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* For boxes marked with *, if blank, Mfr. shall determine and submit as per Appendix L. For all lines, see Appendix L for line-by-line instructions.

GENERAL Special Documentation Package Requirements: ____________

Measurement Units to be used in API Std 650: SI ❑ US Customary ❑

1. Manufacturer* ____________ Contract No.* ____________
   Address* ____________
   Mfg. Serial No.* ____________ Year Built* ____________ Edition & Addendum to *API 650** ____________
2. Purchaser ____________ Contract No. ____________
   Address ____________
   Tank Designation ____________
3. Owner/Operator ____________ Location ____________
4. Size Limitations* ____________ Tank Diameter* ____________ Shell Height* ____________
   07 Capacity: Maximum* ____________ Net Working* ____________ Criteria:* ____________
5. Products Stored:
   Liquid ____________ Max. S.G.: ________ at ________ °__
   Blanketing Gas ____________ Vapor Pressure ________ PSIA at Max. Operating Temp.
   % Aromatic ______ Suppl. Spec. ____________ H_2S Service? Yes ❑ No ❑ Suppl. Spec. ____________
   Other Special Service Conditions? Yes ❑ No ❑ Suppl. Specs. ____________

DESIGN AND TESTING ____________ Purchaser to Review Design Prior to Ordering Material? Yes ❑ No ❑_

6. Applicable API Standard 650 Appendices:* A ❑ B ❑ C ❑ F ❑ G ❑ H ❑ I ❑ J ❑ L ❑ M ❑ O ❑ P ❑ S ❑ U ❑ V ❑ W ❑
7. Max. Design. Temp. _____°__ Design Metal Temp.* _____°__ Design Liquid Level* ____________
   11 Design Pressure _______ External Pressure ________ Pressure Combination Factor ____________
   Maximum Fill Rate ____________ Maximum Emptying Rate ____________
   Flotation Considerations? Yes ❑ No ❑ Flot. Suppl. Spec:* ____________ Applied Supplemental Load Spec. ____________
8. Seismic Design? Yes ❑ No ❑ Appendix E ❑ Alternate Seismic Criteria ____________ Seismic Use Group ______
   MBE Site Class ________ Vertical Seismic Design? Yes ❑ No ❑ Vertical Ground Motion Accelerator A_V: ________
   Basis of Lateral Acceleration (Select one): ❑ Mapped Seismic Parameters? S_S ____ S_1 ____ S_0 ____; ❑ Site-Specific Procedures?: MCE
   Design Required? Yes ❑ No ❑; ❑ Other (Non-ASCE) Methods ____________
   ❑ Freeboard Required for SUG I Design Roof Tie Rods @ Outer Ring?* Yes ❑ No ❑
9. Wind Velocity for non-U.S. sites, 50-yr wind speed (3-sec Gust)* ________
   Top Wind Girder Style* ____________ Dimensions* ____________ Use Top Wind Girder as Walkway? Yes ❑ No ❑
   Intermediate Wind Girders?* Yes ❑ No ❑ Intermediate Wind Girder Style* ____________ Dimensions* ____________
   Check Buckling in Corroded Cond.? Yes ❑ No ❑
10. 07 Shell Design: 1-Ft Mthd?* Yes ❑ No ❑ ; Variable-Des-Pt Mthd?* Yes ❑ No ❑ Alternate ❑; Elastic Anal. Mthd?* Yes ❑ No ❑ Alternate ❑
    Plate Stacking Criteria* Centerline-Stacked? Yes ❑ No ❑ Flush-Stacked? Yes ❑ No ❑ Inside ❑ Outside ❑
    Plate Widths (Shell course heights) and Thicknesses * Numbers below Indicate Course Number.
    1. ________ 2. ________ 3. ________ 4. ________ 5. ________
    6. ________ 7. ________ 8. ________ 9. ________ 10. ________
    11. ________ 12. ________ 13. ________ 14. ________ 15. ________
    Joint Efficiency* ________% Shell-to-Bottom Weld Type* ____________ Shell-to-Bottom Weld Insp Mthd* ____________

Approvals:	Revisions:	Title:
		By: Ck'd: Date:
		Drawing No.: Sheet ___ of ___

API	API Std 650 Storage Tank Data Sheet	Page 2 of 8

* If box is blank, Manufacturer shall determine and submit as per Appendix L.

11. Open-Top and Fixed Roofs: (See Sheet 6 for Floating Roofs) Open Top? * Yes ❑ No ❑
Fixed Roof Type* ____________ Roof Support Columns*: Pipe ❑ Or Structural Shape ❑ ____________ 07
Cone Slope* ________. Dome or Umbrella Radius* ________ Weld Joints* ____________
(Lap, Butt, Other)
Seal Weld Underside of: Lap-Joints? Yes ❑ No ❑; Seal Weld Underside of Wind Girder Joints? Yes ❑ No ❑
Gas-tight? Yes ❑ No ❑ Joint Efficiency* ________%
Minimum Roof Live Load ______psf Balanced Snow Load ________psf Unbalanced Snow Load __________psf
App. Suppl. Load Spec.* __________ Column Lateral Load ____________ 09
Normal Venting Devices*______________ Emergency Venting Devices* ______________
For Non-Frangible Roofs: Seal Weld Roof Plates to Top Angle on the Inside? Yes ❑ No ❑ ; Weld rafters to Roof Plates Yes ❑ No ❑
Roof-to-Shell Detail* ____________ Radial Projection of Horizontal Component of Top Angle* Inward ❑ Outward ❑

12. Bottom: Thickness* ________ Style* ____________ Slope* ________. Weld Joint Type* ____________
Provide Drip Ring? Yes ❑ No ❑ Alternate Spec. ____________
Annular Ring? Yes ❑ No ❑ Annular Ring: Minimum Radial Width* ________ Thickness* ________

13. Foundation: Furnished by*____________ Type* ____________
Soil Allow. Bearing Pressure* ________ Per Spec.* ____________ Anchors: Size* _____ Qty* _____
Foundation Design Loads: Base Shear Force: Wind* _____ Seismic* _____ Overturning Moment: Wind* ______ Seismic* _____
Ring Forces: Weight of Shell + Roof New* _______ Corroded* _______ Roof Live Load* _______ Internal Pressure* _______
Partial Vacuum* ________ Wind* ________ Seismic* ________
Bottom Forces: Floor Wt. New* ______ Corroded* ______ Product Wt.* ______ Water Wt.* _____ Internal Pressure* ______
Partial Vacuum* _________ Other Foundation Loads* ____________ Min. Projection of Fdn. Above Grade: ________ 07

14. Responsibility for Heating Water, if Required: Purchaser ❑ Manufacturer ❑
Hydro-Test Fill Height* ________ Settlement Measurements Required? Yes ❑ No ❑ Extended Duration of Hydro-Test:_________
❑ Predicted Settlement Profile is Attached
Responsibility for Setting Water Quality: Purchaser ❑ Manufacturer ❑ Supplemental Test Water Quality Spec. ____________
Test Water Source & Disposal Tie-In Locations ____________ Hydro-Test Appendix J Tank? Yes ❑ No ❑
Post-Pressure-Test Activities Required of the Manufacturer: Broom Clean ❑ Potable Water Rinse ❑ Dry Interior ❑
Other ❑ ____________

15. Inspection by ____________ in Shop; ____________ in Field
Supplemental NDE Responsibility ____________ Supplemental NDE Spec. ____________
(Purch., Mfg., Other)
Positive Material Identification? Yes ❑ No ❑ PMI Requirements:____________
Max. Plate Thickness for Shearing _______
Must Welds not exceeding 6 mm ($^1/_4$ in.) Be Multi-Pass? Yes ❑ No ❑ Must Welds greater than 6 mm ($^1/_4$ in.) Be Multi-Pass? Yes ❑ No ❑
Leak Test Mthd: Roof* ______________ Shell* ______________ Shell Noz./Manhole Reinf. Plt.* ____________
Bottom* ____________ Floating Roof Components* ______________
Modify or Waive API Dimensional Tolerances (see 7.5)? No ❑ Yes ❑ Specify: ____________
Specify Additional Tolerances, if any, and Circumferential and Vertical Measurement Locations:
- Allowable Plumbness: ________ Measure and Record at a Minimum of ____ Locations or Every ____ m (ft) around the Tank, at the Following Shell Heights: (select one box): ❑ $^1/_3$ H, $^2/_3$ H and H ❑ Top of Each Shell Course ❑ Other: ________
- Allowable Roundness: **________ Measure Radius and Record at a Minimum of ________ Locations or Every ________ m (ft) around the Tank, at the Following Shell Heights (select one box):
❑ Top of Tank, H ❑ $^1/_3$ H, $^2/_3$ H and H ❑ Top of Each Shell Course ❑ Other: ____________

**See Data Sheet Instructions for the Maximum Allowable Additional Radial Tolerance.

Approvals:	Revisions:	Title:
		By: Ck'd: Date:
		Drawing No.: Sheet ___ of ___

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16. Coatings:

11 Internal Linings by: ______________________ Per Spec.* ____________________________________
(Not Req'd., Others, Tank Mfg.)

External Coating by: ______________________ Per Spec.* ____________________________________
(Not Req'd., Others, Tank Mfg.)

Under-Bottom Coating by: ___________________ Per Spec.* ____________________________________
(Not Req'd., Others, Tank Mfg.)

17. Cathodic Protection System? Yes ❑ No ❑ Per Spec.* ____________________________________

18. Leak Detection System? Yes ❑ No ❑ Per Spec.* ____________________________________

19. Release Prevention Barrier? Yes ❑ No ❑ Per Spec.* ____________________________________

20. Tank Measurement System: Required? Yes ❑ No ❑ Remote Capability Required? Yes ❑ No ❑
By:* ______________________________________ Per Spec.* ______________________________________

21. Weight of Tank: Full of Water* ________ Empty* ________ Shipping* _______ Brace/Lift Spec.* ______________________

22. References*: *API Std 650, Appendix L*

23. Remarks*:

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Approvals:	Revisions:	Title:
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		Drawing No.: Sheet ___ of ___

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* If box is blank, Manufacturer shall determine and submit as per Appendix L.

Table 1 MATERIALS OF CONSTRUCTION

Component	Material*/Thickness*	C.A.	Component	Material*	C.A.
Shell, Course __ to __			Reinforcing Pads		
Shell, Course __ to __			Manhole/Nozzle Necks		
Shell, Course __ to __			Manhole/Nozzle Flanges		
Shell, Course __ to __			Flange Covers		
Shell, Course __ to __			Anchor Attachments		
Roof			Submerged Piping		
Bottom			Wetted Structurals		+
Annular Ring			Non-wetted Structurals		+

+ Check here if C.A. is to apply to each exposed surface ☐.

Table 2 BOLTS and ANCHORS

Component	Head Type*	Bolt or Anchor Material*	Nut Material*	Thread Series*	C.A.
Flange Bolting					++
Structural Bolting					++
Anchor Bolts					++

07

++ Total C.A., on the nominal diameter.

Table 3 NOZZLE and MANHOLE SCHEDULE* (for Fixed Roof, Shell, and Bottom)

Mark	Service	Size, NPS, or Dia. (In.)	Neck Sch or Wall Thick.	Reinf. Plate Dimensions	Full Pen. On Open. (Y/N)	Flange Type	Flange Class or Thick.	Gasket Bearing Surf. Dimen. and Finish	Gasket Thick. and Dimen.	Gasket Mat'l. and Descript.	Proj. to FF or CL or from Datum Lines

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* If box is blank, Manufacturer shall determine and submit as per Appendix L.

OTHER TANK APPURTENANCES

24. Platform, Stairway, and Railing: Galvanizing Req'd?* Yes ❑ No ❑ Stairway Style* ____________ Walk Surf. Type* __________
(Straight or Helical)
Stair and Walkway Clear Width* ________________ National Safety Standards* ________________
Architectural/Structural Specification* ________________
Gauger's Platform Req'd? Yes ❑ No ❑ Qty Req'd.* ____________ Per Spec. * ________________

25. Jacket Required?* Yes ❑ No ❑ Other Heaters/Coolers Required?* Yes ❑ No ❑
Supplemental Jacket, Heater, or Cooler Specifications* ________________

26. Mixer/Agitator: Quantity ________ Size* ________ Per Spec.* ________________

27. Insulation: Required? Yes ❑ No ❑ Thickness* ________ Material* ________________
Per Specs* ________________ Responsibility for Insulation and Installation ________________
(Purchaser, Manufacturer, Others)

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28. Structural Attachments: Lift Lugs?* Yes ❑ No ❑ Desc.* ________________
Shell Anchorage?* Yes ❑ No ❑ Type* ________________ Scaffold Cable Support? Yes ❑ No ❑

29. Various Other Items: Welded Flush-Type: Shell Connection ❑ Cleanout Fitting ❑ Waive Application of Appendix P? Yes ❑ No ❑
Miscellany #1 ________________ Miscellany #2 ________________
Miscellany #3 ________________ Miscellany #4 ________________
Miscellany #5 ________________ Miscellany #6 ________________

Table 4 OTHER TANK APPURTENANCES*

Mark	Quantity	Service or Description	Size	Orientation	Height from Datum	Material	Remarks

Approvals:	Revisions:	Title:
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		Drawing No.: Sheet ___ of ___

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* If box is blank, Manufacturer shall determine and submit as per Appendix L.

FLOATING ROOF DATA

30. **Floating Roof Selection**

Design Basis: Appendix C ❑ Or Appendix H ❑

Type of Roof: (External or Internal): Single Deck Pontoon* ❑ Double Deck* ❑

(Internal Only): Tubular Pontoon* ❑ Metallic Sandwich Panel* ❑

Other ❑ ______________________ Supplemental Spec.:__________________

31. **Seals**

Primary Seal: Shoe ❑ Envelope ❑ Wiper/Compression Plate ❑ Other ❑ ______ Supplemental Spec: ____________

Shoe Mechanism: Mfg. Std. ❑ Other ❑ ____________________________________

Electrically Isolate Mechanism from Shoes? Yes ❑ No ❑ Wax Scrapers Required? Yes ❑ No ❑

Nominal Shoe Thickness* __________ Carbon Steel Shoes to be Galvanized? Yes ❑ No ❑

Secondary Seal: Shoe ❑ Envelope ❑ Wiper ❑ None ❑ Other ❑ ____________ Supplemental Spec: __________

32. **Data for All Floating Roofs:**

Overflow Openings in Shell Acceptable? Yes ❑ No ❑ Shell Extension? Yes ❑ No ❑ 11

Roof-Drain Check Valves Required? Yes ❑ No ❑ Roof-Drain Isolation Valves Required? Yes ❑ No ❑

Freeze Protection for Roof Drains Required? No ❑ Yes ❑ Supplemental Requirements: _______________

Roof-Drain Piping to External Nozzles: Mfg. Std. ❑ Armored Flexible Pipe ❑ Swivels in Rigid Pipe ❑ Other ❑ ______________

Foam Dam? Yes ❑ No ❑ Supplemental Spec. __________________________

Nominal Deck Thickness* ____________________

Bulkhead Top Edges to be Liquid-Tight? Yes ❑ No ❑ Seal-weld Underside of Roof? Yes ❑ No ❑

Electrical Bonding: Shunts: Yes❑ No ❑ Cables: Yes ❑ No ❑ Supplemental Spec. __________________________

Qty of Non-Guide-Pole Gauge Wells Required ________ Qty of Sample Hatches Required ________

Guide Pole for Gauging? Yes ❑ No ❑ Slots in Guide Pole? Yes ❑ No ❑ Datum Plates? Yes ❑ No ❑ Striking Plates? Yes ❑ No ❑

Guide Pole Emissions-Limiting Devices: Sliding Cover ❑ Pole Wiper ❑ Pole Sleeve ❑ Float ❑ Float Wiper ❑ Pole Cap ❑

Qty. of Roof Manholes* ______ Minimum High-Roof Clearance Above Bottom: ______

Removable Leg Storage Racks? Yes ❑ No ❑ ; Leg Sleeves ❑ or Fixed Low Legs ❑

33. **Additional Data for External Floating Roofs:**

Weather Shield? Yes ❑ No ❑ Suppl. Spec. _______________

Rolling Ladder Req'd? Yes ❑ No ❑ Field Adjustable Legs? Yes ❑ No ❑

Design Rainfall Intensity _______In./Hr. (mm/hr) Based on a _______ Minute Duration Associated with the __________ Storm

Design Accumulated 24-Hour Rainfall _______In. (mm) Based on the __________ Storm

Distortion and Stability Determinations Required? Yes ❑ No ❑ Supplemental Specification __________________________

Landed Live Load* _____

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34. **Additional Data for Internal Floating Roofs:**

Two-Position Legs? Yes ❑ No ❑ Cable-Supported Roof? Yes ❑ No ❑ Fixed-Roof Inspection Hatches Required?: Yes ❑ No ❑

Internal Roof Drain Required? Yes ❑ No ❑ Omit Distribution Pads Supporting Uniform Live Loads? Yes ❑ No ❑

Corrosion Gauge Required? Yes ❑ No ❑ Fixed Ladder Required?: Yes ❑ No ❑ ; Type of Roof Vent: *____________

Modified Minimum Point Load? Yes ❑ No ❑ Supplemental Specification ______________________________

Mfr. to Leak Test * ___ % of Compartments ❑ in Assembly Yard ❑ in Erected Position ❑ Unknown; see separate contract terms

Roof Erector's Flotation Test: w/ tank hydro ❑ at completion of roof ❑ at later date ❑ ______ Not required ❑

Flotation Test Media: Water ❑ Product ❑ (see H.6.6.1) Water Quality: Potable ❑ Other ❑ See Supplemental Spec ____________

Flotation Test: Duration _______ Fill Height: ______

Flotation Test Items provided by Purchaser (see H.6.7): None ❑ List Attached ❑

Responsible Party for Inspecting Roof during Initial Fill: Purchaser ❑ Other ❑ ________________

07 **Table 5 FLOATING ROOF MATERIALS**

Component	Material*/Thickness*	C.A./Coating*	Component	Material*/Thickness*	C.A./Coating*
Deck Plate			Datum Plate		
Inner Rim Plate			Tubular Pontoon		
Outer Rim Plate			Pontoon Bulkhead		
Foam Dam			Submerged Pipe		
Sandwich Panel Face Plate			Guide Pole		
Sandwich Panel Core			Secondary Seal		
Gauge Well			Secondary Seal Fabric		
Drain Sumps			Wiper Tip		
Opening Sleeves			Wax Scraper		
Floating Suction Lines			Weather Seal		
Primary Fabric Seal			Envelope Fabric		
Foam Log Core			Shoe Mechanisms		
Landing Legs			Primary Seal Shoe		
Landing Leg Bottom Pads			Removable Covers		
Manhole Necks			Rolling Ladder		
Vents			Inlet Diffusers		

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* If box is blank, Manufacturer shall determine and submit as per Appendix L.

Tank Plan and Sketches:

Notes:

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Table L-1—Index of Decisions or Actions Which may be Required of the Tank Purchaser

07	Foreword	5.6.1.1 (Notes 1, 3)	6.1.3
	1.1.2	5.6.1.2	6.2.1
08	1.1.3	Tables 5-2a and 5-2b (Note a)	6.2.3
	1.1.5	5.6.3.2 (*H*, *G*, *CA*)	6.2.4
	1.1.6	5.6.4.1	7.1.1
	1.1.11	5.6.4.6 (*H*)	7.1.4
	Table 1-1 (App. C, E, G, I, L, O, P, V, W)	5.7.1.4	7.2.1.1
	1.1.15	5.7.1.8	7.2.1.7
	1.1.18	Figure 5-6 (Note 5)	7.2.3.3
07	1.1.22	Figure 5-7A (Notes 1, 7)	7.2.4.1
	1.1.28	Figure 5-7B (Note 6)	7.2.4.3
	1.3.2	Figure 5-8 (Note 4)	7.3.1.3
	1.3.3	5.7.2.2	7.3.2.1
	1.4	5.7.2.3 (b)	7.3.2.3
	4.1.1.4	Tables 5-6a and 5-6b (Note c)	7.3.5, 1
08	4.1.2	Tables 5-8a and 5-8b (Note d)	7.3.6.2 (2, 3, 4, 5, 7)
	4.1.3	Tables 5-9a and 5-9b (Note c)	7.3.6.3
	4.1.5 (b)	Figure 5-12 (Note 4)	7.3.6.5 (Note)
	4.2.1.3	5.7.3.4	7.3.7.2
	4.2.5	5.7.4.5	7.4.1
	Table 4-1 (Note 1)	5.7.5.2	7.4.4
	Table 4-2 (Note C)	5.7.6.1.a	7.5.1
	4.2.7.4	5.7.6.1.b	8.1.2.7
	4.2.8.1	5.7.6.2	8.1.4
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	4.2.10.4	5.7.7.1	8.1.7.2
	4.4.1 (g)	5.7.8.1	8.1.8.2
	4.4.2	5.8.2	8.3.2.5
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	4.7	5.8.5.4	8.6.10
	4.9.1.1	5.8.7	8.6.11
	4.9.1.4	5.8.10 (c)	9.2.1.1
07	4.9.1.5	5.8.11.2	10.1.1 (e, f, g, j, k)
	4.9.2	5.8.11.3	Figure 10-1 (Note)
	4.9.3.1	5.9.3.3	10.3 (Note)
	5.1.3.6.1	5.9.6.1 (Note)	A.1.1
	5.1.3.8	5.9.7.1 (t, d)	A.1.2
	5.1.5.3 (b)	5.9.7.2 ($t_{uniform}$, t_{actual})	A.3.4
	5.1.5.4	5.9.7.7	A.4.1 (*G*, *CA*)
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	5.1.5.8 (b)	5.10.2.4	A.8.2
	5.1.5.9 (e)	5.10.2.6	A.9.2
	5.2.1 (a, b, f, g, h, j, 1)	5.10.2.7	B.3.3
	5.2.2	5.10.2.8	B.3.4
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C.3.12.3
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Appendix L
M.1.2 (Note)
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Table S-1a and S-1b (Notes 1, 2, 3, 5) 08
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Appendix V
Appendix W

APPENDIX M—REQUIREMENTS FOR TANKS OPERATING AT ELEVATED TEMPERATURES

M.1 Scope

M.1.1 This appendix specifies additional requirements for API Std 650 tanks with a maximum design temperature exceeding 93°C (200°F) but not exceeding 260°C (500°F).

M.1.2 The following shall not be used for a maximum design temperature above 93°C (200°F):

a. Open-top tanks (see 5.9).

b. Floating-roof tanks (see Appendix C).

c. Structurally-supported aluminum dome roofs (see G.1.1 and note below).

d. Internal floating roofs constructed of aluminum (see H.2.2 and note below).

e. Internal floating roofs constructed of composite material (see H.2.2). Lower temperature limits may apply for this roof material type. 07

● Note: An exception may be made by the Purchaser for Items c and d, if the following criteria are met: 11

a. Allowable stress reductions for aluminum alloys are determined in accordance with Appendix AL, and alloys are evaluated for the potential of exfoliation. 08

b. Gaskets and seals are evaluated for suitability at the maximum design temperature.

M.1.3 Internal floating roofs in accordance with Appendix H may be used for a maximum design temperature above 93°C (200°F), subject to the applicable requirements of this appendix. The vapor pressure of the liquid must be considered. Sealing devices, particularly those of fabric and nonmetallic materials, shall be suitable for the maximum design temperature.

M.1.4 Tanks for small internal pressures in accordance with Appendix F may be used for a maximum design temperature above 93°C (200°F), subject to the requirements of M.3.6, M.3.7, and M.3.8. 07

M.1.5 Shop-assembled tanks in accordance with Appendix J may be used for a maximum design temperature above 93°C (200°F), subject to the applicable requirements of this appendix.

M.1.6 The nameplate of the tank shall indicate that the tank is in accordance with this appendix by the addition of M to the information required by 10.1.1. In addition, the nameplate shall be marked with the maximum design temperature in the space indicated in Figure 10-1.

● M.2 Thermal Effects

This appendix does not provide detailed rules for limiting loadings and strains resulting from thermal effects, such as differential thermal expansion and thermal cycling, that may exist in some tanks operating at elevated temperatures. Where significant thermal effects will be present, it is the intent of this appendix that the Purchaser define such effects. The Manufacturer shall propose, subject to the Purchaser's acceptance, details that will provide strength and utility equivalent to those provided by the details specified by this Standard in the absence of such effects.

For a maximum design temperature above 93°C (200°F), particular consideration should be given to the following thermal effects: 07

a. Temperature differences between the tank bottom and the lower portion of the shell. Such thermal differences may result from factors such as the method and sequence of filling and heating or cooling, the degree of internal circulation, and heat losses to the foundation and from the shell to the atmosphere. With such temperature differences, it may be necessary to provide for increased piping flexibility, an improved bottom-to-shell joint, and a thicker annular ring or bottom sketch plates to compensate for increased rotation of the bottom-to-shell joint (see M.4.2).

b. The ability of the bottom to expand thermally, which may be limited by the method of filling and heating. With such a condition, it may be necessary to provide improved bottom welding in addition to the details suggested in Item a.

c. Temperature differences or gradients between members, such as the shell and the roof or stairways, the shell and stiffeners, the roof or shell and the roof supports, and locations with insulation discontinuities.

d. Whether or not the contents are allowed to solidify and are later reheated to a liquid, including the effect on columns, beams, and rafters. The possible build-up of solids on these components and the potential for plugging of the vent system should also be considered.

e. The number and magnitude of temperature cycles the tank is expected to undergo during its design life.

M.3 Modifications in Stress and Thickness

08 **M.3.1** For a maximum design temperature not exceeding 93°C (200°F), the allowable stress specified in 5.6.2 (see Tables 5-2a and 5-2b) for calculating shell thickness need not be modified.

M.3.2 For a maximum design temperature exceeding 93°C (200°F), the allowable stress specified in 5.6.2 shall be modified as follows: The allowable stress shall be two-thirds the minimum specified yield strength of the material multiplied by the applicable
08 reduction factor given in Tables M-1a and M-1b or the value given in Tables 5-2a and 5-2b for product design stress, whichever is less.

08 **M.3.3** For operating temperatures exceeding 93°C (200°F), the yield strength F_y in 5.10.4.4 shall be multiplied by the applicable reduction factor given in Tables M-1a and M-1b.

M.3.4 The allowable stress of 145 MPa (21,000 lbf/in²) in the equation for shell-plate thickness in A.4.1 shall be multiplied by
08 the applicable reduction factor given in Tables M-1a and M-1b.

07 **M.3.5** The requirements of 5.7.5 for shell manholes, 5.7.7 for flush-type cleanout fittings and of 5.7.8 for flush-type shell connections shall be modified. The thickness of bottom reinforcing plate for flush-type shell cleanouts and flush-type shell connections and bolting flange and cover plates for shell manhole and flush-type shell cleanouts shall be multiplied by the ratio of 205 MPa (30,000 lbf/in.²) to the material yield strength at the maximum design temperature if the ratio is greater than one.

M.3.6 The structural allowable stresses specified in 5.10.3, including the allowable stresses dependent on the modulus of elas-
08 ticity, shall be multiplied by the yield strength reduction factors from Tables M-1a and M-1b at the maximum design temperature.

M.3.7 Text deleted.

09 **M.3.8** Text deleted.

08 **M.3.9** If the anchors are insulated, the allowable stresses specified in Tables 5-21a, 5-21b and 5-22a and 5-22b shall be multiplied by the ratio of the material's yield strength at the maximum design temperature to 205 MPa (30,000 lbf/in.²) if the ratio is less than 1.0 (see Tables M-1a and M-1b for yield strength reduction factors).

Table M-1a—(SI) Yield Strength Reduction Factors

Temperature (°C)	Minimum Specified Yield Strength (MPa) < 310 MPa	From ≥ 310 to < 380 MPa	≥ 380 MPa
94	0.91	0.88	0.92
150	0.88	0.81	0.87
200	0.85	0.75	0.83
260	0.80	0.70	0.79

08

Note: Linear interpolation shall be applied for intermediate values.

Table M-1b—(USC) Yield Strength Reduction Factors

Temperature (°F)	Minimum Specified Yield Strength (lbf/in.²) < 45,000 lbf/in.²	≥ 45,000 to < 55,000 lbf/in.²	≥ 55,000 lbf/in.²
201	0.91	0.88	0.92
300	0.88	0.81	0.87
400	0.85	0.75	0.83
500	0.80	0.70	0.79

Note: Linear interpolation shall be applied for intermediate values.

M.4 Tank Bottoms

M.4.1 Tanks with diameters exceeding 30 m (100 ft) shall have butt-welded annular bottom plates (see 5.1.5.6).

M.4.2 The following simplified procedure is offered as a recommended design practice for elevated-temperature tanks where significant temperature differences between the tank bottom and the lowest shell course are expected. The use of the procedure is not intended to be mandatory. It is recognized that other analytical procedures can be employed as well as that operating conditions may preclude the need for such a procedure.

Shell-to-bottom junctions in elevated-temperature tanks may be evaluated for liquid head and temperature cycles with the formulas, procedures, and exclusions given below. (See Conditions a and b in the note below, which exclude tanks from such analyses.)

Note: A cyclic design life evaluation need not be made if all the criteria of either of the following conditions are met:

a. The design temperature difference (T) is less than or equal to 220°C (400°F), K is less than or equal to 2.0, and C is less than or equal to 0.5.

b. A heated liquid head, in feet, greater than or equal to $0.3(Dt)^{0.5}$ is normally maintained in the tank, except for an occasional cool-down (about once a year) to ambient temperatures; T is less than or equal to 260°C (500°F); and K is less than or equal to 4.0. (For background information on the development of the stress formulas, design life criteria, and C and B factors, see G.G. Karcher, "Stresses at the Shell-to-Bottom Junction of Elevated-Temperature Tanks.")

