

Welded Tanks for Oil Storage

API STANDARD 650
THIRTEENTH EDITION, MARCH 2020

API MONOGRAM PROGRAM EFFECTIVE DATE: SEPTEMBER 1, 2020

ERRATA 1, JANUARY 2021



Special Notes

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

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

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 authorities having jurisdiction with which this publication may conflict.

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

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

API is not undertaking to meet the duties of employers, manufacturers, or suppliers to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions, nor undertaking their obligations to comply with authorities having jurisdiction.

All rights reserved. No part of this work may be reproduced, translated, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the Publisher, API Publishing Services, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001.

Copyright © 2019 American Petroleum Institute

Notice

Instructions for Submitting a Proposed Revision to this Standard Under Continuous Maintenance

The American Petroleum Institute maintains this standard under continuous maintenance procedures. These procedures establish a documented program for regular publication of addenda or revisions, including timely and documented consensus action on requests for revisions to any part of the standard. See Annex D for additional information. Proposed revisions shall be submitted to the Director, Standards Department, American Petroleum Institute, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001, standards@api.org.

Foreword

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

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

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

The verbal forms used to express the provisions in this document are as follows.

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

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

May: As used in a standard, "may" denotes a course of action permissible within the limits of a standard.

Can: As used in a standard, "can" denotes a statement of possibility or capability.

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

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

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

Important Information Concerning Use of Asbestos or Alternative Materials

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

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

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

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

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

Contents

	Page
1 Scope	1-1
1.1 General	1-1
1.2 Limitations	1-3
1.3 Responsibilities	1-4
1.4 Documentation Requirements	1-4
1.5 Formulas	1-4
2 Normative References	2-1
3 Terms and Definitions	3-1
4 Materials	4-1
4.1 General	4-1
4.2 Plates	4-2
4.3 Sheets	4-9
4.4 Structural Shapes	4-14
4.5 Piping and Forgings	4-14
4.6 Flanges	4-17
4.7 Bolting	4-17
4.8 Welding Electrodes	4-18
4.9 Gaskets	4-18
5 Design	5-1
5.1 Joints	5-1
5.2 Design Considerations	5-9
5.3 Special Considerations	5-12
5.4 Bottom Plates	5-14
5.5 Annular Bottom Plates	5-15
5.6 Shell Design	5-16
5.7 Shell Openings	5-28
5.8 Shell Attachments and Tank Appurtenances	5-67
5.9 Top and Intermediate Stiffening Rings (Wind Girders)	5-81
5.10 Roofs	5-92
5.11 Wind Load on Tanks (Overturning Stability)	5-100
5.12 Tank Anchorage	5-102
5.13 Downward Reactions on Foundations	5-110
6 Fabrication	6-1
6.1 General	6-1
6.2 Shop Inspection	6-2
7 Erection	7-1
7.1 General	7-1
7.2 Details of Welding	7-1
7.3 Examination, Inspection, and Repairs	7-5
7.4 Repairs to Welds	7-11
7.5 Dimensional Tolerances	7-12
8 Methods of Examining Joints	8-1
8.1 Radiographic Method	8-1
8.2 Magnetic Particle Examination	8-5
8.3 Ultrasonic Examination	8-5
8.4 Liquid Penetrant Examination	8-5

8.5 Visual Examination	8-6
8.6 Vacuum Testing	8-7
9 Welding Procedure and Welder Qualifications	9-1
9.1 Definitions	9-1
9.2 Qualification of Welding Procedures	9-1
9.3 Qualification of Welders	9-2
9.4 Identification of Welded Joints	9-3
10 Marking	10-1
10.1 Nameplates	10-1
10.2 Division of Responsibility	10-3
10.3 Certification	10-3
Annex A (normative) Optional Design Basis for Small Tanks	A-1
Annex AL (normative) Aluminum Storage Tanks	AL-1
Annex B (informative) Recommendations for Design and Construction of Foundations for Aboveground Oil Storage Tanks	B-1
Annex C (normative) External Floating Roofs	C-1
Annex D (informative) Inquiries and Suggestions for Change	D-1
Annex E (normative) Seismic Design of Storage Tanks	E-1
Annex EC (informative) Commentary on Annex E	EC-1
Annex F (normative) Design of Tanks for Small Internal Pressures	F-1
Annex G (normative) Structurally-Supported Aluminum Dome Roofs	G-1
Annex H (normative) Internal Floating Roofs	H-1
Annex I (normative) Undertank Leak Detection and Subgrade Protection	I-1
Annex J (normative) Shop-assembled Storage Tanks	J-1
Annex K (informative) Sample Applications of the Variable-Design-Point Method to Determine Shell-Plate Thickness	K-1
Annex L (normative) API Standard 650 Storage Tank Data Sheet	L-1
Annex M (normative) Requirements for Tanks Operating at Elevated Temperatures	M-1
Annex N (normative) Use of New Materials That Are Not Identified	N-1
Annex O (normative) Under-bottom Connections	O-1
Annex P (normative) Allowable External Loads on Tank Shell Openings	P-1
Annex R (informative) References for Tanks in Non-petroleum Product Service	R-1
Annex S (normative) Austenitic Stainless Steel Storage Tanks	S-1
Annex SC (normative) Stainless and Carbon Steel Mixed Materials Storage Tanks	SC-1
Annex T (informative) NDE Requirements Summary	T-1
Annex U (normative) Ultrasonic Examination in Lieu of Radiography	U-1
Annex V (normative) Design of Storage Tanks for External Pressure	V-1
Annex W (normative) Commercial and Documentation Recommendations	W-1
Annex X (normative) Duplex Stainless Steel Storage Tanks	X-1
Annex Y (normative) API Monogram	Y-1

Bibliography	Y-5
---------------------------	------------

Figures

4.1a	Minimum Permissible Design Metal Temperature for Materials Used in Tank Shells without Impact Testing (SI)	4-7
4.1b	Minimum Permissible Design Metal Temperature for Materials Used in Tank Shells without Impact Testing (USC)	4-8
4.2	Isothermal Lines of Lowest One-day Mean Temperatures (°F)	4-10
4.3	Governing Thickness for Impact Test Determination of Shell Nozzle and Manhole Materials	4-16
5.1	Typical Vertical Shell Joints	5-3
5.2	Typical Horizontal Shell Joints	5-4
5.3a	Typical Roof and Bottom Joints	5-5
5.3b	Method for Preparing Lap-welded Bottom Plates under Tank Shell	5-6
5.3c	Detail of Double Fillet-groove Weld for Annular Bottom Plates with a Nominal Thickness Greater than 13 mm (1/2 in.)	5-6
5.3d	Spacing of Three-plate Welds at Annular Plates	5-7
5.4	Storage Tank	5-13
5.5	Drip Ring (Suggested Detail)	5-15
5.6	Minimum Weld Requirements for Openings in Shells According to 5.7.3	5-29
5.7a	Shell Manhole	5-34
5.7b	Details of Shell Manholes and Nozzles	5-35
5.8	Shell Nozzles	5-36
5.9	Minimum Spacing of Welds and Extent of Related Radiographic Examination	5-50
5.10	Shell Nozzle Flanges	5-55
5.11	Area Coefficient for Determining Minimum Reinforcement of Flush-type Cleanout Fittings	5-57
5.12	Flush-type Cleanout Fittings	5-58
5.13	Flush-type Cleanout Fitting Supports	5-59
5.14	Flush-type Shell Connection	5-65
5.15	Rotation of Shell Connection	5-68
5.16	Roof Manholes	5-71
5.17	Rectangular Roof Openings with Flanged Covers	5-75
5.18	Rectangular Roof Openings with Hinged Cover	5-76
5.19	Flanged Roof Nozzles	5-77
5.20	Threaded Roof Nozzles	5-77
5.21	Drawoff Sump	5-77
5.22	Scaffold Cable Support	5-78
5.23	Grounding Lug	5-80
5.24	Typical Stiffening-ring Sections for Tank Shells	5-84
5.25	Stairway Opening through Stiffening Ring	5-87
5.26	Some Acceptable Column Base Details	5-97
5.27	Overturning Check for Self-anchored Tanks	5-100
5.28	Typical Anchor Chair	5-107
5.29	Typical Anchor Strap Welded Attachment (for Carbon Steel Tank)	5-108
5.30	Typical Hold-Down Strap Configuration (for Carbon Steel Tank)	5-109
5.31	Butt Weld Joint with Back-up Bar	5-110
6.1	Shaping of Plates	6-2
8.1	Radiographic Requirements for Tank Shells	8-2
10.1	Manufacturer's Nameplate	10-1
10.2	Manufacturer's Certification Letter	10-3
AL.1	Cover Plate Thickness for Shell Manholes and Cleanout Fittings	AL-13
AL.2	Flange Plate Thickness for Shell Manholes and Cleanout Fittings	AL-14
AL.3	Bottom Reinforcing Plate Thickness for Cleanout Fittings	AL-15

AL.4	Stresses in Roof Plates	AL-18
B.1	Example of Foundation with Concrete Ringwall	B-4
B.2	Example of Foundation with Crushed Stone Ringwall	B-5
E.1	Coefficient C_i	E-13
EC.1	Maximum Earthquake Response Spectrum	EC-4
EC.2	Earthquake Response Spectrum Notation	EC-4
EC.3	Site Specific Response Spectrum	EC-5
EC.4	Deterministic Lower Limit on MCE Response Spectrum	EC-5
EC.5	Relationship of Probabilistic and Deterministic Response Spectra	EC-6
EC.6	Sloshing Factor, K_s	EC-7
EC.7	Design Response Spectra for Ground-Supported Liquid Storage Tanks	EC-8
EC.8	Effective Weight of Liquid Ratio	EC-10
EC.9	Center of Action of Effective Forces	EC-10
EC.10	Overturning Moment	EC-12
F.1	Annex F Decision Tree	F-2
F.2	Permissible Details of Compression Rings	F-3
G.1	Data Sheet for a Structurally-Supported Aluminum Dome Added to an Existing Tank	G-2
G.2	Typical Roof Nozzle	G-8
I.1	Concrete Ringwall with Undertank Lead Detection at the Tank Perimeter (Typical Arrangement)	I-2
I.2	Crushed Stone Ringwall with Undertank Leak Detection at the Tank Perimeter (Typical Arrangement)	I-3
I.3	Earthen Foundation with Undertank Leak Detection at the Tank Perimeter (Typical Arrangement)	I-3
I.4	Double Steel Bottom with Leak Detection at the Tank Perimeter (Typical Arrangement)	I-3
I.5	Double Steel Bottom with Leak Detection at the Tank Perimeter (Typical Arrangement)	I-5
I.6	Reinforced Concrete Slab with Leak Detection at the Perimeter (Typical Arrangement)	I-5
I.7	Reinforced Concrete Slab	I-6
I.8	Typical Drawoff Sump	I-7
I.9	Center Sump for Downward-Sloped Bottom	I-7
I.10	Typical Leak Detection Wells	I-8
I.11	Tanks Supported by Grillage Members (General Arrangement)	I-9
O.1	Example of Under-bottom Connection with Concrete Ringwall Foundation	O-3
O.2	Example of Under-bottom Connection with Concrete Ringwall Foundation and Improved Tank Bottom and Shell Support	O-4
O.3	Example of Under-bottom Connection with Earth-type Foundation	O-5
P.1	Nomenclature for Piping Loads and Deformation	P-4
P.2a	Stiffness Coefficient for Radial Load: Reinforcement on Shell ($L/2a = 1.0$)	P-6
P.2b	Stiffness Coefficient for Longitudinal Moment: Reinforcement on Shell ($L/2a = 1.0$)	P-6
P.2c	Stiffness Coefficient for Circumferential Moment: Reinforcement on Shell ($L/2a = 1.0$)	P-7
P.2d	Stiffness Coefficient for Radial Load: Reinforcement on Shell ($L/2a = 1.5$)	P-7
P.2e	Stiffness Coefficient for Longitudinal Moment: Reinforcement on Shell ($L/2a = 1.5$)	P-8
P.2f	Stiffness Coefficient for Circumferential Moment: Reinforcement on Shell ($L/2a = 1.5$)	P-8
P.2g	Stiffness Coefficient for Radial Load: Reinforcement in Nozzle Neck Only ($L/2a = 1.0$)	P-9
P.2h	Stiffness Coefficient for Longitudinal Moment: Reinforcement in Nozzle Neck Only ($L/2a = 1.0$)	P-9
P.2i	Stiffness Coefficient for Circumferential Moment: Reinforcement in Nozzle Neck Only ($L/2a = 1.0$)	P-10
P.2j	Stiffness Coefficient for Radial Load: Reinforcement in Nozzle Neck Only ($L/2a = 1.5$)	P-10
P.2k	Stiffness Coefficient for Longitudinal Moment: Reinforcement in Nozzle Neck Only ($L/2a = 1.5$)	P-11

P.2I	Stiffness Coefficient for Circumferential Moment: Reinforcement in Nozzle Neck Only ($L/2a = 1.5$)	P-11
P.3a	Construction of Nomogram for b_1, b_2, c_1, c_2 Boundary	P-12
P.3b	Construction of Nomogram for b_1, c_3 Boundary	P-12
P.4a	Obtaining Coefficients Y_F and Y_L	P-13
P.4b	Obtaining Coefficient Y_C	P-14
P.5a	Determination of Allowable Loads from Nomogram: F_R and M_L	P-15
P.5b	Determination of Allowable Loads from Nomogram: F_R and M_C	P-15
P.6	Low-type Nozzle with Reinforcement on Shell	P-16
P.7	Allowable-load Nomograms for Sample Problem	P-21
V.1a	Dimensions for Self-supporting Cone Roof	V-6
V.1b	Dimensions for Self-supporting Dome Roof	V-9

