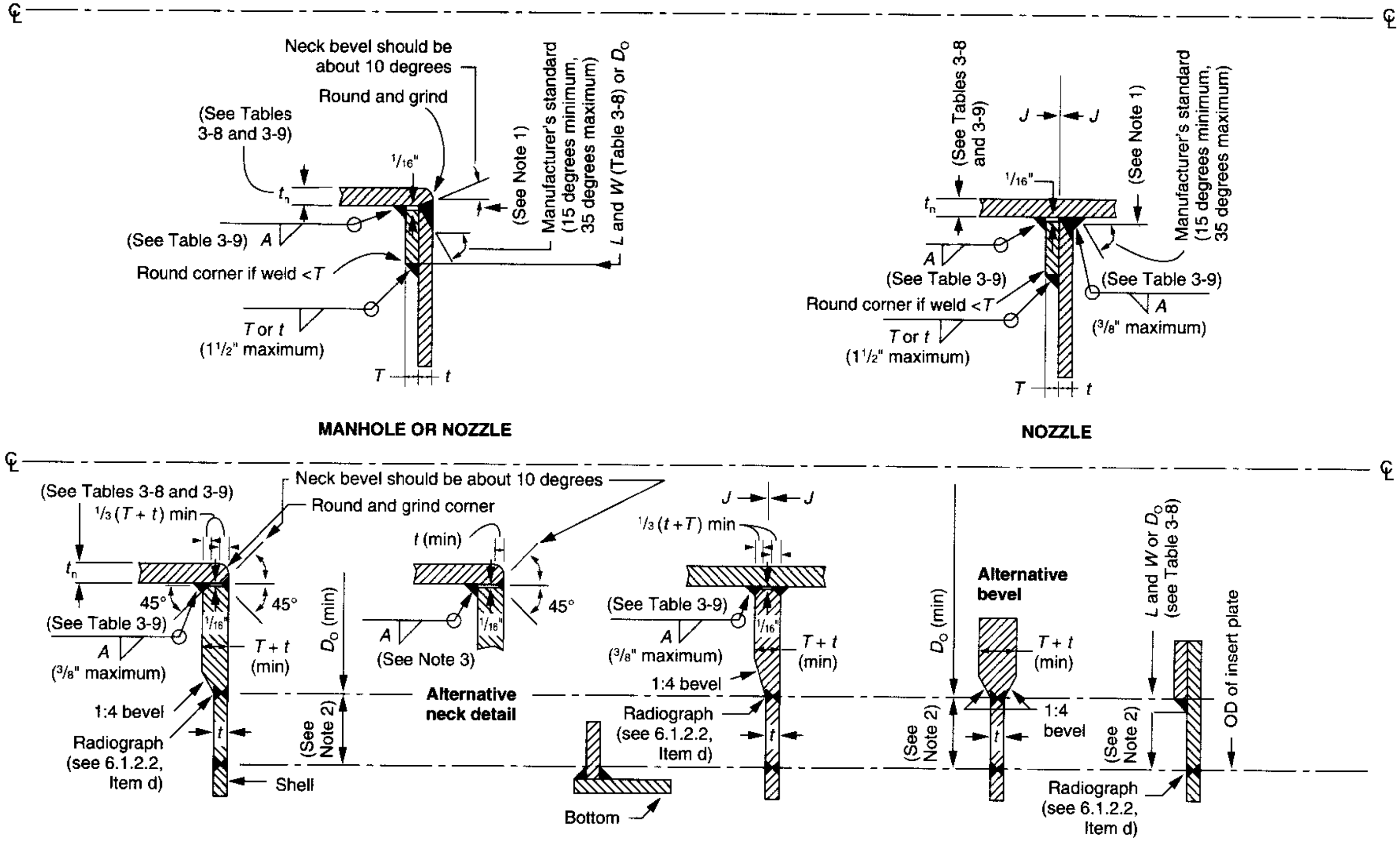
Notes:
1. Gasket material shall be specified by the purchaser. The gasket material shall meet service requirements based on product stored, temperature, and fire resistance.
2. The gasketed face shall be machine finished to provide a minimum gasket-bearing width of ¾ inch.
3. See Table 3-3.
4. See Table 3-4.
5. The size of the weld shall equal the thickness of the thinner member joined.
6. The shell nozzles shown in Table 3-8 may be substituted for manholes.
7. When the shell nozzles shown in Figure 3-5 are used, the minimum centerline heights above the tank bottom given in Table 3-8 are acceptable.
8. For dimensions for D_O, D_R, L, and W, see Table 3-8, Columns 4, 5, and 6.

Figure 3-4A—Shell Manhole



Notes.

1. See Table 3-9, Column 3, for the shell cutout, which shall not be less than the outside diameter of the neck plus ½ inch.
2. Refer to 3.7.3 for minimum spacing of welds at opening connections.
3. The weld size shall be either A (from Table 3-9, based on t) or t_n (minimum neck thickness from Tables 3-4, 3-8, and 3-9), whichever is greater.
4. Other permissible insert details are shown in Figure 3-8 of API Standard 620. The reinforcement area shall conform to 3.7.2.
5. Dimensions and weld sizes that are not shown are the same as those given in Figure 3-4A and Tables 3-4, 3-5, and 3-8 through 3-10.
6. Details of welding bevels may vary from those shown if agreed to by the purchaser.

Figure 3-4B—Details of Shell Manholes and Nozzles

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

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10
Maximum Tank Height (feet)	Equivalent Pressure[a] (pounds per square inch)	Minimum Thickness of Cover Plate[b] (t_c)				Minimum Thickness of Bolting Flange After Finishing[b] (t_f) |94			
		20-inch Manhole	24-inch Manhole	30-inch Manhole	36-inch Manhole	20-inch Manhole	24-inch Manhole	30-inch Manhole	36-inch Manhole
21	9.1	5/16	3/8	7/16	1/2	1/4	1/4	5/16	3/8
27	11.7	3/8	7/16	1/2	9/16	1/4	5/16	3/8	7/16
32	13.9	3/8	7/16	9/16	5/8	1/4	5/16	7/16	1/2
40	17.4	7/16	1/2	5/8	11/16	5/16	3/8	1/2	9/16
45	19.5	1/2	9/16	5/8	3/4	3/8	7/16	1/2	5/8
54	23.4	1/2	9/16	11/16	13/16	3/8	7/16	9/16	11/16
65	28.2	9/16	5/8	3/4	7/8	7/16	1/2	5/8	3/4
75	32.5	5/8	11/16	13/16	15/16	1/2	9/16	11/16	13/16

Note: See Figure 3-4A.

[a] Equivalent pressure is based on water loading.

94 | [b] For addition of corrosion allowance, see 3.7.5.2.