In SI units:

$$N = \left(\frac{9.7 \times 10^3}{KS}\right)^{2.44}$$

(If N is greater than or equal to 1300, cycling at the shell-to-bottom junction is not a controlling factor.)

where

N = number of design liquid level and temperature cycles estimated for the tank design life (usually less than 1300). This design procedure contains a conservative safety margin. It is not necessary to monitor actual in-service temperature and liquid head cycles

K = stress concentration factor for the bottom plate at the toe of the inside shell-to-bottom fillet weld

= 4.0 for shell-to-bottom fillet welds and lap-welded bottom plates

= 2.0 for butt-welded annular plates where the shell-to-bottom fillet welds have been inspected by 100% magnetic particle examination (see 8.2). This magnetic particle examination shall be performed on the root pass at every 13 mm of deposited weld metal while the weld is being made and on the completed weld. The examination shall be performed before hydrostatic testing

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

= one-half the maximum stress range that occurs in the annular plate at the shell-to-bottom junction weld, in MPa. The H and CT terms must be large enough to cause a positive S. A negative S indicates that loading conditions are not sufficient to satisfy the development assumptions of this formula. Specifically stated, the following inequality must be satisfied when the equation for S is used:

$$\left[\frac{58HG}{(Dt)^{0.5}} + \frac{26.2 CTt^{0.5}}{D^{1.5}} - G\right] > \frac{4.8 BS_y t_b^2}{(Dt)^{1.5}}$$

When the equation for S is used, the shell thickness t must be greater than or equal to the annular-plate thickness t_b

T = difference between the minimum ambient temperature and the maximum design temperature (°C)

S_y = specified minimum yield strength of the bottom plate at the maximum design temperature (MPa) 07

D = nominal tank diameter (m)

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

G = design specific gravity of the liquid

t = nominal thickness of the tank's bottom shell course (mm)

t_b = nominal thickness of the annular bottom plate (mm)

• C = factor to account for radial restraint of the tank's shell-to-bottom junction with respect to free thermal expansion (C_{max} = 1.0; C_{min} = 0.25). The actual design value of C shall be established considering the tank's operating and warm-up procedure and heat transfer to the subgrade[29]

= 0.85 if no C factor is specified by the Purchaser

B = foundation factor[29]

= 2.0 for tanks on earth foundations

= 4.0 for tanks on earth foundations with a concrete ringwall

In US Customary units:

$$N = \left(\frac{1.4 \times 10^6}{KS}\right)^{2.44}$$

(If N is greater than or equal to 1300, cycling at the shell-to-bottom junction is not a controlling factor.)

where

N = number of design liquid level and temperature cycles estimated for the tank design life (usually less than 1300). This design procedure contains a conservative safety margin. It is not necessary to monitor actual in-service temperature and liquid head cycles

K = stress concentration factor for the bottom plate at the toe of the inside shell-to-bottom fillet weld

= 4.0 for shell-to-bottom fillet welds and lap-welded bottom plates

= 2.0 for butt-welded annular plates where the shell-to-bottom fillet welds have been inspected by 100% magnetic particle examination (see 8.2). This magnetic particle examination shall be performed on the root pass at every $^1/_2$ in. of deposited weld metal while the weld is being made and on the completed weld. The examination shall be performed before hydrostatic testing

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

= one-half the maximum stress range that occurs in the annular plate at the shell-to-bottom junction weld, in pounds per square inch. The H and CT terms must be large enough to cause a positive S. A negative S indicates that loading conditions are not sufficient to satisfy the development assumptions of this formula. Specifically stated, the following inequality must be satisfied when the equation for S is used:

$$\left[\frac{6.3HG}{(Dt)^{0.5}} + \frac{436CTt^{0.5}}{D^{1.5}} - G\right] > \frac{BS_y t_b^2}{(Dt)^{1.5}}$$

When the equation for S is used, the shell thickness t must be greater than or equal to the annular-plate thickness t_b

[29]G. G. Karcher, "Stresses at the Shell-to-Bottom Junction of Elevated-Temperature Tanks," *1981 Proceedings—Refining Department*, Volume 60, American Petroleum Institute, Washington D.C. 1981, pp. 154 – 159.

T = difference between the minimum ambient temperature and the maximum design temperature (°F). 07

S_y = specified minimum yield strength of the bottom plate at the maximum design temperature (lbf/in.^{2}).

D = nominal tank diameter (ft)

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

G = design specific gravity of the liquid

t = nominal thickness of the tank's bottom shell course (in.)

t_b = nominal thickness of the annular bottom plate (in.)

C = factor to account for radial restraint of the tank's shell-to-bottom junction with respect to free thermal expansion (C_{max} = 1.0; C_{min} = 0.25). The actual design value of C shall be established considering the tank's operating and warm-up procedure and heat transfer to the subgrade[29]

= 0.85 if no C factor is specified by the Purchaser

B = foundation factor[29]

= 2.0 for tanks on earth foundations

= 4.0 for tanks on earth foundations with a concrete ringwall

M.5 Self-Supporting Roofs

M.5.1 The requirements of 5.10.5 and 5.10.6, which are applicable to self-supporting roofs, shall be modified. For a maximum design temperature above 93°C (200°F), the calculated nominal thickness of roof plates, as defined in 5.10.5 and 5.10.6, 11 shall be increased by the ratio of 199,000 MPa (28,800,000 lbf/in.^{2}) to the material's modulus of elasticity at the maximum design temperature.

M.5.2 Tables M-2a and M-2b shall be used to determine the material's modulus of elasticity at the maximum operating temperature. 08

M.6 Wind Girders

In the equation for the maximum height of unstiffened shell in 5.9.7.1, the maximum height (H_1) shall be reduced by the ratio of 09 the material's modulus of elasticity at the maximum design temperature to 199,000 MPa (28,800,000 lbf/in.^{2}) when the ratio is less than 1.0 (see Tables M-2a and M-2b for modulus of elasticity values).

Table M-2a—(SI) Modulus of Elasticity at the Maximum Design Temperature 08

Maximum Design Temperature °C	Modulus of Elasticity MPa
93	199,000
150	195,000
200	191,000
260	188,000

Note: Linear interpolation shall be applied for intermediate values.

08

Table M-2b—(USC) Modulus of Elasticity at the Maximum Design Temperature

Maximum Design Temperature	Modulus of Elasticity
°F	lbf/in.^{2}
200	28,800,000
300	28,300,000
400	27,700,000
500	27,300,000

Note: Linear interpolation shall be applied for intermediate values.

APPENDIX N—USE OF NEW MATERIALS THAT ARE NOT IDENTIFIED

N.1 General

New or unused plates and seamless or welded pipe that are not completely identified as complying with any listed specification may be used in the construction of tanks covered by this Standard, under the conditions specified in N.2.

N.2 Conditions

• **N.2.1** A material may be used if an authentic test record for each heat or heat-treating lot of material is available that proves that the material has chemical requirements and mechanical properties within the permissible range of a specification listed in this Standard. If the test requirements of the listed specification are more restrictive than any specification or authentic tests that have been reported for the material, more restrictive tests shall be performed in accordance with the requirements of the listed specification, and the results shall be submitted to the Purchaser for approval.

• **N.2.2** If an authentic test record is not available or if all the material cannot be positively identified with the test record by legible stamping or marking, the following requirements apply:

a. Each plate shall be subjected to the chemical analysis and physical tests required by the designated specification, with the following modifications: The carbon and manganese contents shall be determined in all check analyses. When the designated specification does not specify carbon and manganese limits, the Purchaser shall decide whether these contents are acceptable. When the direction of rolling is not definitely known, two tension specimens shall be taken at right angles to each other from a corner of each plate, and one tension specimen shall meet the specification requirements.

b. Each length of pipe shall be subjected to a chemical check analysis and sufficient physical tests to satisfy the Purchaser that all of the material is properly identified with a given heat or heat-treatment lot and that the chemical and physical requirements of the designated specification are met. Material specified as suitable for welding, cold bending, close coiling, and the like shall be given sufficient check tests to satisfy the Purchaser that each length of material is suitable for the fabrication procedure to be used.

N.2.3 Charpy V-notch impact tests must be performed when required by Figure 4-1 to verify that the material possesses the toughness required by Tables 4-4a and 4-4b. 08

• **N.2.4** After a material is properly identified with a designated specification and the Purchaser is satisfied that the material complies with the specification in all respects, the testing agency shall stencil or otherwise mark, as permitted by the specification, a serial *S* number on each plate or each length of pipe (or as alternatively provided for small sizes in the specification) in the presence of the Purchaser.

• **N.2.5** Suitable report forms clearly marked "Report on Tests of Nonidentified Materials" shall be furnished by the tank Manufacturer or testing agency. The forms shall be properly filled out, certified by the testing agency, and approved by the Purchaser.

• **N.2.6** The Purchaser shall have the right to accept or reject the testing agency or the test results.

N.2.7 The requirements for fabrication applicable to the designated specification to which the nonidentified material corresponds shall be followed, and the allowable design stress values shall be those specified in this Standard for the corresponding specification.

APPENDIX O—RECOMMENDATIONS FOR UNDER-BOTTOM CONNECTIONS

O.1 Scope

This appendix contains recommendations to be used for the design and construction of under-bottom connections for storage tanks. The recommendations are offered to outline good practice and to point out certain precautions that are to be observed. Reference should be made to Appendix B for considerations involving foundation and subgrade.

O.2 Recommendations

O.2.1 The recommendations of this appendix are intended for use only where significant foundation settlement is not expected. It is not possible to establish precise limits, but if predicted settlement exceeds 13 mm ($^{1}/_{2}$ in.), the recommendations should be subjected to detailed engineering review for possible additions, modifications, or elimination of bottom connections. Particular consideration shall be given to possible differential settlement in the immediate area of the bottom connection and with respect to connecting piping.

● **O.2.2** The arrangement and details of bottom connections may be varied to achieve the utility, tightness, and strength required for the prevailing foundation conditions. The details shown in Figures O-1, O-2, and O-3 are examples. Figures O-1 and O-2 show details used on a concrete ringwall foundation, but similar designs may be used on earth foundations. Figure O-3 shows another detail used on earth foundations. Other arrangements of foundation and connection (including combination sump and pipe) may be used under the provisions of O.2.6. When required by the Purchaser, seismic considerations (see Appendix E) shall be included.

O.2.3 Support of the pipe by the soil and bottom connection shall be evaluated to confirm adequacy and resistance to liquid, static, and dynamic loads. Both deflection and stress shall be considered in the evaluation.

O.2.4 Consideration shall be given to predicted settlement that would affect the relative positions of the tank and pipe or pipe supports outside the tank (see O.2.1).

O.2.5 Bottom connections used in floating-roof tanks shall be provided with a baffle to prevent impingement of the inlet product stream directly against the floating roof.

● **O.2.6** All details are subject to agreement between the Purchaser and the Manufacturer.

O.3 Guideline Examples

O.3.1 CONCRETE VAULT AND RINGWALL (SEE FIGURES O-1 AND O-2)

O.3.1.1 The concrete ceiling vault shown in Figure O-2 provides improved support of the tank bottom and shell and provides more uniform reinforcing-bar distribution around the ringwall opening than the details shown in Figure O-1 provide.

O.3.1.2 Particular attention is required for the backfill specifications and placement of the backfill around the vault area and around the inside of the entire ringwall. Compaction shall be adequate to prevent significant localized settlement.

O.3.1.3 Consideration should be given to the soil characteristics at the different elevations at the bottom of the ringwall and the vault, especially for the deeper vaults to accommodate the larger connections.

● **O.3.1.4** Recommended details and dimensions are shown in Figures O-1 and O-2 and Tables O-1a and O-1b. Dimension *K* is considered adequate to place the connection out of the influence of shell-to-bottom rotation when the tank is statically loaded. Seismic loading shall be analyzed for additional considerations. The method shall be a matter of agreement between the Manufacturer and the Purchaser. When the tank bottom has annular plates (thicker than the tank bottom), it is recommended either to provide at least 300 mm (12 in.) between the edge of the pipe connection or reinforcing plate and the inner edge of the annular plate or to locally extend the annular plate, thickened if necessary, to encompass the bottom connection. The dimensions in Tables O-1a and O-1b may be changed to achieve desired clearances for installations, inspections, and the like. 08

O.3.1.5 Concrete walls, floors, and ceilings shall be designed to meet the minimum requirements of ACI 318 and local soil conditions.

Table O-1a—(SI) Dimensions of Under-Bottom Connections

Inlet Diameter NPS	mm										
D	*B*/2	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*W*/2	*T*[a]	*ST*[b]
6	525	225	350	750	575	300	1125	1975	925	16	ST4WF8.5
8	550	250	400	825	650	300	1150	2050	950	16	ST4WF8.5
12	600	300	450	875	750	300	1200	2150	1000	16	ST6WF13.5
18	675	375	500	950	900	300	1300	2325	1075	16	ST6WF13.5
24	750	450	600	1050	1075	300	1400	2550	1150	16	ST6WF13.5
30	850	525	750	1150	1300	300	1500	2750	1225	16	ST6WF13.5
36	925	625	925	1275	1550	300	1625	3000	1300	16	ST8WF18.0
42	1000	700	1075	1375	1775	300	1725	3200	1375	16	ST8WF18.0
48	1075	825	1225	1475	2025	300	1825	3400	1450	16	ST8WF18.0

[a]Applies only to Figure O-1. For tank heights greater than 19.2 mm – 21.6 mm inclusive, 19-mm plate shall be used. *T* shall not be less than the thickness of the annular plate.
[b]Other composite sections may be used to support the load.
Note: See Figures O-1 and O-2. For diameters not shown, the dimensions of the next larger size shall be used.

08

Table O-1b—(USC) Dimensions of Under-Bottom Connections

Inlet Diameter NPS	in.										
D	*B*/2	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*W*/2	*T*[a]	*ST*[b]
6	21	9	14	30	23	12	44	78	36	$^5/_8$	ST4WF8.5
8	22	10	16	32	26	12	45	81	37	$^5/_8$	ST4WF8.5
12	24	12	18	34	30	12	47	85	39	$^5/_8$	ST6WF13.5
18	27	15	20	37	35	12	51	92	42	$^5/_8$	ST6WF13.5
24	30	18	24	41	42	12	55	100	45	$^5/_8$	ST6WF13.5
30	33	21	30	45	51	12	59	108	48	$^5/_8$	ST6WF13.5
36	36	25	36	50	61	12	64	118	51	$^5/_8$	ST8WF18.0
42	39	28	42	54	70	12	68	126	54	$^5/_8$	ST8WF18.0
48	42	32	48	58	80	12	72	134	57	$^5/_8$	ST8WF18.0

[a]Applies only to Figure O-1. For tank heights greater than 64 ft – 72 ft inclusive, $^3/_4$-in. plate shall be used. *T* shall not be less than the thickness of the annular plate.
[b]Other composite sections may be used to support the load.
Note: See Figures O-1 and O-2. For diameters not shown, the dimensions of the next larger size shall be used.

O.3.2 EARTH FOUNDATION (SEE FIGURE O-3)

O.3.2.1 The detail shown in Figure O-3 provides an alternative arrangement for tanks where a concrete ringwall is not provided.

O.3.2.2 Soil and backfill support capability shall be evaluated to ensure that reasonably uniform settlement (if any) will occur under the loads imposed.

O.3.2.3 When the pipe is connected to the bottom at an angle, consideration should be given to design for unbalanced forces if the pipe is trimmed flush with the bottom.

O.3.2.4 When seismically-induced loadings are specified, such loadings under the tank bottom and shell shall be considered when the depth and type of backfill around and over the pipe are selected.

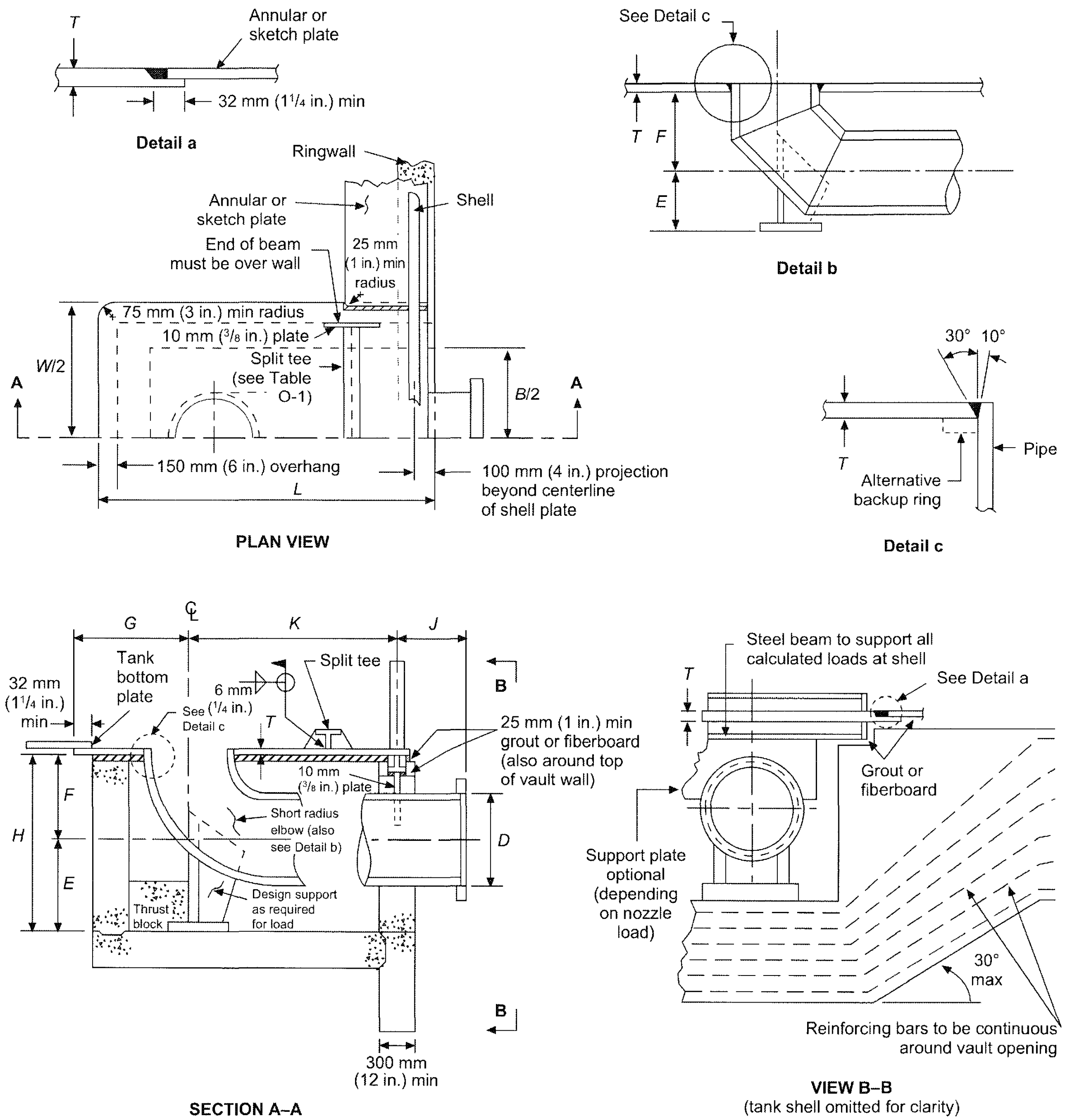
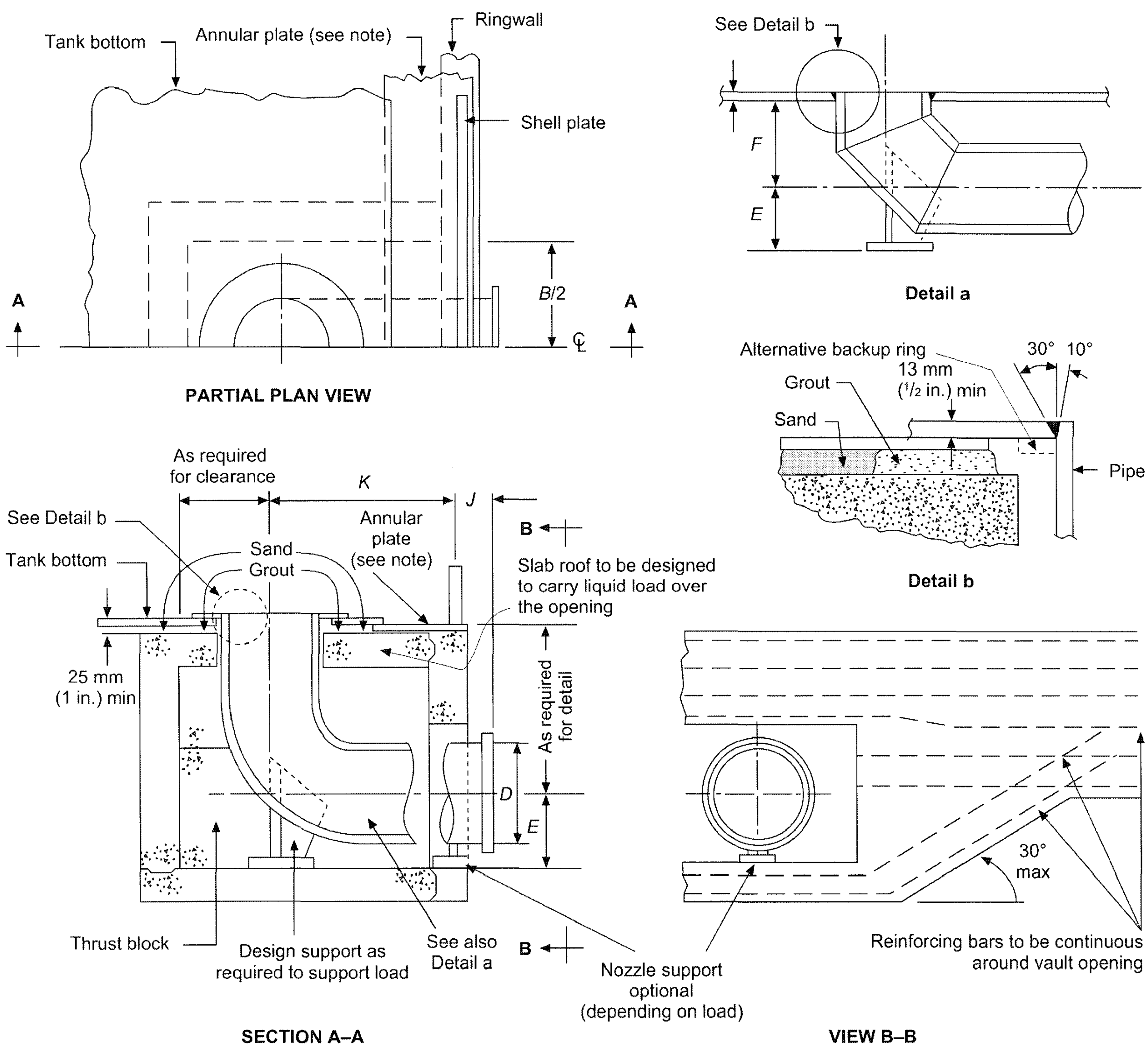
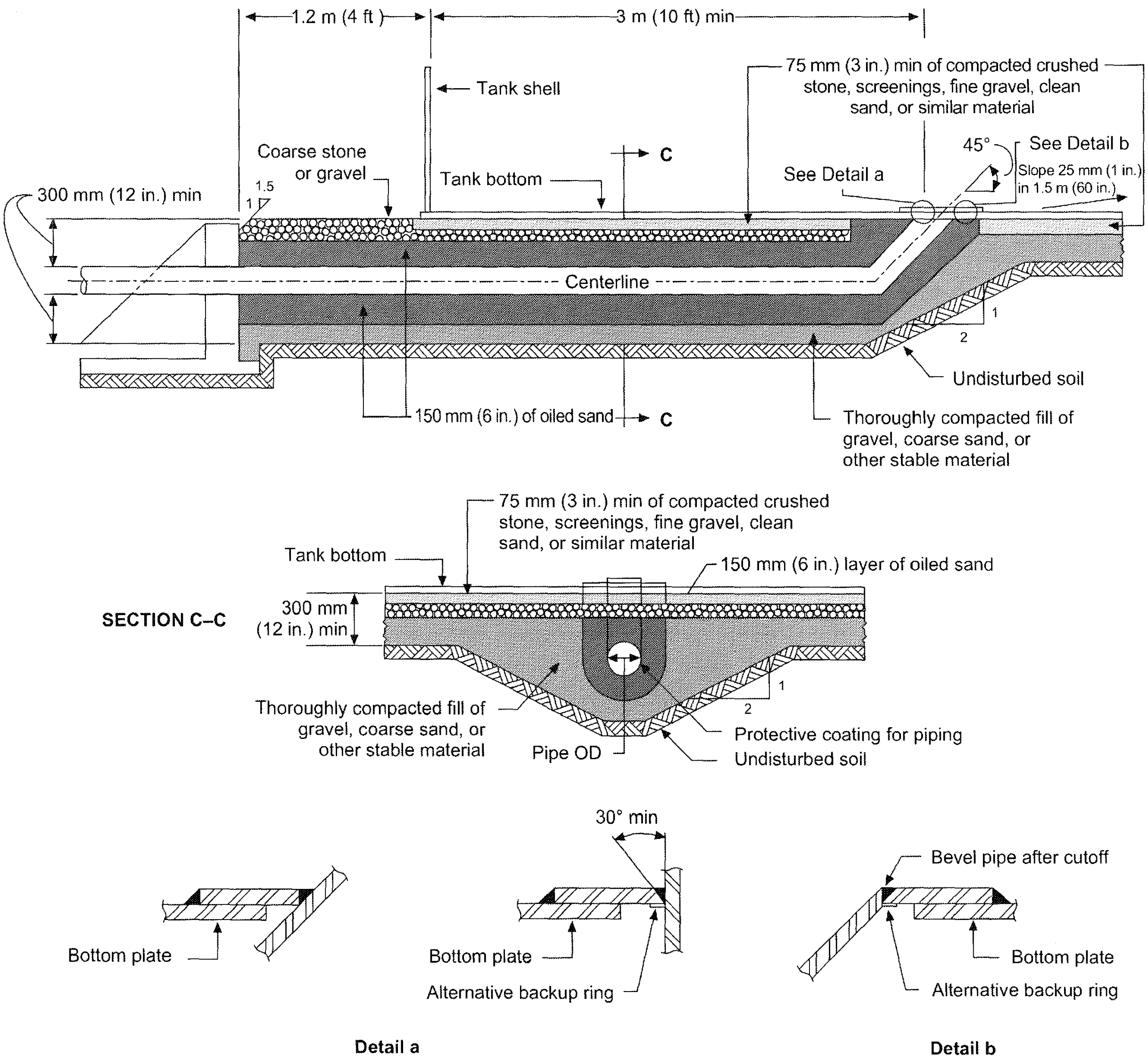


Figure O-1—Example of Under-Bottom Connection with Concrete Ringwall Foundation



Note: If sketch plates are used, a full plate shall be located over the vault.

Figure O-2—Example of Under-Bottom Connection with Concrete Ringwall Foundation and Improved Tank Bottom and Shell Support



Note: This type of connection shall not be used for tanks with a diameter of less than 6 m (20 ft).

Figure O-3—Example of Under-Bottom Connection with Earth-Type Foundation

APPENDIX P—ALLOWABLE EXTERNAL LOADS ON TANK SHELL OPENINGS

• P.1 Introduction

This appendix shall be used (unless specified otherwise by the Purchaser on Line 29 of the Data Sheet) for tanks larger than 36 m
(120 ft) in diameter, and only when specified by the Purchaser for tanks 36 m (120 ft) in diameter and smaller. See W.2(5) for 07
additional requirements.

This appendix presents two different procedures to determine external loads on tank shells. Section P.2 establishes limit loads and P.3 is based on allowable stresses. This appendix is based on H. D. Billimoria and J. Hagstrom's "Stiffness Coefficients and Allowable Loads for Nozzles in Flat Bottom Storage Tanks" and H. D. Billimoria and K. K. Tam's "Experimental Investigation of Stiffness Coefficients and Allowable Loads for a Nozzle in a Flat Bottom Storage Tank."

P.2 Limit Loads

• P.2.1 SCOPE

This appendix establishes requirements for the design of storage-tank openings that conform to Tables 5-6a and 5-6b and 08
will be subjected to external piping loads. The requirements of this appendix represent accepted practice for the design of
shell openings in the lower half of the bottom shell course that have a minimum elevation from the tank bottom and meet
the requirements of Tables 5-6a and 5-6b. It is recognized that the Purchaser may specify other procedures, special factors, 08
and additional requirements. Any deviation from these requirements shall be mutually agreed upon by the Purchaser and
the Manufacturer.

• P.2.2 GENERAL

The design of an external piping system that will be connected to a thin-walled, large-diameter cylindrical vertical storage tank may pose a problem in the analysis of the interface between the piping system and the tank opening connections. The piping designer must consider the stiffness of the tank shell and the radial deflection and meridional rotation of the shell opening at the opening-shell connection resulting from product head, pressure, and uniform or differential temperature between the shell and the bottom. The work of the piping designer and the tank designer must be coordinated to ensure that the piping loads imposed on the shell opening by the connected piping are within safe limits. Although three primary forces and three primary moments may be applied to the mid-surface of the shell at an opening connection, only one force, F_R, and two moments, M_L and M_C, are normally considered significant causes of shell deformation (see P.2.3 for a description of the nomenclature).

P.2.3 NOMENCLATURE

a = outside radius of the opening connection (mm) (in.)

E = modulus of elasticity (MPa) (lbf/in.^{2}) (see Tables P-1a and P-1b) 08

F_R = radial thrust applied at the mid-surface of the tank shell at the opening connection (N) (lbf)

F_P = pressure end load on the opening for the pressure resulting from the design product head at the elevation of the opening centerline, $\pi a^2 P$ (N) (lbf)

G = design specific gravity of the liquid

H = maximum allowable tank filling height (mm) (in.)

K_C = stiffness coefficient for the circumferential moment (N-mm/radian) (in.-lbf/radian)

K_L = stiffness coefficient for the longitudinal moment (N-mm/radian) (in.-lbf/radian)

K_R = stiffness coefficient for the radial thrust load (N/mm) (lbf/in.)

L = vertical distance from the opening centerline to the tank bottom (mm) (in.)