Tables

1.1	Deleted	
4.1	Maximum Permissible Alloy Content	4-5
4.2	Acceptable Grades of Plate Material Produced to National Standards	4-5
4.3a	Linear Equations for Figure 4.1a (SI)	4-9
4.3b	Linear Equations for Figure 4.1b (USC)	4-9
4.4a	Material Groups (SI)	4-11
4.4b	Material Groups (USC)	4-12
4.5a	Minimum Impact Test Requirements for Plates (SI)	4-13
4.5b	Minimum Impact Test Requirements for Plates (USC)	4-13
5.1a	Annular Bottom-plate Thicknesses (t_b) (SI)	5-16
5.1b	Annular Bottom-plate Thicknesses (t_b) (USC)	5-17
5.2a	Permissible Plate Materials and Allowable Stresses (SI)	5-18
5.2b	Permissible Plate Materials and Allowable Stresses (USC)	5-21
5.3a	Thickness of Shell Manhole Cover Plate and Bolting Flange (SI)	5-30
5.3b	Thickness of Shell Manhole Cover Plate and Bolting Flange (USC)	5-30
5.4a	Dimensions for Shell Manhole Neck Thickness (SI)	5-31
5.4b	Dimensions for Shell Manhole Neck Thickness (USC)	5-32
5.5a	Dimensions for Bolt Circle Diameter D_b and Cover Plate Diameter D_b for Shell Manholes (SI)	5-33
5.5b	Dimensions for Bolt Circle Diameter D_b and Cover Plate Diameter D_b for Shell Manholes (USC)	5-33
5.6a	Dimensions for Shell Nozzles (SI)	5-37
5.6b	Dimensions for Shell Nozzles (USC)	5-39
5.7a	Dimensions for Shell Nozzles: Pipe, Plate, and Welding Schedules (SI)	5-40
5.7b	Dimensions for Shell Nozzles: Pipe, Plate, and Welding Schedules (USC)	5-42
5.8a	Dimensions for Shell Nozzle Flanges (SI)	5-43
5.8b	Dimensions for Shell Nozzle Flanges (USC)	5-44
5.9a	Dimensions for Flush-type Cleanout Fittings (SI)	5-45
5.9b	Dimensions for Flush-type Cleanout Fittings (USC)	5-45
5.10a	Minimum Thickness of Cover Plate, Bolting Flange, and Bottom Reinforcing Plate for Flush-Type Cleanout Fittings (SI)	5-46
5.10b	Minimum Thickness of Cover Plate, Bolting Flange, and Bottom Reinforcing Plate for Flush-Type Cleanout Fittings (USC)	5-46
5.11a	Thicknesses and Heights of Shell Reinforcing Plates for Flush-type Cleanout Fittings (SI)	5-47
5.11b	Thicknesses and Heights of Shell Reinforcing Plates for Flush-type Cleanout Fittings (USC)	5-47
5.12a	Dimensions for Flush-type Shell Connections (SI)	5-63
5.12b	Dimensions for Flush-type Shell Connections (USC)	5-64
5.13a	Dimensions for Roof Manholes (SI)	5-70
5.13b	Dimensions for Roof Manholes (USC)	5-70
5.14a	Dimensions for Flanged Roof Nozzles (SI)	5-73

5.14b	Dimensions for Flanged Roof Nozzles (USC)	5-73
5.15a	Dimensions for Threaded Roof Nozzles (SI)	5-74
5.15b	Dimensions for Threaded Roof Nozzles (USC)	5-74
5.16a	Dimensions for Drawoff Sumps (SI)	5-78
5.16b	Dimensions for Drawoff Sumps (USC)	5-78
5.17	Requirements for Platforms and Walkways	5-79
5.18	Requirements for Stairways	5-79
5.19a	Section Moduli (cm ³) of Stiffening-Ring Sections on Tank Shells (SI)	5-85
5.19b	Section Moduli (in. ³) of Stiffening-Ring Sections on Tank Shells (USC)	5-86
5.20a	Uplift Loads (SI)	5-103
5.20b	Uplift Loads (USC)	5-104
5.21	Unfactored (Working Stress) Downward Reactions on Foundations	5-111
7.1a	Minimum Preheat Temperatures (SI)	7-2
7.1b	Minimum Preheat Temperatures (USC)	7-2
A.1a	Typical Sizes and Corresponding Nominal Capacities (m ³) for Tanks with 1800-mm Courses (SI)	A-2
A.1b	Typical Sizes and Corresponding Nominal Capacities (Barrels) for Tanks with 72-in. Courses (USC)	A-3
A.2a	Typical Sizes and Corresponding Nominal Capacities (m ³) for Tanks with 2400-mm Courses (SI)	A-4
A.2b	Typical Sizes and Corresponding Nominal Capacities (Barrels) for Tanks with 96-in. Courses (USC)	A-5
AL.1	Material Specifications	AL-3
AL.2	Joint Efficiency	AL-4
AL.3a	Minimum Mechanical Properties (SI)	AL-4
AL.3b	Minimum Mechanical Properties (USC)	AL-5
AL.4a	Annular Bottom Plate Thickness (SI)	AL-8
AL.4b	Annular Bottom Plate Thickness (USC)	AL-9
AL.5a	Minimum Shell Thickness (SI)	AL-9
AL.5b	Minimum Shell Thickness (USC)	AL-9
AL.6a	Allowable Tensile Stresses for Tank Shell (for Design and Test) (SI)	AL-11
AL.6b	Allowable Tensile Stresses for Tank Shell (for Design and Test) (USC)	AL-12
AL.7a	Allowable Stresses for Roof Plates (SI)	AL-17
AL.7b	Allowable Stresses for Roof Plates (USC)	AL-17
AL.8a	Compressive Moduli of Elasticity E (MPa) at Temperature (°C) (SI)	AL-19
AL.8b	Compressive Moduli of Elasticity E (ksi) at Temperature (°F) (USC)	AL-19
AL.9a	Shell Nozzle Welding Schedule (SI)	AL-20
AL.9b	Shell Nozzle Welding Schedule (USC)	AL-21
E.1	Value of F_a as a Function of Site Class	E-9
E.2	Value of F_v as a Function of Site Class	E-9
E.3	Site Classification	E-12
E.4	Response Modification Factors for ASD Methods	E-15
E.5	Importance Factor (I) and Seismic Use Group Classification	E-16
E.6	Anchorage Ratio Criteria	E-22
E.7	Minimum Required Freeboard	E-26
E.8	Design Displacements for Piping Attachments	E-27
J.1a	Minimum Roof Depths for Shop-assembled Dome-roof Tanks (SI)	J-2
J.1b	Minimum Roof Depths for Shop-assembled Dome-roof Tanks (USC)	J-3
K.1a	Shell-plate Thicknesses Based on the Variable-design-point Method Using 2400-mm Courses and an Allowable Stress of 159 MPa for the Test Condition (SI)	K-18
K.1b	Shell-plate Thicknesses Based on the Variable-design-point Method Using 96-in. Courses and an Allowable Stress of 23,000 lbf/in. ² for the Test Condition (USC)	K-19

K.2a	Shell-plate Thicknesses Based on the Variable-design-point Method Using 2400-mm Courses and an Allowable Stress of 208 MPa for the Test Condition (SI)	K-20
K.2b	Shell-plate Thicknesses Based on the Variable-design-point Method Using 96-in. Courses and an Allowable Stress of 30,000 lbf/in. ² for the Test Condition (USC)	K-21
K.3a	Shell-plate Thicknesses Based on the Variable-design-point Method Using 2400-mm Courses and an Allowable Stress of 236 MPa for the Test Condition (SI)	K-22
K.3b	Shell-plate Thicknesses Based on the Variable-design-point Method Using 96-in. Courses and an Allowable Stress of 34,300 lbf/in. ² for the Test Condition (USC)	K-23
L.1	Index of Decisions or Actions That May be Required of the Tank Purchaser.	L-28
M.1a	Yield Strength Reduction Factors (SI)	M-3
M.1b	Yield Strength Reduction Factors (USC)	M-3
M.2a	Modulus of Elasticity at the Maximum Design Temperature (SI)	M-6
M.2b	Modulus of Elasticity at the Maximum Design Temperature (USC)	M-7
O.1a	Dimensions of Under-Bottom Connections (SI)	O-2
O.1b	Dimensions of Under-Bottom Connections (USC)	O-2
P.1a	Modulus of Elasticity and Thermal Expansion Coefficient at the Design Temperature (SI)	P-3
P.1b	Modulus of Elasticity and Thermal Expansion Coefficient at the Design Temperature (USC)	P-3
S.1a	ASTM Materials for Stainless Steel Components (SI)	S-2
S.1b	ASTM Materials for Stainless Steel Components (USC)	S-3
S.2a	Allowable Stresses for Tank Shells (SI)	S-8
S.2b	Allowable Stresses for Tank Shells (USC)	S-8
S.3a	Allowable Stresses for Plate Ring Flanges (SI)	S-9
S.3b	Allowable Stresses for Plate Ring Flanges (USC)	S-9
S.4	Joint Efficiencies	S-10
S.5a	Yield Strength Values in MPa (SI)	S-10
S.5b	Yield Strength Values in psi (USC)	S-10
S.6a	Modulus of Elasticity at the Maximum Design Temperature (SI)	S-11
S.6b	Modulus of Elasticity at the Maximum Design Temperature (USC)	S-11
U.1a	Flaw Acceptance Criteria for UT Indications May be Used for All Materials (SI)	U-5
U.1b	Flaw Acceptance Criteria for UT Indications May be Used for All Materials (USC)	U-6
X.1	ASTM Materials for Duplex Stainless Steel Components	X-2
X.2a	Allowable Stresses for Tank Shells (SI)	X-5
X.2b	Allowable Stresses for Tank Shells (USC)	X-6
X.3	Joint Efficiencies	X-6
X.4a	Yield Strength Values in MPa	X-8
X.4b	Yield Strength Values in PSI	X-8
X.5a	Modulus of Elasticity at the Maximum Design Temperature (SI)	X-9
X.5b	Modulus of Elasticity at the Maximum Design Temperature (USC)	X-9
X.6a	Hot Forming Temperatures (SI)	X-10
X.6b	Hot Forming Temperatures (USC)	X-10

Welded Tanks for Oil Storage

SECTION 1—SCOPE

1.1 General

1.1.1 This standard establishes minimum requirements for material, design, fabrication, erection, and inspection for vertical, cylindrical, aboveground, closed- and open-top, welded 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 1.1.13). This standard applies only to tanks whose entire bottom is uniformly supported and to tanks in non-refrigerated service that have a maximum design temperature of 93 °C (200 °F) or less (see 1.1.20).

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

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

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

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

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

- **1.1.5** Field-erected tanks shall be furnished completely erected, inspected, and ready for service connections, unless specified otherwise. Shop-fabricated tanks shall be furnished inspected and ready for installation.
- **1.1.6** The annexes of this standard provide a number of design options requiring decisions by the Purchaser, standard requirements, recommendations, and information that supplements the basic standard. Except for Annex L, an Annex becomes a requirement only when the Purchaser specifies an option covered by that Annex or specifies the entire Annex. The designation "Normative" shall be understood to mean mandatory. The designation "informative" shall be understood to mean non-mandatory (i.e. informational data, recommendations, suggestions, commentary, samples, and examples).

The contents of the annexes to this standard are either "normative" or "informative."

"Normative" is further divided into the following.

— Always required (L).

- Required if specified by the Purchaser (A, E, J, Y, U, W).
- Required if special materials are specified by the Purchaser (AL, N, S, SC, X).
- Required if pressure, vacuum, and high temperature are specified by the Purchaser (F, V, M).
- Required if special components or methods of design or construction are specified by the Purchaser (C, G, H, I, O, P).

All other annexes are “informative” (B, D, EC, K, R, T).

Table 1.1 deleted

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

1.1.8 Annex AL provides requirements for aluminum tanks.

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

1.1.10 Annex C provides minimum requirements for pontoon-type and double-deck-type external floating roofs.

1.1.11 Annex D provides requirements for submission of technical inquiries regarding this standard.

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

1.1.13 Annex F provides requirements for the design of tanks subject to a small internal pressure.

1.1.14 Annex G provides requirements for aluminum dome roofs.

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

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

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

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

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

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

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

1.1.22 Annex O provides requirements and recommendations for the design and construction of under-bottom connections for storage tanks.

- **1.1.23** Annex P provides requirements for design of shell openings that conform to Table 5.6a and Table 5.6b that are subject to external piping loads. An alternative or supplemental design may be agreed upon by the Purchaser or Manufacturer.

1.1.24 Annex R provides references to various industry documents and publications that provide additional guidance for both specific design and material selection considerations to reduce or prevent accelerated corrosion mechanisms from damaging a tank in non-petroleum product service.

1.1.25 Annex S provides requirements for stainless steel tanks.

1.1.26 Annex SC provides requirements for mixed material tanks using stainless steel (including austenitic and duplex) and carbon steel in the same tank for shell rings, bottom plates, roof structure, and other parts of a tank requiring high corrosion resistance.

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

1.1.28 Annex U provides requirements covering the substitution of ultrasonic examination in lieu of radiographic examination.

1.1.29 Annex V provides additional requirements for tanks that are designed for external pressure (vacuum) loading greater than 0.25 kPa (1 in. water).

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

1.1.31 Annex X provides requirements for duplex stainless steel tanks.

1.1.32 Annex Y provides requirements for API Licensees wishing to mark their products with the API Monogram.

1.2 Limitations

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

- a) The face of the first flange in bolted flanged connections, unless covers or blinds are provided as permitted in this standard.
- b) The first sealing surface for proprietary connections or fittings.
- c) The first threaded joint on the pipe in a threaded connection to the tank shell.

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

1.3 Responsibilities

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

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

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

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

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

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

- **1.4 Documentation Requirements**

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

1.5 Formulas

Where units are not defined in formulas in this standard, use consistent units (for example, in., in.², in.³, lbf/in.²).