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 (inches)			
	For Manhole Diameter 20 Inches	For Manhole Diameter 24 Inches	For Manhole Diameter 30 Inches	For Manhole Diameter 36 Inches
3/16	3/16	3/16	3/16	3/16
1/4	1/4	1/4	1/4	1/4
5/16	1/4	1/4	5/16	5/16
3/8	1/4	1/4	5/16	3/8
7/16	1/4	1/4	5/16	3/8
1/2	1/4	1/4	5/16	3/8
9/16	1/4	1/4	5/16	3/8
5/8	1/4	1/4	5/16	3/8
11/16	1/4	1/4	5/16	3/8
3/4	1/4	1/4	5/16	3/8
13/16	5/16	1/4	5/16	3/8
7/8	3/8	5/16	5/16	3/8
15/16	7/16	7/16	7/16	7/16
1	7/16	7/16	7/16	7/16
1 1/16	7/16	7/16	7/16	7/16
1 1/8	1/2	1/2	1/2	1/2
1 3/16	9/16	9/16	9/16	9/16
1 1/4	5/8	9/16	9/16	9/16
1 5/16	5/8	5/8	5/8	5/8
1 3/8	11/16	5/8	5/8	5/8
1 7/16	11/16	11/16	11/16	11/16
1 1/2	3/4	3/4	3/4	3/4

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---

[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. |94

[c] For addition of corrosion allowance, see 3.7.5.2. |94

Table 3-5—Dimensions for Bolt Circle Diameter D_b and Cover Plate Diameter D_c for Shell Manholes

Column 1	Column 2	Column 3
Manhole Diameter (inches)	Bolt Circle Diameter D_b (inches)	Cover Plate Diameter D_c (inches)
20	26¼	28¾
24	30¼	32¾
30	36¼	38¾
36	42¼	44¾

Note: See Figure 3-4A.

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(Table 3-6—Dimensions for 30-Inch Shell Manhole (Inches)—was deleted and not replaced by Addendum 1.) 94

94 (Table 3-7—Dimensions for 36-Inch Shell Manhole (Inches)—was deleted and not replaced by Addendum 1.)

Table 3-8—Dimensions for Shell Nozzles (Inches)

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7[c]	Column 8[c]	Column 9[c]
Size of Nozzle	Outside Diameter of Pipe	Nominal Thickness of Flanged Nozzle Pipe Wall[a, h] 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	Minimum Distance from Bottom of Tank to Center of Nozzle	
							Regular Type[d] H_N	Low Type C
				Flanged Fittings				
48	48	[e]	48⅛	96¾	117	16	52	48⅜
46	46	[e]	46⅛	92¾	112	16	50	46⅜
44	44	[e]	44⅛	88¾	107¼	15	48	44⅜
42	42	[e]	42⅛	84¾	102½	15	46	42⅜
40	40	[e]	40⅛	80¾	97¾	15	44	40⅜
38	38	[e]	38⅛	76¾	92¾	14	42	38⅜
36	36	[e]	36⅛	72¾	88	14	40	36⅜
34	34	[e]	34⅛	68¾	83¼	13	38	34⅜
32	32	[e]	32⅛	64¾	78½	13	36	32⅜
30	30	[e]	30⅛	60¾	73½	12	34	30⅜
28	28	[e]	28⅛	56¾	68¾	12	32	28⅜
26	26	[e]	26⅛	52¾	64	12	30	26⅜
24	24	0.50	24⅛	49½	60	12	28	24¾
22	22	0.50	22⅛	45½	55¼	11	26	22¾
20	20	0.50	20⅛	41½	50½	11	24	20¾
18	18	0.50	18⅛	37½	45¾	10	22	18¾
16	16	0.50	16⅛	33½	40¾	10	20	16¾
14	14	0.50	14⅛	29½	36	10	18	14¾
12	12¾	0.50	12⅞	27	33	9	17	13½
10	10¾	0.50	10⅞	23	28¼	9	15	11½
8	8⅝	0.50	8¾	19	23¼	8	13	9½
6	6⅝	0.432	6¾	15¾	19½	8	11	7⅞
4	4½	0.337	4⅝	12	15¼	7	9	6
3	3½	0.300	3⅝	10½	13½	7	8	5¼
2[f]	2⅜	0.218	2½	—	—	6	7	[i]
1½[f]	1.90	0.200	2	—	—	6	6	[i]
				Threaded Fittings				
3[g]	4.00	Coupling	4⅛	11¼	14¼	—	9	5⅝
2[f]	2.875	Coupling	3	—	—	—	7	[i]
1½[f]	2.200	Coupling	2⅜	—	—	—	6	[i]
1[f]	1.576	Coupling	1¹¹⁄₁₆	—	—	—	5	[i]
¾[f]	1.313	Coupling	1⁷⁄₁₆	—	—	—	4	[i]

Note: See Figure 3-5.

[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 3-9, Column 2.

[f] **Flanged nozzles and threaded nozzles in pipe sizes 2 inches 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 3-9, Column 6. Reinforcing plates may be used if desired.**

[g] **A threaded nozzle in a 3-inch pipe size 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.** 94

[i] Refer to 3.7.3. 95

Table 3-9—Dimensions for Shell Nozzles: Pipe, Plate, and Welding Schedules (Inches)

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Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
				Size of Fillet Weld *A*	
Thickness of Shell and Reinforcing Plate[a] *t* and *T*	Minimum Pipe Wall Thickness of Flanged Nozzles[b, c] t_n	Maximum Diameter of Hole in Shell Plate (D_P) Equals Outside Diameter of Pipe Plus	Size of Fillet Weld *B*	Nozzles Larger Than 2 Inches	2-, 1½-, 1-, and ¾-Inch Nozzles
3/16	1/2	5/8	3/16	1/4	1/4
1/4	1/2	5/8	1/4	1/4	1/4
5/16	1/2	5/8	5/16	1/4	1/4
3/8	1/2	5/8	3/8	1/4	1/4
7/16	1/2	5/8	7/16	1/4	1/4
1/2	1/2	5/8	1/2	1/4	5/16
9/16	1/2	3/4	9/16	1/4	5/16
5/8	1/2	3/4	5/8	5/16	5/16
11/16	1/2	3/4	11/16	5/16	5/16
3/4	1/2	3/4	3/4	5/16	5/16
13/16	1/2	3/4	13/16	3/8	5/16
7/8	1/2	3/4	7/8	3/8	5/16
15/16	1/2	3/4	15/16	3/8	5/16
1	1/2	3/4	1	7/16	5/16
1 1/16	9/16	3/4	1 1/16	7/16	5/16
1 1/8	9/16	3/4	1 1/8	7/16	5/16
1 3/16	5/8	3/4	1 3/16	1/2	5/16
1 1/4	5/8	3/4	1 1/4	1/2	5/16
1 5/16	11/16	3/4	1 5/16	1/2	5/16
1 3/8	11/16	3/4	1 3/8	9/16	5/16
1 7/16	3/4	3/4	1 7/16	9/16	5/16
1 1/2	3/4	3/4	1 1/2	9/16	5/16
1 9/16	13/16	3/4	1 1/2	9/16	5/16
1 5/8	13/16	3/4	1 1/2	5/8	5/16
1 11/16	7/8	3/4	1 1/2	5/8	5/16
1 3/4	7/8	3/4	1 1/2	5/8	5/16

Note: See Figure 3-5.

[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 nozzle reinforcing plate may be decreased accordingly. In such cases, the reinforcement and the attachment welding shall conform to the design limits for reinforcement of shell openings specified in 3.7.2.

[b] This column applies to 48-, 46-, 44-, 42-, 40-, 38-, 36-, 34-, 32-, 30-, 28-, and 26-inch flanged nozzles. Refer to 2.5 for piping materials.