M_C = circumferential moment applied to the mid-surface of the tank shell (N-mm) (in.-lbf)

M_L = longitudinal moment applied to the mid-surface of the tank shell (N-mm) (in.-lbf)

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

Design Temperature °C	Modulus of Elasticity (MPa) *E*	Thermal Expansion Coefficient[a] (mm × 10^{-6}/[mm-°C])
20	203,000	—
93	199,000	12.0
150	195,000	12.4
200	191,000	12.7
260	188,000	13.1

[a]Mean coefficient of thermal expansion, going from 20°C to the temperature indicated.
Note: Linear interpolation may be applied for intermediate values.

08 Table P-1b—(USC) Modulus of Elasticity and Thermal Expansion Coefficient at the Design Temperature

Design Temperature °F	Modulus of Elasticity (lbf/in.^{2}) *E*	Thermal Expansion Coefficient[a] (in. × 10^{-6} per in.-°F)
70	29,500,000	—
200	28,800,000	6.67
300	28,300,000	6.87
400	27,700,000	7.07
500	27,300,000	7.25

[a]Mean coefficient of thermal expansion, going from 70°F to the temperature indicated.
Note: Linear interpolation may be applied for intermediate values.

P = pressure resulting from product head at the elevation of the opening centerline (MPa) (lbf/in.^{2})

R = nominal tank radius (mm) (in.)

t = shell thickness at the opening connection (mm) (in.)

ΔT = normal design temperature minus installation temperature (°C) (°F)

W = unrestrained radial growth of the shell (mm) (in.)

W_R = resultant radial deflection at the opening connection (mm) (in.)

X_A = $L + a$ (mm) (in.)

X_B = $L - a$ (mm) (in.)

X_C = L (mm) (in.)

Y_C = coefficient determined from Figure P-4B

Y_F, Y_L = coefficients determined from Figure P-4A

08 α = thermal expansion coefficient of the shell material (mm/[mm-°C]) (in./[in.-°F]) (see Tables P-1a and P-1b)

11 β = characteristic parameter, $1.285/(Rt)^{0.5}$ (1/mm) (1/in.)

λ = $a/(Rt)^{0.5}$

θ = unrestrained shell rotation resulting from product head (radians)

θ_C = shell rotation in the horizontal plane at the opening connection resulting from the circumferential moment (radians)

θ_L = shell rotation in the vertical plane at the opening connection resulting from the longitudinal moment (radians)

P.2.4 STIFFNESS COEFFICIENTS FOR OPENING CONNECTIONS

The stiffness coefficients K_R, K_L, and K_C corresponding to the piping loads F_R, M_L, and M_C at an opening connection, as shown in Figure P-1, shall be obtained by the use of Figures P-2A through P-2L. Figures P-2A through P-2L shall be used to interpolate intermediate values of coefficients.

P.2.5 SHELL DEFLECTION AND ROTATION

P.2.5.1 Radial Growth of Shell

The unrestrained outward radial growth of the shell at the center of the opening connection resulting from product head and/or thermal expansion shall be determined as follows:

In SI units:

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

In US Customary units:

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

P.2.5.2 Rotation of Shell

The unrestrained rotation of the shell at the center of the nozzle-shell connection resulting from product head shall be determined as follows:

In SI units:

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

In US Customary units:

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

P.2.6 DETERMINATION OF LOADS ON THE OPENING CONNECTION

The relationship between the elastic deformation of the opening connection and the external piping loads is expressed as follows:

$$W_R = \frac{F_R}{K_R} - L\tan\left(\frac{M_L}{K_L}\right) + W$$

$$\theta_L = \frac{M_L}{K_L} - \tan^{-1}\left(\frac{F_R}{LK_R}\right) + \theta$$

$$\theta_C = \frac{M_C}{K_C}$$

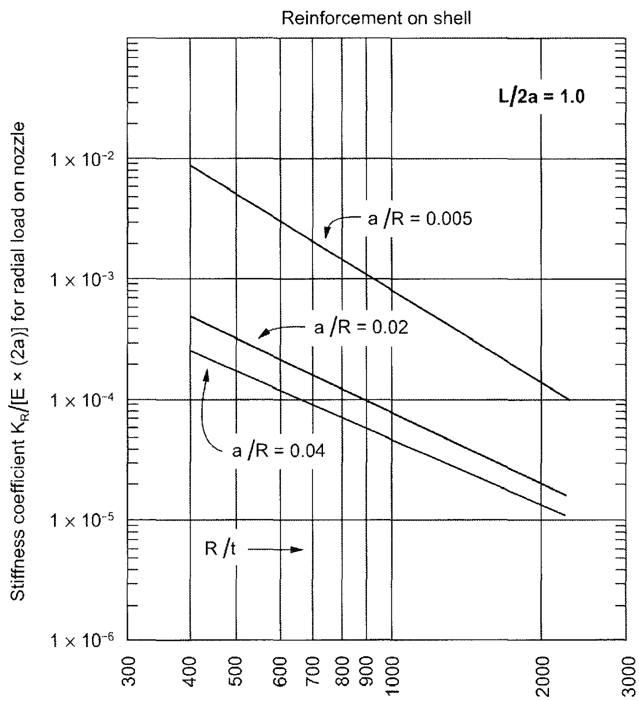


Figure P-1—Nomenclature for Piping Loads and Deformation

K_R, K_L, and K_C are the shell stiffness coefficients determined from Figures P-2A through P-2L. W_R, θ_L, and θ_C are the resultant radial deflection and rotation of the shell at the opening connection resulting from the piping loads F_R, M_L, and M_C and the product head, pressure, and uniform or differential temperature between the shell and the tank bottom. F_R, M_L, and M_C shall be obtained from analyses of piping flexibility based on consideration of the shell stiffness determined from Figures P-2A through P-2L, the shell deflection and rotation determined as described in P.2.5.1 and P.2.5.2, and the rigidity and restraint of the connected piping system.

P.2.7 DETERMINATION OF ALLOWABLE LOADS FOR THE SHELL OPENING

P.2.7.1 Construction of Nomograms

11 **P.2.7.1.1** Determine the nondimensional quantities $X_A/(Rt)^{0.5}$, $X_B/(Rt)^{0.5}$, and $X_C/(Rt)^{0.5}$ for the opening configuration under consideration.

P.2.7.1.2 Lay out two sets of orthogonal axes on graph paper, and label the abscissas and ordinates as shown in Figures P-3A and P-3B, where Y_C, Y_F, and Y_L are coefficients determined from Figures P-4A and P-4B.

P.2.7.1.3 Lay out two sets of orthogonal axes on graph paper, and label the abscissas and ordinates as shown in Figures P-3A and P-3B, where Y_C, Y_F, and Y_L are coefficients determined from Figures P-4A and P-4B.

P.2.7.1.4 Construct four boundaries for Figure P-3A and two boundaries for Figure P-3B. Boundaries b_1 and b_2 shall be constructed as lines at 45-degree angles between the abscissa and the ordinate. Boundaries c_1, c_2, and c_3 shall be constructed as lines at 45-degree angles passing through the calculated value indicated in Figures P-3A and P-3B plotted on the positive x axis.

P.2.7.2 Determination of Allowable Loads

P.2.7.2.1 Use the values for F_R, M_L, and M_C obtained from the piping analyses to determine the quantities $(\lambda/2Y_F)(F_R/F_P)$, $(\lambda/aY_L)(M_L/F_P)$, and $(\lambda/aY_C)(M_C/F_P)$.

P.2.7.2.2 Plot the point $(\lambda/2Y_F)(F_R/F_P)$, $(\lambda/aY_L)(M_L/F_P)$ on the nomogram constructed as shown in Figure P-5A.

P.2.7.2.3 Plot the point $(\lambda/2Y_F)(F_R/F_P)$, $(\lambda/aY_C)(M_C/F_P)$ on the nomogram constructed as shown in Figure P-5B.

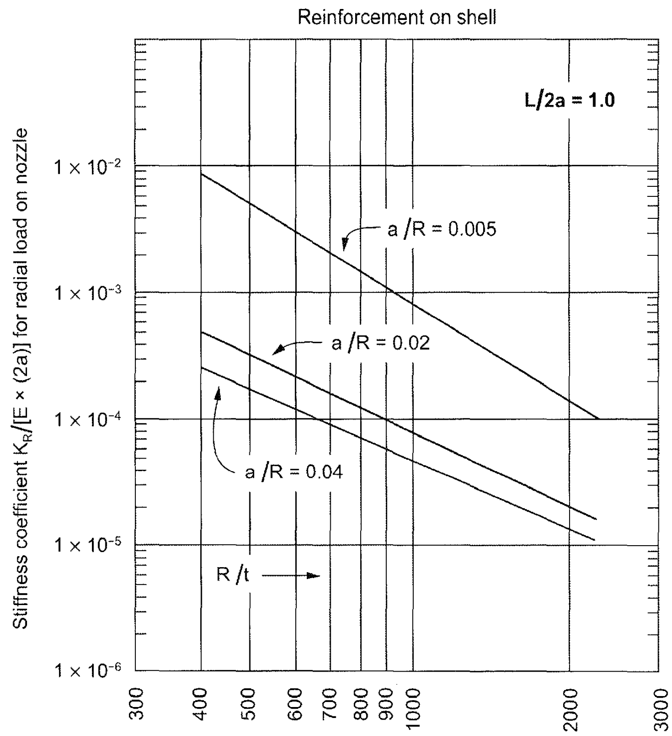


Figure P-2A—Stiffness Coefficient for Radial Load: Reinforcement on Shell ($L/2a$ = 1.0)

11

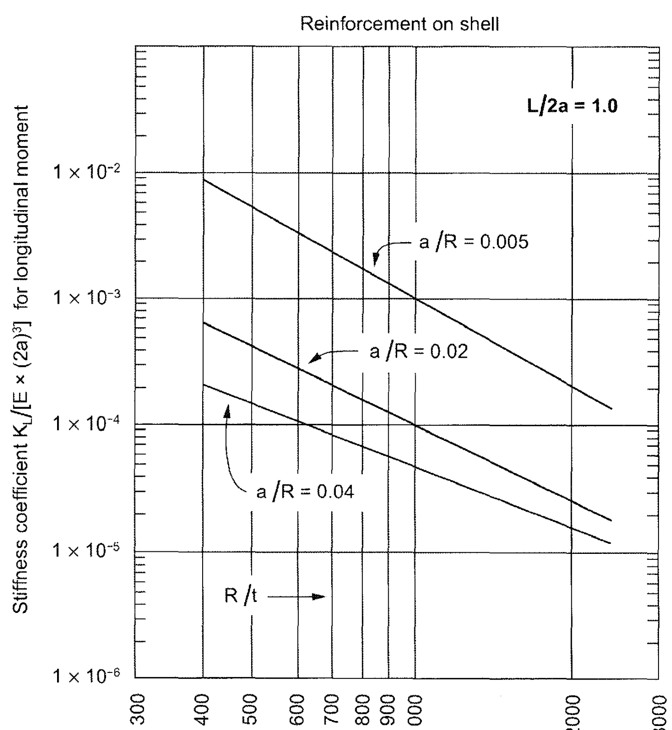


Figure P-2B—Stiffness Coefficient for Longitudinal Moment: Reinforcement on Shell ($L/2a$ = 1.0)

11

11

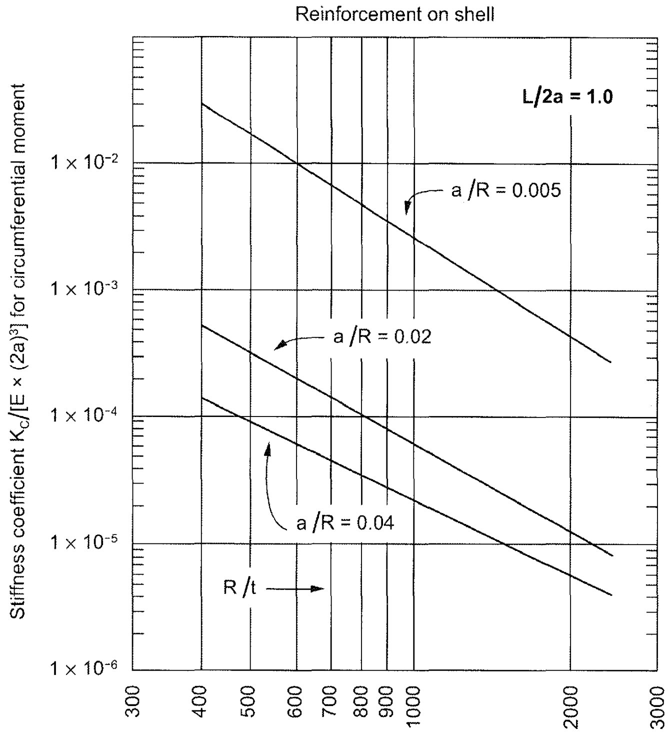


Figure P-2C—Stiffness Coefficient for Circumferential Moment: Reinforcement on Shell ($L/2a$ = 1.0)

11

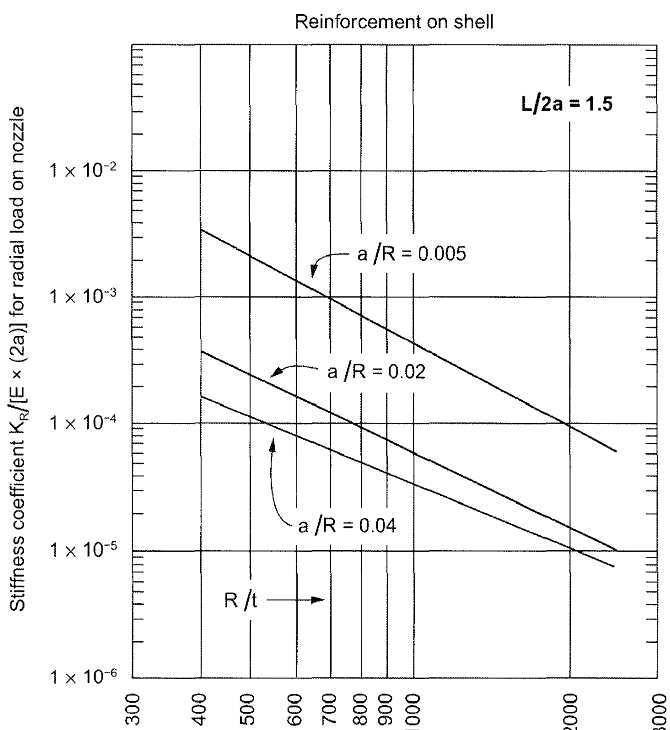


Figure P-2D—Stiffness Coefficient for Radial Load: Reinforcement on Shell ($L/2a$ = 1.5)

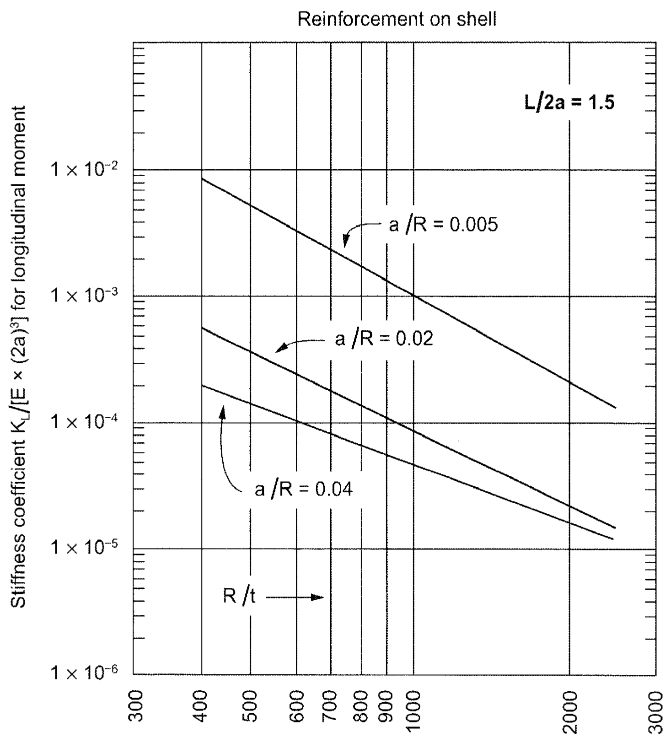


Figure P-2E—Stiffness Coefficient for Longitudinal Moment: Reinforcement on Shell ($L/2a$ = 1.5)

11

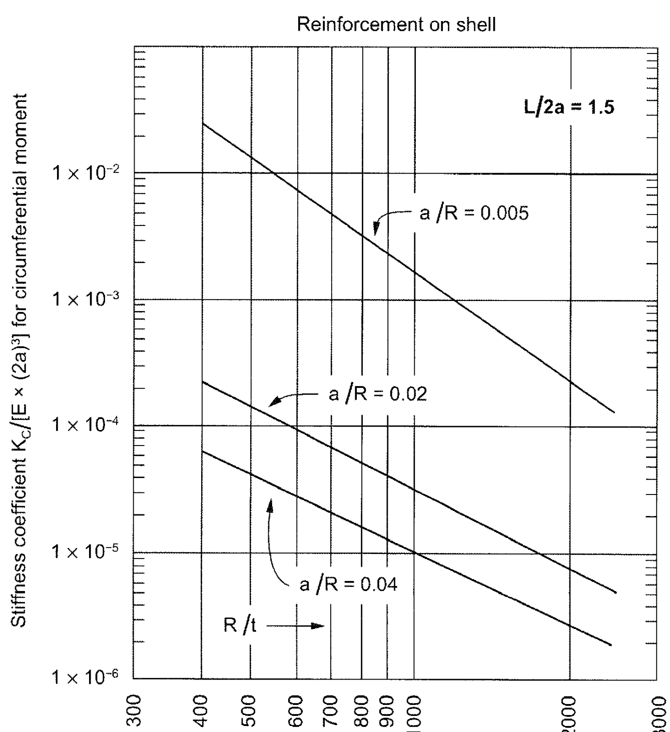


Figure P-2F—Stiffness Coefficient for Circumferential Moment: Reinforcement on Shell ($L/2a$ = 1.5)

11

11

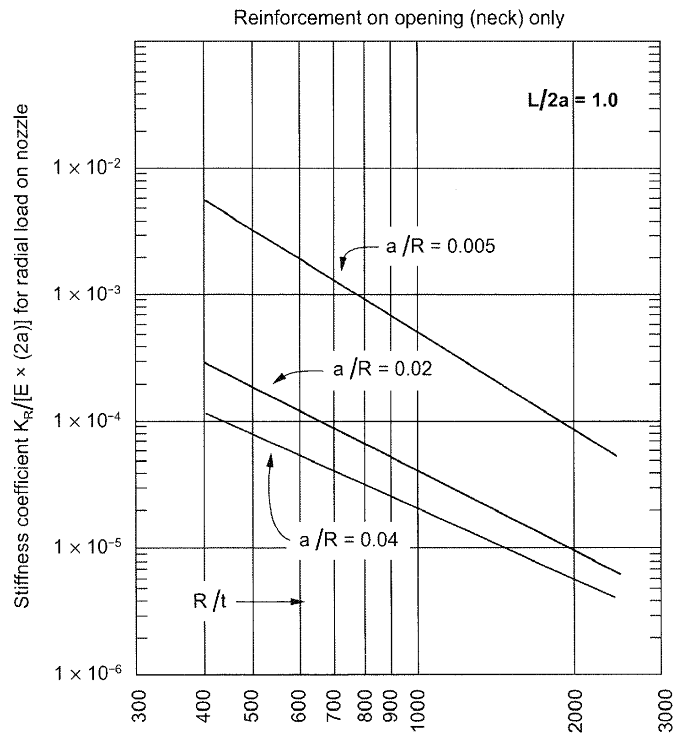


Figure P-2G—Stiffness Coefficient for Radial Load: Reinforcement in Nozzle Neck Only ($L/2a$ = 1.0)

11

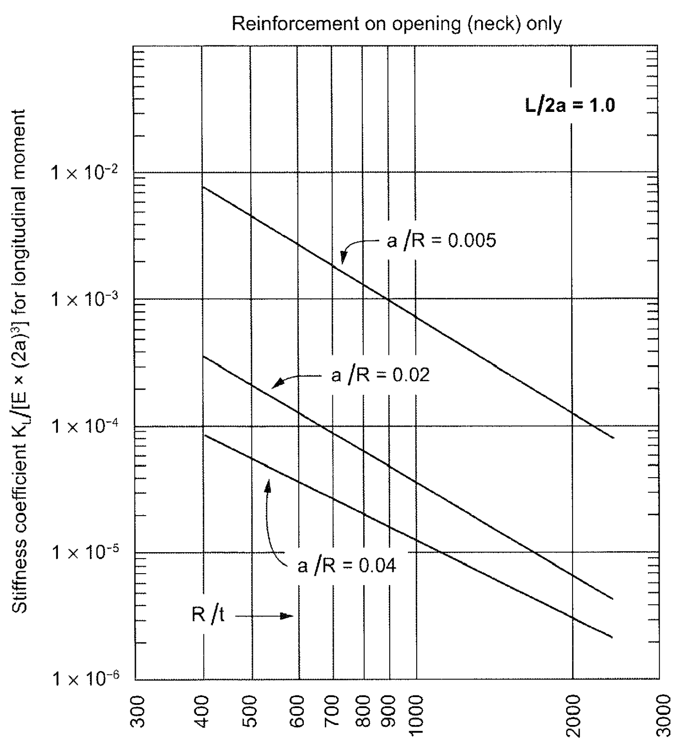


Figure P-2H—Stiffness Coefficient for Longitudinal Moment: Reinforcement in Nozzle Neck Only ($L/2a$ = 1.0)

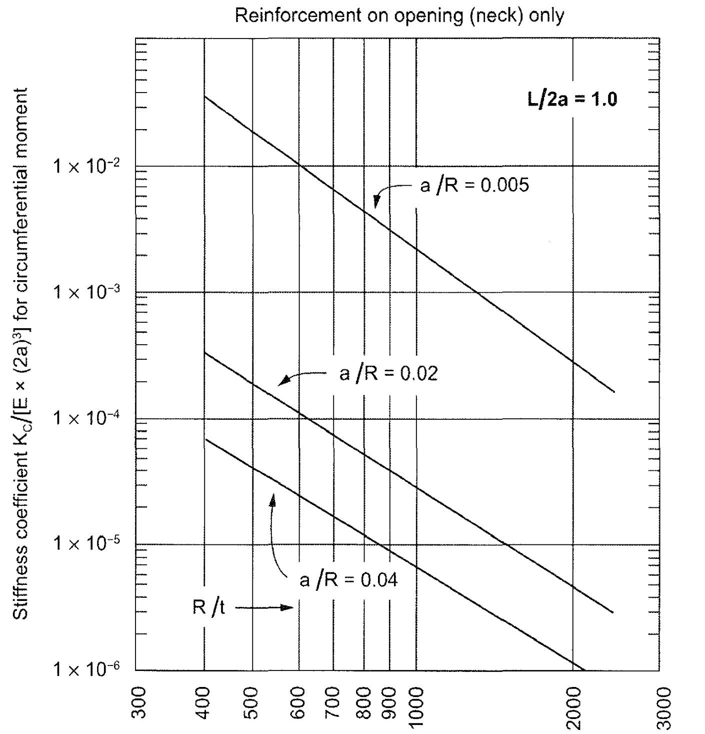


Figure P-2I—Stiffness Coefficient for Circumferential Moment: Reinforcement in Nozzle Neck Only ($L/2a$ = 1.0)

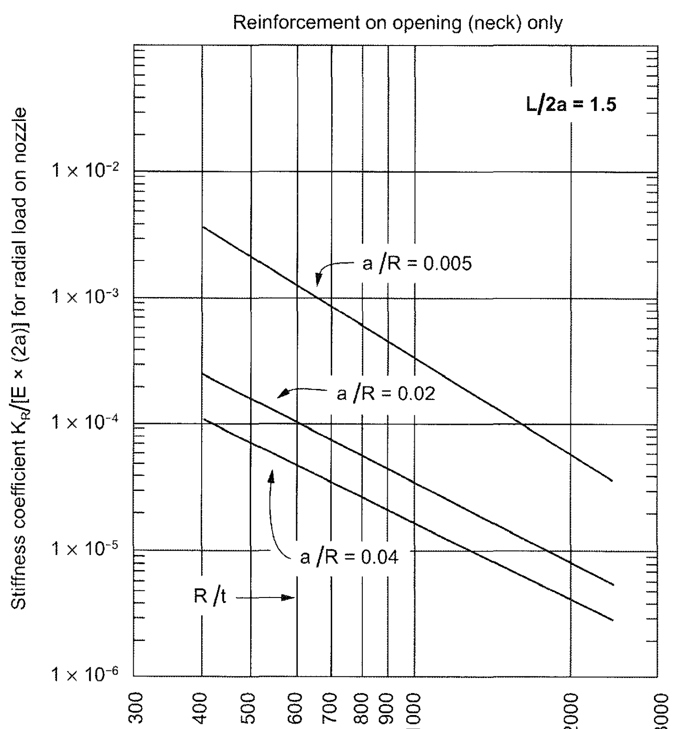


Figure P-2J—Stiffness Coefficient for Radial Load: Reinforcement in Nozzle Neck Only ($L/2a$ = 1.5)

11

11

11

Reinforcement on opening (neck) only

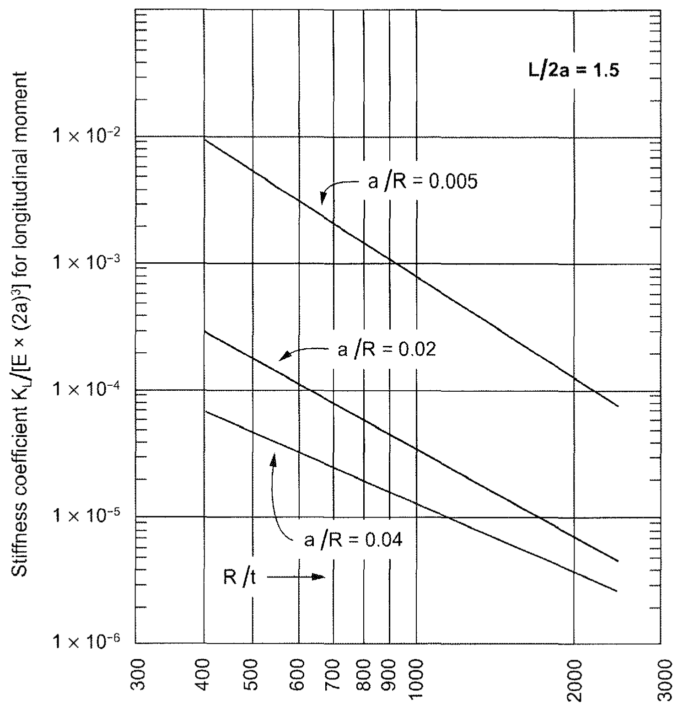


Figure P-2K—Stiffness Coefficient for Longitudinal Moment: Reinforcement in Nozzle Neck Only ($L/2a$ = 1.5)

11

Reinforcement on opening (neck) only

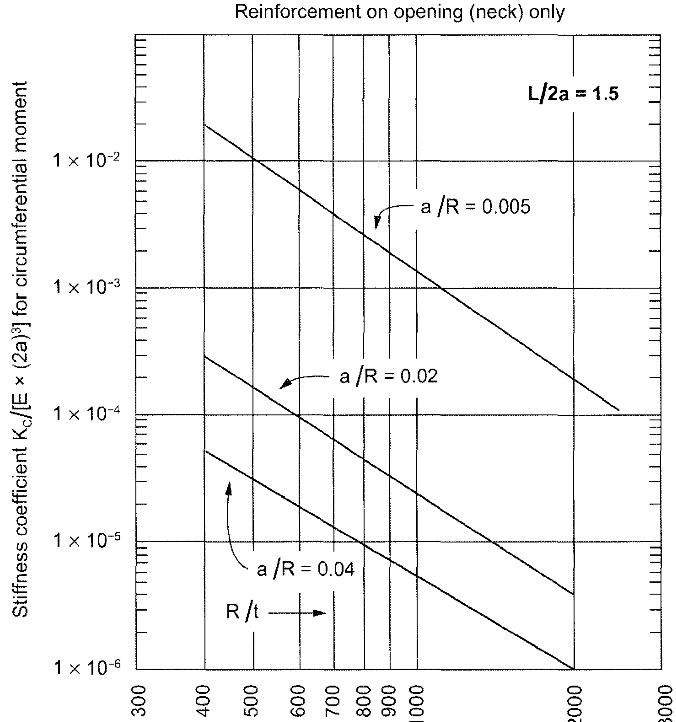


Figure P-2L—Stiffness Coefficient for Circumferential Moment: Reinforcement in Nozzle Neck Only ($L/2a$ = 1.5)

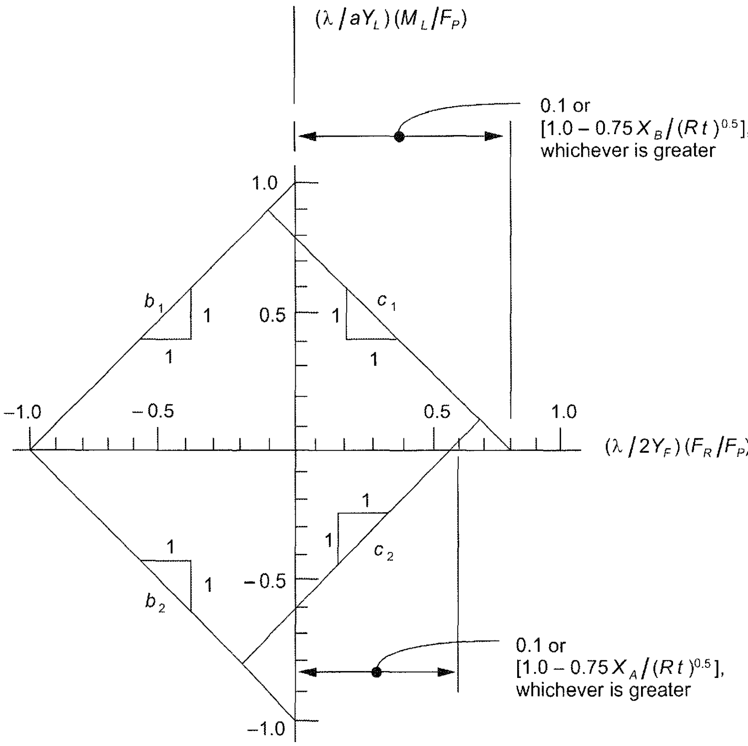


Figure P-3A—Construction of Nomogram for b_1, b_2, c_1, c_2 Boundary

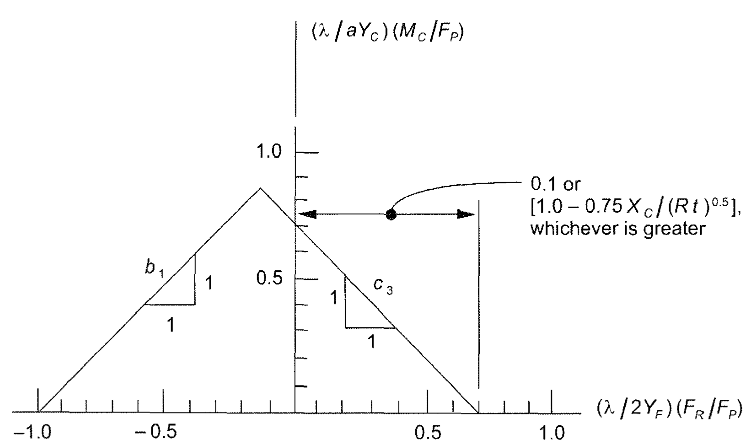


Figure P-3B—Construction of Nomogram for b_1, c_3 Boundary

11

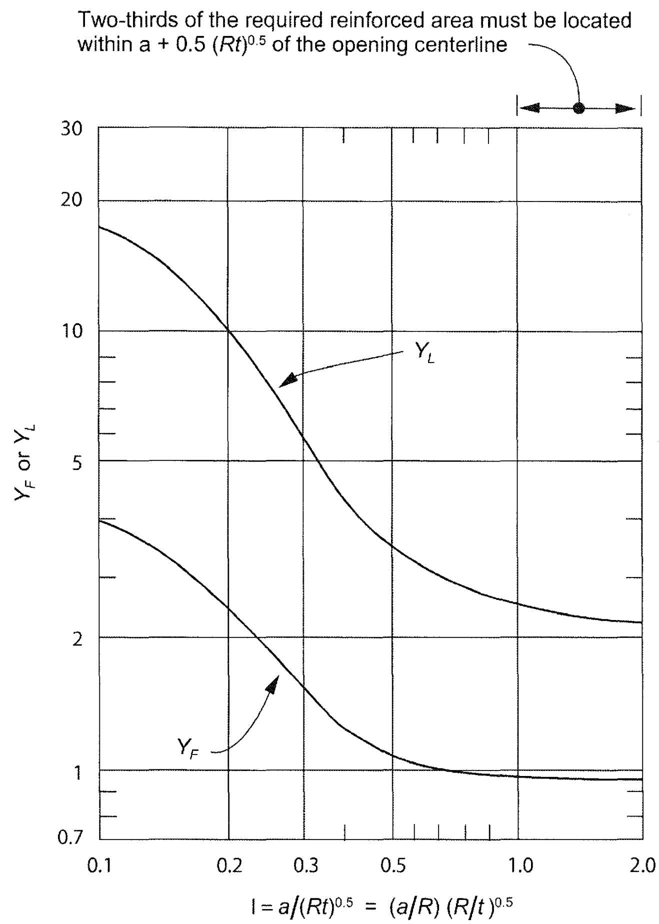


Figure P-4A—Obtaining Coefficients Y_F and Y_L

P.2.7.2.4 The external piping loads F_R, M_L, and M_C to be imposed on the shell opening are acceptable if both points determined from P.2.7.2.2 and P.2.7.2.3 lie within the boundaries of the nomograms constructed for the particular opening-tank configuration.