SECTION 2—NORMATIVE REFERENCES

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Standard 620, *Design and Construction of Large, Welded, Low-Pressure Storage Tanks*

API Standard 2000, *Venting Atmospheric and Low-Pressure Storage Tanks: Non-refrigerated and Refrigerated*

API Specification 5L, *Specification for Line Pipe*

AAI ¹, *Aluminum Design Manual*

AAI, *Aluminum Standards and Data*

AAI, *Specifications for Aluminum Sheet Metal Work in Building Construction*

ACI 318 ², *Building Code Requirements for Reinforced Concrete (ANSI/ACI 318)*

ACI 350, *Environmental Engineering Concrete Structures*

AISC ³, *Design Guide 27, Structural Stainless Steel*

AISC, *Manual of Steel Construction*

ANSI/AISC 360 ⁴, *Specification for Structural Steel Buildings*

ASCE Standard 7-05 ⁵, *Minimum Design Loads for Buildings and Other Structures*

ASCE Standard 7-10, *Minimum Design Loads for Buildings and Other Structures*

ASME B1.20.1 ⁶, *Pipe Threads, General Purpose (Inch) (ANSI/ASME B1.20.1)*

ASME B16.1, *Cast Iron Pipe Flanges and Flanged Fittings (ANSI/ASME B16.1)*

ASME B16.5, *Pipe Flanges and Flanged Fittings (ANSI/ASME B16.5)*

ASME B16.21, *Nonmetallic Flat Gaskets for Pipe Flanges*

ASME B16.47, *Large Diameter Steel Flanges: NPS 26 Through NPS 60 (ANSI/ASME B16.47)*

ASME *Boiler and Pressure Vessel Code*, Section V, "Nondestructive Examination;" Section VIII, "Pressure Vessels," Division 1; and Section IX, "Welding and Brazing Qualifications"

ASNT CP-189 ⁷, *Standard for Qualification and Certification of Nondestructive Testing Personnel*

¹ Aluminum Association Inc., 1400 Crystal Drive, Suite 430, Arlington, Virginia 22202, www.aluminum.org

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

³ American Institute of Steel Construction, One East Wacker Drive, Suite 700, Chicago, Illinois 60601, www.aisc.org

⁴ American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, New York 10036, www.ansi.org

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

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

⁷ American Society for Nondestructive Testing, 1711 Arlinggate Lane, P.O. Box 28518, Columbus, Ohio 43228, www.asnt.org

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

ASTM A6M/A6 ⁸, *General Requirements for Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use*

ASTM A20M/A20, *General Requirements for Steel Plates for Pressure Vessels*

ASTM A27M/A27, *Steel Castings, Carbon, for General Application*

ASTM A36M/A36, *Structural Steel*

ASTM A53, *Pipe, Steel, Black and Hot-Dipped, Zinc-Coated Welded and Seamless*

ASTM A105M/A105, *Forgings, Carbon Steel, for Piping Components*

ASTM A106, *Seamless Carbon Steel Pipe for High-Temperature Service*

ASTM A131M/A131, *Structural Steel for Ships*

ASTM A181M/A181, *Forgings, Carbon Steel, for General-Purpose Piping*

ASTM A182M/A182, *Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service*

ASTM A193M/A193, *Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service*

ASTM A194M/A194, *Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service*

ASTM A213M/A213, *Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes*

ASTM A216M/A216, *Standard Specifications for Steel Castings for High-Temperature Service*

ASTM A234M/A234, *Piping Fittings of Wrought Carbon Steel and Alloy Steel for Moderate and High-Temperature Service*

ASTM A240M/A240, *Heat-Resisting Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels*

ASTM A276, *Stainless Steel Bars and Shapes*

ASTM A283M/A283, *Low and Intermediate Tensile Strength Carbon Steel Plates*

ASTM A285M/A285, *Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength*

ASTM A307, *Carbon Steel Bolts and Studs, 60,000 lbf/in.² Tensile Strength*

ASTM A312M/A312, *Seamless and Welded Austenitic Stainless Steel Pipes*

ASTM A320M/A320, *Alloy Steel Bolting Materials for Low-Temperature Service*

ASTM A333M/A333, *Seamless and Welded Steel Pipe for Low-Temperature Service*

ASTM A334M/A334, *Seamless and Welded Carbon and Alloy-Steel Tubes for Low-Temperature Service*

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

ASTM A350M/A350, *Forgings, Carbon and Low-Alloy Steel, Requiring Notch Toughness Testing for Piping Components*

ASTM A351M/A351, *Castings, Austenitic, Austenitic-Ferritic (Duplex), for Pressure-Containing Parts*

ASTM A358M/A358, *Electric-Fusion-Welded Austenitic Chromium-Nickel Alloy Steel Pipe for High-Temperature Service*

ASTM A370, *Test Methods and Definitions for Mechanical Testing of Steel Products*

ASTM A380, *Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems*

ASTM A403M/A403, *Wrought Austenitic Stainless Steel Piping Fittings*

ASTM A420M/A420, *Piping Fittings of Wrought Carbon Steel and Alloy Steel for Low-Temperature Service*

ASTM A479M/A479, *Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels*

ASTM A480M/A480, *Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip*

ASTM A516M/A516, *Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service*

ASTM A524, *Seamless Carbon Steel Pipe for Atmospheric and Lower Temperatures*

ASTM A537M/A537, *Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel*

ASTM A573M/A573, *Structural Carbon Steel Plates of Improved Toughness*

ASTM A633M/A633, *Normalized High-Strength Low-Alloy Structural Steel*

ASTM A662M/A662, *Pressure Vessel Plates, Carbon-Manganese, for Moderate and Lower Temperature Service*

ASTM A671, *Electric-Fusion-Welded Steel Pipe for Atmospheric and Lower Temperatures*

ASTM A737M/A737, *Pressure Vessel Plates, High-Strength, Low-Alloy Steel*

ASTM A841M/A841, *Standard Specification for Steel Plates for Pressure Vessels, Produced by the Thermo-Mechanical Control Process (TMCP)*

ASTM A924M/A924, *General Requirements for Steel Sheet, Metallic-Coated by the Hot-Dip Process*

ASTM A992M/A992, *Steel for Structural Shapes for Use in Building Framing*

ASTM A1011M/A1011, *Standard Specification for Steel, Sheet and Strip, Hot-Rolled, Carbon, Structural, High-Strength Low-Alloy and High-Strength Low-Alloy with Improved Formability*

ASTM C509, *Cellular Elastomeric Preformed Gasket and Sealing Material*

ASTM D3453, *Flexible Cellular Materials—Urethane for Furniture and Automotive Cushioning, Bedding, and Similar Applications*

ASTM F467, *Standard Specification for Nonferrous Nuts for General Use*

ASTM F467M, *Standard Specification for Nonferrous Nuts for General Use [Metric]*

ASTM F468, *Standard Specification for Nonferrous Bolts, Hex Cap Screws, and Studs for General Use*

ASTM F468M, *Standard Specification for Nonferrous Bolts, Hex Cap Screws, and Studs for General Use [Metric]*

ASTM F593, *Standard Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs*

ASTM F594, *Standard Specification for Stainless Steel Nuts*

AWS A5.1 ⁹, *Specification for Carbon Steel Covered Arc-Welding Electrodes (ANSI/AWS A5.1)*

AWS A5.5, *Specification for Low-Alloy Steel Covered Arc-Welding Electrodes (ANSI/AWS A5.5)*

AWS D1.2, *Structural Welding Code—Aluminum (ANSI/AWS D1.2)*

CSA G40.21 ¹⁰, *Structural Quality Steels, Supplement to National Building Code of Canada*

EN 10025 ¹¹, *Hot Rolled Products of Structural Steels*

ISO 630 ¹², *Structural Steels*

ISO 9712, *Non-destructive testing – Qualification and certification of NDT personnel*

NFPA 11 ¹³, *Standard for Low Expansion Foam*

NFPA 30, *Flammable and Combustible Liquids Code*

U.S. Federal Specifications ¹⁴, A-A-59588B, *Commercial Item Description: Rubber, Silicone*

U.S. Federal Specifications, TT-S-00230C, *Sealing Compound Elastomeric Type, Single Component for Caulking, Sealing, and Glazing in Buildings and Other Structures*

⁹ American Welding Society, 8669 N.W. 36th Street, No. 130, Miami, Florida 33166-6672, www.aws.org.

¹⁰ Canadian Standards Association, 5060 Spectrum Way, Suite 100, Mississauga, Ontario, L4W 5N6, Canada, www.csa.ca.

¹¹ European Committee for Standardization, Avenue Marnix 17, B-1000, Brussels, Belgium, www.cen.eu.

¹² International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, www.iso.org.

¹³ National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169-7471, www.nfpa.org.

¹⁴ Specifications Unit (WFSIS), 7th and D Streets, S.W., Washington, DC 20407.

SECTION 3—TERMS AND DEFINITIONS

For the purposes of this document, the following terms and definitions apply.

3.1

annular plate

A bottom plate welded to the shell that has butt-welded, substantially radial joints and is required by 5.5.1, 5.11.2.3, E.6.2.1.1.3, M.4.1, S.3.1.3, or X.3.2. See 5.5 for dimensional requirements. Also called an “annular bottom plate” or “bottom annular plate.”

3.2

annular ring

The complete collection of annular plates positioned around the perimeter of a tank bottom, whose radial lengths are substantially equal.

3.3

centerline-stacked

The mid-thickness centerlines of plates in all shell courses coincide.

3.4

coating

A term that includes protective materials applied to or bonded to tank surfaces, including paint, protective metals (e.g. galvanizing or cadmium plating), adhered plastic or polyolefin materials. Coatings are used for atmospheric, immersion, or vapor-space service.

3.5

contract

The commercial instrument, including all attachments, used to procure a tank.

3.6

corroded thickness

A design condition equal to the nominal thickness less any specified corrosion allowance.

3.7

corrosion allowance

Any additional thickness specified by the Purchaser for corrosion during the tank service life. Refer to 5.3.2.

3.8

design metal temperature

The lowest temperature considered in the design, which, unless experience or special local conditions justify another assumption, shall be assumed to be 8 °C (15 °F) above the lowest one-day mean ambient temperature of the locality where the tank is to be installed. Isothermal lines of lowest one-day mean temperature are shown in Figure 4.2. The temperatures are not related to refrigerated-tank temperatures (see 1.1.1).

3.9

design specific gravity

The maximum specific gravity of the stored liquid(s) at designated temperatures. The greatest value of all products when tanks are to be designed for multiple products.

3.10**design thickness**

The thickness necessary to satisfy tension and compression strength requirements by this standard or, in the absence of such expressions, by good and acceptable engineering practice for specified design conditions, without regard to construction limitations or corrosion allowances.

3.11**double-deck floating roof**

The entire roof is constructed of closed-top flotation compartments.

3.12**examiner**

A person who performs Nondestructive Examinations (NDE) and is qualified and certified as required in Section 8 for the NDE method performed.

3.13**floating suction line**

Internal piping assembly that allows operator to withdraw product from the upper levels of the tank.

3.14**flush-stacked on the inside**

The inside surfaces of plates in all shell courses coincide.

3.15**inlet diffusers**

Internal fill line piping with impingement plate, baffles, slots, or lateral openings. Diffusers limit splashing and misting of product, prevent product impingement on internal components, and disperse gases introduced into the tank.

3.16**insert plate**

A steel plate that replaces part of a shell plate, with a nominal thickness that is equivalent to, or no more than 3 mm ($1/8$ in.) greater than the nominal thickness of the adjoining material. When an insert plate is equal to the full height of a shell ring, it is considered to be a shell plate.

3.17**inspector**

A representative of an organization who ensures compliance with this standard and is responsible for various quality control and assurance functions, as outlined in this standard.

3.18**liner**

A protective material used as a barrier but not adhered, nor bonded, to the protected surface. Typically used (1) inside a tank to protect steel, (2) under a tank for leak detection (as a "release prevention barrier"), (3) in a dike yard, or (4) on the dikes as secondary containment. Common examples are sheeting made from lead, rubber, plastic, polyolefin, or geosynthetic clay (bentonite). A liner is not a coating.

3.19**lining**

An internal coating that consists of an applied liquid material which dries and adheres to the substrate, or a sheet material that is bonded to the substrate. It is designed for immersion service or vapor-space service. A lining can be reinforced or unreinforced.

3.20**mandatory**

Required sections of the standard become mandatory if the standard has been adopted by a Legal Jurisdiction or if the Purchaser and the Manufacturer choose to make reference to this standard on the nameplate or in the Manufacturer's certification.

3.21**Manufacturer**

The party having the primary responsibility to construct the tank (see 1.3 and 10.2).

3.22**maximum design temperature**

The highest temperature considered in the design, equal to or greater than the highest expected operating temperature during the service life of the tank.

3.23**mechanically-anchored tank**

Tanks that have anchor bolts, straps, or other mechanical devices to anchor the tank to the foundation.

3.24**minimum design specific gravity for floating roof design**

The lowest specific gravity of the stored liquid(s) at designated temperatures. The lowest value of all products when tanks are to be designed for multiple products.

3.25**nominal thickness**

The ordered thickness of the material. This thickness includes any corrosion allowance and is used for determination of PWHT requirements, weld spacing, minimum and maximum thickness limitations, etc.

NOTE The thickness used in the final structure is the nominal thickness plus or minus any tolerance allowed by this standard.

3.26**Purchaser**

The owner or the owner's designated agent, such as an engineering contractor.

3.27**Purchaser's option**

A choice to be selected by the Purchaser and indicated on the Data Sheet. When the Purchaser specifies an option covered by an Annex, the Annex then becomes a requirement.

3.28**recommendation**

The criteria provide a good acceptable design and may be used at the option of the Purchaser and the Manufacturer.

3.29**requirement**

The criteria must be used unless the Purchaser and the Manufacturer agree upon a more stringent alternative design.

3.30**self-anchored tank**

Tanks that use the inherent stability of the self-weight of the tank and the stored product to resist overturning forces.

3.31**single-deck pontoon floating roof**

The outer periphery of the roof consists of closed-top pontoon compartments, with the inner section of the roof constructed of a single deck without flotation means.

3.32**thickened insert plate**

A steel plate that replaces part of a shell plate, with a nominal thickness that is greater than the nominal thickness of the adjoining material by more than 3 mm ($1/8$ in.).

3.33**Welding Terms**

The terms defined in 3.33.1 through 3.33.21 are commonly used welding terms mentioned in this standard. See 5.1.5.2 for descriptions of fusion-welded joints.

3.33.1**automatic welding**

Welding with equipment which performs the welding operation without adjustment of the controls by a welding operator. The equipment may or may not perform the loading and unloading of the work.

3.33.2**backing**

The material—metal, weld metal, carbon, granular flux, and so forth—that backs up the joint during welding to facilitate obtaining a sound weld at the root.

3.33.3**base metal**

The metal or alloy that is welded or cut.

3.33.4**depth of fusion**

The distance that fusion extends into the base metal from the surface melted during welding.

3.33.5**filler metal**

Metal or alloy to be added in making a weld.

3.33.6**fusion**

The melting together of filler metal and base metal, or the melting of base metal only, which results in coalescence.

3.33.7**heat-affected zone**

The portion of the base metal that has not been melted but whose mechanical properties or microstructures have been altered by the heat of welding or cutting.

3.33.8**joint penetration**

The minimum depth a groove weld extends from its face into a joint, exclusive of reinforcement.

3.33.9**lap joint**

A joint between two overlapping members. An overlap is the protrusion of weld metal beyond the bond at the toe of the weld.

3.33.10**machine welding**

Welding with equipment that performs the welding operation under constant observation and control of a welding operator. The equipment may or may not perform the loading and unloading of the work.

3.33.11**manual welding**

Welding wherein the entire welding operation is performed and controlled by hand.

3.33.12**oxygen cutting**

A group of cutting processes wherein the severing of metals is effected by means of the chemical reaction of oxygen with the base metal at elevated temperatures. In case of oxidation-resistant metals, the reaction is facilitated by the use of a flux.