[c] Any specified corrosion allowance shall, by agreement between the purchaser and the manufacturer, be added to either the minimum thickness shown or to the minimum calculated thickness required for pressure head and mechanical strength. In no case shall the thickness provided be less than the minimum thickness shown. 94

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 3-11 through 3-13. When a size intermediate to the sizes given in Tables 3-11 through 3-13 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 48 inches; when the shell material is Group IV, IVA, V, or VI, the height shall not exceed 36 inches.

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:

$$A_{cs} \geq \frac{K_1 h t}{2}$$ 96

Where:

A_{cs} = cross-sectional area of the reinforcement over the top of the opening, in square inches.

K_1 = area coefficient from Figure 3-8.

h = vertical height of clear opening, in inches.

Table 3-10—Dimensions for Shell Nozzle Flanges (Inches)

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12
								Diameter of Bore		Minimum Diameter of Hub at Point of Weld	
Size of Nozzle	Minimum Thickness of Flange[d] Q	Outside Diameter of Flange A	Diameter of Raised Face D	Diameter of Bolt Circle C	Number of Holes	Diameter of Holes	Diameter of Bolts	Slip-on Type: Outside Diameter of Pipe Plus B	Welding-Neck Type[a] B_1	Slip-on Type[b] E	Welding-Neck Type[c] E_1 94
48	2¾	59½	53½	56	44	1⅝	1½	0.25	a	b	c
46	2 11/16	57½	51	53¾	40	1⅝	1½	0.25	a	b	c
44	2⅝	55¼	49	51¾	40	1⅝	1½	0.25	a	b	c
42	2⅝	53	47	49½	36	1⅝	1½	0.25	a	b	c
40	2½	50¾	44¼	47¼	36	1⅝	1½	0.25	a	b	c
38	2⅜	48¾	42¼	45¼	32	1⅝	1½	0.25	a	b	c
36	2⅜	46	40¼	42¾	32	1⅝	1½	0.25	a	b	c
34	2 5/16	43¾	37¾	40½	32	1⅝	1½	0.25	a	b	c
32	2¼	41¾	35¾	38½	28	1⅝	1½	0.25	a	b	c
30	2⅛	38¾	33¾	36	28	1⅜	1¼	0.25	a	b	c
28	2 1/16	36½	31¼	34	28	1⅜	1¼	0.25	a	b	c
26	2	34¼	29¼	31¾	24	1⅜	1¼	0.25	a	b	c
24	1⅞	32	27¼	29½	20	1⅜	1¼	0.19	a	b	c
22	1 13/16	29½	25¼	27¼	20	1⅜	1¼	0.19	a	b	c
20	1 11/16	27½	23	25	20	1¼	1⅛	0.19	a	b	c
18	1 9/16	25	21	22¾	16	1¼	1⅛	0.19	a	b	c
16	1 7/16	23½	18½	21¼	16	1⅛	1	0.19	a	b	c
14	1⅜	21	16¼	18¾	12	1⅛	1	0.19	a	b	c
12	1¼	19	15	17	12	1	⅞	0.13	a	b	c
10	1 3/16	16	12¾	14¼	12	1	⅞	0.13	a	b	c
8	1⅛	13½	10⅝	11¾	8	⅞	¾	0.10	a	b	c
6	1	11	8½	9½	8	⅞	¾	0.10	a	b	c
4	15/16	9	6 3/16	7½	8	¾	⅝	0.06	a	b	c
3	15/16	7½	5	6	4	¾	⅝	0.06	a	b	c
2	¾	6	3⅝	4¾	4	¾	⅝	0.07	a	b	c
1½	11/16	5	2⅞	3⅞	4	⅝	½	0.07	a	b	c

Note: See Figure 3-7. The facing dimensions for slip-on and welding-neck flanges in sizes 1½ through 20 inches and size 24 inches are identical to those specified in ASME B16.5 for Class 150 steel flanges. The facing dimensions for flanges in sizes 30, 36, 42, and 48 inches are in agreement with ASME B16.1 for Class 125 cast iron flanges. The dimensions for large flanges may conform to Series B of ASME B16.47.

[a] B_1 = inside diameter of pipe.

94 [b] E = outside diameter of pipe + $2t_n$.

[c] E_1 = outside diameter of pipe.

94 [d] Corrosion allowance, if specified, need not be added to flange and cover thicknesses complying with ASME B16.5 Class 150, ASME B16.1 Class 125, and ASME B16.47 flanges.

t = calculated thickness of the lowest shell course, in inches, 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 1/16 inch but no more than ⅛ inch greater than the thickness of the adjacent plates in the lowest shell course or shall be in conformance with Table 3-13 (except for the 8 × 16-inch opening, for which the plates may be of equal thickness). The thickness of the shell reinforcing plate and the neck plate shall be the same as the thickness of the shell plate in the cleanout-opening assembly.

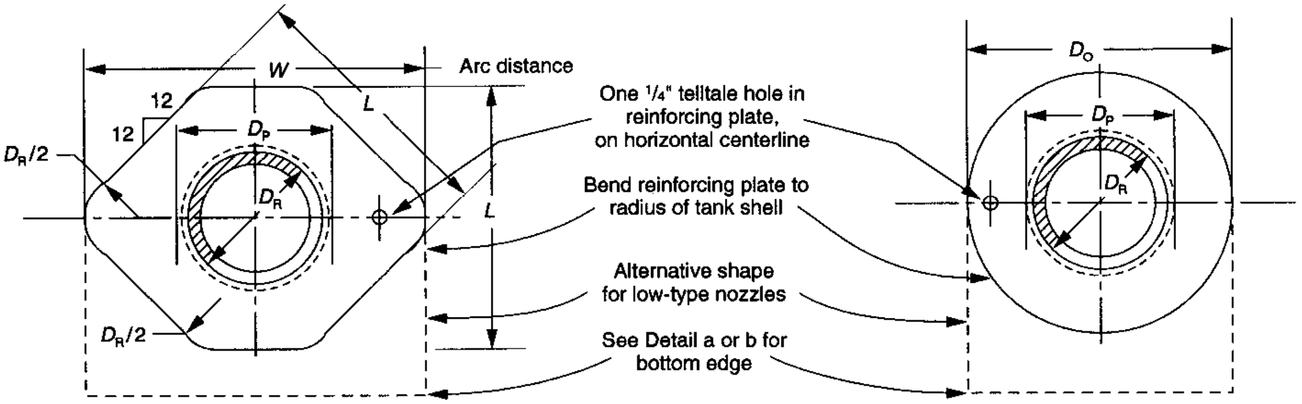
The reinforcement in the plane of the shell shall be provided within a height L above the bottom of the opening. L shall not exceed $1.5h$ except that, in the case of small openings, $L - h$ shall not be less than 6 inches. Where this exception results in an L that is greater than $1.5h$, only the portion 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.