P.2.8 MANUFACTURER AND PURCHASER RESPONSIBILITY

- **P.2.8.1** The Manufacturer is responsible for furnishing to the Purchaser the shell stiffness coefficients (see P.2.4) and the unrestrained shell deflection and rotation (see P.2.5). The Purchaser is responsible for furnishing to the Manufacturer the magnitude of the shell-opening loads (see P.2.6). The Manufacturer shall determine, in accordance with P.2.7, the acceptability of the shell-opening loads furnished by the Purchaser. If the loads are excessive, the piping configuration shall be modified so that the shell-opening loads fall within the boundaries of the nomograms constructed as in P.2.7.1.

- **P.2.8.2** Changing the elevation of the opening and changing the thickness of the shell are alternative means of reducing stresses, but because these measures can affect fabrication, they may be considered only if mutually agreed upon by the Purchaser and the Manufacturer.

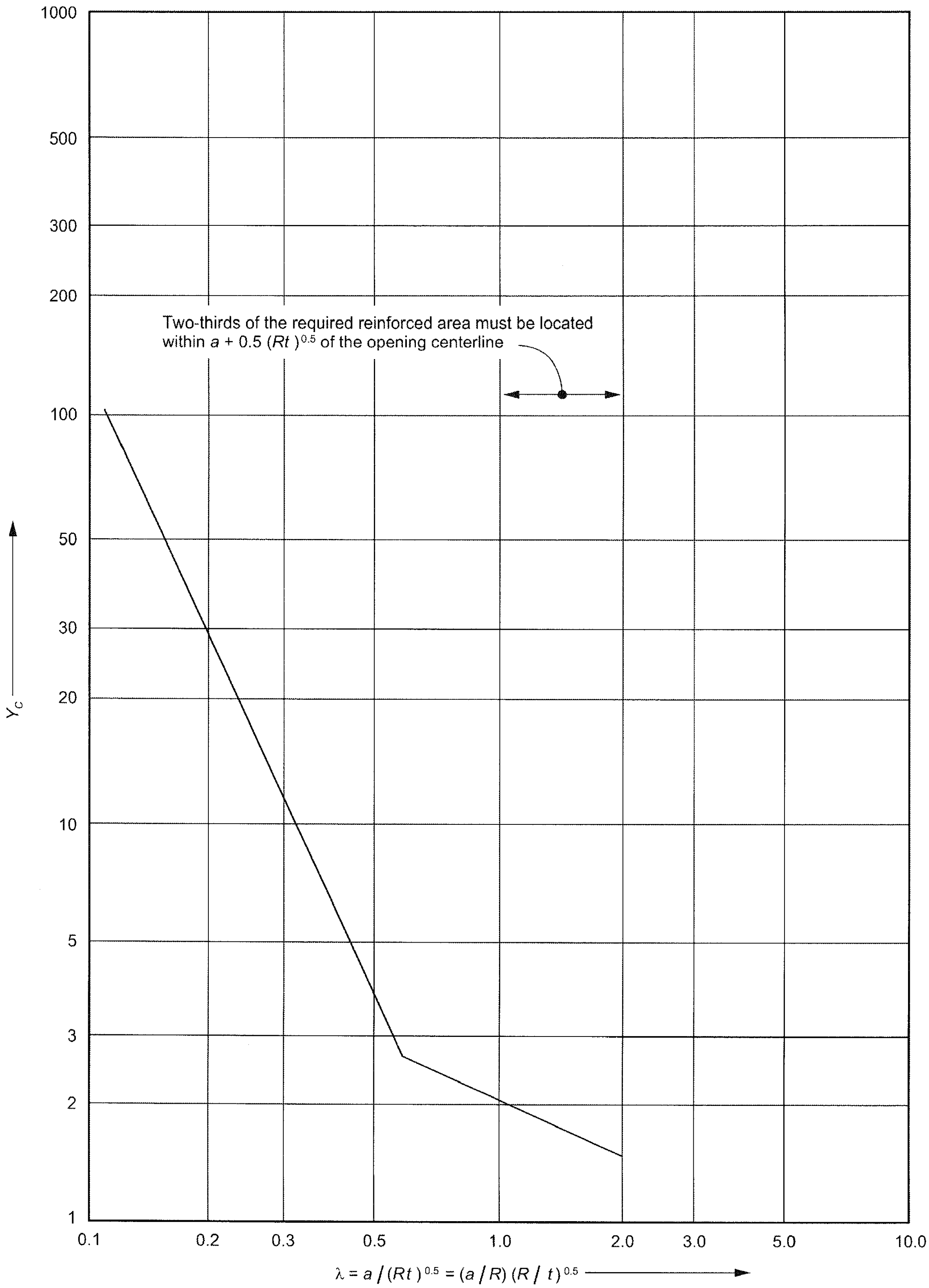


Figure P-4B—Obtaining Coefficient Y_C

P.2.9 SAMPLE PROBLEM

P.2.9.1 Problem

A tank is 80 m (260 ft) in diameter and 19.2 m (64 ft) high, and its bottom shell course is 34 mm (1.33 in.) thick. The tank has a low-type nozzle with an outside diameter of 610 mm (24 in.) in accordance with API Std 650, and the nozzle centerline is
11 630 mm (24.75 in.) up from the bottom plate, with reinforcement on the shell (see Figure P-6). What are the end conditions (W, θ, K_R, K_L, and K_C) for an analysis of piping flexibility? What are the limit loads for the nozzle?

a = 305 mm (12 in.),

L = 630 mm (24.75 in.),

H = 19,200 mm (64 × 12 = 768 in.),

11 ΔT = 90° – 20° = 70°C (200° – 70° = 130°F),

R = 80,000/2 = 40,000 mm ((260 × 12)/2 = 1560 in.),

11 G = 1.0

t = 34 mm (1.33 in.).

P.2.9.2 Solution

P.2.9.2.1 Calculate the stiffness coefficients for the nozzle-tank connection:

R/t = 40,000/34 = 1176 (1560/1.33 = 1173)

a/R = 305/40,000 = 0.008 (12/1560 = 0.008)

$L/2a$ = 630/610 @ 1.0 (24.75/24 @ 1.0)

11 For the radial load (from Figure P-2A),

In SI units:

$$\frac{K_R}{E(2a)} = 3.1 \times 10^{-4}$$

$$K_R = (3.1 \times 10^{-4})(199{,}000 \text{ N/mm}^2)(610 \text{ mm})$$

11 $$= 3.9 \times 10^4 \text{ N/mm}$$

In US Customary units:

$$\frac{K_R}{E(2a)} = 3.1 \times 10^{-4}$$

$$K_R = (3.1 \times 10^{-4})(28.8 \times 10^6 \text{ lb/in.}^2)(24 \text{ in.})$$

$$= 2.14 \times 10^5 \text{ lbf/in.}$$

11 For the longitudinal moment (from Figure P-2B),

In SI units:

$$\frac{K_L}{E(2a)^3} = 4.4 \times 10^{-4}$$

11 $$K_L = (4.4 \times 10^{-4})(199{,}000 \text{ N/mm}^2)(610 \text{ mm})^3$$

$$= 2.0 \times 10^{10} \text{ N-mm/rad}$$

In US Customary units:

11 $$\frac{K_L}{E(2a)^3} = 4.3 \times 10^{-4}$$

$$K_L = (4.3 \times 10^{-4})(28.8 \times 10^6)(24)^3$$

$$= 1.7 \times 10^8 \text{ in.-lb/rad}$$

For the circumferential moment (from Figure P-2C), 11

In SI units:

$$\frac{K_C}{E(2a)^3} = 9.4 \times 10^{-4}$$

$$K_C = (9.4 \times 10^{-4})(199{,}000 \text{ N/mm}^2)(610 \text{ mm})^3$$ 11

$$= 4.2 \times 10^{10} \text{ N-mm/rad}$$

In US Customary units:

$$\frac{K_C}{E(2a)^3} = 9.3 \times 10^{-4}$$

$$K_C = (9.3 \times 10^{-4})(28.8 \times 10^6)(24)^3$$ 11

$$= 3.7 \times 10^8 \text{ in.-lb/rad}$$

P.2.9.2.2 Calculate the unrestrained shell deflection and rotation at the nozzle centerline resulting from the hydrostatic head of the full tank:

In SI units:

$$\beta = \frac{1.285}{(Rt)^{0.5}} = \frac{1.285}{(40{,}000 \times 34)^{0.5}} = 0.00110/\text{mm}$$ 11

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

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

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

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

$$= 59.77 \text{ mm}$$

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

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

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

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

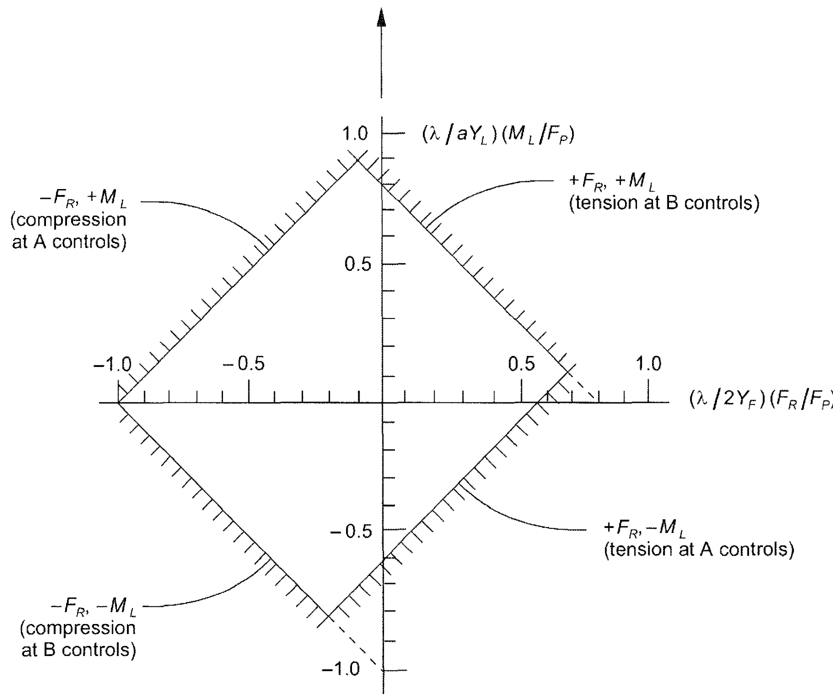


Figure P-5A—Determination of Allowable Loads from Nomogram: F_R and M_L

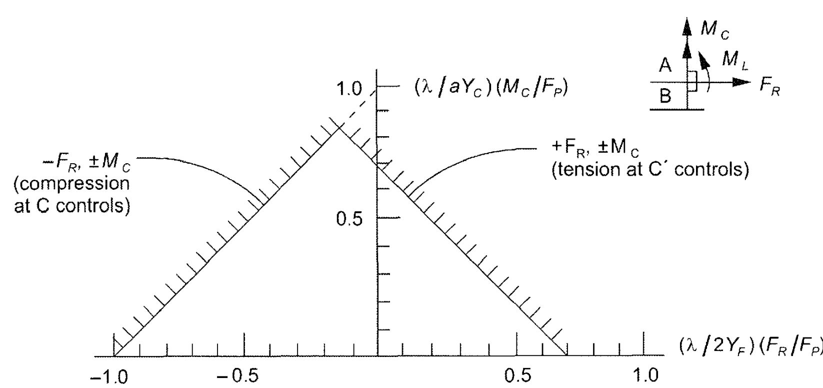


Figure P-5B—Determination of Allowable Loads from Nomogram: F_R and M_C

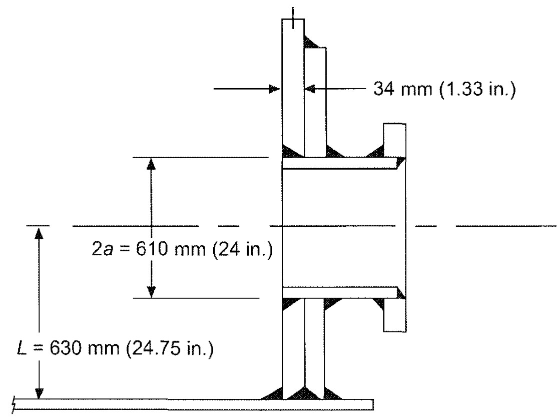


Figure P-6—Low-Type Nozzle with Reinforcement on Shell 11

In US Customary units:

$$\beta = \frac{1.285}{(Rt)^{0.5}} = \frac{1.285}{(1560 \times 1.33)^{0.5}} = 0.0282/\text{in.}$$ 11

$$\beta L = (0.0282)(24.75) = 0.7 \text{ rad}$$

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

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

$$+ (6.67 \times 10\text{–}6)(1560)(130)$$

$$= 2.39 \text{ in.}$$

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

$$= \frac{0.036(1)(768)(1560)^2}{(28.8 \times 10^6)(1.33)}\left\{\frac{1}{768} - 0.0282 e^{-0.7}[\cos(0.7) + \sin(0.7)]\right\}$$ 11

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

Perform the analysis of piping flexibility using W, θ, K_R, K_L, and K_C as the end conditions at the nozzle-to-piping connection.

X_A = 935 mm (36.75 in.)

X_B = 325 mm (12.75 in.)

X_C = 630 mm (24.75 in.)

Determine the allowable loads for the shell opening, as shown in P.9.2.3. 11

P.2.9.2.3 Determine the nondimensional quantities:

In SI units:

$$\frac{X_A}{(Rt)^{0.5}} = \frac{935}{[(40{,}000)(34)]^{0.5}} = 0.80$$

$$\frac{X_B}{(Rt)^{0.5}} = \frac{325}{[(40{,}000)(34)]^{0.5}} = 0.28$$

$$\frac{X_C}{(Rt)^{0.5}} = \frac{630}{[(40{,}000)(34)]^{0.5}} = 0.54$$

11 $$\lambda = \frac{a}{(Rt)^{0.5}} = \frac{305}{[(40{,}000)(34)]^{0.5}} = 0.26$$

In US Customary units:

$$\frac{X_A}{(Rt)^{0.5}} = \frac{36.75}{[(1560)(1.33)]^{0.5}} = 0.81$$

$$\frac{X_B}{(Rt)^{0.5}} = \frac{12.75}{[(1560)(1.33)]^{0.5}} = 0.28$$

$$\frac{X_C}{(Rt)^{0.5}} = \frac{24.75}{[(1560)(1.33)]^{0.5}} = 0.54$$

11 $$\lambda = \frac{a}{(Rt)^{0.5}} = \frac{12}{[(1560)(1.33)]^{0.5}} = 0.26$$

From Figures P-4A and P-4B,

Y_F = 1.9/N (1.9/lbf)

11 Y_L = 7.2/N-mm (7.2/in.-lbf)

Y_C = 13.4/N-mm (13.6/in.-lbf)

P.2.9.2.4 Construct the load nomograms (see Figure P-7):

In SI units:

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

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

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

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

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

$$\frac{\lambda}{2Y_F}\left(\frac{F_R}{F_P}\right) = \frac{0.26}{(2)(1.9)}\left(\frac{F_R}{53{,}200}\right) = 1.29 \times 10^{-6} F_R$$

$$\frac{\lambda}{aY_L}\left(\frac{M_L}{F_P}\right) = \frac{0.26}{(305)(7.2)}\left(\frac{M_L}{53{,}200}\right) = 2.22 \times 10^{-9} M_L$$ 11

$$\frac{\lambda}{aY_C}\left(\frac{M_C}{F_P}\right) = \frac{0.26}{(305)(13.4)}\left(\frac{M_C}{53{,}200}\right) = 1.19 \times 10^{-9} M_C$$

In US Customary units:

$$1.0 - 0.75\frac{X_B}{(Rt)^{0.5}} = 1.0 - 0.75\left(\frac{12.75}{45.6}\right) = 0.79$$

$$1.0 - 0.75\frac{X_A}{(Rt)^{0.5}} = 1.0 - 0.75\left(\frac{36.75}{45.6}\right) = 0.40$$

$$1.0 - 0.75\frac{X_C}{(Rt)^{0.5}} = 1.0 - 0.75\left(\frac{24.75}{45.6}\right) = 0.59$$

$$F_P = P\pi a^2 = \left[\frac{(62.4)(1.0)}{1728}\right][(64)(12) - 24.75]\pi 12^2$$

$$= 12{,}142 \text{ pounds}$$

$$\frac{\lambda}{2Y_F}\left(\frac{F_R}{F_P}\right) = \frac{0.26}{(2)(1.9)}\left(\frac{F_R}{12{,}142}\right) = 5.64 \times 10^{-6} F_R$$

$$\frac{\lambda}{aY_L}\left(\frac{M_L}{F_P}\right) = \frac{0.26}{(12)(7.2)}\left(\frac{M_L}{12{,}142}\right) = 2.48 \times 10^{-7} M_L$$ 11

$$\frac{\lambda}{aY_C}\left(\frac{M_C}{F_P}\right) = \frac{0.26}{(12)(13.6)}\left(\frac{M_C}{12{,}142}\right) = 1.31 \times 10^{-7} M_C$$

P.2.9.2.5 Determine the limiting piping loads.

In SI units:

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

For F_R, $\frac{\lambda}{2Y_F}\left(\frac{F_R}{F_P}\right) = 1.29 \times 10^{-6} F_R \leq 0.4$ 11

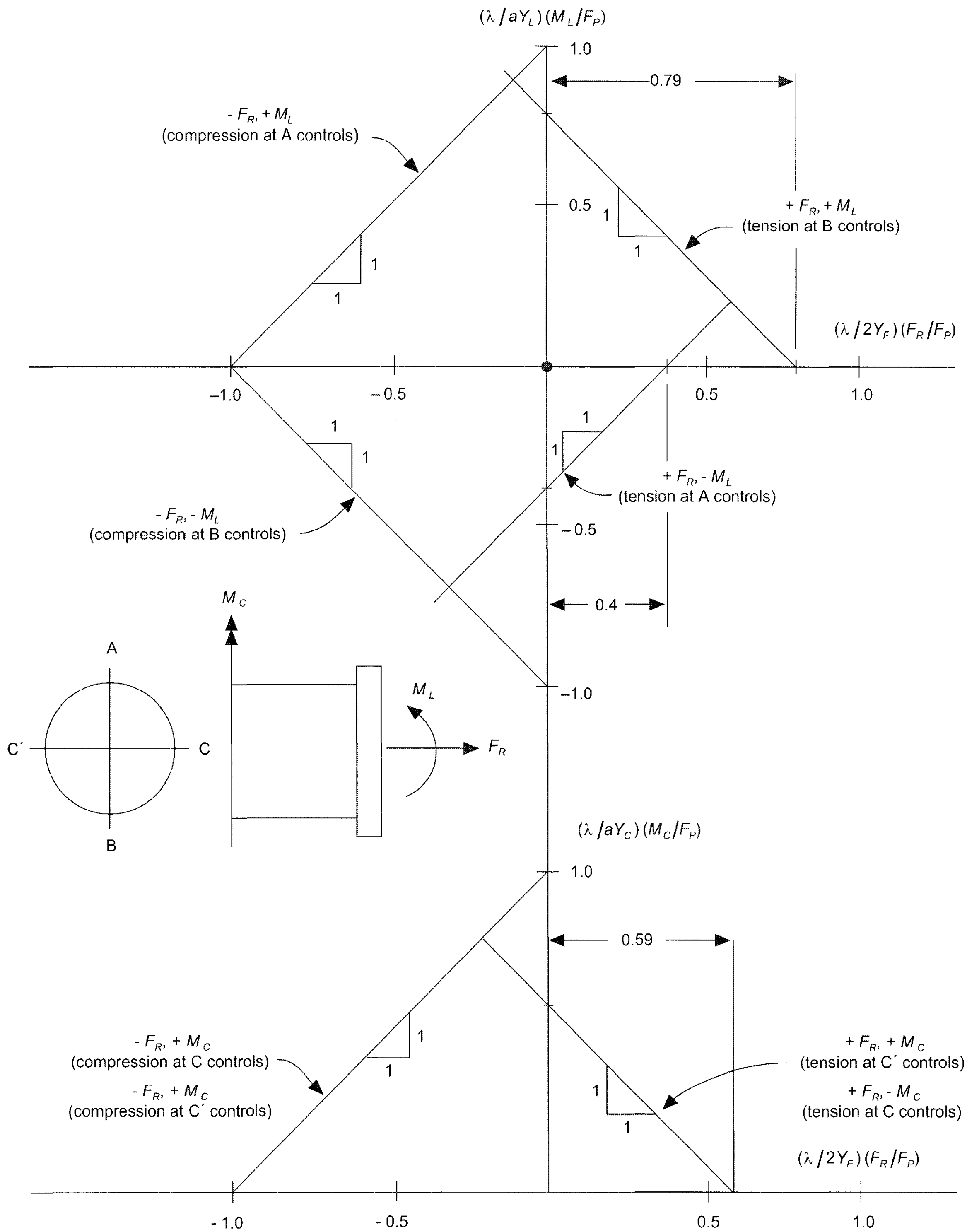


Figure P-7—Allowable-Load Nomograms for Sample Problem

Therefore,

$$F_{R\max} = \frac{0.4}{1.29 \times 10^{-6}} = 310{,}000 \text{ N (tension at A controls)}$$

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

For M_C, $\frac{\lambda}{aY_C}\left(\frac{M_C}{F_P}\right) = 1.19 \times 10^{-9} M_C \leq 0.59$

Therefore,

$$M_{C\max} = \frac{0.59}{1.19 \times 10^{-9}} = 4.96 \times 10^{8} \text{ N-mm (tension at C' controls)}$$

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

For M_L, $\frac{\lambda}{aY_L}\left(\frac{M_L}{F_P}\right) = 2.22 \times 10^{-9} M_L \leq 0.4$

Therefore,

$$M_{L\max} = \frac{0.4}{2.22 \times 10^{-9}} = 1.80 \times 10^{8} \text{ N-mm (tension at A controls)}$$

In US Customary units:

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

For F_R, $\frac{\lambda}{2Y_F}\left(\frac{F_R}{F_P}\right) = 5.64 \times 10^{-6} F_R \leq 0.4$ 11

Therefore,

$$F_{R\max} = \frac{0.4}{5.64 \times 10^{-6}} = 70{,}900 \text{ lbf (tension at A controls)}$$

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

For M_C, $\frac{\lambda}{aY_C}\left(\frac{M_C}{F_P}\right) = 1.31 \times 10^{-7} M_C \leq 0.59$

Therefore,

$$M_{C\max} = \frac{0.59}{1.31 \times 10^{-7}} = 4.50 \times 10^{6} \text{ in.-lbf (tension at C' controls)}$$

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

For M_L, $\frac{\lambda}{aY_L}\left(\frac{M_L}{F_P}\right) = 2.48 \times 10^{-7} M_L \leq 0.4$

Therefore,

$$M_{L\max} = \frac{0.4}{2.48 \times 10^{-7}} = 1.61 \times 10^{6} \text{ in.-lbf (tension at A controls)}$$

P.2.9.3 Summary

The limiting piping loads are as follows:

In SI units:

$$F_{R\max} = 310{,}000 \text{ N (tension at A controls)}$$

$$M_{C\max} = 4.96 \times 10^8 \text{ N-mm (tension at C}' \text{ controls)}$$

$$M_{L\max} = 1.8 \times 10^8 \text{ N-mm (tension at A controls)}$$

11 In US Customary units:

$$F_{R\max} = 70{,}900 \text{ lbf (tension at A controls)}$$

$$M_{C\max} = 4.50 \times 10^6 \text{ in.-lbf (tension at C}' \text{ controls)}$$

$$M_{L\max} = 1.61 \times 10^6 \text{ in.-lbf (tension at A controls)}$$

Note: This section is based on the paper "Analysis of Nozzle Loads in API 650 Tanks" [30]

[30]Analysis of Loads for Nozzles in API 650 Tanks, M. Lengsfeld, K.L. Bardia, J. Taagepera, K. Hathaitham, D.G. LaBounty, M.C. Lengsfeld. Paper PVP-Vol 430, ASME, New York, 2001

09 **DELETED (Section P.3 Deleted in its Entirety)**

APPENDIX R—LOAD COMBINATIONS

R.1 For the purposes of this Standard, loads are combined in the following manner. Design rules account for these load combinations, including the absence of any load other than D_L in the combinations:

(a) Fluid and Internal Pressure:

$$D_L + F + P_i$$

(b) Hydrostatic Test: 07

$$D_L + (H_t + P_t)$$

(c) Wind and Internal Pressure:

$$D_L + W + F_p(P_i)$$ 11

(d) Wind and External Pressure:

$$D_L + W + 0.4P_e$$

(e) Gravity Loads:

1) $D_L + (L_r \text{ or } Su \text{ or } Sb) + 0.4P_e$

2) $D_L + P_e + 0.4(L_r \text{ or } S_u \text{ or } S_b)$ 09

(f) Seismic:

$$D_L + F + E + 0.1S_b + F_p(P_i)$$ 11

(g) Gravity Loads for Fixed Roofs with Suspended Floating Roofs:

1) $D_L + D_f + (L_r \text{ or } S) + P_e + 0.4\{P_{fe} \text{ or } L_{f1} \text{ or } L_{f2}\}$

2) $D_L + D_f + \{P_{fe} \text{ or } L_{f1} \text{ or } L_{f2}\} + 0.4\{(S \text{ or } L_r) + P_e\}$ 11

Notes:

1. In the combinations listed in (g), Df, P_{fe}, L_{f1} and L_{f2} shall be applied as point loads at the cable attachment to the fixed roof. 08
2. Design External Pressure, P_e, shall be considered as 0 kPa (0 lbf/ft^2) for tanks with circulation vents meeting Appendix H requirements.

• **R.2** The pressure combination factor (Fp) is defined as the ratio of normal operating pressure to design pressure, with a minimum value of 0.4. 11

APPENDIX S—AUSTENITIC STAINLESS STEEL STORAGE TANKS

S.1 Scope

S.1.1 This appendix covers materials, design, fabrication, erection, and testing requirements for vertical, cylindrical, aboveground, closed- and open-top, welded, austenitic stainless steel storage tanks constructed of material grades 201-1, 201LN, 304, 304L, 316, 316L, 317, and 317L. This appendix does not cover stainless steel clad plate or strip-lined construction. 09

• **S.1.2** This appendix applies only to tanks in nonrefrigerated services with a maximum design temperature not exceeding 260°C (500°F). Tanks designed to this appendix shall be assigned a maximum design temperature no less than 40°C (100°F). It is cautioned that exothermic reactions occurring inside unheated storage tanks can produce temperatures exceeding 40°C (100°F).