3.33.13**porosity**

The existence of gas pockets or voids in metal.

3.33.14**reinforcement of weld**

Weld metal on the face of a groove weld in excess of the metal necessary for the specified weld size.

3.33.15**semiautomatic arc welding**

Arc welding with equipment that controls only the filler metal feed. The advance of the welding is manually controlled.

3.33.16**slag inclusion**

Nonmetallic solid material entrapped in weld metal or between weld metal and base metal.

3.33.17**undercut**

A groove melted into the base metal adjacent to the toe of a weld and left unfilled by weld metal.

3.33.18**weld metal**

The portion of a weld that has been melted during welding.

3.33.19**welded joint**

A union of two or more members produced by the application of a welding process.

3.33.20**welder**

One who performs manual or semiautomatic welding.

3.33.21**welding operator**

One who operates automatic or machine welding equipment.

SECTION 4—MATERIALS

4.1 General

4.1.1 Miscellaneous information is contained in 4.1.1.1 through 4.1.1.4.

4.1.1.1 See the Data Sheet for material specifications.

4.1.1.2 Rimmed or capped steels are not permitted.

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

- 4.1.1.4 Because of hydrogen embrittlement and toxicity concerns, cadmium-plated components shall not be used without the expressed consent of the Purchaser.

- 4.1.2 Materials used in the construction of tanks shall conform to the specifications listed in this section, subject to the modifications and limitations indicated in this standard. Material produced to specifications other than those listed in this section may be employed, provided that the material is certified to meet all of the requirements of an applicable material specification listed in this standard and the material's use is approved by the Purchaser. The Manufacturer's proposal shall identify the material specifications to be used. When this standard does not address material requirements for miscellaneous items and appurtenances, the Purchaser and/or the Manufacturer shall supply additional material requirements using a supplement to the Data Sheet.

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

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

4.1.5 When a tank is designed to the requirements of this standard using plate material from Group-I through Group-IIIA steels, the tank Manufacturer responsible for any proposed material substitution to use Group-IV through Group-VI steels must do the following.

- a) Maintain all of the original design criteria for the lower stress Group-I through Group IIIA steels.
- b) Obtain the prior written approval of the Purchaser.
- c) Ensure that all of the design, fabrication, erection, and inspection requirements for the material being substituted will meet the lower stress Group I through Group IIIA specifications for items including but not limited to:
 - 1) material properties and production process methods;
 - 2) allowable stress levels;
 - 3) notch toughness;
 - 4) welding procedures and consumables;
 - 5) thermal stress relief;

- 6) temporary and permanent attachment details and procedures;
- 7) nondestructive examinations.
- d) Include the pertinent information in the documents provided to the Purchaser, including a certification statement that the substituted material fully complies with 4.1.5 in all respects, and provide all other records covered by the work processes applied to the material such as impact testing, weld procedures, nondestructive examinations, and heat treatments.

4.2 Plates

4.2.1 General

4.2.1.1 Except as otherwise provided for in 4.1, plates shall conform to one of the specifications listed in 4.2.2 through 4.2.6, subject to the modifications and limitations in this standard.

4.2.1.2 Plate for shells, roofs, and bottoms shall be ordered on an edge-thickness basis as specified in 4.2.1.2.1 and 4.2.1.2.2.

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

4.2.1.2.2 An underrun not more than 0.3 mm (0.01 in.) from the computed design thickness or the minimum permitted thickness is acceptable.

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

4.2.1.4 Shell plates are limited to a maximum thickness of 45 mm (1.75 in.) unless a lesser thickness is stated in this standard or in the plate specification. Plates used as thickened inserts or flanges may be thicker than 45 mm (1.75 in.). Plates, as designated in 4.2.10.1 and thicker than 40 mm (1.5 in.), shall be normalized or quench tempered, killed, made to fine-grain practice, and impact tested.

4.2.1.5 Plate components not listed in 4.2.10.1 (i.e. nonpressure boundary compression components) shall be limited to the maximum thickness as designated by ASTM, CSA, ISO, EN, or other recognized national standard.

4.2.2 ASTM Specifications

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

- a) ASTM A36M/A36 for plates to a maximum thickness of 40 mm (1.5 in.). None of the specifications for the appurtenant materials listed in Table 1 of ASTM A36M/A36 are considered acceptable for tanks constructed under this standard unless it is expressly stated in this standard that the specifications are acceptable.
- b) ASTM A131M/A131, Grade A, for plates to a maximum thickness of 13 mm (0.5 in.); Grade B for plates to a maximum thickness of 25 mm (1 in.); and Grade EH36 for plates to a maximum thickness of 45 mm (1.75 in.) [thickened insert plates and flanges to a maximum thickness of 50 mm (2 in.)].
- c) ASTM A283M/A283, Grade C, for plates to a maximum thickness of 25 mm (1 in.).

- d) ASTM A285M/A285, Grade C, for plates to a maximum thickness of 25 mm (1 in.).
- e) ASTM A516M Grades 380, 415, 450, 485/A516, Grades 55, 60, 65, and 70, for plates to a maximum thickness of 40 mm (1.5 in.) [thickened insert plates and flanges to a maximum thickness of 100 mm (4 in.)].
- f) ASTM A537M/A537, Class 1 and Class 2, for plates to a maximum thickness of 45 mm (1.75 in.) [thickened insert plates to a maximum thickness of 100 mm (4 in.)].
- g) ASTM A573M Grades 400, 450, 485/A573, Grades 58, 65, and 70, for plates to a maximum thickness of 40 mm (1.5 in.).
- h) ASTM A633M/A633, Grades C and D, for plates to a maximum thickness of 45 mm (1.75 in.) [thickened insert plates to a maximum thickness of 100 mm (4.0 in.)].
- i) ASTM A662M/A662, Grades B and C, for plates to a maximum thickness of 40 mm (1.5 in.).
- j) ASTM A737M/A737, Grade B, for plates to a maximum thickness of 40 mm (1.5 in.).
- k) ASTM A841M/A841 Grade A, Class 1 and Grade B, Class 2 for plates to a maximum thickness of 40 mm (1.5 in.) [thickened insert plates to a maximum thickness of 65 mm (2.5 in.)].

4.2.3 CSA Specification

CSA Specification G40.21, Grades 260W/(38W), 300W/(44W), and 350W/(50W) are acceptable for plates within the limitations stated below. If impact tests are required, WT Grades are required.

- a) Grades 260W/(38W) and 300W/(44W) are acceptable for plate to a maximum thickness of 25 mm (1 in.) if semi-killed and to a maximum thickness of 40 mm (1.5 in.) if fully killed and made to fine-grain practice.
- b) Grade 350W/(50W) is acceptable for plate to a maximum thickness of 45 mm (1.75 in.) [thickened insert plates to a maximum thickness of 100 mm (4 in.)] if fully killed and made to fine-grain practice.
- c) All CSA specification plates shall be ordered with the tensile strength limited to no greater than 140 MPa (20 ksi) above the minimum specification.

4.2.4 ISO Specifications

Plate furnished to ISO 630 in Grades S275 and S355 is acceptable within the following limitations:

- a) Grade S275 in Qualities C and D for plate to a maximum thickness of 40 mm (1.5 in.);
- b) Grade S355 in Qualities C and D for plate to a maximum thickness of 45 mm (1.75 in.) [thickened insert plates to a maximum thickness of 50 mm (2 in.)].

4.2.5 EN Specifications

Plate furnished to EN 10025 in Grades S275 and S355 is acceptable within the following limitations:

- a) Grade S275 in Qualities J0 and J2 for plate to a maximum thickness of 40 mm (1.5 in.);
- b) Grade S355 in Qualities J0, J2 and K2 for plate to a maximum thickness of 45 mm (1.75 in.) [thickened insert plates to a maximum thickness of 50 mm (2 in.)].

● 4.2.6 National Standards

Plates produced and tested in accordance with the requirements of a recognized national standard and within the mechanical and chemical limitations of one of the grades listed in Table 4.2 are acceptable when approved by the Purchaser. The requirements of this group do not apply to the ASTM, CSA, ISO, and EN specifications listed in 4.2.2, 4.2.3, 4.2.4, and 4.2.5. 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.

4.2.7 General Requirements for Delivery

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

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

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

4.2.7.4 For plate that is to be made to specifications that limit the maximum manganese content to less than 1.60 %, the limit of the manganese content may be increased to 1.60 % (heat) at the option of the plate producer to maintain the required strength level, provided that the maximum carbon content is reduced to 0.20 % (heat) and the weldability of the plate is given consideration. The material shall be marked "Mod" following the specification listing. The material shall conform to the product analysis tolerances of Table B in ASTM A6M/A6.

4.2.7.5 The use or presence of columbium, vanadium, nitrogen, copper, nickel, chromium, or molybdenum shall not exceed the limitations of Table 4.1 for all Group VI materials (see Table 4.4a and Table 4.4b) and CSA G40.21 Grades 350W/(50W) and 350WT/(50WT); ISO 630 Grade S355; and EN 10025 Grade S355.

4.2.8 Heat Treatment of Plates

4.2.8.1 When specified by the plate purchaser, fully killed plates shall be heat treated to produce grain refinement by either normalizing or heating uniformly for hot forming. If the required treatment is to be obtained in conjunction with hot forming, the temperature to which the plates are heated for hot forming shall be equivalent to and shall not significantly exceed the normalizing temperature. If the treatment of the plates is not specified to be done at the plate producer's plant, testing shall be carried out in accordance with 4.2.8.2.

4.2.8.2 When a plate purchaser elects to perform the required normalizing or fabricates by hot forming (see 4.2.8.1), the plates shall be accepted on the basis of mill tests made on full-thickness specimens heat treated in accordance with the plate purchaser's order. If the heat-treatment temperatures are not indicated on the contract, the specimens shall be heat treated under conditions considered appropriate for grain refinement and for meeting the test requirements. The plate producer shall inform the plate purchaser of the procedure followed in treating the specimens at the steel mill.

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

- **4.2.8.4** The tensile tests shall be performed on each plate as heat treated.

Table 4.1—Maximum Permissible Alloy Content

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

NOTE 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.

NOTE 2 On product analysis, the material shall conform to these requirements, subject to the product analysis tolerances of the specification.

NOTE 3 When columbium is added either singly or in combination with vanadium, it shall be restricted to plates of 13 mm (0.50 in.) maximum thickness unless combined with 0.15 % minimum silicon.

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

Table 4.2—Acceptable Grades of Plate Material Produced to National Standards (See 4.2.6)

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

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

^c Yield strength + tensile strength ≤ 0.75, based on the minimum specified yield and tensile strength unless actual test values are required by the Purchaser.

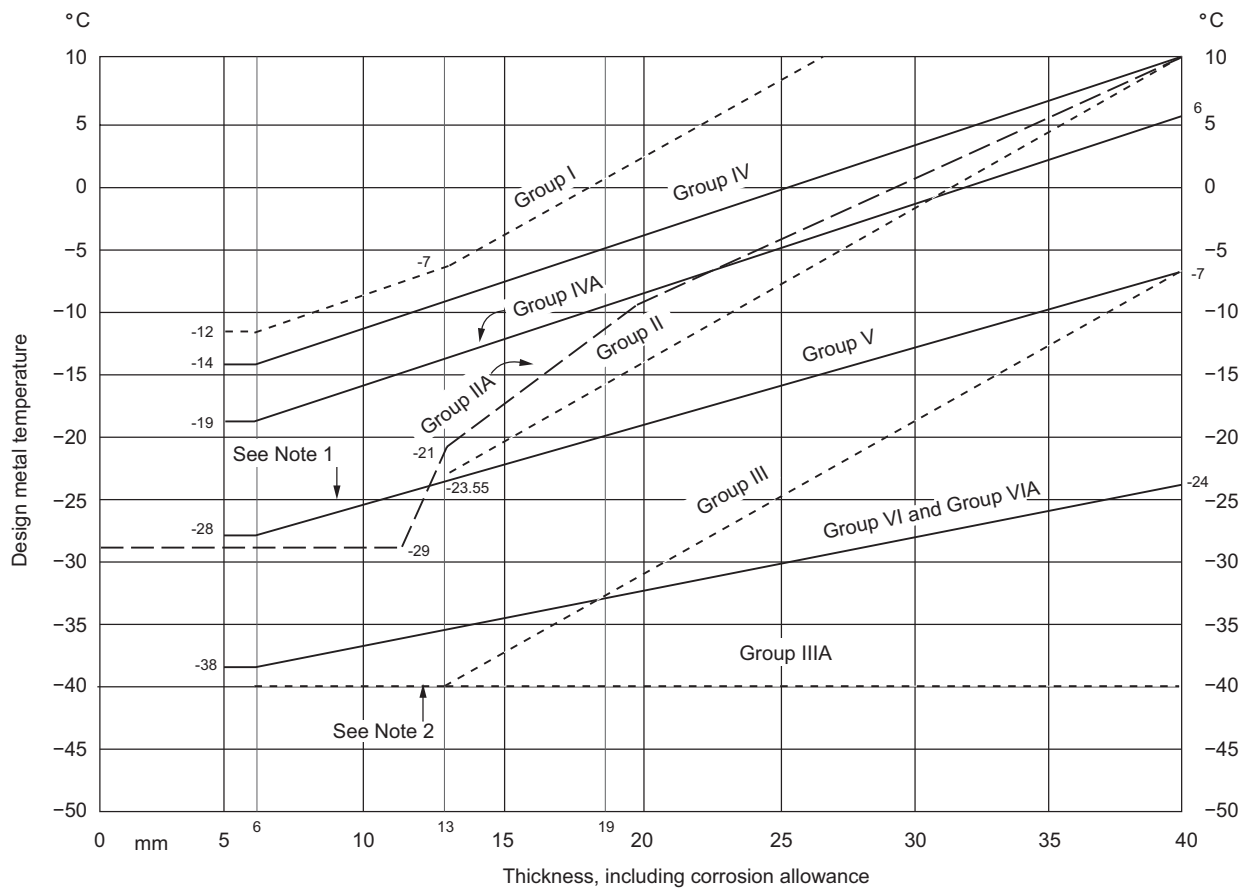
^d Nonrimming only.