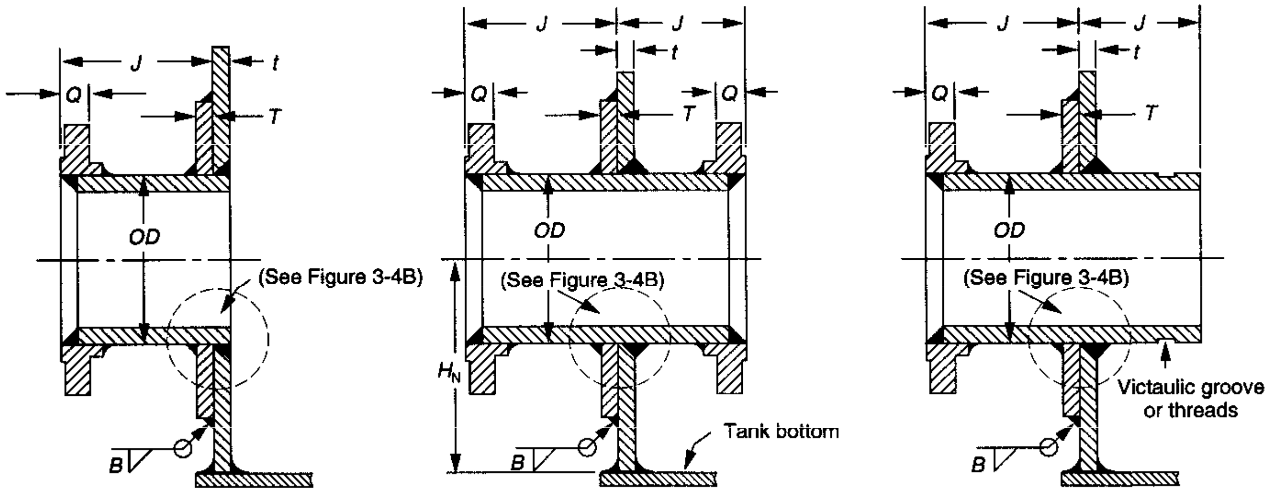
b. Any thickness of the shell plate in the cleanout-door assembly that is greater than the thickness of the adjacent plates in the lowest shell course.

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 10 inches 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:



REINFORCING PLATE



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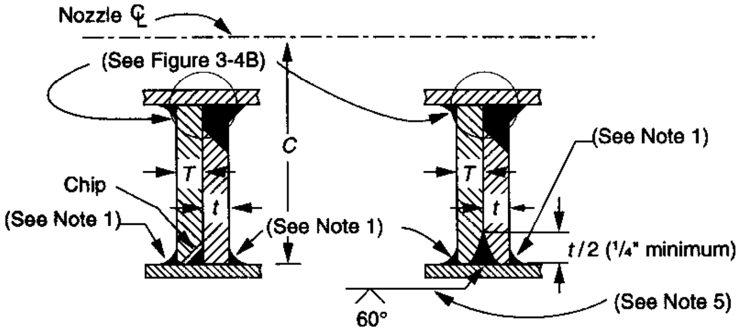
REGULAR–TYPE FLANGED NOZZLES, 3 INCHES OR LARGER
(Bolt holes shall straddle flange centerlines)



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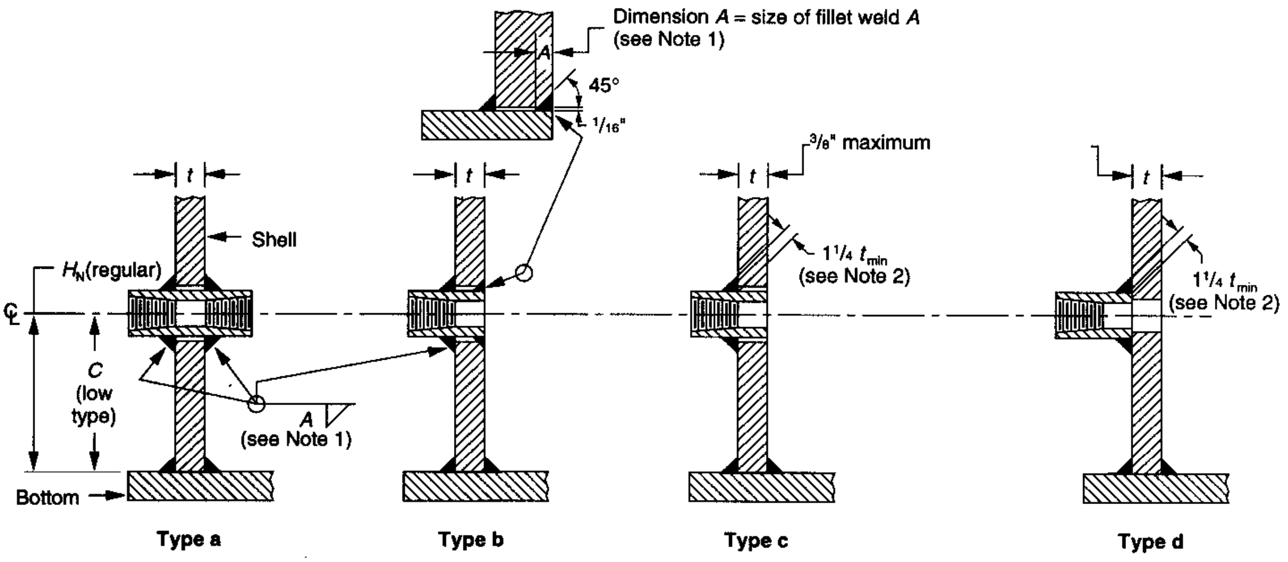
LOW-TYPE FLANGED NOZZLES, 3 INCHES OR LARGER
(Bolt holes shall straddle flange centerlines)

Notes:
1. See 3.1.5.7 for information on the size of welds.
2. See 3.8.8 for information on the couplings used in shell nozzles.
3. Nozzles 3 inches or larger require reinforcement.
4. Details of welding bevels may vary from those shown if agreed to by the purchaser.
5. Shop weld not attached to bottom plate.

Figure 3-5—Shell Nozzles (See Tables 3-8, 3-9, and 3-10)



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THREADED-TYPE SHELL NOZZLES, ¾ INCH THROUGH 2 INCHES

Notes:
1. See Table 3-9, Column 6.
2. t_{min} shall be ¾ inch or the thickness of either part joined by the fillet weld, whichever is less.

Figure 3-5—Continued

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

Where:

t_b = minimum thickness of the bottom reinforcing plate, in inches.
h = vertical height of clear opening, in inches.
b = horizontal width of clear opening, in inches.
H = maximum design liquid level (see 3.6.3.2), in feet.

3.7.7.7 The dimensions of the cover plate, bolting flange, bolting, and bottom reinforcing plate shall conform to Tables 3-11 and 3-12.

3.7.7.8 The material for the shell plate in the cleanout-opening assembly, the shell reinforcing plate, the tank-bottom reinforcing plate, and the neck plate shall conform to 2.2.9 and Figure 2-1 for the respective thicknesses at the stated design metal temperature for the tank, and the strength of the material shall be consistent with the strength of the

Table 3-11—Dimensions for Flush-Type Cleanout Fittings (Inches)

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
8	16	46	4	14	1¼	4	3½	3¼	22	¾
24	24	72	12	29	1½	4	3¾	3½	36	¾
36	48	106	18[c]	41	1½	4½	4¾	4¼	46	1
48[d]	48	125	24	51½	1½	4½	5	4½	52	1