S.1.3 DELETED 11

S.1.4 The minimum thicknesses specified in this appendix are corroded thicknesses unless otherwise stated.

S.1.5 This appendix states only the requirements that differ from the basic rules in this Standard. For requirements not stated, the basic rules must be followed.

S.2 Materials

S.2.1 SELECTION AND ORDERING

S.2.1.1 Materials shall be in accordance with Tables S-1a and S-1b. 08

Table S-1a—(SI) ASTM Materials for Stainless Steel Components

Plates and Structural Members (Note 1)	Piping and Tubing—Seamless or Welded (Note 2)	Forgings (Notes 2, 3)	Bolting and Bars (Notes 4, 5)
A 240M, Type 201-1	A 213M, Grade TP 201	A 182M, Grade F 304	A 193M, Class 1, Grades B8, B8A, and B8M
A 240M, Type 201LN	A 213M, Grade TP 304	A 182M, Grade F 304L	A 194M, Grades B8, B8A, B8M, and B8MA
A 240M, Type 304	A 213M, Grade TP 304L	A 182M, Grade F 316	A 320M, Grades B8, B8A, B8M, and B8MA
A 240M, Type 304L	A 213M, Grade TP 316	A 182M, Grade F 316L	A 479M, Type 304
A 240M, Type 316	A 213M, Grade TP 316L	A 182M, Grade F 317	A 479M, Type 304L
A 240M, Type 316L	A 213M, Grade TP 317	A 182M, Grade F 317L	A 479M, Type 316
A 240M, Type 317	A 213M, Grade TP 317L		A 479M, Type 316L
A 240M, Type 317L	A 312M, Grade TP 304		A 479M, Type 317
	A 312M, Grade TP 304L		
	A 312M, Grade TP 316		
	A 312M, Grade TP 316L		
	A 312M, Grade TP 317		
	A 312M, Grade TP 317L		
	A 358M, Grade 304		
	A 358M, Grade 304L		
	A 358M, Grade 316		
	A 358M, Grade 316L		
	A 403M, Class WP 304		
	A 403M, Class WP 304L		
	A 403M, Class WP 316		
	A 403M, Class WP 316L		
	A 403M, Class WP 317		
	A 403M, Class WP 317L		

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Notes:

• 1. Unless otherwise specified by the Purchaser, plate, sheet, or strip shall be furnished with a No. 1 finish and shall be hot-rolled, annealed, and descaled.

• 2. Carbon steel flanges and/or stub ends may be used by agreement between the Purchaser and the Manufacturer, providing the design and details consider the dissimilar properties of the materials used and are suitable for the intended service.

• 3. Castings shall not be used unless specified by the Purchaser. If specified, castings shall meet ASTM A 351 and shall be inspected in accordance with ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1, Appendix 7.

4. All bars in contact with the product shall be furnished in the hot-rolled, annealed, and descaled condition.

• 5. Other bolting materials may be used by agreement between the Purchaser and the Manufacturer.

Table S-1b—(USC) ASTM Materials for Stainless Steel Components

Plates and Structural Members (Note 1)	Piping and Tubing—Seamless or Welded (Note 2)	Forgings (Notes 2, 3)	Bolting and Bars (Notes 4, 5)
A 240, Type 201-1	A213, Grade TP 201	A 182, Grade F 304	A 193, Class 1, Grades B8, B8A, and B8M
09 A 240, Type 201LN	A213, Grade TP 304	A 182, Grade F 304L	A 194, Grades 8, 8A, 8M, and 8MA
A 240, Type 304	A213, Grade TP 304L	A 182, Grade F 316	A320, Grades B8, B8A, B8M, and B8MA
A 240, Type 304L	A213, Grade TP 316	A 182, Grade F 316L	A 479, Type 304
A 240, Type 316	A213, Grade TP 316L	A 182, Grade F 317	A 479, Type 304L
A 240, Type 316L	A213, Grade TP 317	A 182, Grade F 317L	A 479, Type 316
A 240, Type 317	A213, Grade TP 317L		A 479, Type 316L
A 240, Type 317L	A 312, Grade TP 304		A 479, Type 317
09 A 276, Type 201	A 312, Grade TP 304L		
A 276, Type 304	A 312, Grade TP 316		
A 276, Type 304L	A 312, Grade TP 316L		
A 276, Type 316	A 312, Grade TP 317		
A 276, Type 316L	A 312, Grade TP 317L		
A 276, Type 317	A 358, Grade 304		
	A 358, Grade 304L		
	A 358, Grade 316		
	A 358, Grade 316L		
	A 403, Class WP 304		
	A 403, Class WP 304L		
	A 403, Class WP 316		
	A 403, Class WP 316L		
	A 403, Class WP 317		
	A 403, Class WP 317L		

Notes:

• 1. Unless otherwise specified by the Purchaser, plate, sheet, or strip shall be furnished with a No. 1 finish and shall be hot-rolled, annealed, and descaled.

• 2. Carbon steel flanges and/or stub ends may be used by agreement between the Purchaser and the Manufacturer, providing the design and details consider the dissimilar properties of the materials used and are suitable for the intended service.

• 3. Castings shall not be used unless specified by the Purchaser. If specified, castings shall meet ASTM A 351 and shall be inspected in accordance with ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1, Appendix 7.

4. All bars in contact with the product shall be furnished in the hot-rolled, annealed, and descaled condition.

• 5. Other bolting materials may be used by agreement between the Purchaser and the Manufacturer.

• **S.2.1.2** Selection of the type/grade of stainless steel depends on the service and environment to which it will be exposed and
11 the effects of fabrication processes (see S.4.3.2 and S.4.4.3). The Purchaser shall specify the type/grade.

S.2.1.3 External structural attachments may be carbon steels meeting the requirements of Section 4 of this Standard, providing they are protected from corrosion and the design and details consider the dissimilar properties of the materials used. (This does
07 not include shell, roof, or bottom openings and their reinforcement.) Carbon steel attachments (e.g., clips for scaffolding) shall not be welded directly to any internal surface of the tank. For stainless steel tanks subject to external fire impingement, the use of galvanizing on attachments, including ladders and platforms, is not recommended.

• S.2.2 PACKAGING

Packaging stainless steel for shipment is important to its corrosion resistance. Precautions to protect the surface of the material depend on the surface finish supplied and may vary among Manufacturers. Normal packaging methods may not be sufficient to
11 protect the material from normal shipping damage. If the intended service requires special precautions, special instructions shall be specified by the Purchaser.

S.2.3 IMPACT TESTING

Impact tests are not required for austenitic stainless steel base metals.

S.3 Design

S.3.1 TANK BOTTOMS

S.3.1.1 Shell-to-Bottom Fillet Welds

The attachment weld between the bottom edge of the lowest course shell plate and the bottom plate shall comply with the following values:

Nominal Thickness of Shell Plate		Minimum Size of Fillet Weld	
(mm)	(in.)	(mm)	(in.)
5	0.1875	5	$^3/_{16}$
>5 to 25	>0.1875 to 1.0	6	$^1/_4$
>25 to 45	>1.0 to 1.75	8	$^5/_{16}$

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S.3.1.2 Bottom Plates

All bottom plates shall have a corroded thickness of not less than 5 mm ($^3/_{16}$ in.). Bottom plates which weld to shell plates thicker than 25 mm (1.0 in.) shall have a corroded thickness of not less than 6 mm ($^1/_4$ in.). Unless otherwise agreed to by the Purchaser, all rectangular and sketch plates (bottom plates on which the shell rests that have one end rectangular) shall have a minimum nominal width of not less than 1,200 mm (48 in.). 11

S.3.1.3 Annular Bottom Plates

Butt-welded annular bottom plates meeting the requirements of 5.5.2 through 5.5.5 are required when either the bottom shell course maximum product stress is greater than 160 MPa (23,200 lbf/in.^{2}) or the bottom shell course maximum test stress is greater than 172 MPa (24,900 lbf/in.^{2}). 09

S.3.2 SHELL DESIGN

S.3.2.1 General

S.3.2.1.1 The required nominal shell thickness shall not be less than the greatest of the design shell thickness plus corrosion allowance, hydrostatic test shell thickness, or the nominal thickness listed in 5.6.1.1 (note 4 does not apply). 11

S.3.2.1.2 Unless otherwise agreed to by the Purchaser, the shell plates shall have a minimum width of 1200 mm (48 in.).

S.3.2.2 Shell Thickness Calculation

The requirements of 5.6 shall be followed, except as modified in S.3.2.2.1 through S.3.2.2.3. 08

S.3.2.2.1 Allowable stresses for all shell thickness calculation methods are provided in Tables S-2a and S-2b

S.3.2.2.2 Appendix A is not applicable.

S.3.2.2.3 The following formulas for design shell thickness and test shell thickness may alternatively be used for tanks 60 m (200 ft) in diameter and smaller.

In SI units:

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

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

where

t_d = design shell thickness (mm),

t_t = hydrostatic test shell thickness (mm),

D = nominal diameter of tank (m) (see 5.6.1.1),

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

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

E = joint efficiency, 1.0, 0.85, or 0.70 (see Table S-4),

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

S_d = allowable stress for the design condition (MPa) (see Tables S-2a and S-2b),

08 S_t = allowable stress for hydrostatic test condition (MPa) (see Tables S-2a and S-2b).

In US Customary units:

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

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

where

t_d = design shell thickness (in.),

t_t = hydrostatic test shell thickness (in.),

D = nominal diameter of tank (ft) (see 5.6.1.1),

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

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

E = joint efficiency, 1.0, 0.85, or 0.70 (see Table S-4),

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

08 S_d = allowable stress for the design condition (lbf/in.^{2}) (see Tables S-2a and S-2b),

S_t = allowable stress for hydrostatic test condition (lbf/in.^{2}) (see Tables S-2a and S-2b).

Note: The allowable stresses recognize the increased toughness of stainless steels over carbon steels and the relatively low yield/tensile ratios of the stainless steels. The increased toughness permits designing to a higher proportion of the yield strength, however, the Manufacturer and Purchaser shall be aware that this may result in permanent strain (see Tables S-2a and S-2b). 08

S.3.3 SHELL OPENINGS

S.3.3.1 The minimum nominal thickness of connections and openings shall be as follows:

Size of Nozzle	Minimum Nominal Neck Thickness
NPS 2 and less	Schedule 80S
NPS 3 and NPS 4	Schedule 40S
Over NPS 4	6 mm (0.25 in.)

Note: Reinforcement requirements of 5.7 must be maintained.

S.3.3.2 Thermal stress relief requirements of 5.7.4 are not applicable.

11 **S.3.3.3** Shell manholes shall be in conformance with 5.7.5 except that the corroded thickness requirements of bolting flange and cover plate shall be multiplied by the greater of (a) the ratio of the material yield strength at 40°C (100°F) to the material yield strength at the maximum design temperature, or (b) the ratio of 205 MPa (30,000 psi) to the material yield strength at the maximum design temperature.

S.3.3.4 As an alternative to S.3.3.3, plate ring flanges may be designed in accordance with API Std 620 rules using the allowable stresses given in Tables S-3a and S-3b. 08

S.3.3.5 Allowable weld stresses for shell openings shall conform to 5.7.2.8 except S_d = the maximum allowable design stress (the lesser value of the base materials joined) permitted by Tables S-2a and S-2b. 07

S.3.4 ROOF DESIGN AND ROOF MANHOLES 08

S.3.4.1 The yield strength given in Tables S-5a and S-5b shall be used for F_y in 5.10.4.4.

S.3.4.2 All stainless steel components of the roof manhole shall have a nominal thickness of not less than 5 mm (3/16 in.). 11

S.3.4.3 In 5.10.3.1 the required structural specification for stress limitations shall be modified to ASCE 8 Specification for the Design of Cold-Formed Stainless Steel Structural Members. The portion of the specification Appendix D entitled, "Allowable Stress Design," shall be used in determining allowable unit stress. 09

S.3.4.4 In 5.10.3.4 for columns, the AISC reference shall be modified to ASCE 8. Modified allowable stress values for l/r > 120 are not applicable.

S.3.5 APPENDIX F—MODIFICATIONS

S.3.5.1 DELETED

S.3.5.2 In F.7.1, the shell thickness shall be as specified in S.3.2 except that the pressure P (in kPa [in. of water]) divided by $9.8G$ ($12G$) shall be added to the design liquid height in meters (ft). 09

S.3.5.3 DELETED

S.3.6 APPENDIX M—MODIFICATIONS

S.3.6.1 Appendix M requirements shall be met for stainless steel tanks with a maximum design temperature over 40°C (100°F) as modified by S.3.6.2 through S.3.6.7.

S.3.6.2 Allowable shell stress shall be in accordance with Tables S-2a and S-2b. 08

S.3.6.3 In M.3.5, the requirements of 5.7.7 for flush-type cleanout fittings and of 5.7.8 for flush-type shell connections shall be modified. The thickness of the bottom reinforcing plate, bolting flange, and cover plate shall be multiplied by the greater of (a) the ratio of the material yield strength at 40°C (100°F) to the material yield strength at the maximum design temperature, or (b) the ratio of 205 MPa (30,000 psi) to the material yield strength at the maximum design temperature. (See Tables S-5a and S-5b for yield strength.) 11 08

S.3.6.4 In M.3.6, the stainless steel structural allowable stress shall be multiplied by the ratio of the material yield strength at the maximum design temperature to the material yield strength at 40°C (100°F). (See Tables S-5a and S-5b for yield strength.) 11 08

S.3.6.5 DELETED 11

S.3.6.6 In M.5.1, the requirements of 5.10.5 and 5.10.6 shall be multiplied by the ratio of the material modulus of elasticity at 40°C (100°F) to the material modulus of elasticity at the maximum design temperature. (See Tables S-6a and S-6b for modulus of elasticity.) 08

S.3.6.7 In M.6 (the equation for the maximum height of unstiffened shell in 5.9.7.1), the maximum height shall be multiplied by the ratio of the material modulus of elasticity at the maximum design temperature of 40°C (100°F). 08

S.4 Fabrication and Construction

S.4.1 GENERAL

Special precautions must be observed to minimize the risk of damage to the corrosion resistance of stainless steel. Stainless steel shall be handled so as to minimize contact with iron or other types of steel during all phases of fabrication, shipping, and construction. The following sections describe the major precautions that should be observed during fabrication and handling. 11

S.4.2 STORAGE

Storage should be under cover and well removed from shop dirt and fumes from pickling operations. If outside storage is necessary, provisions should be made for rainwater to drain and allow the material to dry. Stainless steel should not be stored in contact with carbon steel. Materials containing chlorides, including foods, beverages, oils, and greases, should not come in contact with stainless steel.

S.4.3 THERMAL CUTTING

S.4.3.1 Thermal cutting of stainless steel shall be by the iron powder burning carbon arc or the plasma-arc method.

S.4.3.2 Thermal cutting of stainless steel may leave a heat-affected zone and intergranular carbide precipitates. This heat-affected zone may have reduced corrosion resistance unless removed by machining, grinding, or solution annealing and quenching. The Purchaser shall specify if the heat-affected zone is to be removed.

S.4.4 FORMING

S.4.4.1 Stainless steels shall be formed by a cold, warm, or hot forming procedure that is noninjurious to the material.

S.4.4.2 Stainless steels may be cold formed, providing the maximum strain produced by such forming does not exceed 10% and control of forming spring-back is provided in the forming procedure.

S.4.4.3 Warm forming at 540°C (1000°F) – 650°C (1200°F) may cause intergranular carbide precipitation in 304, 316, and 317 grades of stainless steel. Unless stainless steel in this sensitized condition is acceptable for the service of the equipment, it will be necessary to use 304L, 316L, or 317L grades or to solution anneal and quench after forming. Warm forming shall be performed only with agreement of the Purchaser.

S.4.4.4 Hot forming, if required, may be performed within a temperature range of 900°C (1650°F) – 1200°C (2200°F).

S.4.4.5 Forming at temperatures between 650°C (1200°F) and 900°C (1650°F) is not permitted.

S.4.5 CLEANING

S.4.5.1 When the Purchaser requires cleaning to remove surface contaminants that may impair the normal corrosion resistance, it shall be done in accordance with ASTM A 380, unless otherwise specified. Any additional cleanliness requirements for the intended service shall be specified by the Purchaser.

08 Table S-2a—(SI) Allowable Stresses for Tank Shells.

	Type	Min. Yield MPa	Min. Tensile MPa	Allowable Stress (S_d) (in MPa) for Maximum Design Temperature Not Exceeding					
09				40°C	90°C	150°C	200°C	260°C	S_t Ambient
	201-1	260	515	155	136	125	121	--	234
	201LN	310	655	197	172	153	145	143	279
	304	205	515	155	155	140	128	121	186
	304L	170	485	145	132	119	109	101	155
	316	205	515	155	155	145	133	123	186
08	316L	170	485	145	131	117	107	99	155
	317	205	515	155	155	145	133	123	186
	317L	205	515	155	155	145	133	123	186

Notes:
1. S_d may be interpolated between temperatures.
2. The design stress shall be the lesser of 0.3 of the minimum tensile strength or 0.9 of the minimum yield strength. The factor of 0.9 of yield corresponds to a permanent strain of 0.10%. When a lower level of permanent strain is desired, the Purchaser shall specify a reduced yield factor in accordance with Table Y-2 of ASME Section II, Part D. The yield values at the different maximum design temperatures can be obtained from Tables S-5a.
3. For dual-certified materials (e.g., ASTM A 182M/A 182 Type 304L/304), use the allowable stress of the grade specified by the Purchaser.

Table S-2b—(USC) Allowable Stresses for Tank Shells 08

Type	Min. Yield psi	Min. Tensile psi	Allowable Stress (S_d) (in psi) for Maximum Design Temperature Not Exceeding					
			100°F	200°F	300°F	400°F	500°F	S_t Ambient
201-1	38,000	75,000	22,500	19,700	18,100	17,500	--	34,200
201LN	45,000	95,000	28,500	24,900	22,200	21,100	20,700	40,500
304	30,000	75,000	22,500	22,500	20,300	18,600	17,500	27,000
304L	25,000	70,000	21,000	19,200	17,200	15,800	14,700	22,500
316	30,000	75,000	22,500	22,500	21,000	19,300	17,900	27,000
316L	25,000	70,000	21,000	19,000	17,000	15,500	14,300	22,500
317	30,000	75,000	22,500	22,500	21,000	19,300	17,900	27,000
317L	30,000	75,000	22,500	22,500	21,000	19,300	17,900	27,000

Notes:

1. S_d may be interpolated between temperatures.
2. The design stress shall be the lesser of 0.3 of the minimum tensile strength or 0.9 of the minimum yield strength. The factor of 0.9 of yield corresponds to a permanent strain of 0.10%. When a lower level of permanent strain is desired, the Purchaser shall specify a reduced yield factor in accordance with Table Y-2 of ASME Section II, Part D. The yield values at the different maximum design temperatures can be obtained from Table S-5b.
3. For dual-certified materials (e.g., ASTM A 182M/A 182 Type 304L/304), use the allowable stress of the grade specified by the Purchaser.

Table S-3a—(SI) Allowable Stresses for Plate Ring Flanges 08

Type	Allowable Stress (S_t) (in MPa) for Maximum Design Temperature Not Exceeding				
	40°C	90°C	150°C	200°C	260°C
201-1	155	133	115	104	--
201LN	197	167	151	143	138
304	140	115	103	95	89
304L	117	99	88	81	75
316	140	119	107	99	92
316L	117	97	87	79	73
317	140	119	108	99	92
317L	140	119	108	99	92

Notes:

1. Allowable stresses may be interpolated between temperatures.
2. The allowable stresses are based on a lower level of permanent strain.
3. The design stress shall be the lesser of 0.3 of the minimum tensile strength or $^2/_3$ of the minimum yield strength.
4. For dual-certified materials (e.g., ASTM A 182M/A 182 Type 304L/304), use the allowable stress of the grade specified by the Purchaser.

S.4.5.2 When welding is completed, flux residue and weld spatter shall be removed mechanically using stainless steel tools.

S.4.5.3 Removal of excess weld metal, if required, shall be done with a grinding wheel or belt that has not been previously used on other metals.

08 Table S-3b—(USC) Allowable Stresses for Plate Ring Flanges

		Allowable Stress (S_t) (in psi) for Maximum Design Temperature Not Exceeding				
09	Type	100°F	200°F	300°F	400°F	500°F
	201-1	22,500	19,300	16,700	15,100	--
	201LN	28,500	24,200	21,900	20,700	20,000
	304	20,000	16,700	15,000	13,800	12,900
	304L	16,700	14,300	12,800	11,700	10,900
	316	20,000	17,200	15,500	14,300	13,300
08	316L	16,700	14,100	12,600	11,500	10,600
	317	20,000	17,300	15,600	14,300	13,300
	317L	20,000	17,300	15,600	14,300	13,300

Notes:
1. Allowable stresses may be interpolated between temperatures.
2. The allowable stresses are based on a lower level of permanent strain.
3. The design stress shall be the lesser of 0.3 of the minimum tensile strength or $^2/_3$ of the minimum yield strength.
• 4. For dual-certified materials (e.g., ASTM A 182M/A 182 Type 304L/304), use the allowable stress of the grade specified by the Purchaser.

Table S-4—Joint Efficiencies

Joint Efficiency	Radiograph Requirements
1.0	Radiograph per 8.1.2
0.85	Radiograph per A.5.3
0.70	No radiography required

Table S-5a—(SI) Yield Strength Values in MPa

		Yield Strength (in MPa) for Maximum Design Temperature Not Exceeding				
	Type	40°C	90°C	150°C	200°C	260°C
	201-1	260	199	172	157	--
	201LN	310	250	227	214	207
	304	205	170	155	143	134
09	304L	170	148	132	121	113
	316	205	178	161	148	137
	316L	170	145	130	119	110
	317	205	179	161	148	138
	317L	205	179	161	148	138

Notes:
1. Interpolate between temperatures.
2. Reference: Table Y-1 of ASME Section II, Part D.

Table S-5b—(USC) Yield Strength Values in psi

Type	Yield Strength (in psi) for Maximum Design Temperature Not Exceeding					
	100°F	200°F	300°F	400°F	500°F	
201-1	38,000	28,900	25,000	22,700	--	
201LN	45,000	36,300	32,900	31,100	30,000	
304	30,000	25,000	22,500	20,700	19,400	
304L	25,000	21,400	19,200	17,500	16,400	
316	30,000	25,800	23,300	21,400	19,900	09
316L	25,000	21,100	18,900	17,200	15,900	
317	30,000	25,900	23,400	21,400	20,000	
317L	30,000	25,900	23,400	21,400	20,000	

Notes:
1. Interpolate between temperatures.
2. Reference: Table Y-1 of ASME Section II, Part D.

Table S-6a—(SI) Modulus of Elasticity at the Maximum Design Temperature 08

Maximum Design Temperature (°C) Not Exceeding	Modulus of Elasticity (MPa)	
40	194,000	
90	190,000	
150	186,000	09
200	182,000	
260	179,000	

Note: Interpolate between temperatures. 08

Table S-6b—(USC) Modulus of Elasticity at the Maximum Design Temperature

Maximum Design Temperature (°F) Not Exceeding	Modulus of Elasticity (psi)	
100	28,100,000	
200	27,500,000	09
300	27,000,000	
400	26,400,000	
500	25,900,000	

Note: Interpolate between temperatures. 08

S.4.5.4 Chemical cleaners used shall not have a detrimental effect on the stainless steel and welded joints and shall be disposed of in accordance with laws and regulations governing the disposal of such chemicals. The use of chemical cleaners shall always be followed by thorough rinsing with water and drying (see S.4.9).

S.4.6 BLAST CLEANING

If blast cleaning is necessary, it shall be done with sharp acicular grains of sand or grit containing not more than 2% by weight iron as free iron or iron oxide. Steel shot or sand used previously to clean nonstainless steel is not permitted.

S.4.7 PICKLING

If pickling of a sensitized stainless steel is necessary, an acid mixture of nitric and hydrofluoric acids shall not be used. After pickling, the stainless steel shall be thoroughly rinsed with water and dried.

S.4.8 PASSIVATION OR IRON FREEING

When passivation or iron freeing is specified by the Purchaser, it may be achieved by treatment with nitric or citric acid. The use of hydrofluoric acid mixtures for passivation purposes is prohibited for sensitized stainless.

S.4.9 RINSING

S.4.9.1 When cleaning and pickling or passivation is required, these operations shall be followed immediately by rinsing, not allowing the surfaces to dry between operations.

• **S.4.9.2** Rinse water shall be potable and shall not contain more than 200 parts per million chloride at temperatures below 40°C (100°F), or no more than 100 parts per million chloride at temperatures above 40°C (100°F) and below 65°C (150°F), unless specified otherwise by the Purchaser.

S.4.9.3 Following final rinsing, the equipment shall be completely dried.

S.4.10 HYDROSTATIC TESTING

07 **S.4.10.1** The rules of 7.3.5 apply to hydrostatic testing except that the penetrating oil test in 7.3.5(2) shall be replaced with liquid penetrant examination conducted by applying the penetrant on one side and developer on the opposite side of the welds. The dwell time must be at least one hour.

• **S.4.10.2** The materials used in the construction of stainless steel tanks may be subject to severe pitting, cracking, or rusting if they are exposed to contaminated test water for extended periods of time. The Purchaser shall specify a minimum quality of test water that conforms to the following requirements:

• a. Unless otherwise specified by the Purchaser, water used for hydrostatic testing of tanks shall be potable and treated, containing at least 0.2 parts per million free chlorine.

b. Water shall be substantially clean and clear.

c. Water shall have no objectionable odor (that is, no hydrogen sulfide).

d. Water pH shall be between 6 and 8.3.

e. Water temperature shall be below 50°C (120°F).

• f. The chloride content of the water shall be below 50 parts per million, unless specified otherwise by the Purchaser.

• **S.4.10.3** When testing with potable water, the exposure time shall not exceed 21 days, unless specified otherwise by the Purchaser.

S.4.10.4 When testing with other fresh waters, the exposure time shall not exceed 7 days.

S.4.10.5 Upon completion of the hydrostatic test, water shall be completely drained. Wetted surfaces shall be washed with potable water when nonpotable water is used for the test and completely dried. Particular attention shall be given to low spots, crevices, and similar areas. Hot air drying is not permitted.

S.4.11 WELDING

S.4.11.1 Tanks and their structural attachments shall be welded by any of the processes permitted in 7.2.1.1 or by the plasma arc process. Galvanized components or components coated with zinc-rich coating shall not be welded directly to stainless steel.

S.4.11.2 Weld procedure qualifications for stainless steel alloys shall demonstrate strength matching the base metals joined (i.e., 3XX stainless shall be welded with a matching E3XX or ER3XX filler metal).

S.4.11.3 For the 300 series stainless steel materials, the filler metal mechanical properties and chemistry shall both match the
09 type of base metals joined (i.e., 3XX stainless shall be welded with a matching E3XX or ER3XX filler metal).

S.4.11.4 For the 200 series stainless steel materials, filler metals of matching composition are not available. The Manufacturer, with approval of the Purchaser, shall select the appropriate filler metal, taking into account the corrosion resistance and mechanical properties required for the joint.

S.4.11.5 Dissimilar material welds (stainless steels to carbon steels) shall use filler metals of E309/ER309 or higher alloy content.

S.4.11.6 Two stainless steel plates identical in material type may be welded together prior to erection in order to form a single shell plate subassembly. Plates welded together shall have thicknesses within 1.6 mm ($^{1}/_{16}$ in.) of each other with the maximum plate thickness being 13 mm ($^{1}/_{2}$ in.). No more than two plates shall be used to form one subassembly. Vertical edges of the pair of plates comprising a subassembly shall be aligned. The vertical joint offset requirement of 5.1.5.2 (b) shall be applied only between the subassembly and plates above and below it. The subassembly shall conform to the dimensional tolerances contained in Section 7 and shall be subjected to inspection requirements contained in Section 8. At least 25% of vertical spot radiographs shall be made at the subassembly horizontal weld to field vertical weld intersection. All welding procedure specifications shall be in accordance with Section 9. 11

S.4.12 WELDING PROCEDURE AND WELDER QUALIFICATIONS

Impact tests are not required for austenitic stainless steel weld metal and heat-affected zones.

• S.4.13 POSTWELD HEAT TREATMENT

Postweld heat treatment of austenitic stainless steel materials need not be performed unless specified by the Purchaser.

S.4.14 INSPECTION OF WELDS

S.4.14.1 Radiographic Inspection of Butt-Welds

Radiographic examination of butt-welds shall be in accordance with 8.1 and Table S-4.

S.4.14.2 Inspection of Welds by Liquid Penetrant Method

The following component welds shall be examined by the liquid penetrant method before the hydrostatic test of the tank:

a. The shell-to-bottom inside attachment weld.

b. All welds of opening connections in tank shell that are not completely radiographed, including nozzle and manhole neck welds and neck-to-flange welds.

c. All welds of attachments to shells, such as stiffeners, compression rings, clips, and other nonpressure parts for which the thickness of both parts joined is greater than 19 mm ($^{3}/_{4}$ in.).

d. All butt-welded joints in tank annular plates on which backing strips are to remain.

S.5 Marking

Brazing shall be deleted from 10.1.2.

S.6 Appendices

The following appendices are modified for use with austenitic stainless steel storage tanks:

a. Appendix A is not applicable to tanks built to this appendix, except for the radiography requirements of A.5.3 subject to the joint efficiency used.

• b. Appendix C may be used; however, the Purchaser shall identify all materials of construction.

c. Appendix F is modified as outlined in S.3.5 of this appendix.

d. Appendix J may be used, except the nominal shell thickness for all tank diameters shall not be less than 5 mm ($^{3}/_{16}$ in.). 11

e. Appendix K is not applicable to tanks built to this appendix.

f. Appendix M is modified as outlined in S.3.6 of this appendix.

g. Appendix N is not applicable.

h. Appendix O may be used; however, the structural members of Tables O-1a and O-1b shall be of an acceptable grade of material.

i. All other appendices may be used without modifications.