4.2.9 Impact Testing of Plates

- **4.2.9.1** When required by the Purchaser or by 4.2.10, a set of Charpy V-notch impact specimens shall be taken from plates after heat treatment (if the plates have been heat treated), and the specimens shall fulfill the stated energy requirements. Test coupons shall be obtained adjacent to a tension-test coupon. Each full-size impact specimen shall have its central axis as close to the plane of one-quarter plate thickness as the plate thickness will permit.
- 4.2.9.2** 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 A20.
- 4.2.9.3** An impact test shall be performed on three specimens taken from a single test coupon or test location. The average value of the specimens (with no more than one specimen value being less than the specified minimum value) shall comply with the specified minimum value. If more than one value is less than the specified minimum value, or if one value is less than two-thirds the specified minimum value, three additional specimens shall be tested, and each of these must have a value greater than or equal to the specified minimum value.
- 4.2.9.4** The test specimens shall be Charpy V-notch Type A specimens (see ASTM A370), with the notch perpendicular to the surface of the plate being tested.
- 4.2.9.5** For a plate whose thickness is insufficient to permit preparation of full-size specimens [10 mm × 10 mm (0.394 in. × 0.394 in.)], tests shall be made on the largest subsize specimens that can be prepared from the plate. Subsize specimens shall have a width along the notch of at least 80 % of the material thickness.
- 4.2.9.6** The impact energy values obtained from subsize specimens shall not be less than values that are proportional to the energy values required for full-size specimens of the same material.
- 4.2.9.7** The testing apparatus, including the calibration of impact machines and the permissible variations in the temperature of specimens, shall conform to ASTM A370 or an equivalent testing apparatus conforming to national standards or ISO standards.

4.2.10 Toughness Requirements

- 4.2.10.1** The thickness and design metal temperature of all shell plates, shell reinforcing plates, shell insert plates and thickened insert plates, bottom plates welded to the shell, plates used for manhole and nozzle necks, plate-ring shell-nozzle flanges, blind flanges, and manhole cover plates shall be in accordance with Figure 4.1a and Figure 4.1b. Notch toughness evaluation of plate-ring flanges, blind flanges, and manhole cover plates shall be based on "governing thickness" as defined in 4.5.4.3. In addition, plates more than 40 mm (1.5 in.) thick shall be of killed steel made to fine-grain practice and heat treated by normalizing, normalizing and tempering, or quenching and tempering, and each plate as heat treated shall be impact tested according to 4.2.11.2. Each TMCP A841 plate-as-rolled shall be impact tested. Impact test temperature and required energy shall be in accordance with 4.2.11.2 in lieu of the default temperature and energy given in A841.
- 4.2.10.2** Subject to the Purchaser's approval, thermo-mechanical-control-process (TMCP) plates (plates produced by a mechanical-thermal rolling process designed to enhance notch toughness) may alternatively be used where heat treated plates are normally required by 4.2.10.1 because of thickness over 40 mm (1.5 in.). In this case, each TMCP plate-as-rolled shall receive Charpy V-notch impact energy testing in accordance with 4.2.9, 4.2.10, and 4.2.11. When TMCP steels are used, consideration should be given to the service conditions outlined in 5.3.3.
- **4.2.10.3** Plates less than or equal to 40 mm (1.5 in.) thick may be used at or above the design metal temperatures indicated in Figure 4.1a and Figure 4.1b without being impact tested. To be used at design metal temperatures lower than the temperatures indicated in Figure 4.1a and Figure 4.1b, plates shall demonstrate adequate notch toughness in accordance with 4.2.11.3 unless 4.2.11.2 or 4.2.11.4 has been specified by the Purchaser. For heat-treated material



NOTE 1 The Group II and Group V lines coincide at thicknesses less than 13 mm.

NOTE 2 The Group III and Group IIIA lines coincide at thicknesses less than 13 mm.

NOTE 3 The materials in each group are listed in Table 4.4a and Table 4.4b.

NOTE 4 Deleted.

NOTE 5 Use the Group IIA and Group VIA curves for pipe and flanges (see 4.5.4.2 and 4.5.4.3).

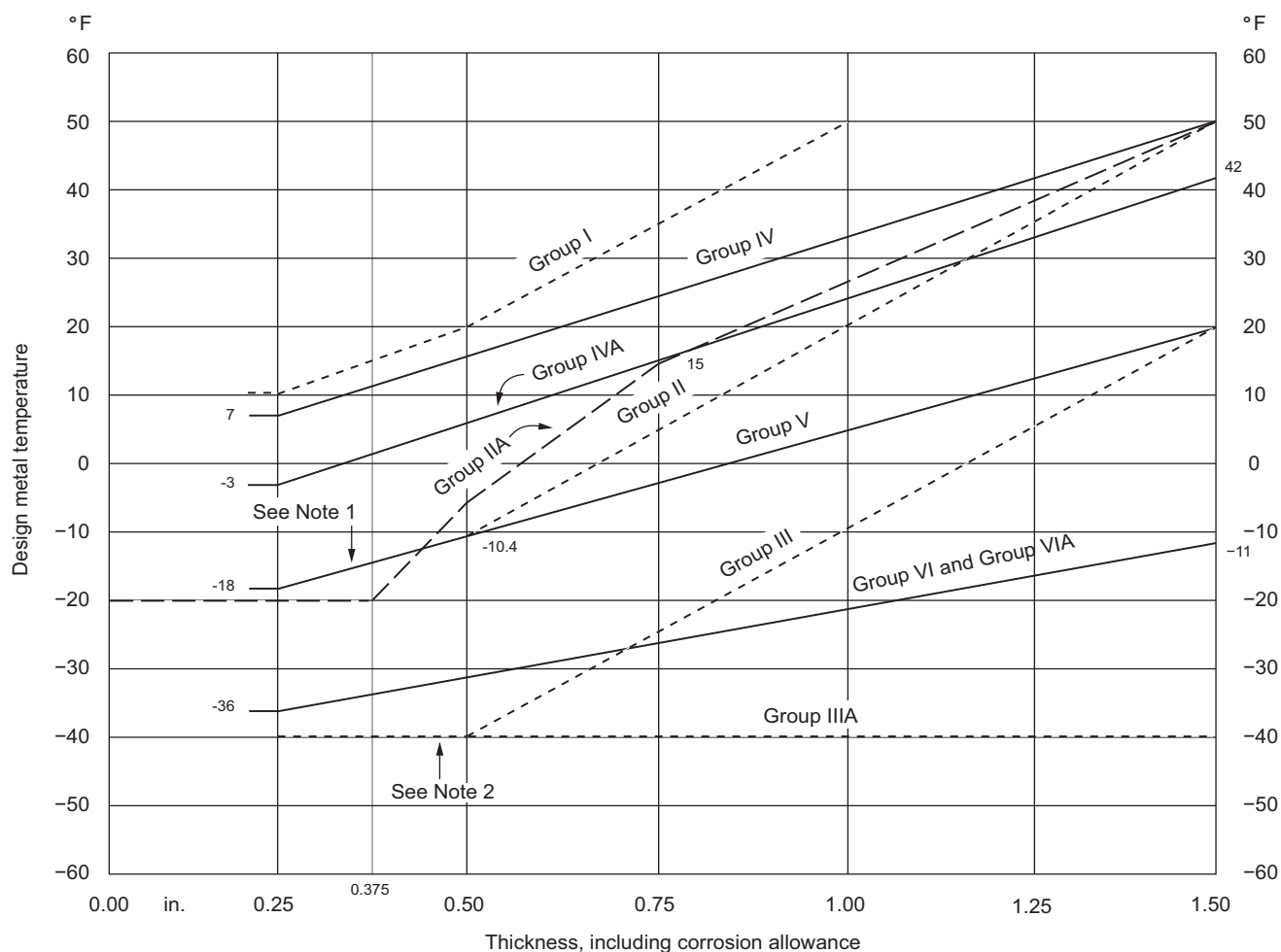
NOTE 6 Linear equations provided in Table 4.3a can be used to calculate Design Metal Temperature (DMT) for each API material group and the thickness range.

Figure 4.1a—Minimum Permissible Design Metal Temperature for Materials Used in Tank Shells without Impact Testing (SI)

(normalized, normalized and tempered, or quenched and tempered), notch toughness shall be demonstrated on each plate as heat treated when 4.2.11.2 requirements are specified. Isothermal lines of lowest one-day mean temperature are shown in Figure 4.2.

4.2.10.4 Plate used to reinforce shell openings and insert plates or thickened insert plates shall be of the same material as the shell plate to which they are attached or shall be of any appropriate material listed in Table 4.4a, Table 4.4b, Figure 4.1a, and Figure 4.1b. Except for nozzle and manway necks, the material shall be of equal or greater yield and tensile strength and shall be compatible with the adjacent shell material (see 4.2.10.1 and 5.7.2.3, Item d).

4.2.10.5 The requirements in 4.2.10.4 apply only to shell nozzles and manholes. Materials for roof nozzles and manholes do not require special toughness.



NOTE 1 The Group II and Group V lines coincide at thicknesses less than $\frac{1}{2}$ in.

NOTE 2 The Group III and Group IIIA lines coincide at thicknesses less than $\frac{1}{2}$ in.

NOTE 3 The materials in each group are listed in Table 4.4a and Table 4.4b.

NOTE 4 Deleted.

NOTE 5 Use the Group IIA and Group VIA curves for pipe and flanges (see 4.5.4.2 and 4.5.4.3).

NOTE 6 Linear equations provided in Table 4.3b can be used to calculate Design Metal Temperature (DMT) for each API material group and the thickness range.

Figure 4.1b—Minimum Permissible Design Metal Temperature for Materials Used in Tank Shells without Impact Testing (USC)

4.2.11 Toughness Procedure

4.2.11.1 When a material's toughness must be determined, it shall be done by one of the procedures described in 4.2.11.2, 4.2.11.3, and 4.2.11.4, as specified in 4.2.10.

Table 4.3a—Linear Equations for 4.1a (SI)

API Group #	Thickness Range	Equation
I	$6 \leq X < 13$	$Y = 0.714X - 16.286$
I	$13 \leq X \leq 25$	$Y = 1.417X - 25.417$
II	$6 \leq X < 13$	$Y = 0.634X - 31.81$
II	$13 \leq X \leq 40$	$Y = 1.243X - 39.72$
IIA	$10 \leq X < 13$	$Y = 2.667X - 55.667$
IIA	$13 \leq X \leq 19$	$Y = 2X - 47$
IIA	$19 \leq X \leq 40$	$Y = 0.905X - 26.19$
III	$6 \leq X \leq 13$	$Y = -40$
III	$13 \leq X \leq 40$	$Y = 1.222X - 55.89$
IIIA	$6 \leq X \leq 40$	$Y = -40$
IV	$6 \leq X \leq 40$	$Y = 0.7059X - 18.235$
IVA	$6 \leq X \leq 40$	$Y = 0.7353X - 23.412$
V	$6 \leq X \leq 40$	$Y = 0.6176X - 31.71$
VI, VIA	$6 \leq X \leq 40$	$Y = 0.4112X - 40.471$
Y = Design Metal Temperature (°C) X = Thickness including corrosion (mm)		

Table 4.3b—Linear Equations for 4.1b (USC)

API Group #	Thickness Range	Equation
I	$0.25 \leq X < 0.5$	$Y = 40X$
I	$0.5 \leq X \leq 1.0$	$Y = 60X - 10$
II	$0.25 \leq X < 0.5$	$Y = 30.4X - 25.6$
II	$0.5 \leq X \leq 1.5$	$Y = 60.4X - 40.6$
IIA	$0.375 \leq X < 0.5$	$Y = 120X - 65$
IIA	$0.5 \leq X \leq 0.75$	$Y = 80X - 45$
IIA	$0.75 \leq X \leq 1.5$	$Y = 46.667X - 20$
III	$0.25 \leq X \leq 0.5$	$Y = -40$
III	$0.5 \leq X \leq 1.5$	$Y = 60X - 70$
IIIA	$0.25 \leq X \leq 1.5$	$Y = -40$
IV	$0.25 \leq X \leq 1.5$	$Y = 34.4X - 1.6$
IVA	$0.25 \leq X \leq 1.5$	$Y = 36X - 12$
V	$0.25 \leq X \leq 1.5$	$Y = 30.4X - 25.6$
VI, VIA	$0.25 \leq X \leq 1.5$	$Y = 20X - 41$
Y = Design Metal Temperature (°F) X = Thickness including corrosion (in.)		

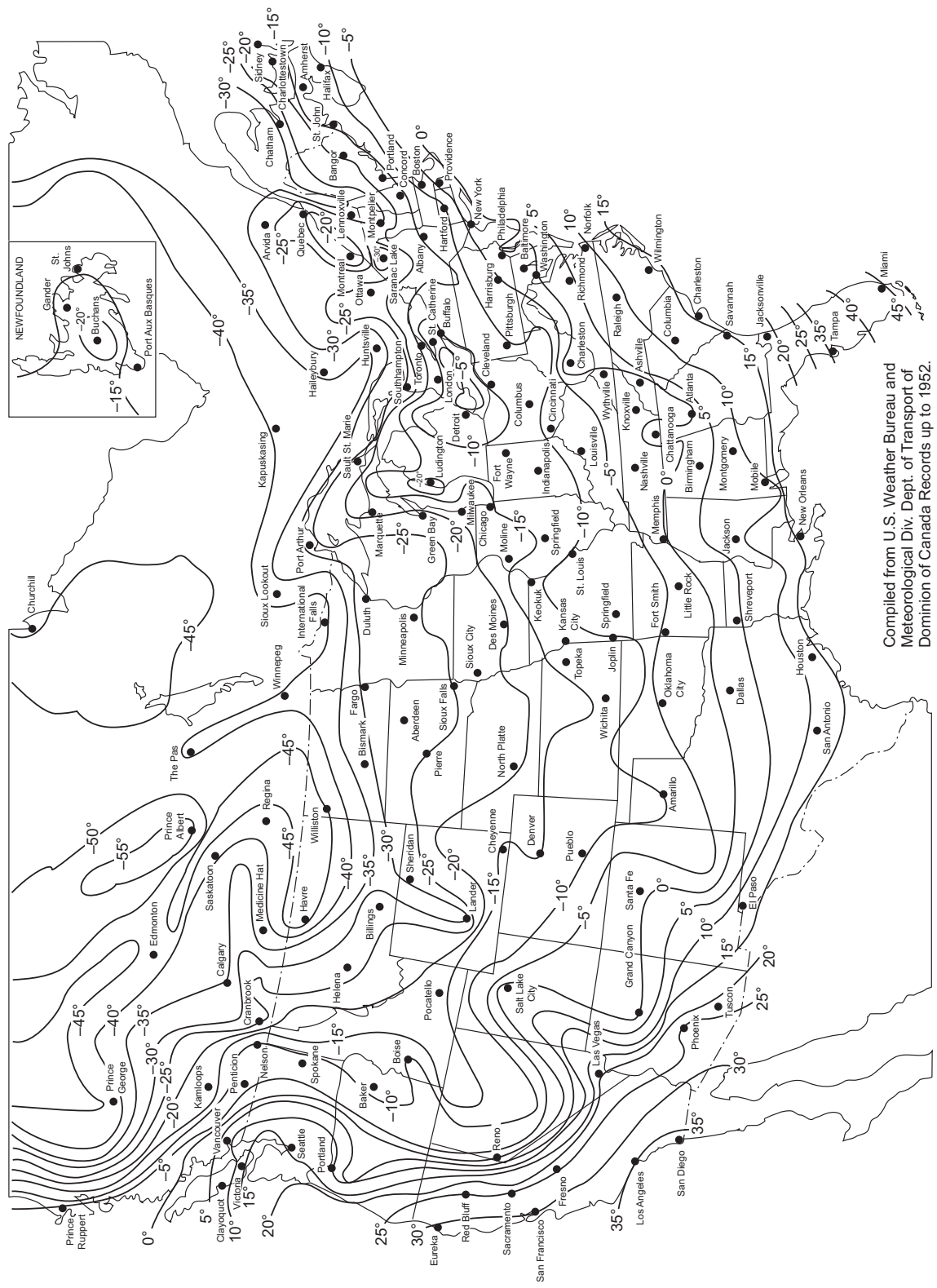
4.2.11.2 Each plate as rolled or heat treated shall be impact tested in accordance with 4.2.9 at or below the design metal temperature to show Charpy V-notch longitudinal (or transverse) values that fulfill the minimum requirements of Table 4.5a and Table 4.5b (see 4.2.9 for the minimum values for one 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.