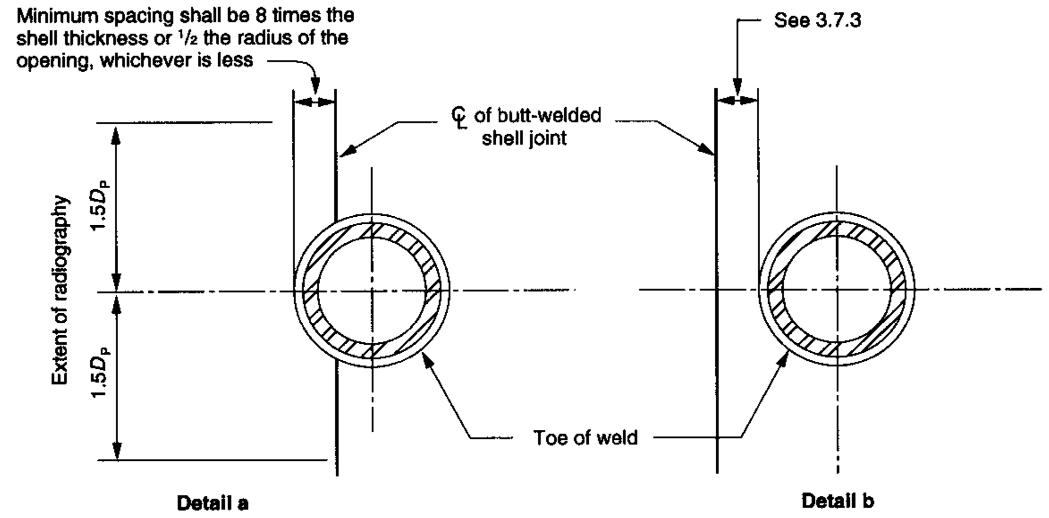
Note: See Figure 3-9.

[a] For neck thicknesses greater than 1$\frac{9}{16}$ inches, increase f_3 as necessary to provide a $\frac{1}{16}$-inch clearance between the required neck-to-flange weld and the head of the bolt.

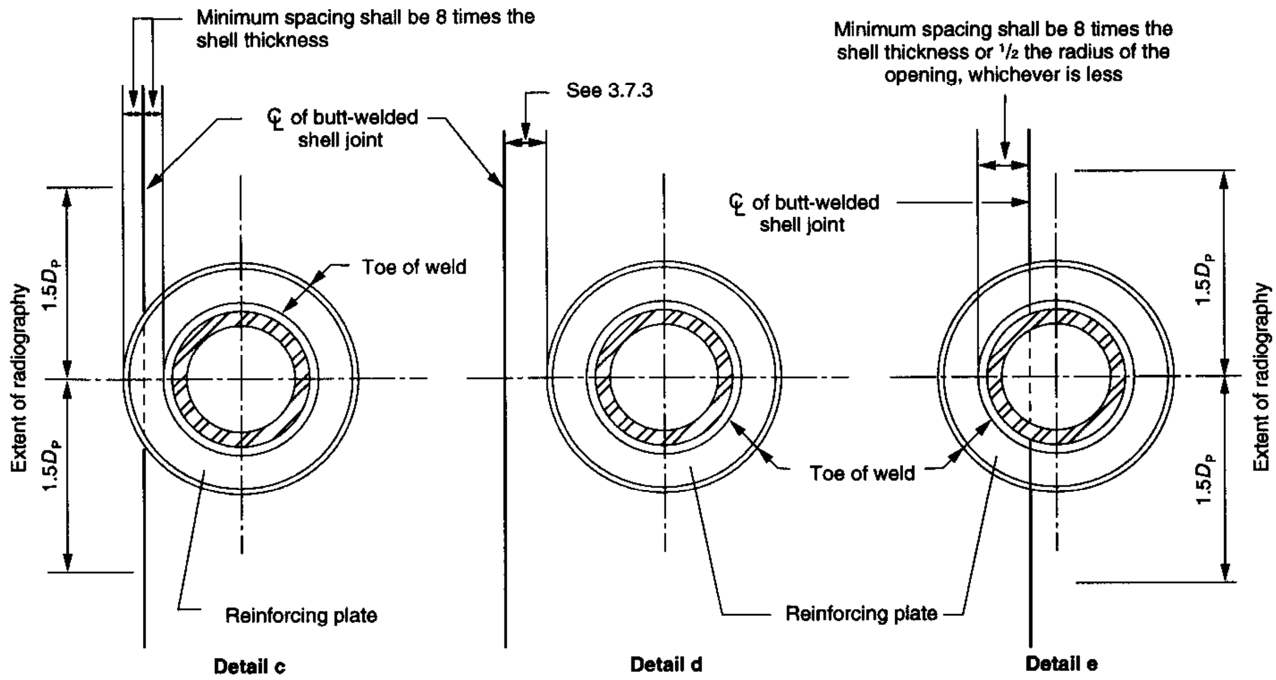
[b] Refers to spacing at the lower corners of the cleanout-fitting flange.

[c] For Groups IV, IVA, V, and VI, 24 inches.

[d] Only for Group I, II, III, or IIIA shell materials (see 3.7.7.2).



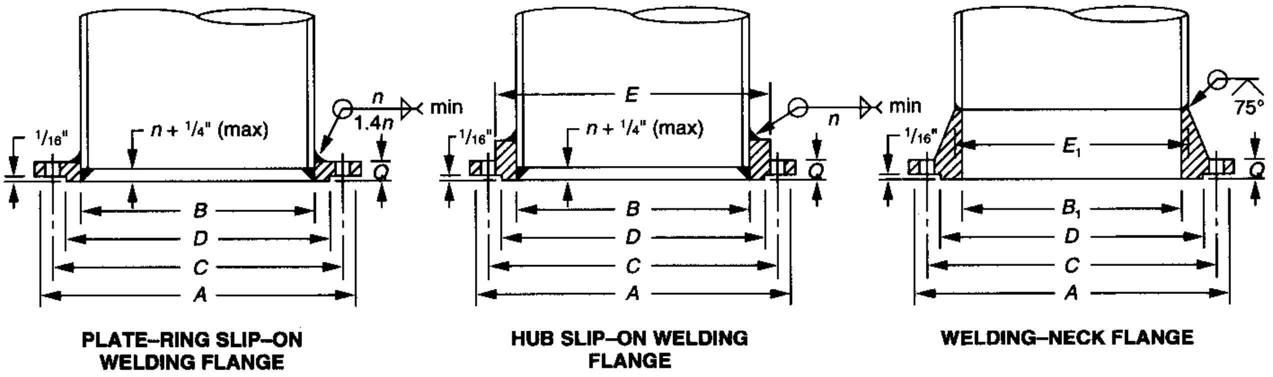
PENETRATION WITHOUT REINFORCING PLATE



PENETRATION WITH REINFORCING PLATE

Note: D_p = diameter of opening.

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



Note: The *n* designated for weld thickness is the nominal pipe wall thickness (see Tables 3-8 and 3-9).

Figure 3-7—Shell Nozzle Flanges (See Table 3-10)

shell material. The material for the cover plate, bolting flange, and bolting shall conform to Section 2.

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.