APPENDIX SC—STAINLESS AND CARBON STEEL MIXED MATERIALS STORAGE TANKS

SC.1 Scope

SC.1.1 This appendix covers materials, design, fabrication, erection, and testing requirements for vertical, cylindrical, aboveground, closed- and open-top, welded, storage tanks constructed with stainless steel and carbon steel. Generally, in this appendix the term stainless steel includes austenitic or duplex unless noted otherwise. Stainless steel and carbon steel may be used in the same tank for shell rings, bottom plates, roof structure and other parts of a tank to provide product storage for conditions that require only certain portions of the tanks to provide added corrosion resistance. These tanks are mixed material tanks. Stainless steel and carbon steel plates may be mixed in the bottom, roof or within any shell course. This appendix does not cover stainless steel clad plate or strip lined construction.

SC.1.2 This appendix applies only to tanks in non-refrigerated services with a maximum design temperature not exceeding 93°C (200°F). Mixed material tanks operating at temperatures greater than 93°C (200°F) are not addressed in this appendix. For the purposes of this appendix, the design temperature shall be the maximum design temperature as specified by the Purchaser. It is cautioned that exothermic reactions occurring inside unheated storage tanks can produce temperatures exceeding 40°C (100°F).

SC.1.3 This appendix states only the requirements that differ from the basic rules in this standard. For requirements not stated, the basic rules must be followed including Appendix S and Appendix X as applicable. References to paragraphs in this appendix shall be to the basic document unless stipulated otherwise.

SC.1.4 For limitations due to thermal effects see S.3.6 and X.3.7.

SC.1.5 The nameplate of the tank shall indicate that the tank is in accordance with this appendix by the addition of Appendix SC to the information required by 10.1.1. In addition, the nameplate shall be marked with the maximum design temperature in the space indicated in Figure 10.1. 09

SC.2 Materials

SC.2.1 Materials shall be in accordance with Section 4, Appendix S, and Appendix X.

● **SC.2.2** Selection of the type/grade of stainless steel and carbon steel for mixed material tanks depends on the service and environment to which it will be exposed and the effects of fabrication processes. (S.4.3.2, S.4.4.3, and X.2.1.1) The Purchaser shall select the type/grade. The Purchaser shall also specify which components shall be stainless steel.

SC.2.3 Components of a tank including shell, roof, bottom or bottom openings and their reinforcement may be carbon steels meeting the requirements of Section 4, provided they are protected from corrosion and the design and details consider the dissimilar properties of the materials used. Carbon steel attachments (e.g., clips for scaffolding) shall not be welded directly to any internal stainless steel tank surface.

SC.2.4 Impact tests are not required for austenitic stainless steel base metals. See X.2.3.2 for impact testing requirements for duplex stainless steel. Carbon steels in a mixed material tank shall require impact testing in accordance with the basic document.

SC.2.5 Welding of stainless steel to carbon steel shall use stainless steel electrodes appropriate for the type/grade of stainless steel used and the welding process employed.

SC.3 Design

When the design temperature exceeds 40°C (100°F) and the diameter exceeds 30 m (100 ft), a structural analysis of the entire tank structure is required to adequately predict stresses due to differential movements when austenitic stainless steel is joined to either carbon steel or duplex stainless steel components such as bottom to first shell course, adjacent shell courses, and roof to top shell course. The material combination of this paragraph applies to all other sub-paragraphs in Section SC.3. No analysis of stresses from differential movements is required for duplex stainless steel joined to carbon steel.

SC.3.1 BOTTOM

SC.3.1.1 When the bottom plate and first shell course are of different materials, the design shall account for differential component expansion.

SC.3.1.2 When the annular plate and first shell course are of different materials and the design temperature is greater than 40°C (100°F), the design shall account for differential shell component expansion. When the first shell course is carbon steel and the annular plate is stainless steel, the requirements of 5.5.1 shall apply.

SC.3.2 SHELL DESIGN

09 **SC.3.2.1** The variable point design method shall not be used for design of mixed material tank shells.

SC.3.2.2 Austenitic stainless steel insert plates shall not be used in carbon steel or duplex stainless steel plates and carbon steel or duplex stainless steel insert plates shall not be used in austenitic stainless steel plates except when an evaluation for differential movement due to temperature is performed.

SC.3.2.3 Where adjacent shell courses are of different materials and the design temperature is greater than 40°C (100°F), the design shall account for differential shell course expansion with regard to out of plane bending in the carbon steel plates. Use of stiffeners or thicker carbon steel plates may be required.

11 **SC.3.2.4** The required nominal shell thickness shall not be less than the greatest of the design shell thickness plus corrosion allowance, hydrostatic test shell thickness, or the nominal plate thickness listed in 5.6.1.1 (note 4 does not apply to the first shell courses made of stainless steel material).

SC.3.3 When the roof and shell are of different materials and the operating temperature is greater than 40°C (100°F), the design shall account for differential component expansion. Use of stiffeners or thicker component members may be required.

SC.3.4 NOZZLES AND MANWAYS

SC.3.4.1 Reinforcement requirements of 5.7 must be maintained except insert plates shall comply with SC 3.2.2.

● **SC.3.4.2** Nozzles and manways shall be of the same material as the shell course unless otherwise specified by the Purchaser.

SC.3.4.3 Reinforcing plates for shell penetrations shall be carbon steel to carbon steel and stainless steel to stainless steel even if the nozzle material differs from the shell material.

09 SC.4 Miscellaneous Requirements

SC.4.1 Chemical cleaners and pickling solutions used shall not have a detrimental effect on the stainless steel or carbon steel in mixed material tanks and their welded joints. Chemical cleaners and pickling solutions shall be disposed of in accordance with laws and regulations governing the disposal of such chemicals. The use of chemical cleaners shall always be followed by thorough rinsing with potable water and drying (see S.4.9 and X.4.5).

SC.4.2 Impact tests are not required for austenitic stainless steel weld metals and heat-affected zones. Impact tests of the carbon steel or duplex stainless steel heat affected zone shall be performed when required by the basic document or Appendix X.

● **SC.4.3** Postweld heat treatment of austenitic stainless steel and duplex stainless steel materials need not be performed unless specified by the Purchaser. PWHT of carbon steel components shall be performed when required by the basic document. For mixed material nozzle assemblies, the PWHT requirements of 5.7.4 are not mandatory except when specified by the Purchaser. The Purchaser is cautioned that mixed material nozzles with duplex stainless steel should not be PWHT due to the potential damaging effects of high temperature on the duplex material. The Purchaser is advised to discuss with a materials consultant or mill representative to determine what PWHT can be done for the specific material/chemistry/configuration.

SC.4.4 Surfaces of carbon steel plates shall be free of rust and scale prior to welding to stainless steel plates.

SC.4.5 At butt welds between stainless and carbon steel, at least one side of the joint shall be beveled with land not to exceed $t/3$ in order to prevent excessive weld metal dilution.

SC.4.6 Internal galvanic corrosion will occur by using mixed material construction and additional mitigation such as appropriate localized coatings should be considered.

SC.4.7 Where substantial quantities of uncoated stainless steel are welded to coated carbon steel, accelerated corrosion rates are possible at holidays in the carbon steel coating.

APPENDIX T—NDE REQUIREMENTS SUMMARY

Process	Welds Requiring Inspection	Reference Section
Air Test	Reinforcement plate welds inside and outside to 100 kPa (15 lbf/in.^{2}).	7.3.4
Air Test	Roofs designed to be airtight if roof seams are not vacuum-box tested.	7.3.7.1a
Air Test	Appendix F roofs during hydro-test of tanks.	F.4.4
Air Test	Aluminum dome roofs if required to be gas-tight.	G.10.1.2
Air Test	Shop built tanks if not tested per 7.3.2 – 7.3.7.	J.4.2.2
Air Test	Shop fabricated compartments (pontoons). Test in shop and field.	H.6.4
Hydro	Tank shell.	7.3.6
MT	Flush-type shell connections: Nozzle-to-tank shell, Repad welds, shell-to-bottom reinforcing pad welds on the root pass, each 12.5 mm ($^1/_2$ in.) of weld, and completed weld. After stress relieving before hydro-test.	5.7.8.11
MT	Permanent attachment welds and temporary weld removal areas on Group IV, IVA, V, and VI materials.	7.2.3.5
MT	Completed welds of stress relieved assemblies before hydro-test.	7.2.3.6
MT	First pass of the internal shell-to-bottom weld unless inspected by penetrating oil or PT or VB. Not required if the final weld is tested by pressure (see 7.3.4.2) or if agreed to by Purchaser and the final weld is tested by MT, PT or VB.	7.2.4.1a
MT	Final shell-to-bottom welds, inside and outside instead of MT, PT, pen. oil, or VB of the initial inside pass.	7.2.4.3c
MT	Shell-to-bottom fillet welds including the root pass, 20 mm ($^1/_2$ in.), and final surface of Appendix M tanks for which the stress concentration factor of K = 2.0 is used.	M.4.2
MT	Non-structural small attachments such as insulation clips (not supports) studs and pins not welded by capacitor discharge. Unless tested by liquid penetrant.	7.2.1.11
Pen. Oil	All seams of internal floating roofs exposed to liquid or vapors unless VB tested.	H.6.2
Pen. Oil	First pass of the internal shell-to-bottom weld if approved instead of MT or PT.	7.2.4.1d
Pen. Oil	Tank shell if no water for hydrostatic test.	7.3.5
Pen. Oil	Deck seams of external floating roofs.	C.4.2
Pen. Oil	Welded shell joints above the hydrostatic test water level unless vacuum-box tested.	7.3.6.1
Pen. Oil	Compartment welds of external floating roofs not tested with internal pressure or VB.	C.3.6
PT	Permanent attachment welds and temporary weld removal areas on Group IV, IVA, V, VI materials instead of MT if approved.	7.2.3.5
PT	Welds attaching nozzles, manways, and clean out openings instead of MT if approved.	7.2.3.6
PT	First pass of the internal shell-to-bottom weld if approved instead of MT.	7.2.4.1b or c
PT	Final shell-to-bottom welds, inside and outside instead of MT, PT, pen. oil, or VB of the initial inside pass.	7.2.4.3c
PT	All aluminum structural welds and components joined by welding.	G.11.3
PT	Stainless steel tank shell-to-bottom welds, opening connections not radiographed all welds of attachments to shells, and all butt welds of annular plates on which backing strips are to remain.	S.4.14.2
PT	Non-structural small attachments such as insulation clips (not supports) studs and pins not welded by capacitor discharge. Unless tested by magnetic particle.	7.2.1.11

07

	RT	Shell plate butt welds unless examined by UT with Purchaser approval. RT is not required for Appendix A, J, and S tanks where the Joint Efficiency of 0.7 is used.	7.3.2.1, A.5.3, S.4.14.1
	RT	Butt welds of annular plates that are required by 7.5.1 or M.4.1.	8.1.2.9
	RT	Flush-type shell connections: 100% of all longitudinal butt welds in the nozzle neck and transition piece, if any, and the first circumferential butt weld in the neck closest to the shell, excluding the neck-to-flange weld.	5.7.8.11
	RT	Shell vertical and horizontal welds which have intersecting openings and repads—100% over weld length 3 times the diameter of the opening.	5.7.3.4
	Tracer Gas	Entire length of bottom weld joints as an alternative to vacuum-box testing.	7.3.3.b
	UT	Shell plate butt welds if approved by Purchaser.	7.3.2.1
	VB	First pass of the internal shell-to-bottom weld if approved instead of MT, PT, or Pen. Oil.	7.2.4.1e
	VB	Bottom welds.	7.3.4a
	VB	Welds of roofs designed to be gas-tight if not air tested.	7.3.7.1
	VB	All seams of internal floating roofs exposed to liquid or vapors if not tested by penetrating oil.	H.6.2
	VB	Seams of flexible membrane liners for leak protection.	I.6.2
	VB	Welded shell joints above the hydrostatic test water level unless tested with penetrating oil.	7.3.6.1
	VB	Shell-to-bottom weld joints.	7.2.4.3c
07	VE	Flush type shell connections: Nozzle-to-tank shell, repad welds, shell-to-bottom reinforcing pad welds on the root pass, each 20 mm ($^1/_2$ in.) of weld, and completed weld. After stress relieving before hydro-test.	5.7.8.11
	VE	Tack of shell butt welds left in place.	7.2.1.8
	VE	Permanent attachment welds and temporary weld removal areas on Group IV, IVA, V, and VI materials.	7.2.3.5
	VE	Completed welds of stress relieved assemblies before hydro-test.	7.2.3.6
	VE	First pass and final weld inside and outside of the internal shell-to-bottom weld.	7.2.4.1, 7.2.4.2, 7.2.4.3
	VE	All shell plate butt welds.	7.3.2.1
	VE	All fillet welds including roof plate welds.	7.3.2.2
	VE	Upper side of the upper deck welds of pontoon and double deck floating roofs.	C.4.4
	VE	All aluminum structural welds and components joined by welding.	G.11.3
	VE	Joint fit-up of butt welds of bottoms supported by grillage and each weld pass.	I.7.4
	VE	Non-structural small attachments such as insulation clips (not supports) studs and pins including those welded by capacitor discharge.	7.2.1.11
	VE	Leak barrier, leak barrier penetrations, attachments to ringwalls and other appurtenances.	I.6.1
	VE	Bottom welds.	7.3.3
	VE	Roof welds not designed to be gas-tight.	7.3.7.2
	Water	Bottom welds if not vacuum-box or tracer gas tested.	7.3.3c
	Water	External floating roofs—flotation test.	C.4.3
	Water	External floating roof drain pipe and hose systems with pressure.	C.4.5
	Water	Aluminum dome roofs after completion.	G.10.1.1
	Water	Internal floating roofs flotation test.	H.7.3

Definitions:

MT = Magnetic Particle Examination

Pen Oil = Penetrating Oil Test

PT = Liquid Penetrant Examination

RT = Radiographic Testing

VB = Vacuum-Box Testing

VE = Visual Examination

Acceptance Standards:

MT: ASME Section VIII, Appendix 6 (Paragraphs 6-3, 6-4, 6-5)

PT: ASME Section VIII, Appendix 8, (Paragraphs 8-3, 8-4, 8-5)

RT: ASME Section VIII, Paragraph UW-51(b)

Tracer Gas: API Std 650, Section 8.6.11

UT: For welds examined by UT in lieu of RT, acceptance standards are in Appendix U. For UT when RT is used for the requirements of 7.3.2.1, the acceptance standard is as agreed upon by the Manufacturer and Purchaser.

VB: API Std 650, Section 8.6

VE: API Std 650, Section 8.5

Examiner Qualifications:

MT: API Std 650, Section 8.2.3. 07

PT: API Std 650, Section 8.2.3

RT: ASNT SNT-TC-1A Level II or III. Level-I personnel may be used under the supervision of a Level II or Level III with a written procedure in accordance with ASME Section V, Article 2.

Tracer Gas: None

UT: For welds examined by UT in lieu of RT, the inspector must be ASNT-TC-1A or CP-189 Level II or Level III. For UT when RT is used for the requirements of 7.3.2.1, the required qualifications are ASNT-TC-1A Level II or Level III. A Level I may be used with restrictions—see API Std 650, Section 8.3.2.

VB: None

VE: None

Procedure Requirements:

MT: ASME Section V, Article 7

PT: ASME Section V, Article 6

RT: A procedure is not required. However, the examination method must comply with ASME Section V, Article 2. Acceptance standards shall be in accordance with ASME Section VIII, Paragraph UW-51(b).

UT: For shell welds examined by UT in lieu or RT, ASME, Section V, Article 4 and U.3.5. For welds when RT is used for the requirements of 7.3.2.1, ASME Section V.

VB: None

VE: None

Tracer Gas: API Std 650, Section 8.6.11.a.

APPENDIX U—ULTRASONIC EXAMINATION IN LIEU OF RADIOGRAPHY

U.1 General

U.1.1 PURPOSE

This appendix provides detailed rules for the use of the ultrasonic examination (UT) method for the examination of tank seams as permitted by 7.3.2.1. This alternative is limited to joints where the thickness of the thinner of the two members joined is greater than or equal to 10 mm ($^3/_8$ in.).

U.1.2 APPLICATION AND EXTENT

The provisions of 8.1 governing:

a. When adjacent plates may be regarded as the same thickness,

b. Application (see 8.1.1), and

c. Number and Locations (see 8.1.2)

shall apply to this ultrasonic method. When these sections refer to radiography, for purposes of this appendix, they shall be read as applied to UT.

U.2 Definitions

a. **documenting:** Preparation of text and/or and figures.

b. **evaluation:** All activities required in U.6.3 through U.6.6 to determine the acceptability of a flaw.

c. **flaw:** A reflector that is not geometric or metallurgical in origin that may be detectable by nondestructive testing but is not necessarily rejectable. 07

d. **flaw categorization:** Whether a flaw is a surface flaw or is a subsurface flaw (see U.6.4). Note that a flaw need not be surface-breaking to be categorized as a surface flaw.

e. **flaw characterization:** The process of quantifying the size, location and shape of a flaw. See U.6.3 for size and location. The only shape characterization required by this appendix is applied to the results of supplemental surface examination by MT or PT (see U.6.6.2).

f. **indication:** That which marks or denotes the presence of a reflector.

g. **interpretation:** The determination of whether an indication is relevant or non-relevant. i.e., whether it originates from a geometric or metallurgical feature or conversely originates from a flaw (see U.6.2).

h. **investigation:** Activities required to determine the interpretation of an indication (see U.6.1 and U.6.2).

i. **recording:** The writing of ultrasonic data onto an appropriate electronic medium.

j. **reflector:** An interface at which an ultrasonic beam encounters a change in acoustic impedance and at which at least part of the energy is reflected.

U.3 Technique

● **U.3.1** The UT volume shall include the weld metal, plus the lesser of 25 mm (1 in.) or *t* of adjoining base metal on each side of the weld unless otherwise agreed upon by the Purchaser and the Manufacturer.

U.3.2 UT for the detection of flaws shall be performed using automated, computer-based data acquisition except that scanning of adjacent base metal for flaws that can interfere with the examination may be performed manually. UT for sizing of flaws shall be performed as described in U.6.3.1

● **U.3.3** A documented examination strategy or scan plan shall be provided showing transducer placement, movement, and component coverage that provides a standardized and repeatable methodology for weld acceptance. The scan plan shall also include ultrasonic beam angle to be used, beam directions with respect to weld centerline, and tank material volume examined for each weld. The documentation shall be made available to the Owner upon request.

U.3.4 Data from the examination volume, per U.3.1, shall be recorded and/or documented as follows:

a. For automated computer-based scans, data shall be recorded using the same system essential variables, specified value or
07 range of values, used for the demonstration of the procedure per U.4.3.

b. For manual scans, results shall be documented in a written report.

• **U.3.5** The UT shall be performed in accordance with a written procedure which has been reviewed and approved by the Purchaser and conforms to the requirements of Section V, Article 4, except that:

08 a. the calibration block shown in Figure T-434.2.1 of Section V, Article 4 shall be used, and

b. for examination techniques that provide plate quality information (e.g., TOFD), the initial base material straight-beam examination need not be performed.

U.3.6 The examination methodology (including U.6.6) shall be demonstrated to be effective over the full weld volume. It is recognized that Time of Flight Diffraction (TOFD) may have limitations in detection of flaws at the surface such that it may be necessary to supplement TOFD with pulse-echo techniques suitable for the detection of near-field and far-field flaws. The variety of surface and sub-surface category flaws in the test plate mandated by U.4.3a are intended to ensure that any such limitations are adequately addressed.

U.4 Personnel Qualifications and Training

07 **U.4.1 Personnel Qualifications**—Personnel performing and evaluating UT examinations shall be qualified and certified in accordance with their employer's written practice. ASNT SNT-TC-IA or CP-189 shall be used as a guideline. Only Level-II or Level-III personnel shall perform UT examinations, analyze the data, or interpret the results.

U.4.2 Qualification Records—Qualification records of certified personnel shall be approved by the Manufacturer and maintained by their employer.

• **U.4.3 Personnel Testing**—Personnel who acquire and analyze UT data shall be trained using the equipment of U.3.2, and the procedure of U.3.5 above. Additionally, they shall pass a practical examination based on the technique on a blind test plate. The testing program details shall be by agreement between the Purchaser and the inspection company but shall in any case include the following elements as a minimum:

a. The test plate shall contain a variety of surface and sub-surface category flaws including multiple flaws described in U.6.5.
08 Some of the flaws shall be acceptable and others unacceptable per the applicable criteria of Tables U-1a or U-1b.

b. The practical examination should cover detection, interpretation, sizing, plotting, categorization, grouping, and characterization that is sufficient to cover the cases outlined in U.6.

c. Criteria for passing the test shall include limits on the number of miscalls, both of rejectable flaws missed or accepted and acceptable regions rejected.

d. Testing shall be facilitated by a third-party or by the Purchaser.

U.5 Level III Review

U.5.1 The final data package shall be reviewed by a UT Level-III individual qualified in accordance with U.4.1 and U.4.3 above. The review shall include:

07 a. The ultrasonic data record.

b. Data interpretations.

c. Evaluations of indications performed by another qualified Level-II or Level-III individual. The data review may be performed by another individual from the same organization.

U.5.2 Alternatively, the review may be achieved by arranging for a data acquisition and initial interpretation by a Level-II individual qualified in accordance with. U.4.1 and U.4.3 above, and a final interpretation and evaluation shall be performed by a Level-III individual qualified per U.5.1.

U.6 Interpretation and Evaluation

U.6.1 Investigation Criteria—Reflectors that produce a response greater than 20% of the reference level shall be investigated. Alternatively, for methods or techniques that do not use amplitude recording levels, sized reflectors longer than 40% of the

acceptable surface or subsurface flaws in Tables U-1a and U-1b shall be investigated. The investigation shall interpret whether the 08
indication originates from a flaw or is a geometric indication in accordance with U.6.2 below. When the reflector is determined to 07
be a flaw, the flaw shall be evaluated and acceptance criteria of Tables U-1a and U-1b as applicable shall apply. 08

U.6.2 Interpretation as Geometric/Metallurgical—Ultrasonic indications of geometric and metallurgical origin shall be interpreted as follows:

U.6.2.1 Indications that are determined to originate from the surface configurations (such as weld reinforcement or root geom- 07
etry) or variations in metallurgical structure of materials may be interpreted as geometric indications, and

a. Need not be sized or categorized in accordance with U.6.3 and U.6.4 below;

b. Need not be compared to the allowable flaw acceptance criteria of Tables U-1a and U-2b; 08

c. The maximum indication amplitude (if applicable) and location shall be documented, for example: internal attachments, 200% DAC maximum amplitude, one (1) in. above the weld centerline, on the inside surface, from 90° to 95°.

U.6.2.2 The following steps shall be taken to classify an indication as geometric:

a. Interpret the area containing the indication in accordance with the applicable examination procedure;

b. Plot and verify the indication's coordinates, provide a cross-sectional display showing the indication's position and any surface conditions such as root or counter-bore; and

c. Review fabrication or weld prep drawings.

U.6.2.3 Alternatively, other NDE methods or techniques may be applied to interpret an indication as geometric (e.g., alterna- 07
tive UT beam angles, radiography, ID and/or OD profiling).

U.6.3 FLAW SIZING

U.6.3.1 Flaws shall be sized using automated, computer-based data acquisition or by a supplemental manual technique that has been demonstrated to perform acceptably per U.4.3 above.

U.6.3.2 The dimensions of the flaw shall be defined by the rectangle that fully contains the area of the flaw. The length (*l*) of the flaw shall be drawn parallel to the inside pressure-retaining surface of the component. The height (*h*) of the flaw shall be drawn normal to the inside pressure-retaining surface.

U.6.4 FLAW CATEGORIZATION

If the space between the surface and the flaw in the through-thickness direction is less than one-half the measured height of the flaw, then the flaw shall be categorized as a surface flaw with flaw height extending to the surface of the material.

U.6.5 GROUPING OF MULTIPLE FLAWS

U.6.5.1 Discontinuous flaws that are oriented primarily in parallel planes shall be considered to lie in a single plane if the dis-
tance between the adjacent planes is equal to or less than 13 mm (1/2 in.). 08

U.6.5.2 If the space between two flaws aligned along the axis of weld is less than the length of the longer of the two, the two flaws shall be considered a single flaw.

U.6.5.3 If the space between two flaws aligned in the through-thickness direction is less than the height of the flaw of greater 07
height, the two flaws shall be considered a single flaw.

U.6.6 FLAW ACCEPTANCE CRITERIA

U.6.6.1 Acceptance Criteria Tables—Flaw dimensions resulting after the application of the rules of U.6.3, U.6.4 and U.6.5
shall be evaluated for acceptance using the criteria of Tables U-1a and U-1b. 08

U.6.6.2 Surface Examination—Flaws categorized as surface flaws during the UT examination may or may not be surface-
connected. Therefore, unless the UT data analysis confirms that the flaw is not surface-connected, a supplemental surface exami- 07
nation (MT or PT) shall be performed in accordance with 8.2 or 8.4 as applicable for all surface flaws. Any flaws which are
detected by MT or PT and characterized as planar are unacceptable regardless of length.

U.7 Repairs

All repaired areas, plus the lesser of 25 mm (1 in.) or *t* of the adjoining weld on each side of the repair, shall be reinspected per this Appendix.

07 ## U.8 Flaw Documentation

In addition to the data record prescribed by U.3.4, written documentation shall be produced for each unacceptable flaw and those acceptable flaws that either exceed 50% of reference level for amplitude based techniques or exceed 75% of the acceptable length for non-amplitude techniques.

Table U-1a—(SI) Flaw Acceptance Criteria for UT Indications May be Used for All Materials

	Thickness at Weld (t)[a] mm	ACCEPTABLE FLAW LENGTHS—(l) mm							
		For Surface Flaw[b] With Height, (h) mm			For SubSurface Flaw With Height, (h) mm				
		2	2.5	3	2	3	4	5	6
	10 to <13	8	8	4	14	5	4	Not allowed	Not allowed
08	13 to < 19	8	8	4	38	8	5	4	3
	19 to < 25	8	8	4	75	13	8	6	5
	25 to < 32	9	8	4	100	20	9	8	6
	32 to < 40	9	8	4	125	30	10	8	8
	40 to < 44	9	8	4	150	38	10	9	8

a. t = thickness of the weld excluding any allowable reinforcement. For a butt weld joining members having different thickness at the weld, t is
07 the thinner of the two.
b. Any surface flaw, to be deemed acceptable, must satisfy both the size limitations of this table and additionally satisfy the MT/PT characterization limitations of U.6.6.2

Table U-1b—(USC) Flaw Acceptance Criteria for UT Indications May be Used for All Materials

	Thickness at Weld (t)[a] in.	ACCEPTABLE FLAW LENGTHS—(l) in.							
		For Surface Flaw[b] With Height, (h) in.			For SubSurface Flaw With Height, (h) in.				
		0.08	0.10	0.12	0.08	0.12	0.16	0.2	0.24
08	0.375 to < 0.50	0.30	0.30	0.15	0.55	0.20	0.15	Not allowed	Not allowed
	0.50 to < 0.75	0.30	0.30	0.15	1.50	0.30	0.20	0.15	0.10
	0.75 to < 1.0	0.30	0.30	0.15	3.00	0.50	0.30	0.25	0.20
	1.0 to < 1.25	0.35	0.30	0.15	4.00	0.80	0.35	0.30	0.25
	1.25 to < 1.50	0.35	0.30	0.15	5.00	1.20	0.40	0.30	0.30
	1.50 to < 1.75	0.35	0.30	0.15	6.00	1.50	0.40	0.35	0.30

a. t = thickness of the weld excluding any allowable reinforcement. For a butt weld joining members having different thickness at the weld, t
07 is the thinner of the two.
b. Any surface flaw, to be deemed acceptable, must satisfy both the size limitations of this table and additionally satisfy the MT/PT characterization limitations of U.6.6.2

APPENDIX V—DESIGN OF STORAGE TANKS FOR EXTERNAL PRESSURE

• V.1 Scope

This appendix provides minimum requirements that may be specified by the Purchaser for tanks that are designed to operate with external pressure (vacuum) loading as a normal operating condition. This appendix is intended to apply to tanks for which the normal operating external pressure exceeds 0.25 kPa (0.036 lbf/in.^{2}) but does not exceed 6.9 kPa (1.0 lbf/in.^{2}). This appendix is intended for use with tanks subject to uniform external pressure. The requirements in this appendix represent accepted practice for application to flat-bottom tanks. However, the Purchaser may specify other procedures or additional requirements. Any deviation from the requirements of this appendix must be by agreement between the Purchaser and the Manufacturer. See V.11 for a discussion of the technical basis for this appendix.

V.2 General

The design procedures presented in this appendix are intended to allow the user to evaluate the design of the bottom, shell and fixed roof of tanks that operate under partial vacuum conditions. See Appendix R for requirements for combining external pressure loads with other design loads. The requirements of this appendix are not intended to supersede the requirements of other appendices of this Standard that may be specified. For Appendix AL, M, S and SC tanks, the variables in the equations prescribed in this appendix shall be modified in accordance with the requirements of Appendices AL, M, S and SC, respectively. 08

V.3 Nomenclature and Definitions

V.3.1 NOMENCLATURE

θ = angle between a horizontal plane and the surface of the roof plate (degrees)

A_{reqd} = total required cross-sectional area of the stiffener region, mm^2 (in.^{2})

A_{stiff} = required cross-sectional area of stiffener, mm^2 (in.^{2}) Note: A_{stiff} must be at least $^1/_2 \times A_{total}$

D = nominal tank diameter, m (ft)

D_L = dead load, the weight of the tank or tank component calculated using nominal thickness unless otherwise specified, kPa (lb/ft^2) 11

E = modulus of elasticity of the roof plate material, MPa, (lb/in.^{2})

f = smallest of the allowable tensile stresses (see Tables 5-2a and 5-2b) of the roof plate material, shell plate material or stiffener ring material at the maximum operating temperature, MPa (lb/in.^{2}) 08

f_c = smallest of the allowable compressive stresses of the roof plate material, shell plate material, bottom plate material or stiffener ring material at the maximum operating temperature, MPa (lb/in.^{2}). $f_c = 0.4F_y$ of components considered for the intermediate and bottom stiffener regions. However, f_c need not be less than 103 MPa (15,000 lb/in.^{2}). $f_c = 0.6F_y$ of components considered for the top end stiffener region. However, f_c need not be less than 140 MPa (20,000 lb/in.^{2}).