4.2.11.3 For plate in the as-rolled condition, the thickest plate from each heat shall be impact tested. For TMCP material, each plate-as-rolled shall be impact tested. Impact testing shall be in accordance with 4.2.9 and shall fulfill the impact requirements of 4.2.11.2 at the design metal temperature.

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

4.3 Sheets

Sheets for fixed and floating roofs shall conform to ASTM A1011M, Grade 33. They shall be made by the open-hearth or basic oxygen process. Copper-bearing steel shall be used if specified by the Purchaser. Sheets shall be ordered on a thickness basis. An underrun not more than 0.3 mm (0.01 in.) from the computed design thickness or the minimum permitted thickness is acceptable.



NOTE °C = (°F – 32)/1.8

Figure 4.2—Isothermal Lines of Lowest One-Day Mean Temperatures (°F)

Table 4.4a—Material Groups (SI)

(See Figure 4.1a and Note 1 below.)

Group I As Rolled, Semi-Killed		Group II As Rolled, Killed or Semi-Killed		Group III As Rolled, Killed Fine-Grain Practice		Group IIIA Normalized, Killed Fine-Grain Practice	
Material	Notes	Material	Notes	Material	Notes	Material	Notes
A283M C		A131M B	6	A573M-400		A573M-400	9
A285M C	2	A36M	5	A516M-380		A516M-380	9
A131M A		G40.21-260W		A516M-415		A516M-415	9
A36M	3	Grade 250	7	G40.21-260W	8	G40.21-260W	8, 9
Grade 235	3			Grade 250	8	Grade 250	8, 9
Grade 250	5						
Group IV As Rolled, Killed Fine-Grain Practice		Group IVA As Rolled, Killed Fine-Grain Practice		Group V Normalized, Killed Fine-Grain Practice		Group VI Normalized or Quenched and Tempered, Killed Fine-Grain Practice Reduced Carbon	
Material	Notes	Material	Notes	Material	Notes	Material	Notes
A573M-450		A662M C		A573M-485	9	A131M EH 36	
A573M-485		A573M-485	10	A516M-450	9	A633M C	
A516M-450		G40.21-300W	8, 10	A516M-485	9	A633M D	
A516M-485		G40.21-350W	8, 10	G40.21-300W	8, 9	A537M Class 1	
A662M B		ISO S275 D	8	G40.21-350W	8, 9	A537M Class 2	12
G40.21-300W	8	ISO S355 D	8				
G40.21-350W	8	ENS275	8				
ISO S275 C	8	EN S355 (J2 or K2)	8			A737M B	
ISO S355 C	8					A841M, Grade A, Classes 1 and 2	11, 12, 13, 14
EN S275 J0	8					A841M, Grade B, Classes 1 and 2	11, 12, 13, 14
EN355 J0	8						
Grade 275	8						
NOTES 1. Most of the listed material specification numbers refer to ASTM specifications (including Grade or Class); there are, however, some exceptions: G40.21 (including Grade) is a CSA specification, and Grade 235, Grade 250, and Grade 275 are related to national standards (see 4.2.6). 2. Must be semi-killed or killed. 3. Thickness ≤ 20 mm. 4. Deleted. 5. Manganese content shall be 0.80 % to 1.2 % by heat analysis for thicknesses greater than 20 mm, except that for each reduction of 0.01 % below the specified carbon maximum, an increase of 0.06 % manganese above the specified maximum will be permitted up to the maximum of 1.35 %. Thicknesses ≤ 20 mm shall have a manganese content of 0.80 % to 1.2 % by heat analysis. 6. Thickness ≤ 25 mm. 7. Must be killed. 8. Must be killed and made to fine-grain practice. 9. Must be normalized. 10. Must have chemistry (heat) modified to a maximum carbon content of 0.20 % and a maximum manganese content of 1.60 % (see 4.2.7.4). 11. Produced by the thermo-mechanical control process (TMCP). 12. See 5.7.4.9 for tests on simulated test coupons for material used in stress-relieved assemblies. 13. See 4.2.10 for impact test requirements (each plate-as-rolled tested). 14. A841 Classes 1,2 (Grades A and B only) with the following modification: Carbon Equivalent (CE) shall be per Supplementary Requirement S77.							

Table 4.4b—Material Groups (USC)

(See Figure 4.1b and Note 1 below.)

Group I As Rolled, Semi-killed		Group II As Rolled, Killed or Semi-killed		Group III As Rolled, Killed Fine-Grain Practice		Group IIIA Normalized, Killed Fine-Grain Practice	
Material	Notes	Material	Notes	Material	Notes	Material	Notes
A283 C		A131 B	6	A573-58		A573-58	9
A285 C	2	A36	5	A516-55		A516-55	9
A131 A		G40.21-38W		A516-60		A516-60	9
A36	3	Grade 250	7	G40.21-38W	8	G40.21-38W	8, 9
Grade 235	3			Grade 250	8	Grade 250	8, 9
Grade 250	5						
Group IV As Rolled, Killed Fine-Grain Practice		Group IVA As Rolled, Killed Fine-Grain Practice		Group V Normalized, Killed Fine-Grain Practice		Group VI Normalized or Quenched and Tempered, Killed Fine-Grain Practice Reduced Carbon	
Material	Notes	Material	Notes	Material	Notes	Material	Notes
A573-65		A662 C		A573-70	9	A131 EH 36	
A573-70		A573-70	10	A516-65	9	A633 C	
A516-65		G40.21-44W	8, 10	A516-70	9	A633 D	
A516-70		G40.21-50W	8, 10	G40.21-44W	8, 9	A537 Class 1	
A662 B		ISO S275 D	8	G40.21-50W	8, 9	A537 Class 2	12
G40.21-44W	8	ISO S355 D	8				
G40.21-50W	8	ENS275 J2	8				
ISO S275 C	8	EN S355 (J2 or K2)	8			A737 B	
ISO S355 C	8					A841M, Grade A, Classes 1 and 2	11, 12, 13, 14
EN S275 J0	8					A841M, Grade B, Classes 1 and 2	11, 12, 13, 14
EN355 J0	8						
Grade 275	8						

NOTES

- Most of the listed material specification numbers refer to ASTM specifications (including Grade or Class); there are, however, some exceptions: G40.21 (including Grade) is a CSA specification, and Grade 235, Grade 250, and Grade 275 are related to national standards (see 4.2.6).
- Must be semi-killed or killed.
- Thickness ≤ 0.75 in.
- Deleted.
- Manganese content shall be 0.80% to 1.2% by heat analysis for thicknesses greater than 0.75 in., except that for each reduction of 0.01% below the specified carbon maximum, an increase of 0.06% manganese above the specified maximum will be permitted up to the maximum of 1.35%. Thicknesses ≤ 0.75 in. shall have a manganese content of 0.80% to 1.2% by heat analysis.
- Thickness ≤ 1 in.
- Must be killed.
- Must be killed and made to fine-grain practice.
- Must be normalized.
- Must have chemistry (heat) modified to a maximum carbon content of 0.20% and a maximum manganese content of 1.60% (see 4.2.7.4).
- Produced by the thermo-mechanical control process (TMCP).
- See 5.7.4.9 for tests on simulated test coupons for material used in stress-relieved assemblies.
- See 4.2.10 for impact test requirements (each plate-as-rolled tested).
- A841 Classes 1,2 (Grades A and B only) with the following modification: Carbon Equivalent (CE) shall be per Supplementary Requirement S77.

Table 4.5a—Minimum Impact Test Requirements for Plates (SI) (See Note)

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

^a See Table 4.4a.

^b Interpolation is permitted when determining minimum average impact value for plate thickness between the named thicknesses.

NOTE For plate ring flanges, the minimum impact test requirements for all thicknesses shall be those for *t* ≤ 40 mm.

Table 4.5b—Minimum Impact Test Requirements for Plates (USC) (See Note)

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

^a See Table 4.4b.

^b Interpolation is permitted when determining minimum average impact value for plate thickness between the named thicknesses.

NOTE For plate ring flanges, the minimum impact test requirements for all thicknesses shall be those for *t* ≤ 1.5 in.

4.4 Structural Shapes

4.4.1 Structural steel shall conform to one of the following specifications.

- a) ASTM A36M/A36.
- b) ASTM A131M/A131.
- c) ASTM A992M/A992.
- d) Structural Steels listed in AISC, *Manual of Steel Construction*.
- e) CSA G40.21, Grades 260W(38W), 300W(44W), 350W(50W), 260WT(38WT), 300WT(44WT), and 350WT(50WT). Imperial unit equivalent grades of CSA Specification G40.21, shown in parenthesis, are also acceptable.
- f) ISO 630, Grade E275, Qualities B, C, and D.
- g) EN 10025, Grade S275, Qualities JR, J0, and J2.
- h) Recognized national standards. Structural steel that is produced in accordance with a recognized national standard and that meets the requirements of Table 4.2 is acceptable when approved by the Purchaser.
- **4.4.2** All steel for structural shapes shall be made by the open-hearth, electric-furnace, or basic oxygen process. Copper-bearing steel is acceptable when approved by the Purchaser.

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

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

4.5 Piping and Forgings

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

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

- a) API Spec 5L, Grades A, B, and X42;
- b) ASTM A53M/A53, Grades A and B;
- c) ASTM A106 M/A106, Grades A and B;
- d) ASTM A234M/A234, Grade WPB;
- e) ASTM A333M/A333, Grades 1 and 6;
- f) ASTM A334M/A334, Grades 1 and 6;
- g) ASTM A420M/A420, Grade WPL6;

- h) ASTM A524, Grades I and II;
- i) ASTM A671 (see 4.5.3).

4.5.1.2 The following specifications are acceptable for forgings:

- a) ASTM A105M/A105;
- b) ASTM A181M/A181;
- c) ASTM A350M/A350, Grades LF1 and LF2.

4.5.2 Unless ASTM A671 pipe is used (electric-fusion-welded pipe) (see 4.5.3), material for shell nozzles and shell manhole necks shall be seamless pipe, seamless forging, or plate material as specified in 4.2.10.1. When shell materials are Group IV, IVA, V, or VI, seamless pipe shall comply with ASTM A106, Grade B; ASTM A524; ASTM A333M/A333, Grade 6; or ASTM A334M/A334, Grade 6.

4.5.3 When ASTM A671 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 A671.
- c) The plate specification for the pipe shall satisfy the requirements of 4.2.7, 4.2.8, and 4.2.9 that are applicable to that plate specification.
- d) Impact tests for qualifying the welding procedure for the pipe longitudinal welds shall be performed in accordance with 9.2.2.

4.5.4 Except as covered in 4.5.3, the toughness requirements of pipe and forgings to be used for shell nozzles and manholes shall be established as described in 4.5.4.1, 4.5.4.2, 4.5.4.3, and 4.5.4.4.

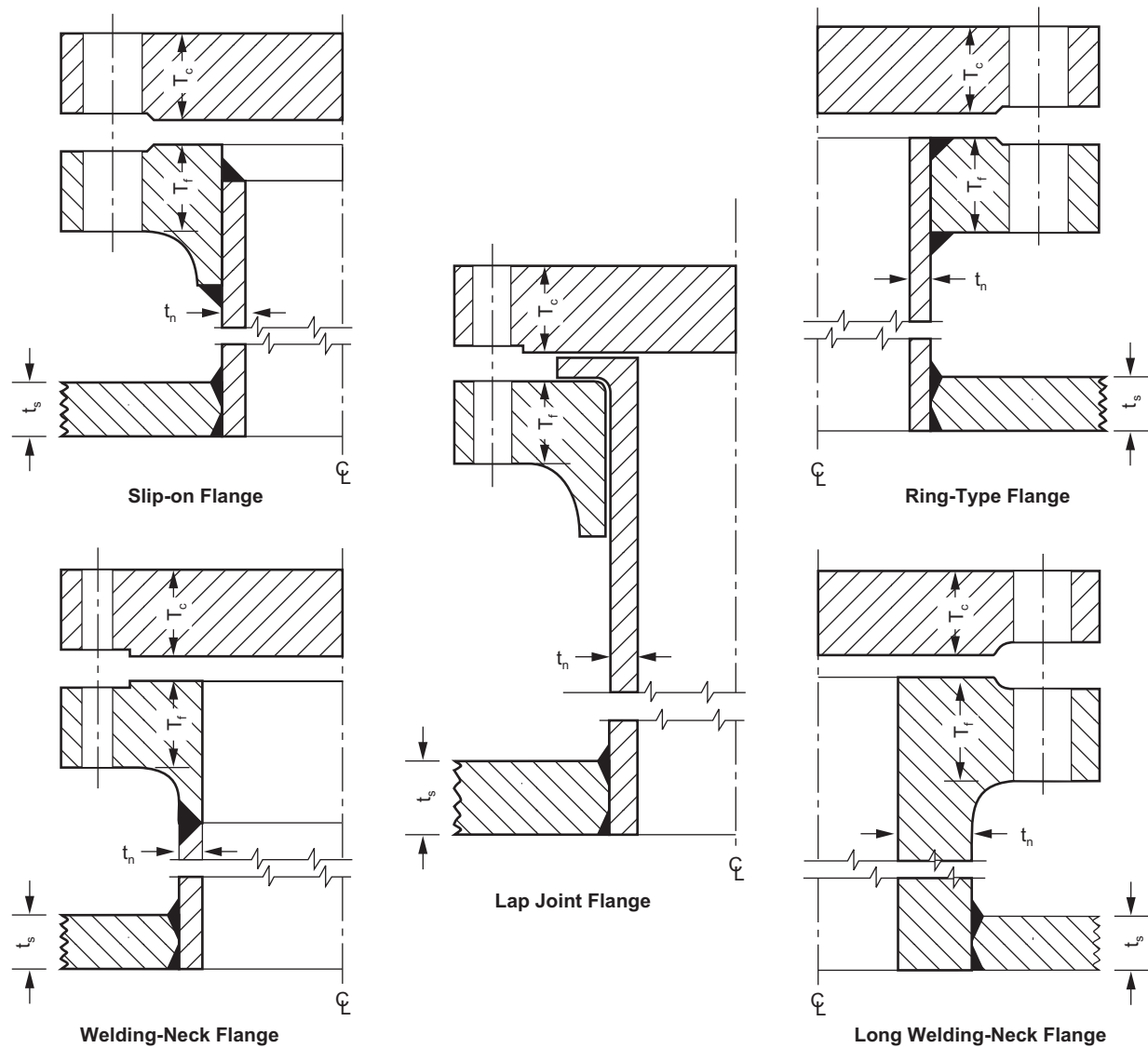
4.5.4.1 Piping materials made according to ASTM A333M/A333, A334M/A334, A350M/A350, and A420, Grade WPL6 may be used at a design metal temperature no lower than the impact test temperature required by the ASTM specification for the applicable material grade without additional impact tests (see 4.5.4.4).