(text continued on page 3-29)

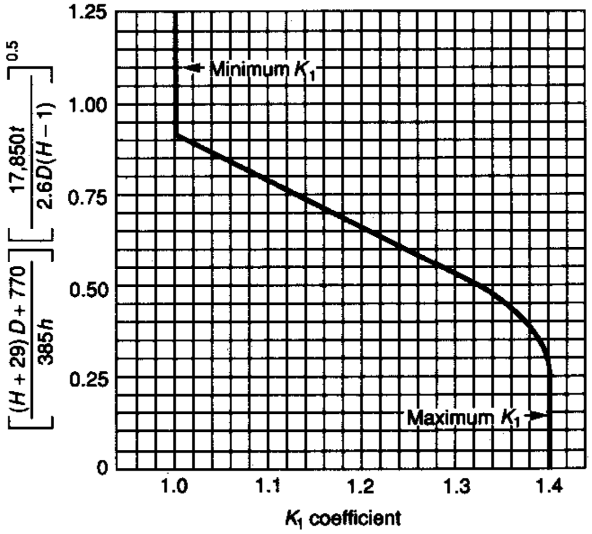


Figure 3-8—Area Coefficient for Determining Minimum Reinforcement of Flush-Type Cleanout Fittings

Table 3-12—Minimum Thickness of Cover Plate, Bolting Flange, and Bottom Reinforcing Plate for Flush-Type Cleanout Fittings (Inches)

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)							
		8 × 16		24 × 24		36 × 48		48 × 48	
Maximum Tank Height (feet) H	Equivalent Pressure[a] (pounds per square inch)	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
20	8.7	3/8	1/2	3/8	1/2	5/8	13/16	5/8	7/8
34	14.7	3/8	1/2	1/2	1/2	3/4	1	13/16	1 1/8
41	17.8	3/8	1/2	1/2	9/16	7/8	1 1/8	7/8	1 3/16
53	23	3/8	1/2	9/16	5/8	15/16	1 1/4	1	1 5/16
60	26	7/16	1/2	5/8	11/16	1	1 5/16	1 1/8	1 3/8
64	27.8	7/16	1/2	5/8	11/16	1 1/16	1 3/8	1 1/8	1 7/16
72	31.2	7/16	1/2	11/16	3/4	1 1/8	1 7/16	1 3/16	1 1/2

Note: See Figure 3-9.

[a] Equivalent pressure is based on water loading.

[b] Maximum of 1 inch.

[c] Maximum of 1 1/8 inches.

[d] Maximum of 1 1/2 inches.

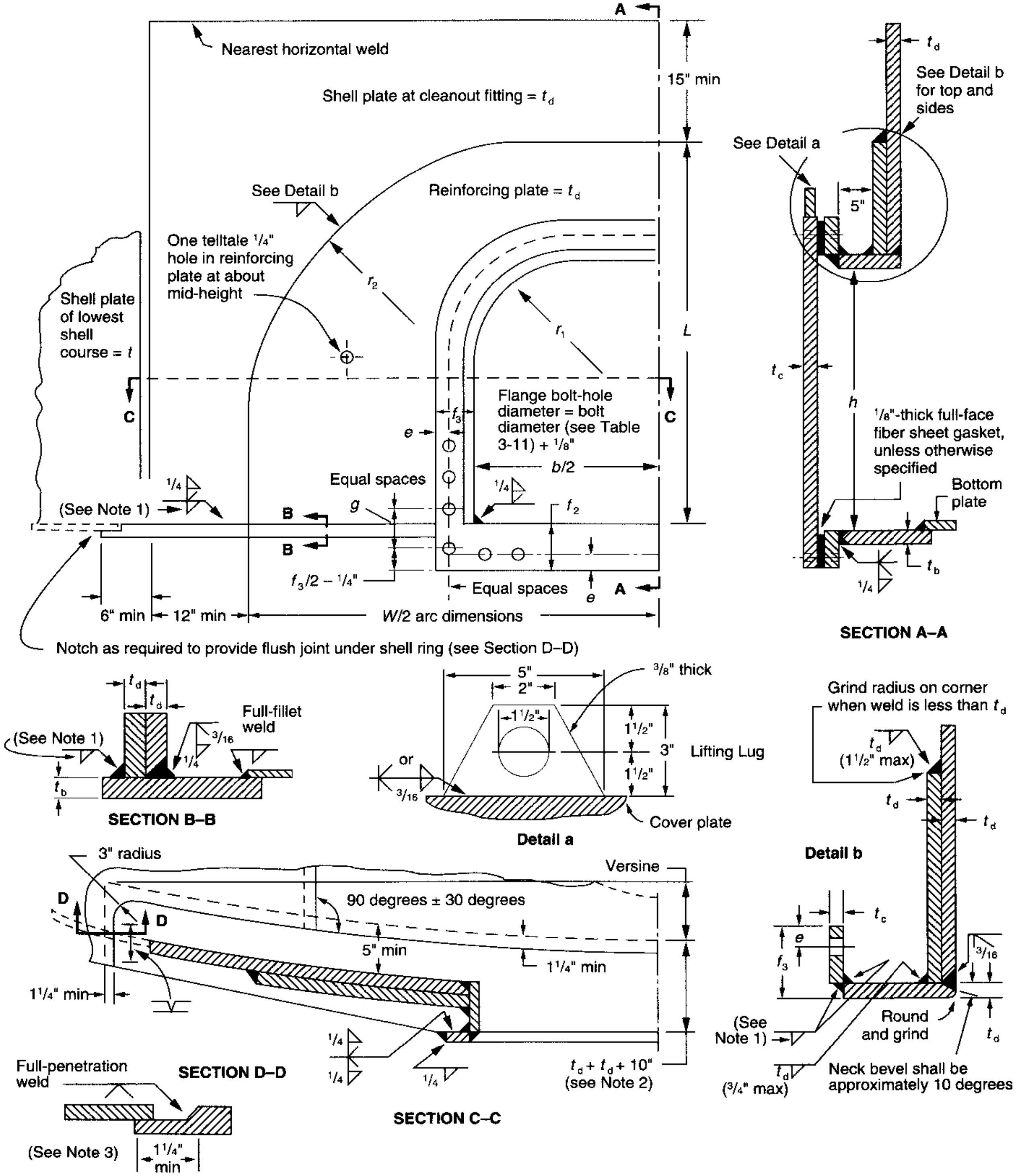
[e] Maximum of 1 3/4 inches.

Table 3-13—Thicknesses and Heights of Shell Reinforcing Plates for Flush-Type Cleanout Fittings (Inches)