F_y = yield strength of the component at the maximum operating temperature, MPa (lb/in.^{2})

G_{in} = unit weight of liquid inside tank, kg/m^3 (lb/ ft^3)

G_{out} = unit weight of flood liquid, kg/m^3 (lb/ ft^3) (1000 kg/m^3 [62.4 lb/ ft^3] for water)

H = shell height, m (ft)

$h_1, h_2 \ldots h_n$ = height of shell courses 1, 2, 3, through n, respectively, m (ft)

H_{in} = height or depth of liquid inside tank, m (ft)

H_{safe} = maximum height of unstiffened shell permitted, based on t_{smin}, m (ft) 11

HTS = Transformed height of tank shell, m (ft)

I_{act} = The actual moment of inertia of the stiffener ring region, cm^4 (in.^{4})

I_{reqd} = required moment of inertia of the stiffener ring, cm^4 (in.^{4})

DELETED 11

L_1, L_2 = distances between adjacent intermediate stiffeners or intermediate stiffener and top of shell or bottom of shell, respectively, m (ft)

L_r = minimum roof live load on horizontal projected area of the roof, kPa (lb/ft^2) = 1.0kPa (20 lb/ft^2)

L_s = $(L_1 + L_2) / 2$, m (ft)

N = number of waves into which a shell will buckle under external pressure

N_s = number of intermediate stiffeners

P_e = specified external pressure, kPa (lb/ft^2)

P_r = total design external pressure for design of roof, kPa (lb/ft^2).

P_s = total design external pressure for design of shell, kPa (lb/ft^2). P_s = the greater of 1) the specified design external
08 pressure, P_e, excluding wind or 2) $W + 0.4P_e$ (see R.2 of Appendix R for an important consideration).

ψ = stability factor (see V.8.1 for values)

Q = radial load imposed on the intermediate stiffener by the shell, N/m (lb/in.)

q_s = first moment of area of stiffener for design of stiffener attachment weld, mm^3 (in.^{3})

R = roof dish radius, m (ft)

S = specified snow load, kPa (lb/ft^2)

S_d = allowable design stress, Mpa, (lb/in.^{2})

t = nominal shell thickness, mm (in.)

t_b = nominal thickness of bottom plate under the shell, mm (in.)

t_{cone} = required nominal thickness of cone roof plate, mm (in.). Maximum corroded thickness shall be 12.5 mm (0.5 in.)

t_{dome} = required nominal thickness of dome roof plate, mm (in.). Maximum corroded thickness shall be 12.5 mm (0.5 in.)

11 $t_{s1}, t_{s2} \ldots t_{sn}$ = nominal thickness of cylindrical shell course 1, 2…n, mm (in.), where the subscript numbering is from top to bottom of the shell. Note: The subscript 1 denotes the top shell course and *n* denotes the lowest shell course.

t_{shell} = nominal thickness of shell at level under consideration, mm (in.)

t_{smin} = nominal thickness of thinnest shell course, mm (in.)

V_1 = radial load imposed on the stiffener by the shell, N/m (lb/in.)

V_{s1} = radial pressure load imposed on the stiffener from the shell for sizing the stiffener attachment weld, N/m (lb/ft)

v_s = radial shear load on stiffener for sizing the stiffener attachment weld, N (lb)

V_{s2} = weld shear flow load imposed for sizing the stiffener attachment weld, N/m (lb/ft)

W = maximum wind pressure consistent with the specified design wind velocity, kPa (lb/ft^2). The maximum wind
08 pressure shall be calculated as follows (see 5.9.7.1, Note 2):

In SI units:

08
$$W = 1.48\left(\frac{V}{190}\right)^2$$

In US Customary units:

08
$$W = 31\left(\frac{V}{120}\right)^2$$

where

• V = specified design wind velocity (3-sec gust), kph (mph),

W_{bott} = weight of bottom plate, kg/m^2 (lb/ft^2)

w_{shell} = contributing width of shell on each side of intermediate stiffener, mm (in.)

X_{btm} = length of bottom plate within tension/compression ring region, mm (in.). $X_{btm} = 16\ t_b$

X_{cone} = length of cone roof within tension/compression ring region, mm (in.)

X_{dome} = length of umbrella or dome roof within tension/compression ring region, mm (in.)

X_{shell} = length of shell within tension/compression ring region, mm (in.)

V.3.2 DEFINITIONS

● **V.3.2.1 specified external pressure:** External pressure specified on the tank data sheet (see Appendix L) by the Purchaser. This specified value excludes any external pressure due to wind.

V.3.2.2 total design external pressure for the roof (P_r): Sum of the specified external pressure and the roof live load or snow load and the dead load as provided in V.7.1.

V.3.2.3 total design external pressure for the shell (P_s): Sum of the specified external pressure and the external pressure due to wind as combined in V.8.1.2. 08

V.4 Construction Tolerances

The procedures prescribed in this appendix are only valid for tanks that satisfy the construction tolerances of 7.5.

● V.5 Corrosion Allowance

Unless specified otherwise by the Purchaser, the evaluation of tanks in accordance with the requirements of this appendix may be based on the nominal thickness of the pressure-resisting components. If the nature of the tank service conditions is such that corrosion will result in a uniform loss of thickness of the affected components, the Purchaser should specify that corrosion allowance be deducted from the nominal thickness used in the evaluation. 11

● V.6 Testing

Testing of the tank design for external pressure is not required by this appendix, but may be performed if specified by the Purchaser.

V.7 Fixed Roof

The total design external pressure loading, P_r, on the roof is determined by the following equation:

$$P_r = \text{The greater of } D_L + (L_r \text{ or } S) + 0.4\ P_e \text{ or } D_L + P_e + 0.4\ (L_r \text{ or } S)$$

V.7.1 COLUMN-SUPPORTED CONE ROOF

Column-supported cone roofs may be used on tanks designed for external pressure, providing the design and construction satisfy the following requirements.

● **V.7.1.1** The roof plate spanning between support rafters may be designed as a simple beam spanning several supports, or as a catenary beam spanning between supports, or as a diaphragm, by agreement between the Purchaser and the Manufacturer. Regardless of the design method selected, the following considerations shall be addressed in the design:

a. Allowable stress for both membrane and bending.

b. Joint efficiency of welds joining the roof plates together.

c. Assumed end fixity conditions for plate (beam) span.

d. Allowable deflection criteria.

If the roof plate is designed as a catenary beam, the following additional considerations shall be addressed in the design.

e. Possibility of stress reversal and fatigue loading of welds at and between supports of the roof plate.

V.7.1.2 Additional guidance on the design of supported cone roof plates for pressure loading may be found in References 8 and 9, for example, and in other published texts.

V.7.2 SELF-SUPPORTING CONE ROOF

V.7.2.1 The required thickness of the roof plate is determined by the following equation. However, the thickness shall not be less than that required by 5.10.5.1.

In SI units:

08 $$t_{cone} = \frac{83D}{\sin\theta}\sqrt{\frac{P_r}{1.72E}}$$

In US Customary units:

08 $$t_{cone} = \frac{D}{\sin\theta}\sqrt{\frac{P_r}{0.248E}}$$

V.7.2.2 The total required cross-sectional area in the cone roof-to-shell joint region for external pressure on the roof is determined by the following equation.

In SI units:

08 $$A_{reqd} = \frac{125 P_r D^2}{f \tan\theta}$$

In US Customary units:

08 $$A_{reqd} = \frac{P_r D^2}{8 f \tan\theta}$$

V.7.2.3 The length of cone roof considered to be within the top tension/compression ring region is determined by the following equation (see Figure V.1A):

In SI units:

08 $$X_{cone} = 13.4\sqrt{\frac{Dt_{cone}}{\sin\theta}}$$

In US Customary units:

08 $$X_{cone} = 1.47\sqrt{\frac{Dt_{cone}}{\sin\theta}}$$

V.7.2.4 The vertical dimension measured from the top of the shell or top angle considered to be within the tension/compression ring region is determined by the following equation (see Figure V.1A):

In SI units:

For the top tension/compression region:

$$X_{shell} = 13.4\sqrt{Dt_{s1}}$$

For the bottom tension/compression region:

$$X_{shell} = 13.4\sqrt{Dt_{sn}}$$

In US Customary units:

For the top tension/compression region:

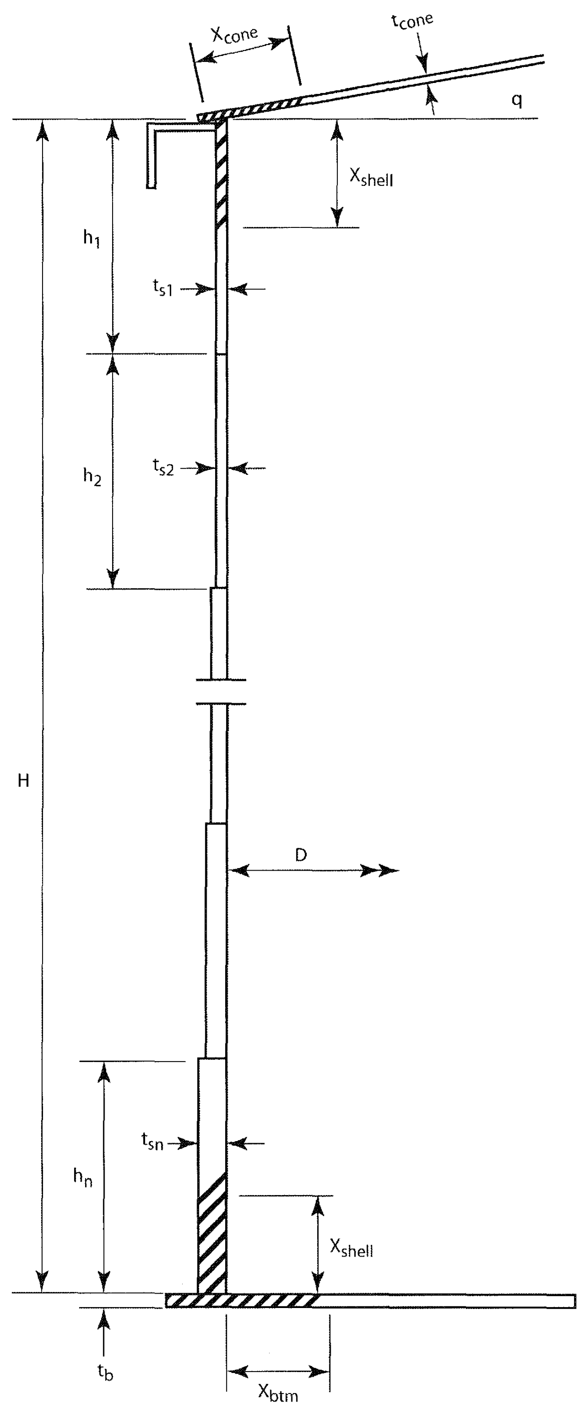
$$X_{shell} = 1.47\sqrt{Dt_{s1}}$$

For the bottom tension/compression region:

$$X_{shell} = 1.47\sqrt{Dt_{sn}}$$

V.7.2.5 The required cross-sectional area of the top stiffener structural shape is determined by the following equation:

11 $$A_{stiff} = A_{reqd} - t_{s1}X_{shell} - t_{cone}X_{cone}$$



Note: See Appendix F, Figure F-2 for alternative configurations and associated limitations on structural section used for top stiffener.

Figure V-1A—Dimensions for Self-Supporting Cone Roof

V.7.3 SELF-SUPPORTING DOME OR UMBRELLA ROOF

V.7.3.1 The required thickness of the roof plate is determined by the following equations. However, the thickness shall not be less than that required by 5.10.6.1. (Note that design in accordance with API Std 620 is permitted for dished dome roofs meeting the requirements of API Std 620, 5.10.5.1.)

In SI units:

11

$$t_{dome} = 141R\sqrt{\frac{P_r}{E}} \text{ (for umbrella and dome roofs)}$$

In US Customary units:

$$t_{dome} = 4.47R\sqrt{\frac{P_r}{E}} \text{ (for umbrella and dome roofs)}$$

V.7.3.2 The total required cross-sectional area in the dome or umbrella roof-to-shell joint region for external pressure on the roof is determined by the following equation. However, the area shall not be less than that required by 5.10.6.2.

In SI units:

$$A_{reqd} = \frac{300P_rRD}{f}$$

In US Customary units:

$$A_{reqd} = \frac{P_rRD}{3.375f}$$

V.7.3.3 The length of dome or umbrella roof considered to be within the top tension/compression ring region is determined by the following equation:

In SI units:

08

$$X_{dome} = 19.0\sqrt{RT_{dome}}$$

In US Customary units:

$$X_{dome} = 2.1\sqrt{RT_{dome}}$$

V.7.3.4 The length of shell considered to be within the top tension/compression ring region is determined by the following equation (see Figure V.1B):

In SI units:

08

$$X_{shell} = 13.4\sqrt{Dt_{s1}}$$

In US Customary units:

08

$$X_{shell} = 1.47\sqrt{Dt_{s1}}$$

V.7.3.5 The required cross-sectional area of the top stiffener structural shape is determined by the following equation:

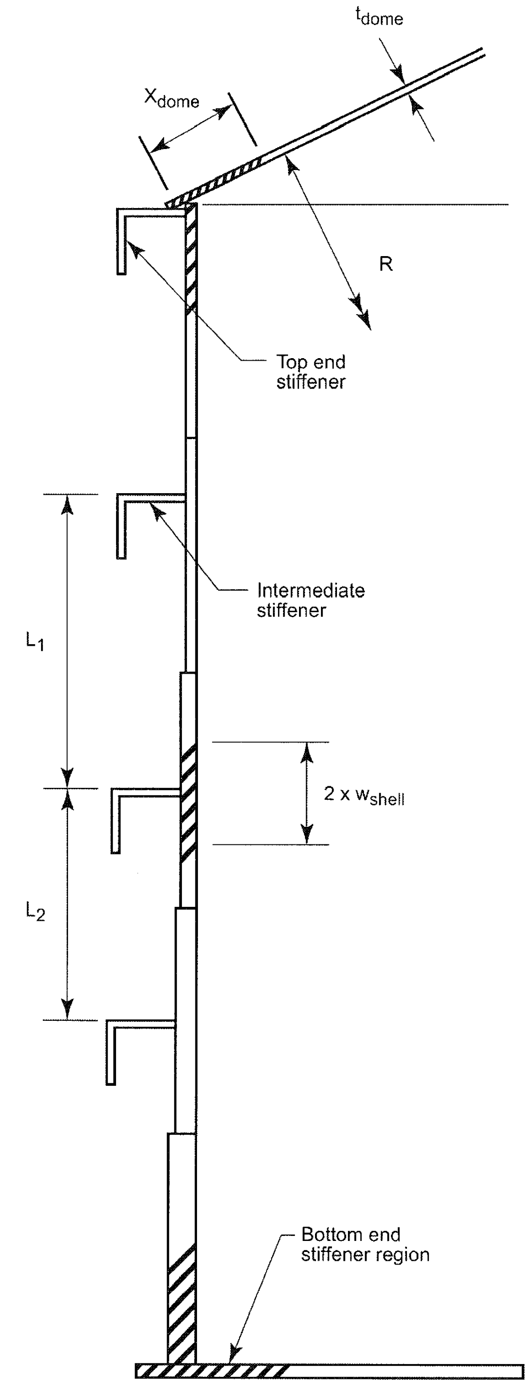
11

$$A_{stiff} = A_{reqd} - t_{s1}X_{shell} - t_{dome}X_{dome}$$

$$A_{stiff} = 7.21 - (0.3125)(7.21) - (0.529)(11.7)$$

$$A_{stiff} = -1.23 \text{ in.}^2$$

Note: This value should be recalculated, if necessary, after selection of final shell thickness.



08

Note: See Appendix F, Figure F-2 for alternative configurations and associated limitations on structural section used for top stiffener.

Figure V-1B—Dimensions for Self-Supporting Dome Roof

V.8 Shell

V.8.1 UNSTIFFENED SHELLS

The procedure utilizes the nominal thickness of thinnest shell course and the transformed shell method to establish intermediate stiffener number and locations. The equations in V.8.1.2 and V.8.1.3 contain variables for a stability factor, ψ, that is dependent upon the magnitude of the vacuum pressure. The equations also include a 0.8 "knockdown" factor for imperfections in the cylindrical shell geometry. Shells shall be checked for two conditions: 1) the combined wind plus vacuum, and 2) for vacuum pressure alone. Each condition shall be checked using the appropriate stability factor, ψ, as follows:

In SI Units:

Condition 1—Wind plus specified external (vacuum) pressure

ψ = 1.0 for wind plus vacuum pressure [when vacuum pressure (*Pe*) is less than or equal to 0.25 kPa]. For this case, Appendix V is not mandatory.

ψ = [Pe + 0.70]/0.95 for wind plus vacuum pressure [when vacuum pressure (*Pe*) is greater than 0.25 kPa but less than or equal to 0.70 kPa].

11 ψ = [Pe/0.48] for wind plus vacuum pressure [when vacuum pressure (*Pe*) is greater than 0.70 kPa; however, ψ need not exceed 2.5.

Condition 2—Specified external (vacuum) pressure only

ψ = 3.0

In US Customary Units:

Condition 1—Wind plus specified external (vacuum) pressure

ψ = 1.0 for wind plus vacuum pressure [when vacuum pressure (*Pe*) is less than or equal to 5.2 psf]. For this case, Appendix V is not mandatory.

ψ = [Pe + 15]/20 for wind plus vacuum pressure [when vacuum pressure (*Pe*) is greater than 5.2 psf but less than or equal to 15 psf].

ψ = [Pe/10] for wind plus vacuum pressure [when vacuum pressure (*Pe*) is greater than 15 psf; however, ψ need not exceed 2.5.

Condition 2—Specified external (vacuum) pressure only

ψ = 3.0

V.8.1.1 For an unstiffened tank shell subjected to external pressure sufficient to cause buckling, buckling will occur elastically if the following criterion* is satisfied. Note that this criterion will typically be satisfied except for very small, exceptionally thick tanks. If this criterion is not satisfied, external pressure effects should be evaluated in accordance with the requirements of the ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1.

In SI units:

$$\left(\frac{D}{t_{smin}}\right)^{0.75}\left[\left(\frac{H_{TS}}{D}\right)\left(\frac{F_y}{E}\right)^{0.5}\right] \geq 0.00675$$

In US Customary units:

$$\left(\frac{D}{t_{smin}}\right)^{0.75}\left[\left(\frac{H_{TS}}{D}\right)\left(\frac{F_y}{E}\right)^{0.5}\right] \geq 0.19$$

The equations in the following sections are applicable, providing the shell satisfies the criterion of this section.

08 **V.8.1.2** The design external pressure (using the appropriate ψ from V.8.1.1) and the specified external (vacuum) pressure (using ψ = 3.0) shall not exceed for an unstiffened tank.

* Source is The Structural Research Council (SSRC) text "Guide to Stability Design Criteria for Metal Structures," Section 14.3.5.

In SI units:

$$P_s \text{ or } P_e \le \frac{E}{15203\psi\left(\frac{H_{TS}}{D}\right)\left(\frac{D}{t_{smin}}\right)^{2.5}}$$

In US Customary units: 08

$$P_s \text{ or } P_e \le \frac{0.6E}{\psi\left(\frac{H_{TS}}{D}\right)\left(\frac{D}{t_{smin}}\right)^{2.5}}$$

V.8.1.3 The equation in V.8.1.2 can be rewritten to calculate the nominal thickness of the thinnest shell course required for a specified design external pressure as 11

In SI units:

$$t_{smin} \ge \frac{47.07(\psi H_{TS} P_s)^{0.4}\ D^{0.6}}{(E)^{0.4}}$$

In US Customary units: 08

$$t_{smin} \ge \frac{1.23(\psi H_{TS} P_s)^{0.4}\ D^{0.6}}{(E)^{0.4}}$$

V.8.1.4 For tanks with shell courses of varying thickness, the transformed shell height, H_{TS}, for the tank shell is determined in accordance with the following procedure:

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

b. The transformed width of each individual shell course is calculated by multiplying the actual shell height by the ratio $(t_{s1}/t_{act})^{2.5}$. Note that $t_{s1} = t_{act}$ for the top shell course.

The transformed shell height is determined from the following equation:

$$H_{TS} = h_1\left(\frac{t_{s1}}{t_{s1}}\right)^{2.5} + h_2\left(\frac{t_{s1}}{t_{s2}}\right)^{2.5} + \ldots h_n\left(\frac{t_{s1}}{t_{sn}}\right)^{2.5}$$

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

V.8.2 CIRCUMFERENTIALLY STIFFENED SHELLS

Tank shells may be strengthened with circumferential stiffeners to increase the resistance to buckling under external pressure loading. When circumferential stiffeners are used to strengthen the cylindrical shell to resist buckling due to external pressure, the design of the stiffeners shall meet the following requirements.

V.8.2.1 Number and Spacing of Intermediate Stiffener Rings

V.8.2.1.1 Calculate the transformed shell height in accordance with V.8.1.4. (See V.10 for a numerical example of the calculation of the transformed shell height.)

V.8.2.1.2 Calculate the maximum spacing of intermediate stiffeners. The equation in V.8.1.3 can be rearranged to solve for a "safe height" of shell, H_{safe}, as follows. H_{safe} is the maximum height of unstiffened shell permitted, based on the transformed shell thickness (t_{s1}).

In SI units:

$$H_{safe} = \frac{(t_{smin})^{2.5}(E)}{15203D^{1.5}(P_s)\psi}$$

In US Customary units: 08

$$H_{safe} = \frac{0.6(t_{smin})^{2.5}(E)}{D^{1.5}(P_s)\psi}$$

V.8.2.1.3 Calculate the number of intermediate stiffeners required, N_s, based on H_{safe}, in accordance with the following equation. A zero or negative value of N_s means that no intermediate stiffeners are required. Round up the calculated value of N_s to the nearest integer for use in V.8.2.1.4 and subsequent calculations.

$$N_s + 1 = \frac{H_{TS}}{H_{Safe}}$$

V.8.2.1.4 Maximum stiffener spacing for each shell thickness shall be:

08

$$L_X = \left[\frac{H_{TS}}{(N_s + 1)}\right]\left[\frac{t_{sx}}{t_{smin}}\right]^{2.5}$$

where

L_X = the stiffener spacking for a given shell thickness,

t_{sx} = the thickness of the shell in question.

V.8.2.2 Intermediate Stiffener Ring Design

V.8.2.2.1 The number of waves, N, into which a shell will theoretically buckle under uniform external pressure is determined in accordance with the following equation:

In SI units:

$$N^2 = \sqrt{\frac{445D^3}{t_{smin} H_{TS}^2}} \leq 100$$

In US Customary units:

$$N^2 = \sqrt{\frac{5.33D^3}{t_{smin} H_{TS}^2}} \leq 100$$

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

V.8.2.2.2 The distance between adjacent intermediate stiffeners on the actual shell for shells of non-uniform thickness is determined in accordance with the following procedures.

11 a. Maximum spacing, L_s, on nominal thickness of the thinnest shell course, $t_{smin} = H_{TS} / (N_s + 1)$

b. Maximum spacing, L_s on other shell thicknesses = $[H_{TS} / (N_s + 1)](t_{sx} / t_{smin})^{2.5}$, where t_{sx} is the individual shell thickness.

c. Where the spacing between stiffeners includes different shell thicknesses, adjust the actual spacing using the transformed shell spacings adjusted accordingly. See V.10 for a numerical example of this procedure.

V.8.2.2.3 The radial load imposed on the stiffener by the shell is determined in accordance with the following equation:

In SI units:

$$Q = 1000 P_s L_s$$

In US Customary units:

$$Q = \frac{P_s L_s}{12}$$

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

V.8.2.2.4 The actual moment of inertia of the intermediate stiffener region, I_{act} shall be greater than or equal to the total required moment of inertia of this region, I_{reqd}, where:

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

In SI units:

$$w_{shell} = 13.4\sqrt{Dt_{shell}} \text{ on each side of stiffener}$$

In US Customary units:

$$w_{shell} = 1.47\sqrt{Dt_{shell}} \text{ on each side of stiffener}$$

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

V.8.2.2.5 The required moment of inertia of the intermediate stiffener region, I_{reqd} is determined in accordance with the following equation:

In SI uni3ts

$$I_{reqd} = \frac{37.5QD^3}{E(N^2 - 1)}$$

In US Customary units:

$$I_{reqd} = \frac{648QD^3}{E(N^2 - 1)}$$

V.8.2.2.6 In addition to the moment of inertia requirements stated above, the intermediate stiffener region shall satisfy the following area requirements.

V.8.2.2.6.1 The total required cross-sectional area of the intermediate stiffener region, A_{reqd}, is determined in accordance with the following equation:

In SI units:

$$A_{reqd} = \frac{QD}{2f_c}$$

In US Customary units:

$$A_{reqd} = \frac{6QD}{f_c}$$

V.8.2.2.6.2 The required cross-sectional area of the intermediate stiffener structural shape alone, A_{stiff}, is determined in accordance with the following equation:

In SI units:

$$A_{stiff} = A_{reqd} - 26.84\,t_{shell}\sqrt{Dt_{shell}}$$

In US Customary units:

$$A_{stiff} = A_{reqd} - 2.94\,t_{shell}\sqrt{Dt_{shell}}$$

A_{stiff} (actual) must be greater than or equal to A_{stiff} required.
A_{stiff} (actual) must also be greater than or equal to 0.5 A_{reqd}.

V.8.2.3 End Stiffeners

The actual moment of inertia of the end stiffener region, I_{act} must be greater than or equal to the total required moment of inertia of this region, I_{reqd}, where:

I_{act} = the actual moment of inertia of the end stiffener ring region, consisting of the combined moment of inertia of the end stiffener and the shell within a contributing distance on one side of the end stiffener. No credit shall be taken for the roof portion in this region, however credit may be taken for a portion of the bottom plate. The width of bottom plate considered effective as an end stiffener shall be not more than $16t_b$, where t_b is the thickness of the bottom or annular plates, unless a detailed stress analysis demonstrates that a greater width may be used. The contributing distance on one side of the stiffener is determined in accordance with the following equation: 07

In SI units:

For the top end stiffener:

$$w_{shell} = 13.4\sqrt{Dt_{sl}}$$

For the bottom end stiffener:

$$w_{shell} = 13.4\sqrt{Dt_{sn}}$$

In US Customary units:

For the top end stiffener:

$$w_{shell} = 1.47\sqrt{Dt_{sl}}$$

For the bottom end stiffener:

$$w_{shell} = 1.47\sqrt{Dt_{sn}}$$

V.8.2.3.1 The radial load imposed on the end stiffener by the shell is determined in accordance with the following equation:

In SI units:

$$V_1 = 250 P_s H$$

In US Customary units:

$$V_1 = \frac{P_s H}{48}$$

V.8.2.3.2 The required moment of inertia of the end stiffener region, I_{reqd} is determined in accordance with the following equation:

In SI units

$$I_{reqd} = \frac{37.5\, V_1 D^3}{E(N^2 - 1)}$$

In US Customary units:

09 $$I_{reqd} = \frac{648\, V_1 D^3}{E(N^2 - 1)}$$

V.8.2.3.3 In addition to the moment of inertia requirements stated above, the end stiffener region shall satisfy the following area requirements.

V.8.2.3.3.1 The total required cross-sectional area of the end stiffener region, A_{reqd}, is determined in accordance with the following equation:

In SI units:

$$A_{reqd} = \frac{V_1 D}{2f}$$

In US Customary units:

$$A_{reqd} = \frac{6\, V_1 D}{f}$$

V.8.2.3.3.2 The required cross-sectional area of the end stiffener structural shape alone, A_{stiff}, is determined in accordance with the following equation:

For cone roof top end stiffener:

$$A_{stiff} = A_{reqd} - t_{cone}X_{cone} - t_{s1}X_{shell}$$

For dome or umbrella roof top end stiffener:

$$A_{stiff} = A_{reqd} - t_{s1}X_{shell} - t_{dome}X_{dome}$$ 11

For bottom end stiffener:

$$A_{stiff} = A_{reqd} - t_bX_{btm} - t_{sn}X_{shell}$$

A_{stiff} (actual) must be greater than or equal to A_{stiff} (required).

V.8.2.4 Strength of Stiffener Attachment Weld

Stiffening ring attachment welds shall be sized to resist the full radial pressure load from the shell between stiffeners, and shear loads acting radially across the stiffener caused by external design loads carried by the stiffener (if any) and a computed radial shear equal to 2% of the stiffening ring's compressive load.

V.8.2.4.1 The radial pressure load from the shell shall be determined in accordance with the following formula:

$$V_{s1} = P_sL_s$$

V.8.2.4.2 The radial shear load shall be determined in accordance with the following formula:

$$v_s = 0.01P_sL_sD$$

V.8.2.4.3 The weld shear flow due to the radial shear load shall be determined in accordance with the following formula:

$V_{s2} = v_sq_s/I_s$, where q_s is the first moment of area of the stiffener.

V.8.2.4.4 The combined load for the design of the weld shall be determined in accordance with the following formula:

$$W_w = (V_{s1}^2 + V_{s2}^2)^{1/2}$$

V.8.2.4.5 The minimum fillet weld leg size shall be the smallest of the shell thickness at the location of the stiffener, the stiffener thickness at the weld location, or 6 mm ($^1/_4$ in.).

V.8.2.5 Lateral Bracing of Stiffener

The projecting part of a stiffening ring without an outer vertical flange need not be braced if the width of the projecting part in a radial vertical plane does not exceed 16 times its thickness. When this condition is not satisfied, the stiffening ring shall be laterally braced in accordance with the requirements of API Std 620, 5.12.5.8.

V.9 Bottom

● **V.9.1** The bottom of the tank shall be evaluated for external pressure loading if either of the following conditions is applicable. These conditions do not need to be considered simultaneously unless specified by the Purchaser.