4.5.4.2 Other pipe and forging materials shall be classified under the material groups shown in Figure 4.1a and Figure 4.1b as follows:

- a) Group IIA—API Spec 5L, Grades A, B, and X42; ASTM A106M/A106, Grades A and B; ASTM A53M/A53, Grades A and B; ASTM A181M/A181; ASTM A105M/A105; and A234M/A234, Grade WPB;
- b) Group VIA—ASTM A524, Grades I and II.

4.5.4.3 The materials in the groups listed in 4.5.4.2 may be used at nominal thicknesses, including corrosion allowance, at a design metal temperature no lower than those shown in Figure 4.1a and Figure 4.1b without impact testing (see 4.5.4.4 and Figure 4.3). The governing thicknesses to be used in Figures 4.1a and Figure 4.1b shall be as follows:

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



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

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

Figure 4.3—Governing Thickness for Impact Test Determination of Shell Nozzle and Manhole Materials (see 4.5.4.3)

4.5.4.4 When impact tests are required by 4.5.4.1 or 4.5.4.3, they shall be performed in accordance with the requirements, including the minimum energy requirements, of ASTM A333M/A333, Grade 6, for pipe or ASTM A350M/A350, Grade LF1, for forgings at a test temperature no higher than the design metal temperature. Except for the plate specified in 4.2.9.2, the materials specified in 4.5.1 and 4.5.2 for shell nozzles, shell manhole necks, and all forgings used on shell openings shall have a minimum Charpy V-notch impact strength of 18 J (13 ft-lbf) (full-size specimen) at a temperature no higher than the design metal temperature.

4.6 Flanges

4.6.1 Flange Material

4.6.1.1 Forged slip on, ring-type, welding neck, long welding neck, and lap joint flanges shall conform to the material requirements of ASME B16.5.

4.6.1.2 Plate material used for nozzle flanges shall have physical properties better than or equal to those required by ASME B16.5. Plate material used for manhole flanges shall be per 4.2. Plate for shell nozzle and shell manhole flange material shall conform to 4.2.10.1 or 4.2.10.2.

- **4.6.2** Lap joint flanges shall not be used without the approval of the Purchaser.
- **4.6.3** For nominal pipe sizes greater than NPS 24, flanges that conform to ASME B16.47, Series B, may be used, subject to the Purchaser's approval. Particular attention should be given to ensuring that mating flanges of appurtenances are compatible.

4.7 Bolting

- a) Unless otherwise specified on the Data Sheet, Table 2, flange bolting shall conform to ASTM A193 B7 and the dimensions specified in ASME B18.2.1. Nuts shall conform to ASTM A194 Grade 2H and the dimensions specified in ASME B18.2.2. Both shall be heavy hex pattern. All bolts and nuts shall be threaded in accordance with ASME B1.13M (SI), or with ASME B1.1(US) as follows:
 - 1) bolts up to and including 1 in. diameter: UNC Class 2A fit
 - 2) nuts for bolts up to and including 1 in. diameter: UNC Class 2B fit
 - 3) bolts 1.125 in. diameter and larger: 8N Class 2A fit
 - 4) nuts for bolts 1.125 in. diameter and larger: 8N Class 2B fit
- b) Unless otherwise specified on the Data Sheet, Table 2, anchors shall be one of the following:
 - 1) round bar to ASTM A36, threaded and galvanized;
 - 2) bolts to ASTM F1554, Grade 36 or 55, galvanized.

Nuts for anchors shall be galvanized heavy hex. Welding is not permitted on anchors that are galvanized. Bolts with minimum specified yield strength greater than 55 ksi are prohibited.
- c) All other bolting shall conform to ASTM A307 or A193M/A193. A325M/A325 may be used for structural purposes only. The Purchaser should specify on the order what shape of bolt heads and nuts is desired and whether regular or heavy dimensions are desired.

4.8 Welding Electrodes

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

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

4.9 Gaskets

4.9.1 General

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

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

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

- **4.9.1.4** No joint sealing compound, gasket adhesive, adhesive positioning tape, or lubricant shall be used on the sealing surfaces of gaskets, or flanges during joint make-up unless specifically allowed by the Purchaser. When these materials are approved by the Purchaser, consideration should be given to chemical compatibility with the gasket and flange materials.
- **4.9.1.5** Spare gaskets are not required unless specified in the Data Sheet, Line 23.

4.9.2 Service

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

4.9.3 Test

- **4.9.3.1** Test gaskets must have comparable dimensions and compressibility characteristics as service gaskets. Descriptions of gaskets for temporary use only as test gaskets shall be submitted for Purchaser's approval.
- **4.9.3.2** For joints that will not be disassembled after testing, the test gasket must be the specified service gasket.
- **4.9.3.3** Except for stainless steel bolting, flange bolts and nuts used for testing are acceptable for use in the completed tank.

SECTION 5—DESIGN

5.1 Joints

5.1.1 Definitions

The definitions in 5.1.1.1 through 5.1.1.8 apply to tank joint designs. (See 9.1 for definitions that apply to welders and welding procedures. See Section 3 for additional definitions.)

5.1.1.1

butt-weld

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

5.1.1.2

double-welded butt joint

A joint between two abutting parts lying in approximately the same plane that is welded from both sides.

5.1.1.3

double-welded lap joint

A joint between two overlapping members in which the overlapped edges of both members are welded with fillet welds.

5.1.1.4

fillet weld

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

5.1.1.5

full-fillet weld

A fillet weld whose size is equal to the thickness of the thinner joined member.

5.1.1.6

single-welded butt joint with backing

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

5.1.1.7

single-welded lap joint

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

5.1.1.8

tack weld

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

5.1.2 Weld Size

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

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

5.1.3 Restrictions on Joints

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

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

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

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

5.1.3.5 Lap-welded joints, as tack-welded, shall be lapped as follows.

- Double-welded joints shall be lapped at least five times the nominal thickness of the thinner plate joined, or 50 mm (2 in.), whichever is smaller.
- Single-welded joints shall be lapped at least five times the nominal thickness of the thinner plate joined, or 25 mm (1 in.), whichever is smaller.

5.1.3.6 Weld passes are restricted as follows:

- **5.1.3.6.1** For bottom plate welds and roof plate welds for all materials, and for shell-to-bottom welds for Groups I, II, III, and IIIA materials, the following weld size requirements apply:
 - a) For manual welding processes, fillet weld legs or groove weld depths greater than 6 mm ($1/4$ in.) shall be multipass, unless otherwise specified on the Data Sheet, Line 15.
 - b) For semi-automatic, machine, and automatic welding processes, fillet weld legs or groove weld depths greater than 10 mm ($3/8$ in.) shall be multipass, unless otherwise specified on the Data Sheet, Line 15.

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

5.1.3.7 Attachments to tank exterior surfaces shall be as follows.

- a) Except as provided in item b. below, all attachments to tank exterior surfaces shall be completely seal welded (no intermittent welding) to minimize rust streaking.
 - b) If specified on the Data Sheet, intermittent welding is permitted for:
 - 1) wind girders as described in 5.1.5.8;
 - 2) attachments to surfaces that will be covered by insulation;
 - 3) attachments to surfaces of corrosion-resistant materials, including but not limited to stainless steel (See Annex S and Annex X) and aluminum (See Annex AL).
- **5.1.3.8** Except as permitted in 5.1.5.5 and 5.1.5.6, permanent weld joint backing strips are permitted only with the approval of the Purchaser.

5.1.4 Welding Symbols

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



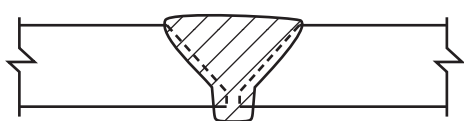
5.1.5 Typical Joints

5.1.5.1 General

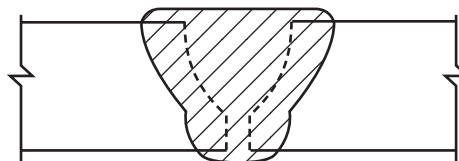
- a) Typical tank joints are shown in Figure 5.1, Figure 5.2, Figure 5.3a, Figure 5.3b, and Figure 5.3c.
- b) The top surfaces of bottom welds (butt-welded annular plates, butt-welded sketch plates, or Figure 5.3b joints) shall be ground flush where they will contact the bottoms of the shell, insert plates, thickened insert plates, or reinforcing plates.

5.1.5.2 Vertical Shell Joints

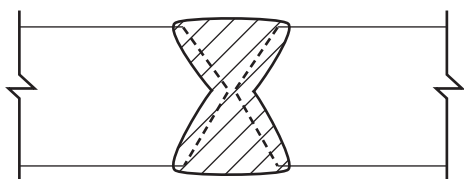
- a) Vertical shell joints shall be butt joints with complete penetration and complete fusion attained by double welding or other means that will obtain the same quality of deposited weld metal on the inside and outside weld surfaces to meet the requirements of 7.2.1 and 7.2.3. The suitability of the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



Single-V butt joint



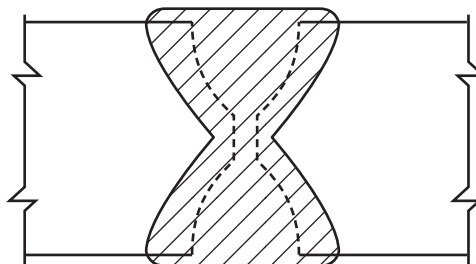
Single-U butt joint



Double-V butt joint



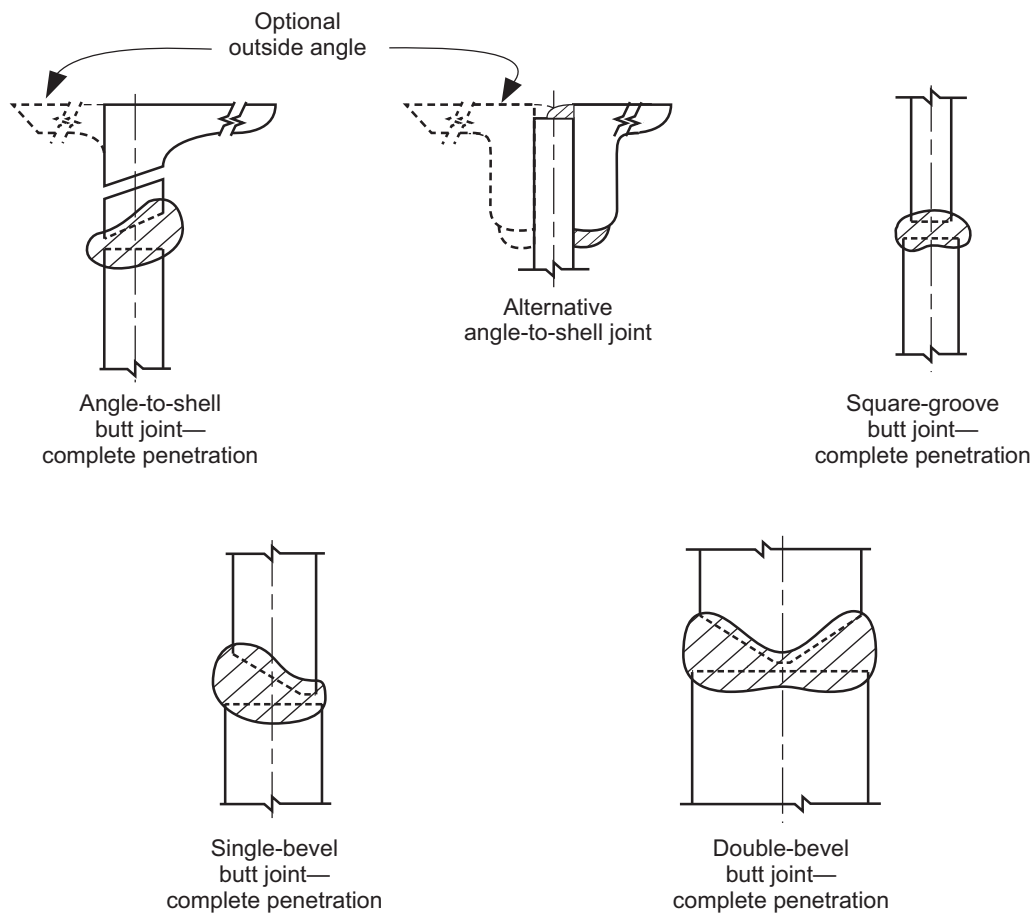
Square-groove butt joint



Double-U butt joint

NOTE See 5.1.5.2 for specific requirements for vertical shell joints.

Figure 5.1—Typical Vertical Shell Joints



NOTE See 5.1.5.3 for specific requirements for horizontal shell joints.