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)							
		8 × 16		24 × 24		36 × 48		48 × 48	
Thickness of Lowest Shell Course t	Maximum Design Liquid Level[a] (feet) H	Thickness of Shell and Reinforcing Plate t_d	Height of Shell Reinforcing Plate L	Thickness of Shell and Reinforcing Plate t_d	Height of Shell Reinforcing Plate L	Thickness of Shell and Reinforcing Plate t_d	Height of Shell Reinforcing Plate L	Thickness of Shell and Reinforcing Plate t_d	Height of Shell Reinforcing Plate L
3/16	72	3/16	14	1/4	34 1/4	1/4	51 1/4	1/4	68 1/4
1/4	72	1/4	14	5/16	35 1/4	5/16	53	5/16	70 1/2
5/16	72	5/16	14	3/8	35 3/4	3/8	54	3/8	72
3/8	16	3/8	14	7/16	33	7/16	52 1/4	7/16	72
3/8	26	3/8	14	7/16	34 1/4	7/16	54	1/2	68
3/8	72	3/8	14	7/16	36	1/2	51	1/2	68 1/4
7/16	17	7/16	14	1/2	33 1/2	1/2	52	1/2	72
7/16	28	7/16	14	1/2	34	1/2	54	9/16	69
7/16	72	7/16	14	1/2	35 3/4	9/16	52	9/16	69 1/2
1/2	18	1/2	14	9/16	33 3/4	9/16	51 3/4	9/16	72
1/2	31	1/2	14	9/16	34	9/16	54	5/8	70
1/2	72	1/2	14	9/16	35 1/2	5/8	52 1/2	5/8	70 1/2
9/16	19	9/16	14	5/8	34	5/8	51 1/2	5/8	72
9/16	34	9/16	14	5/8	34	5/8	54	11/16	70 1/2
9/16	72	9/16	14	5/8	35 1/4	11/16	52 3/4	11/16	71
5/8	22	5/8	14	11/16	34	11/16	51 1/2	11/16	72
5/8	40	5/8	14	11/16	34	11/16	54	3/4	71
5/8	72	5/8	14	11/16	35	3/4	53	3/4	71 3/4
11/16	24	11/16	14	3/4	34 1/4	3/4	51 1/4	3/4	72
11/16	44	11/16	14	3/4	34 1/4	3/4	54	13/16	71 1/4
11/16	70	11/16	14	3/4	34 1/2	13/16	52 3/4	13/16	72
3/4	26	3/4	14	13/16	34 1/2	13/16	51 1/2	13/16	72
3/4	51	3/4	14	13/16	34 1/2	13/16	54	7/8	71 3/4
3/4	70	3/4	14	13/16	34 1/2	7/8	52 1/2	7/8	72
3/4	72	3/4	14	13/16	34 1/2	7/8	52 3/4	7/8	72
13/16	29	13/16	14	7/8	34 1/2	7/8	51 3/4	7/8	72
13/16	60	13/16	14	7/8	34 1/2	7/8	54	15/16	72
13/16	70	13/16	14	7/8	34 1/2	15/16	52 1/2	15/16	72
13/16	72	13/16	14	7/8	34 1/2	15/16	52 1/2	15/16	72
7/8	32	7/8	14	15/16	34 1/2	15/16	51 3/4	15/16	72
7/8	70	7/8	14	15/16	34 1/2	15/16	54	1	72
7/8	72	7/8	14	15/16	34 1/2	1	52 1/4	1	72
15/16	36	15/16	14	1	34 3/4	1	52	1	72
15/16	72	15/16	14	1	34 3/4	1	53 3/4	1 1/16	72
1	41	1	14	1 1/16	34 3/4	1 1/16	52	1 1/16	72
1	72	1	14	1 1/16	34 3/4	1 1/16	53 1/4	1 1/8	72
1 1/16	46	1 1/16	14	1 1/8	34 3/4	1 1/8	52 1/4	1 1/8	72
1 1/16	72	1 1/16	14	1 1/8	34 3/4	1 1/8	52 3/4	1 3/16	71 1/2
1 1/8	52	1 1/8	14	1 3/16	35	1 3/16	52 1/4	1 3/16	72
1 1/8	72	1 1/8	14	1 3/16	35	1 3/16	52 1/4	1 1/4	71 1/4
1 3/16	58	1 3/16	14	1 1/4	35	1 1/4	52 1/4	1 1/4	72
1 3/16	72	1 3/16	14	1 1/4	35	1 1/4	52 1/4	1 5/16	71
1 1/4	64	1 1/4	14	1 5/16	35	1 5/16	52 1/2	1 5/16	72
1 1/4	72	1 1/4	14	1 5/16	35	1 5/16	52 1/2	1 3/8	70 1/2
1 5/16	72	1 5/16	14	1 3/8	35	1 3/8	52 1/2	1 3/8	72
1 3/8	72	1 3/8	14	1 7/16	35	1 7/16	52 1/2	1 7/16	71
1 7/16	72	1 7/16	14	1 1/2	35 1/4	1 1/2	52 3/4	1 1/2	70 3/4
1 1/2	72	1 1/2	14	1 9/16	35 1/4	1 9/16	52 3/4	1 9/16	70 1/4
1 5/8	72	1 5/8	14	1 11/16	35 1/4	1 11/16	52 3/4	—	—
1 3/4	72	1 3/4	14	1 15/16	35 1/4	1 15/16	52 3/4	—	—

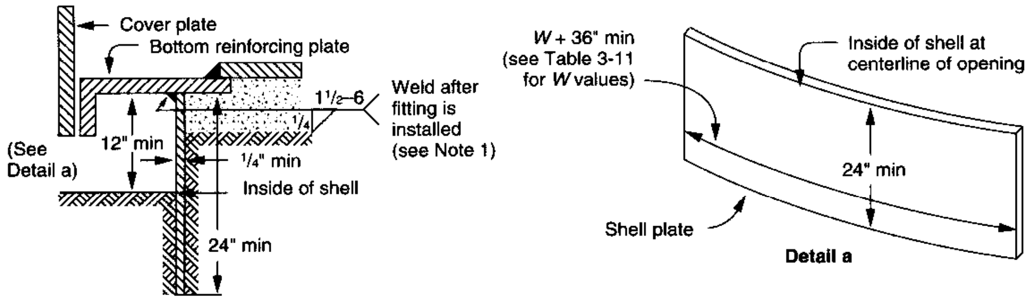
Note: See Figure 3-9. Dimensions t_d and L may be varied within the limits defined in 3.7.7.

[a] See 3.6.3.2.

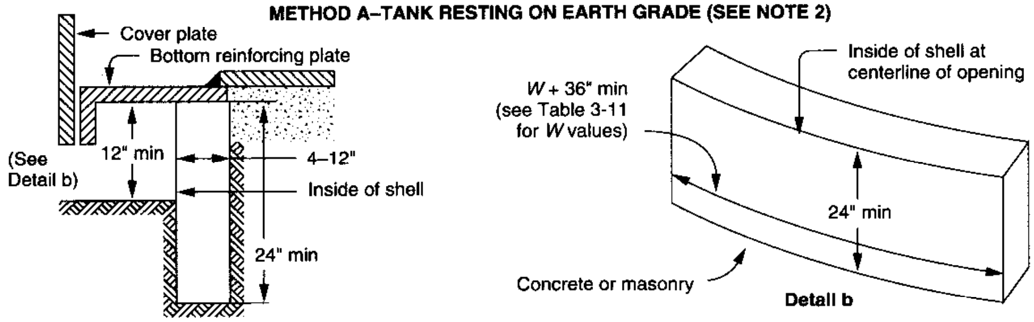


Notes:
1. Thickness of thinner plate joined (½ inch maximum).
2. When an annular plate is provided, the reinforcing plate shall be regarded as a segment of the annular plate and shall be the same width as the annular plate.
3. When the difference between the thickness of the annular ring and that of the bottom reinforcing plate is less than ¼ inch, 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. 94

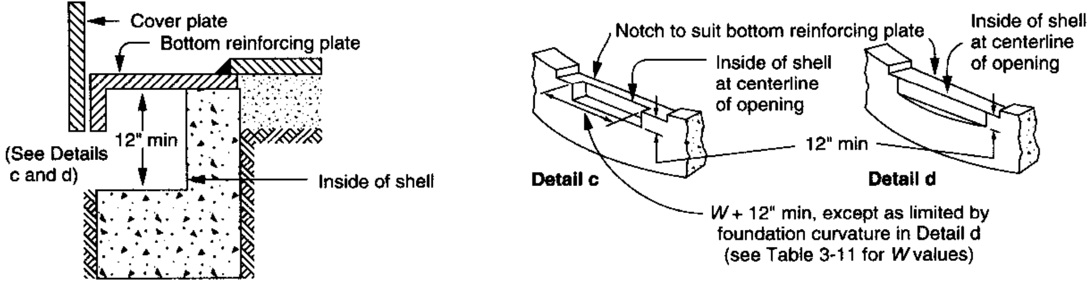
Figure 3-9—Flush-Type Cleanout Fittings (See Tables 3-11, 3-12, and 3-13)



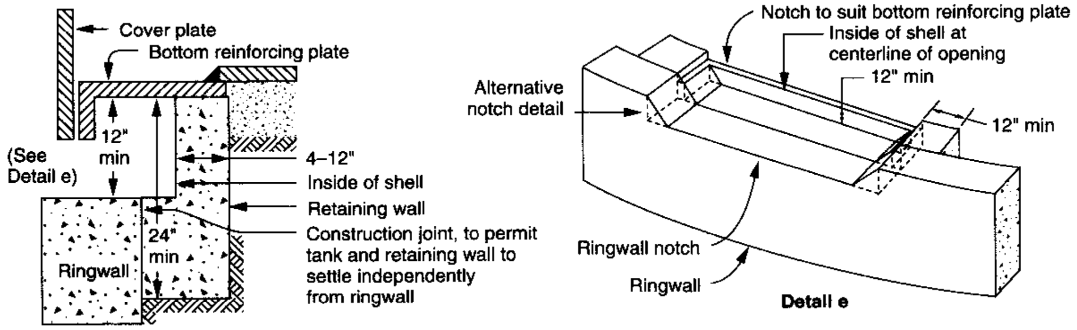
METHOD A–TANK RESTING ON EARTH GRADE (SEE NOTE 2)



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 12 inches.

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)

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 36 inches.
d. The maximum height, h, of the opening in the cylindrical shell shall not exceed 12 inches.
e. The thickness, t_a, of the bottom transition plate in the assembly shall be $\frac{1}{2}$ inch minimum or, when specified, the same as the thickness of the tank annular plate.

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 3-14 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 1100°F–1200°F for 1 hour per inch 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 assembly shall be at least $\frac{1}{16}$ inch but no more than $\frac{1}{8}$ inch greater than the thickness of the adjacent plates in the lowest shell course (except for the 8 × 8-inch opening, for which the plates may be of equal thickness).
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 6 inches. 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 10 inches 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):

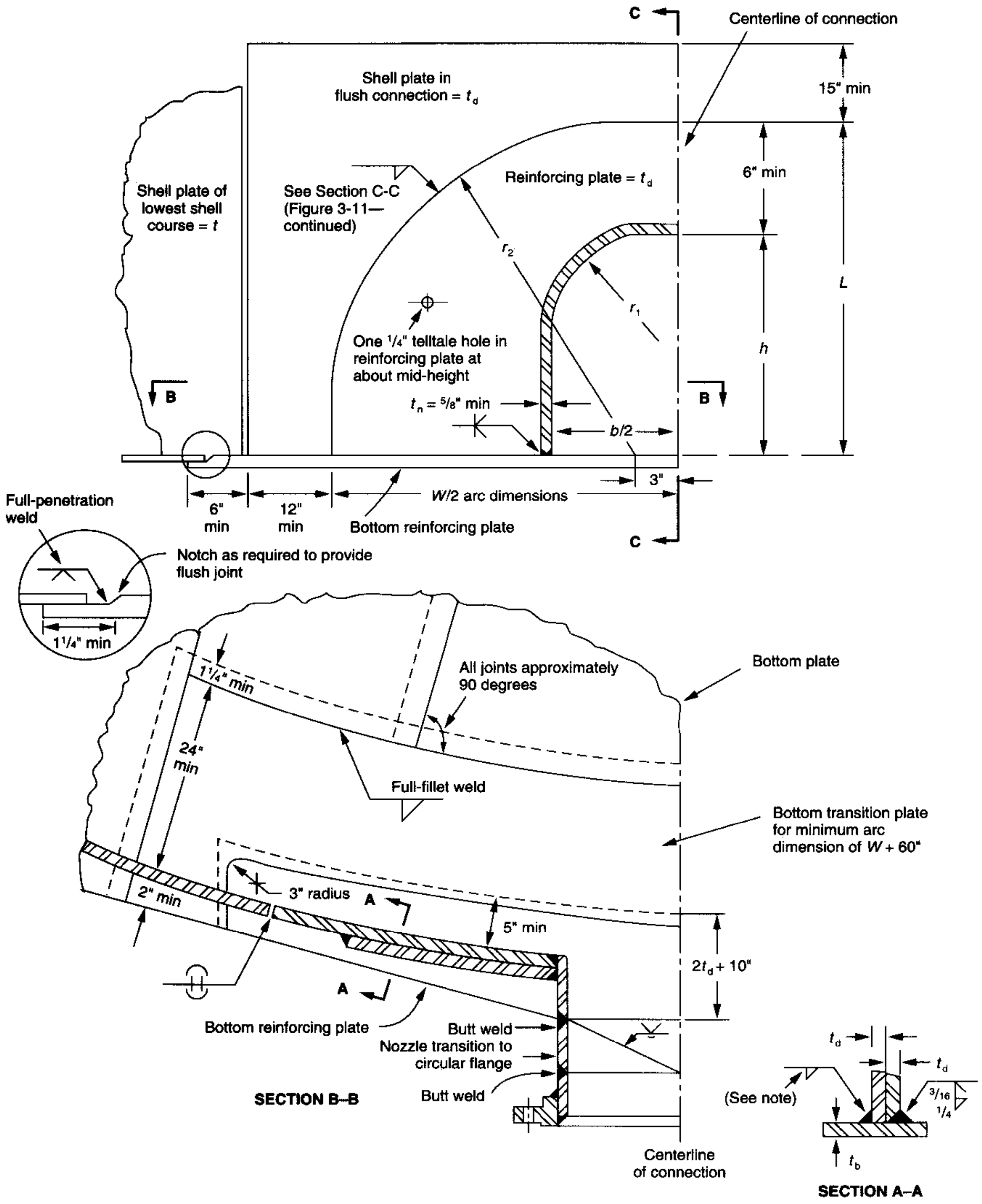
$$t_b = \frac{h^2}{14{,}000} + \frac{b}{310}\sqrt{H}$$

The minimum value of t_b shall be $\frac{5}{8}$ inch for $H = 48$, $\frac{11}{16}$ inch for $H = 56$, and $\frac{3}{4}$ inch for $H = 64$.
g. The minimum thickness of the nozzle neck and transition piece, t_n, shall be $\frac{5}{8}$ inch. External loads applied to the connection may require t_n to be greater than $\frac{5}{8}$ inch.

3.7.8.5 The material for the shell plate in the connection assembly, the shell reinforcing plate, the nozzle-neck plate, the bottom reinforcing plate, and the nozzle transition piece shall conform to 2.2.9 and Figure 2-1 for the respective thicknesses at the stated design metal temperature for the tank, and the strength of the material shall be consistent with the strength of the shell material. The material for the bolting flange and the bolting shall conform to 2.6 and 2.7.

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.



Note: Thickness of thinner plate joined (½ inch maximum).

Figure 3-11—Flush-Type Shell Connection