Figure 5.2—Typical Horizontal Shell Joints

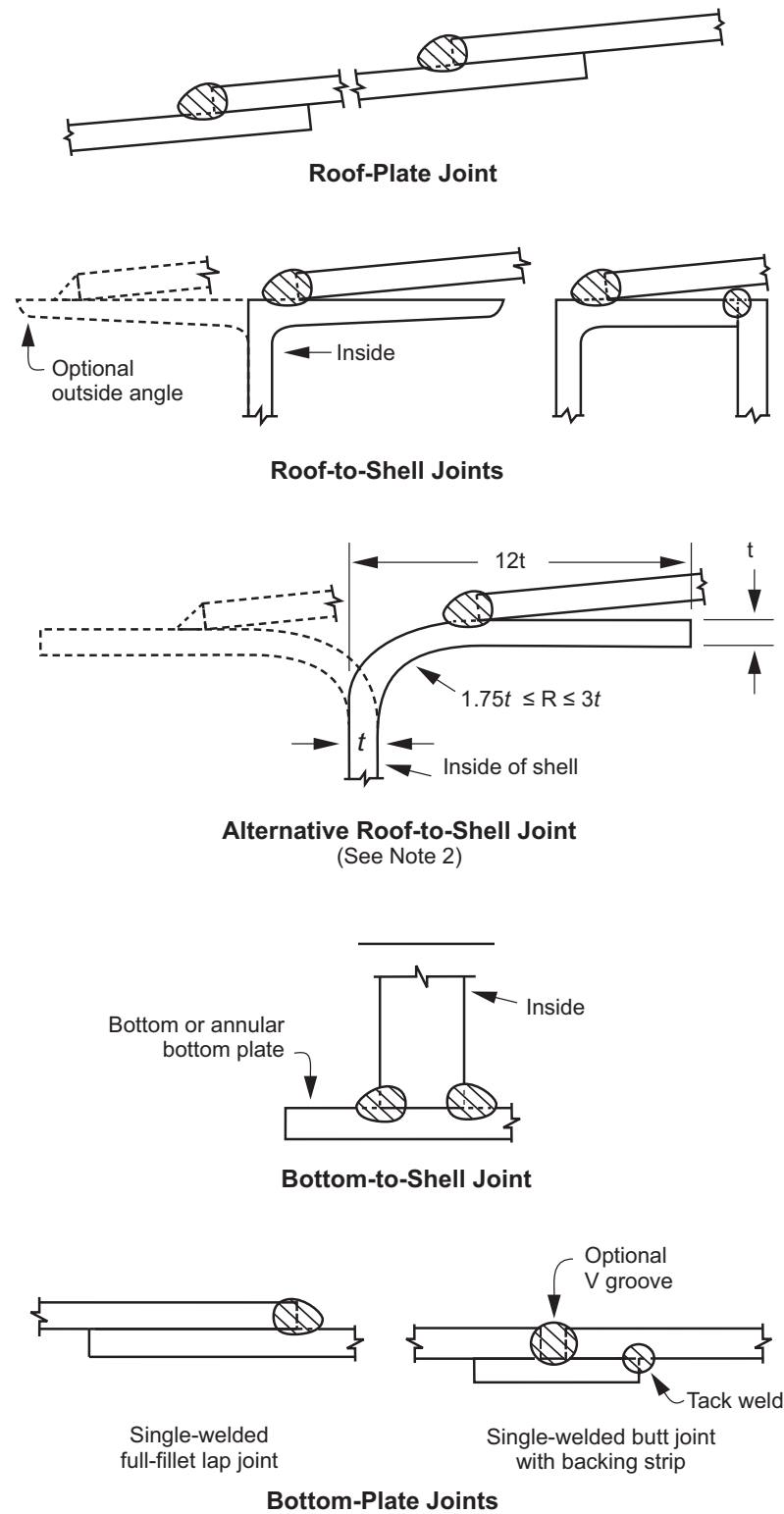
5.1.5.3 Horizontal Shell Joints

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

5.1.5.4 Lap-Welded Bottom Joints

- **5.1.5.4.1** Lap-welded bottom plates shall be reasonably rectangular. Additionally, plate may be either square cut or may have mill edges. Mill edges to be welded shall be relatively smooth and uniform, free of deleterious deposits, and have a shape such that a full fillet weld can be achieved. Unless otherwise specified by the Purchaser, lap welded plates on sloped bottoms shall be overlapped in a manner to reduce the tendency for liquid to puddle during draw-down.

5.1.5.4.2 Three-plate laps in tank bottoms shall be at least 300 mm (12 in.) from each other, from the tank shell, and from joints between annular plates and the bottom. A three-plate lap is created where three plates come together and all plates are joined to one another by lap welds. A location where two bottom plates are lap-welded to each other and are lapped onto or under an annular plate constitutes a three-plate lap, but lapping a single bottom plate onto or under a butt-welded annular plate splice does not constitute a three-plate lap weld since the two annular plates are not joined together by a lap weld. Lap joint connections to butt-welded annular plates are illustrated in Figure 5.3a.



NOTE 1 See 5.1.5.4 through 5.1.5.9 for specific requirements for roof and bottom joints.

NOTE 2 The alternative roof-to-shell joint is subject to the limitations of 5.1.5.9, Item f.

Figure 5.3a—Typical Roof and Bottom Joints

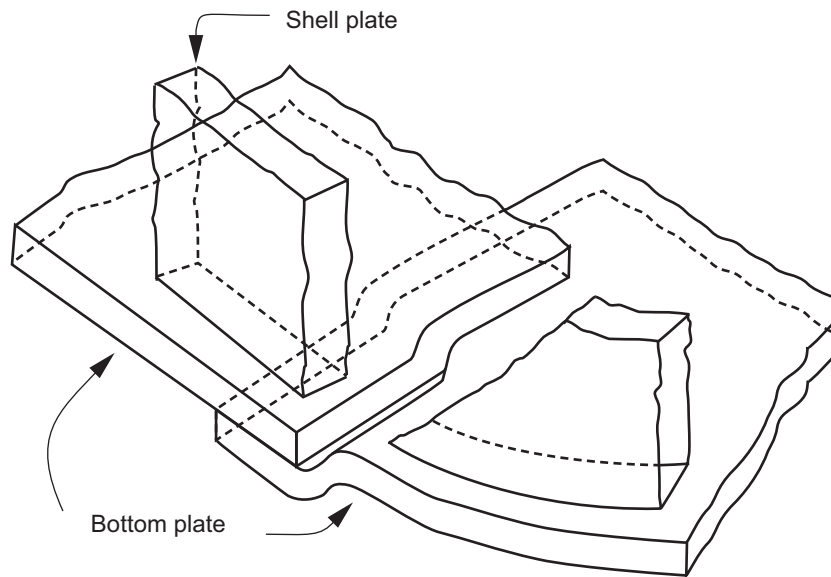
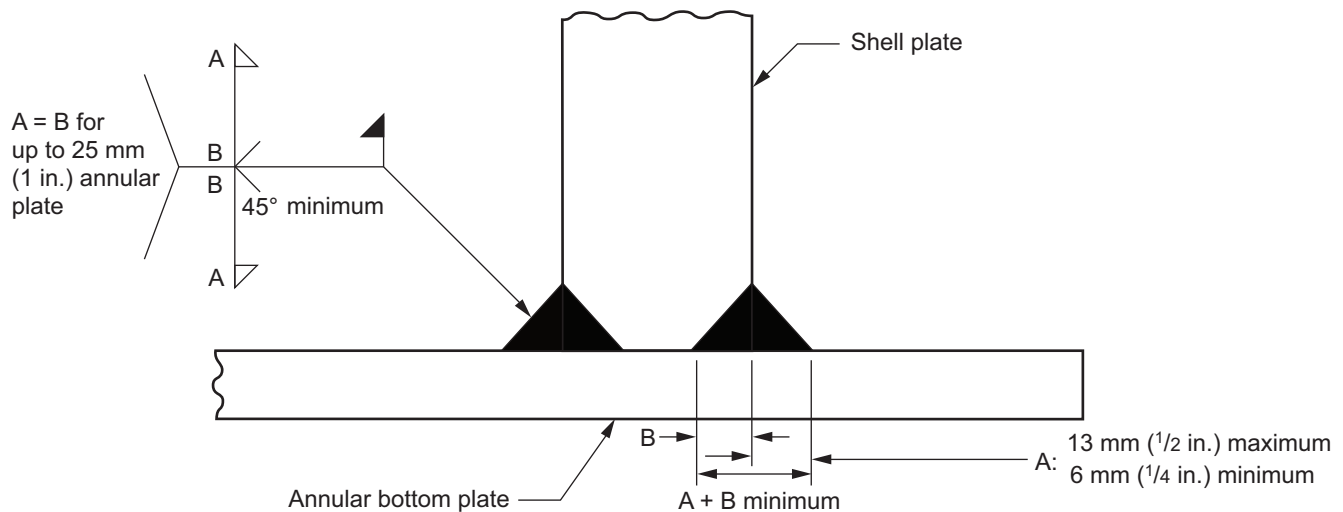


Figure 5.3b—Method for Preparing Lap-welded Bottom Plates under Tank Shell (See 5.1.5.4)



NOTE 1 A = Fillet weld size limited to 13 mm (1/2 in.) maximum.

NOTE 2 A + B = Thinner of shell or annular bottom plate thickness.

NOTE 3 Groove weld B may exceed fillet size A only when annular plate is thicker than 25 mm (1 in.).

Figure 5.3c—Detail of Double Fillet-groove Weld for Annular Bottom Plates with a Nominal Thickness Greater than 13 mm (1/2 in.) (See 5.1.5.7, Item b)

5.1.5.4.3 Bottom plates need to be welded on the top side only, with a continuous full-fillet weld on all seams. Lap-welded bottom plates under the bottom shell ring shall have the outer ends of the joints fitted and lap-welded to form a smooth bearing surface for the shell plates, as shown in Figure 5.3b. Lap-welded bottom plates shall be seal-welded to each other on the exposed outer periphery of their lapped edges.

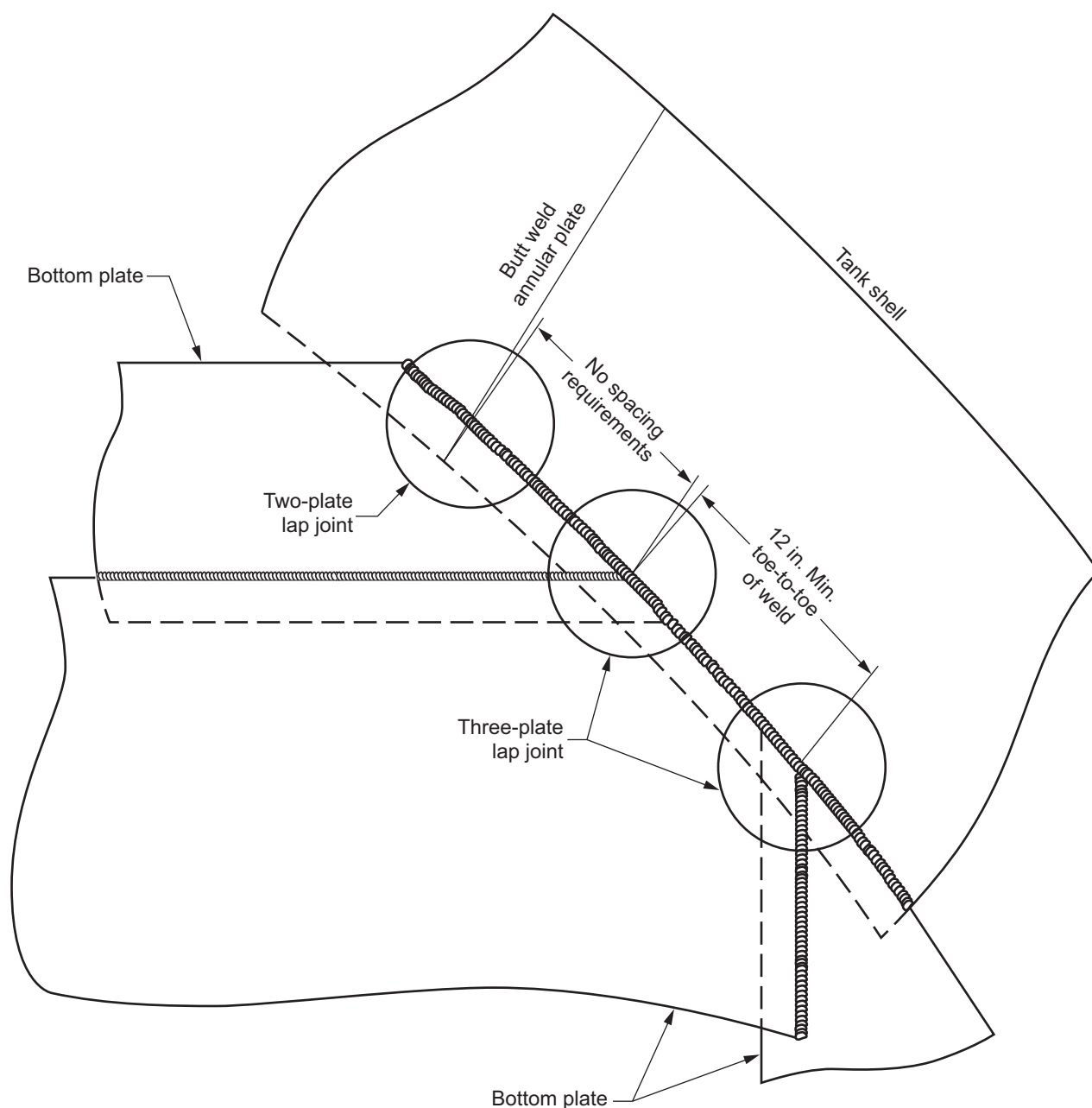


Figure 5.3d—Spacing of Three-Plate Welds at Annular Plates

• 5.1.5.5 Butt-Welded Bottom Joints

Butt-welded bottom plates shall have their parallel edges prepared for butt welding with either square or V grooves. Butt-welds shall be made using an appropriate weld joint configuration that yields a complete penetration weld. Typical permissible bottom butt-welds without a backing strip are the same as those shown in Figure 5.1. The use of a backing strip at least 3 mm ($1/8$ in.) thick tack welded to the underside of the plate is permitted. Butt-welds using a backing strip are shown in Figure 5.3a. If square grooves are employed, the root openings shall not be less than 6 mm ($1/4$ in.). A metal spacer shall be used to maintain the root opening between the adjoining plate edges unless the Manufacturer submits another method of butt-welding the bottom for the Purchaser's approval. Three-plate joints in the tank bottom shall be at least 300 mm (12 in.) from each other and from the tank shell.