1. If the total design external pressure force on the bottom plate exceeds the sum of the weight of the bottom plates plus the weight of any product required by the Purchaser to remain in the tank when external pressure is acting, membrane stresses in the bottom must be evaluated.

2. If the area around the tank will be subject to flooding with liquid, provisions should be included in the design of the tank and its operating procedures to ensure that the tank contains sufficient liquid to counteract bottom uplift resulting from exter-

nal flooding conditions. If the tank cannot be filled with liquid of sufficient depth to counteract the uplift from the liquid pressure under the bottom of the tank, membrane stresses in the bottom must be evaluated.

V.9.2 In both of the above cases, the bottom may be evaluated as a membrane subjected to uniform loading and restrained by the compression ring characteristics of the bottom-to-shell junction. For column-supported roofs, the design of the columns shall consider the additional axial loading due to external pressure.

V.9.3 The following provisions apply when Condition 2 in V.9.1 exists.

V.9.3.1 Calculation of external (flooding) pressure:

The calculation of the hydrostatic external pressure due to flooding is performed using the equation:

$$P = G_{out}H,$$

Rule 1:
When flooding of the area surrounding a tank is possible, the most effective way to prevent damage to the shell or bottom is to maintain an equivalent or higher level of liquid inside the tank whenever flooding occurs. The required minimum level of liquid to be maintained inside the tank is calculated as follows:

$$(G_{in} \times H_{in}) + W_{bott} / (\pi \times R^2) \geq G_{out} \times H_{out},$$

Rule 2:
When it is not possible to satisfy the equation in Rule 1, the tank and anchorage, if used, shall be designed to safely resist the unbalanced pressure resulting from flood liquid. As a minimum, the following components shall be evaluated:

● **V.9.3.2 allowable stress:** Unless otherwise specified, the flooding described above may be considered a temporary loading and the allowable stress increased accordingly. However, the increase in allowable stress shall not exceed 33% of the basic allowable stress for the subject component when evaluating the component for flood loading.

V.9.3.3 anchorage: For tanks that are mechanically anchored, the anchorage devices shall be adequate to resist the uplift and shear forces resulting from the pressure due to external flood liquid. If the tank is not mechanically anchored, provisions should be made to guide the tank back into its original position when the flooding conditions recede.

V.9.3.4 attached piping and sump: Piping and other components connecting the tank to the ground or another structure shall be capable of withstanding, without damage or failure, loads and movements due to any unbalanced pressures resulting from flooding of the area around the tank. If a sump is used, the design of the sump shall consider the possibility of the sump floating out of its pit during a flooding event.

V.9.3.5 bottom plate: Under the pressure of external flood liquid without counterbalancing internal liquid, the bottom plate will tend to deform or "balloon" upwards. As the bottom deforms and is subject to additional unbalanced pressure, membrane stresses increase in the bottom plate. The bottom plate shall be capable of withstanding this deformation without overstress of the plate or the attaching welds.

V.9.3.6 corner joint: As the bottom plate deforms upwards, compressive stresses and bending stresses in the shell-to-bottom joint increase. The shell plate and bottom plate components of the shell-to-bottom joint within the effective compression ring limits shall be proportioned to maintain combined stresses within the yield strength corresponding to the weaker of the two components.

V.10 Example Calculations

The following example calculations illustrate, in US Customary units, the use of this appendix.

V.10.1 DATA

Tank diameter = 75 ft-0 in.
Tank shell height = 48 ft-0 in.
Design liquid level = 48 ft-0 in.
Specific gravity of liquid = 1.0
Allowable design stress, S_d = 23,200 lb/in.^{2}

Allowable stress in tension ring, $f = 21{,}600$ lb/in.^{2}
Minimum yield strength of all steel = 36,000 lb/in.^{2}
Specified corrosion allowance = None
Tank bottom plate thickness = $^3/_8$ in.
Design external pressure = 0.6 lb/in.^{2}g (86.4 lb/ft^2)
Design wind velocity (3-sec gust) = 120 mph (Maximum wind pressure, $W = 31$ lb/ft^2)
Design snow load = 0 lb/ft^2
Roof design live load = 25 lb/ft^2
Modulus of Elasticity, $E = 30{,}000{,}000$ lb/in.^{2}
Shell course heights and thicknesses calculated by the one-foot method are as follows:

Course Number	$(H-1)$ (ft)	Required Thickness (in.)	Minimum Thickness (in.)
1	7	0.059	$^5/_{16}$*
2	15	0.126	$^5/_{16}$*
3	23	0.193	$^5/_{16}$*
4	31	0.261	$^5/_{16}$*
5	39	0.328	0.328
6	47	0.395	0.395

* The thicknesses of the upper four shell courses were increased from those required for hydrostatic pressure to eliminate need for an intermediate wind girder.

V.10.2 EXTERNAL PRESSURE CALCULATIONS

1. Select roof type: Try a self-supporting cone roof with a 20-degree slope from horizontal.

From **V.7**,

$$P_r = \text{The greater of } D_L + (L_r \text{ or } S) + 0.4P_e \text{ or } D_L + P_e + 0.4\,(L_r \text{ or } S),$$

where:

D_L = 20.4 lb/ft^2 (Estimated assuming $^1/_2$-in. roof plate),

L_r = 25 lb/ft^2,

S = 0 lb/ft^2,

P_e = 0.6 lb/in.^{2} = 86.4 lb/ft^2,

P_r = 20.4 + 25 + 0.4 (86.4) = 80.0 lb/ft^2, or,

P_r = 20.4 + 86.4 + 0.4 (25) = 116.8 lb/ft^2 (Governs).

The required nominal thickness of the cone roof plate is calculated from **V.7.2.1**, as follows: 11

$$t_{cone} = \frac{D}{\sin\phi}\sqrt{\frac{P_r}{0.248E}}$$ 08

$$t_{cone} = \frac{75}{0.342}\sqrt{\frac{116.8}{7{,}440{,}000}}$$

$t_{cone} = 0.869$ in., this thickness is not practical. Consider a supported cone roof or a self-supporting dome roof.

Try a lap-welded dome roof with a dish radius of 1.0 x D = 1.0 × 75 = 75 ft. Assuming the plate weight does not change significantly, the required thickness of the dome plate is calculated from **V.7.3.1** as follows:

$$t_{dome} = 4.47R\sqrt{\frac{P_r}{E}}$$

$$t_{dome} = 4.47(75)\sqrt{\frac{116.8}{30,000,000}}$$

t_{dome} = 0.661 in., this thickness is not practical for lap-welding.

Consider a butt-welded dome roof with a dish radius of 0.8 x D = 0.8 x 75 = 60 ft-0 in. Again assuming the plate weight does not change significantly, the required thickness of the dome plate is calculated from **V.7.3.1** as follows:

$$t_{dome} = 4.47R\sqrt{\frac{P_r}{E}}$$

$$t_{dome} = 4.47(60)\sqrt{\frac{116.8}{30,000,000}}$$

t_{dome} = 0.529 in., this thickness is practical for butt-welding. (Alternatively, a supported cone roof could be used.)

2. Calculate the roof tension ring area required at the junction of the roof and cylindrical shell:

From **V.7.3.2**, the required tension ring area is calculated as follows:

$$A_{reqd} = \frac{P_r RD}{3.375f}$$

$$A_{reqd} = \frac{116.8(60)(75)}{3.375(21,600)}$$

A_{reqd} = 7.21 sq. in.

From **V.7.3.3**, the length of effective roof plate contributing to the tension ring area is calculated as follows:

$$X_{dome} = 2.1\sqrt{RT_{dome}}$$

07

$$X_{dome} = 2.1\sqrt{60(0.529)}$$

X_{dome} = 11.7 in.

From **V.7.3.4**, the length of effective shell plate contributing to the tension ring area is calculated as follows:

$$X_{shell} = 1.47\sqrt{Dt_{s1}}$$

08

$$X_{shell} = 1.47\sqrt{75(0.3125)}$$

X_{shell} = 7.21 in. (Note: This value should be recalculated, if necessary, after selection of final shell thickness.)

From **V.7.3.5**, the required area of the stiffener is calculated as follows:

$A_{stiff} = A_{reqd} - t_{s1}X_{shell} - t_{dome}X_{dome}$

11 A_{stiff} = 7.21 – (0.3125)(7.21) – (0.529)(11.7)

A_{stiff} = –1.23 sq. in., Stiffener is not required

Note: This value should be recalculated, if necessary, after selection of final shell thickness.)

3. Check that buckling will occur elastically in the unstiffened cylindrical shell:

From **V.8.1.1**, elastic buckling will occur if the following equation is satisfied:

$$\left(\frac{D}{t_{smin}}\right)^{0.75}\left[\left(\frac{H_{TS}}{D}\right)\left(\frac{F_y}{E}\right)^{0.5}\right] \geq 0.00675$$

$$\left(\frac{75}{0.3125}\right)^{0.75}\left[\left(\frac{43.54}{75}\right)\left(\frac{36}{30{,}000}\right)^{0.5}\right] = 1.23 \geq 0.19 \text{, thus buckling will be elastic.}$$

Note: This value should be recalculated, if necessary, after selection of final shell thickness.)

4. Calculate the minimum shell thickness required for the combined loading from design external pressure and wind:

From **V.8.1.3**, the required minimum shell thickness is calculated as follows:

$$t_{smin} \geq \frac{1.23(\psi H_{TS} P_s)^{0.4}\ D^{0.6}}{(E)^{0.4}}$$ 09

where

P_s = the greater of 1) the specified design external pressure excluding wind or 2) $W + 0.4P_e$, where W is the specified design wind pressure, lb/ft^2,

P_s = 0.6 lb/in^2 = 86.4 lb/ft^2 or 31 + 0.4 (86.4) = 65.6 lb/ft^2.

$$t_{smin} \geq \frac{1.23(3 \times 43.54 \times 86.4)^{0.4}\,75^{0.6}}{(30{,}000{,}000)^{0.4}} = 1.35 \text{ in.}$$

$t_{smin} \geq$ 0.698 in. 09

ψ = 3.0 08

5. Calculate the transformed shell height:

Course Number	Actual Shell Course Height (ft)	Thickness (in.)	Transformed Shell Course Height * (ft)
1	8	0.3125	8.00
2	8	0.3125	8.00
3	8	0.3125	8.00
4	8	0.3125	8.00
5	8	0.328	7.09
6	8	0.395	4.45
Sum =	48 ft	Sum =	43.54 ft
* For example, the transformed height of No. 5 shell course = $(0.3125/.328)^{2.5}(8)$ = 7.09 ft (see V.8.1.4.b)			

The required minimum thickness is greater than the available thickness and the shell must be stiffened.

6. Calculate the maximum spacing of intermediate stiffeners:

From V.8.2.1.2,

$$H_{safe} = \frac{0.6(t_{smin})^{2.5}(E)}{\psi D^{1.5}(P_s)}$$ 09

$$H_{safe} = \frac{0.6(0.3125)^{2.5}(30{,}000{,}000)}{3(75)^{1.5}\ (86.4)}$$

H_{safe} = 5.84 ft

7. Calculate the number of intermediate stiffeners required, N_S, based on H_{safe}:

From V.8.2.1.3,

$$N_S + 1 = H_{TS} / H_{safe}$$

$$N_S + 1 = 43.54 / 5.84 = 7.46$$

$$N_S = 7$$

Actual spacing for 7 stiffeners = 43.54 / 8 = 5.44 ft

8. Calculate the intermediate stiffener spacing for the non-uniform shell thickness:

From V.8.2.2.2,

Intermediate stiffener spacing on 0.3125-in. shell plate is,

$$L_S = H_{TS} / (N_S + 1) = 43.54 / (7 + 1) = 5.44 \text{ ft}$$

Intermediate stiffener spacings on 0.328 in. and 0.395 in. shell plate are,

$$L_S = [H_{TS} / (N_S + 1)](t_{sx} / t_{smin})^{2.5}$$

$$L_S = [43.54 / (8)](0.328/0.3125)^{2.5} = 6.14 \text{ ft}$$

$$L_S = [43.54 / (8)](0.395/0.3125)^{2.5} = 9.77 \text{ ft}$$

Locate 5 stiffeners on 0.3125 in. shell at spacing = 5.44 ft

Locate the 6^{th} stiffener as follows:

Available $^5/_{16}$-in. shell plate = (4 × 8 ft) – (5 × 5.44 ft) = 4.8 ft

Length of 0.328-in. shell required = (5.44 – 4.8) × $(0.328 / 0.3125)^{2.5}$ = 0.722 ft

Location of 6^{th} stiffener = 32 + 0.722 = 32.722 ft from top of tank

Location of 7^{th} stiffener = 32.722 + 6.14 = 38.862 ft

Check that the remaining unstiffened shell length is equal to the transformed shell stiffener spacing:

Difference between actual and transformed shell height = 48 – 43.55 = 4.45 ft

Length of 0.328-in. shell below stiffener = 40 – 38.862 = 1.138 ft

Transformed shell stiffener spacing = 1.138 × $(0.3125/0.328)^{2.5}$ + 4.45 = 5.44 ft – *OK*

9. If fewer stiffeners and thicker shell plates is a more economical solution, the design can be adjusted as follows:

Assume, for this example, a uniform shell thickness equal to the thickness of the lowest shell course, i.e., t_{avg} = 0.395 in.

H_{safe} is then calculated as follows:

08

$$H_{safe} = \frac{0.6(0.395)^{2.5}(30{,}000{,}000)}{3(75)^{1.5}(733.36)(86.4)}$$

$$H_{safe} = 10.48 \text{ ft}$$

For t_{avg} = 0.395 in., H_{TS} is recalculated to be equal to 48 ft

The number of stiffeners required is:

$$N_S + 1 = 48 / 10.48 = 4.58;\ N_S = 4$$

Actual spacing for 4 stiffeners = 48 / 5 = 9.6 ft

10. Calculate the number of buckling waves: 07

From V.8.2.2.1,

$$N^2 = \sqrt{\frac{5.33D^3}{t_{s\min}L_s^2}} \leq 100;\ L_s = (L_1 + L_2)/2 = (9.6 + 9.6)/2 = 9.6\text{ft}$$ 08

$$N^2 = \sqrt{\frac{5.33(75)^3}{(0.395)(9.6)^2}} = 249 > 100;\ N = \ > 10, \text{ therefore use } 10$$

11. Calculate the radial load on a circumferential stiffener placed 9.6 ft from the top of the shell. 07

From V.8.2.2.3, the radial load is calculated as follows:

$$Q = \frac{P_s L_s}{12};\ \text{where } P_s = 86.4\ \text{lb/ft}^2$$

$$Q = \frac{(86.4)(9.6)}{12} = 69.1\ \text{lb/in.}$$

12. Calculate the total contributing shell width acting with the intermediate stiffener: 07

From V.8.2.2.4,

$$2 \times w_{\text{shell}} = 2 \times 1.47\sqrt{Dt_{\text{shell}}};\ \text{where } t_{\text{shell}} = 0.395\text{ in.}$$

$$2 \times 1.47\sqrt{(75)(0.395)};\ 16.0\text{ in.}$$

13. Calculate the required moment of inertia of the intermediate stiffener region: 07

From V.8.2.2.5, the required moment of inertia is calculated as follows:

$$I_{\text{reqd}} = \frac{648QD^3}{E(N^2 - 1)}$$

$$I_{\text{reqd}} = \frac{648(69.1)(75)^3}{30{,}000{,}000(100 - 1)}$$

$$I_{\text{reqd}} = 6.36\text{ in.}^4$$

14. Calculate the total area required in the intermediate stiffener region: 07

From V.8.2.2.6.1, the required area is calculated as follows:

$$A_{\text{reqd}} = \frac{6QD}{f}$$

$$A_{\text{reqd}} = \frac{6(69.1)(75)}{(14,400)}$$ 07

$$A_{\text{reqd}} = 2.16\text{ in.}^2$$

07 **15. Calculate the required area of the stiffener section:**

From V.8.2.2.6.2, the required area is calculated as follows:

$$A_{stiff} = A_{reqd} - 2.94\, t_{shell}\sqrt{Dt_{shell}}$$

$$A_{stiff} = 2.16 - 2.94(0.395)\sqrt{(75)(0.395)}$$

07 $A_{stiff} = -4.2$ in.^{2}; the stiffener section area must be ≥ 1.08 sq. in. ($= \frac{1}{2} \times A_{reqd}$)

Select a rolled section that will satisfy the area and inertia requirements. By inspection, since the stiffener spacing is constant, the section selected is adequate for all 4 stiffeners.

07 **16. Calculate the required properties of the top stiffener:**

From V.8.2.3, the contributing distance of the cylindrical shell is calculated as follows:

$$W_{shell} = 1.47\sqrt{Dt_{s1}}$$

$$W_{shell} = 1.47\sqrt{(75)(0.395)}$$

$$W_{shell} = 8.0 \text{ in.}$$

From V.8.2.3.1, the radial load on the top stiffener is calculated as follows:

$$V_1 = \frac{P_s H}{48}$$

$$V_1 = \frac{86.4(48)}{48}$$

$$V_1 = 86.4 \text{ lb/in.}$$

From V.8.2.3.2, the required moment of inertia of the top stiffener is calculated as follows:

$$I_{reqd} = \frac{684\, V_1 D^3}{E(N^2 - 1)}$$

$$I_{reqd} = \frac{684(86.4)(75)^3}{30{,}000{,}000(99)}$$

$$I_{reqd} = 8.39 \text{ in.}^4$$

From V.8.2.3.3.1, the required area of the top stiffener region is calculated as follows:

$$A_{reqd} = \frac{6\, V_1 D}{f}$$

$$A_{reqd} = \frac{6(86.4)(75)}{21{,}600}$$

$$A_{reqd} = 1.80 \text{ sq. in.}$$

From **V.8.2.3.3.2**, the required area of the top stiffener section is calculated as follows:

$$A_{stiff} = A_{reqd} - t_{s1}X_{shell} - t_{dome}X_{dome}$$

$$A_{stiff} = 1.80 - (0.395)(8.0) - (0.529)(11.7) = -7.55 \text{ in.}$$

The stiffener section area must be ≥ 0.90 sq. in. (= $^1/_2 \times A_{total}$) 11

Select a rolled section that will satisfy the area and inertia requirements.

17. Calculate the required properties of the bottom stiffener region:

From V.8.2.3, the contributing distance of the cylindrical shell is calculated as follows:

$$W_{shell} = 1.47\sqrt{Dt_{sn}}$$

$$W_{shell} = 1.47\sqrt{(75)(0.395)}$$

$$W_{shell} = 8.0 \text{ in.}$$

From V.8.2.3.2, the required moment of inertia of the bottom stiffener is calculated as follows:

$$I_{reqd} = \frac{684\,V_1D^3}{E(N^2-1)}$$

$$I_{reqd} = \frac{684(86.4)(75)^3}{30{,}000{,}000(99)}$$

$$I_{reqd} = 8.39 \text{ in.}^4$$

From V.8.2.3.3.1, the required area of the bottom stiffener region is calculated as follows:

$$A_{reqd} = \frac{6\,V_1D}{f}$$

$$A_{reqd} = \frac{6(86.4)(75)}{21{,}600}$$

$$A_{reqd} = 1.80 \text{ sq. in.}$$

From V.8.2.3.3.2, the required area of the bottom stiffener section is calculated as follows:

$$A_{stiff} = A_{reqd} - t_{sn}X_{shell} - t_bX_{btm}$$

$$A_{stiff} = 1.80 - (0.395)(8.0) - (0.375)(6.0) = -3.61 \text{ in.}$$ 11

The contributing portion of the shell-to-bottom joint has a calculated moment of inertia of 20.2 in.^{4} and will satisfy the area and inertia requirements. Thus, an additional stiffener is not necessary.

V.11 Technical Basis of This Appendix

The organization of this appendix was modeled after a proprietary DuPont Standard SG 11.4 S. API appreciates DuPont's consent to utilize their standard as a model without any restriction or reservation to develop this appendix. The equations prescribed in this appendix were generally extracted from the same proprietary standard and are based on the same fundamental equations from various public domain references used to develop the proprietary standard. However, where appropriate, the nomenclature was changed to be consistent with API Std 650. Some equations have been modified from the proprietary standard to be consistent with API Std 650 safety factors or other design considerations. For example, some equations have been modified to be consistent with Reference 2. Where necessary, equations have been added for consistency with API Std 650 design principles, such as incorporation of the transformed shell method.

V.12 References

1. DuPont Corporate Engineering Standard SG11.4S, *Field Erected Storage Tank Design Procedures,* Section 5, External Pressure Design.
2. API Publication, *Stability of API Standard 650 Tank Shells,* Raymund V. McGrath.
3. The Structural Research Council (SSRC), *Guide to Stability Design Criteria for Metal Structures,* Section 14.3.5.
4. Code Case 2286, "Alternative Rules for Determining Allowable Compressive Stresses for Cylinders, Cones, Spheres and Formed Heads," Cases of ASME *Boiler and Pressure Vessel Code.*
5. Welding Research Council Bulletin 406, "Proposed Rules for Determining Allowable Compressive Stresses for Cylinders, Cones, Spheres and Formed Heads," C. D. Miller and K. Mokhtarian.
6. American Society of Mechanical Engineers (ASME) *Boiler and Pressure Vessel Code,* Section VIII, Division 1.
7. American Iron & Steel Institute (AISI) Publication, *Steel Plate Engineering Data, Volume 2.*
8. ASME Paper 65-MET-15, "Theoretical and Experimental Study of Steel Panels in Which Membrane Tension is Developed," by J. S. McDermott.
9. Machine Design Magazine, December 9, 1976, "Stress Analysis of Pressurized Panels," by J. A. Martinelli.

APPENDIX W—COMMERCIAL AND DOCUMENTATION RECOMMENDATIONS

• The following commercial and documentation recommendations apply to all tanks when specified by the Purchaser on the Data Sheet.

• W.1 Document Submittals and Review

• W.1.1 GENERAL

1. Technical documents listed below shall be submitted by the Manufacturer for review by the Purchaser at specified times during a project. Additional documents may be required and shall be a matter of agreement between the Purchaser and the Manufacturer. Submittals and reviews shall be in accordance with contractual schedule agreements. All documents shall be in reproducible form agreeable to the Purchaser.

2. Unless specified otherwise by the Purchaser, the minimum required content of the technical documentation packages shall be as described in this appendix.

• W.1.2 QUOTATION OR BID DOCUMENT PACKAGE

1. All quotations shall be submitted in accordance with this Standard and Purchaser's requirements listed in the Data Sheet. In addition, a second quotation containing alternates to Purchaser's requirements may be quoted for Purchaser's consideration provided the alternates are clearly marked as such and are completely described in that bid.

2. The Manufacturer shall mark and return the Purchaser's previously prepared Data Sheet. Some entries will not be determined until completion of negotiations and/or completion of the detailed design. Such entries may remain blank for this submittal. The bid shall include the design wind speed and design snow load that will be used in the design by the Manufacturer. 07

3. The Manufacturer shall provide a list of all engineered accessories being purchased from suppliers, indicating the Manufacturer, and model or part number. Alternatively, when a specific Manufacturer is not known at the time of bidding, a list of Manufacturer-approved suppliers may be submitted. Excluded from the list requirement are commodities such as plate, pipe, flanges, and bolts. Included in the list are items such as floating roofs, dome roofs, roof seals, pressure vents, gauges, and instrumentation. Also, see C.1.1.

• W.1.3 DESIGN REVIEW DOCUMENT PACKAGES

Unless specified otherwise, a Purchaser's review of Manufacturer's design calculations and general arrangement drawings is required before the order of materials. Unless specified otherwise, the Purchaser's review of the documents listed in Items 3 through 7 below is required prior to the start of fabrication. Work may begin following conclusion of any negotiations generated by the review process. A copy of the review packages with any annotations including nozzle size, orientations, projections, placement and elevations of ladders, platforms, stairs, and attachments, etc., shall be returned to the Manufacturer. The Manufacturer shall promptly revise/update the drawings, calculations, and information on the **Data Sheet** showing all review-generated changes and shall submit copies to the Purchaser. The Design Review Document shall consist of at least the following:

1. Manufacturer's design calculations as described in W.2 and structural loads for foundation design.

2. General arrangement drawings with complete material specification.

3. Detailed fabrication drawings.

4. Welding procedure specifications (WPSs) and procedure qualification records (PQRs). This shall include weld hardness criteria when required by the Purchaser. Review of duplicate weld procedures for multiple tanks is not required when written permission is received from the Purchaser.

5. Heat treatment procedures (if required).

6. Nondestructive examination procedures and testing procedures.

7. Description of proposed test gaskets (see 4.9), including material properties, dimensions, and design characteristics.

W.1.4 INTERIM DOCUMENTS DURING CONSTRUCTION

The Manufacturer shall promptly submit revised documents describing any design or construction changes to the Purchaser. Copies of Material Test Reports applicable to components listed in 4.2.9.1 shall be forwarded to the Purchaser upon receipt of the reports.

• W.1.5 POST-CONSTRUCTION DOCUMENT PACKAGE

Upon completion of construction and testing, copies of a Manufacturer's data book shall be supplied in the quantities specified in the contract. Each copy shall contain at least the documents listed below:

1. Final general arrangement and detail fabrication drawings, marked "as-built" by the Manufacturer, complete with dimensions and data, with complete materials specification and parts list.
2. Design calculations described in W.2.
3. Copies of Material Test Reports applicable to shell plates and annular plates.
4. Reports of the results of all tests including weld hardness (when weld hardness criteria are specified), and reports of all nondestructive examinations. Radiographic films shall also be included. For tank pressure test data, include results and duration of pressure test(s), test water level, fill rate, imposed pneumatic pressure, hold times, drain rate, etc.
5. Shell and bottom elevation measurements for hydro-test.
6. Nameplate facsimile.
7. Manufacturer's certification per Figure 10-2.
8. The **Data Sheet** reflecting as-built conditions.

07 9. A drawing that lists the following for each shell course:
   a. The required shell thicknesses for both the design condition (including corrosion allowance) and the hydrostatic test condition.
   b. The nominal thickness used.
   c. The material specification.
   d. The allowable stresses.
10. Nominal thicknesses used for materials other than shell plates.
11. Handling criteria and rigging instructions (for shop-built tanks only).

W.2 Manufacturer's Calculations

All manual calculations shall include relevant formulas and source paragraphs in this Standard or in other specifications or engineering practices, values used in the formulas, calculated results, and acceptance criteria used. Where a computer program performs design calculations, a program description shall be given, including name and version of the program, program limitations and assumptions used, and a brief description of what the program does. These calculations and/or computer programs shall address at least the following:

1. Determination of design thicknesses for all pressure boundary elements to satisfy all specified loading conditions, which may include contents, pressure, partial vacuum, dead loads, live loads, snow loads, rain loads, roof flotation, dike or flood plain partial submergence, wind, and seismic activity.
2. Overturning check and anchorage due to wind forces, seismic forces, and internal pressure, if applicable.
3. Seismic design requirements (e.g., base shear, longitudinal compression, sliding friction resistance checks, overturning moment checks, and anchorage), if applicable.
4. Shell stability checks to determine whether shell stiffeners or increased shell course thicknesses will be required.
5. • Unless specified otherwise by the Purchaser, whenever the tank diameter exceeds 36 m (120 ft), shell stiffness coefficients, maximum unrestrained radial deflection, angle of rotation of bottom course shell nozzles, and the nomographs for moments and forces that these nozzles can safely sustain from connected piping shall be provided in accordance with pro-

visions of Appendix P. Alternate analysis techniques, such as the finite element method, may also be used to satisfy this requirement.

6. Any additional calculations specified by the Purchaser to show compliance with this Standard and any appendices invoked.

W.3 Manufacturer's Drawing Contents

All Manufacturer's drawings shall be thoroughly checked for accuracy and completeness before sending for Purchaser review. Manufacturer's drawing(s) shall show, as a minimum, the following information:

1. An updated list of drawings for each tank shall be resubmitted each time drawings are revised and reissued.
2. Identification of the storage tank as designated by the Purchaser.
3. Reference to applicable practices, standards, specifications, details, and associated drawings and sketches.
4. Materials of construction, designated corrosion allowance(s), and gasket specifications.
5. Extent of postweld heat treatments.
6. Extent of radiography to be applied to bottom, shell, and roof butt-welds.
7. Shell design joint efficiencies, for Appendices A, J, and S.
8. Complete details and dimensions of the tank, including external and internal attachments and appurtenances supplied by Manufacturer and sub-contractors.
9. Bottom slope.
10. Nominal plate thicknesses for shell, roof, reinforcement, and bottom.
11. Location of all welded seams. All welds shall be either pictorially detailed or identified by use of the standard welding symbols of ANSI/AWS A2.4. Welding procedures shall be listed for each weld. A "weld map" may be used if it clearly indicates the weld procedure specification used for every joint. 07
12. For flanges other than those conforming to ASME B16.5 or ASME B16.47, and marked accordingly, show all dimensions and finish of flange face.
13. Facsimile of nameplate with data to be stamped thereon with location and details of fabrication of nameplate bracket.
14. Empty, operating, and test weight of tank.
15. Loads on foundation as also shown on the **Data Sheet**, Line 13.
16. Foundation plans and construction details (if supplied by the Manufacturer or the sub-contractor).

W.4 Bids for Floating Roofs

W.4.1 Bids for tanks having floating roofs shall contain sufficient engineering data, including material specifications for both metallic and non-metallic components, nominal thicknesses, and sufficient information (see C.3.4.1 and C.3.4.2 or H.2.1, as applicable) to enable the Purchaser to verify that the bidder has considered all specified design requirements.

W.4.2 Manufacturer shall list in the quotation all roof accessories furnished and included in the base price of the roof. If any accessories are purchased from other suppliers, the Manufacturer shall provide that supplier's name and the model or part number.

W.4.3 Manufacturer shall state the lowest and highest operating level of roof in the quotation.

W.4.4 Manufacturer shall clearly describe the extent of electrical grounding and shunts included as a part of the floating roof design.

W.4.5 Manufacturer shall provide a cross-section of all seals showing materials and complete details of construction with the bid.

W.4.6 The Manufacturer shall submit with the bid the minimum and the maximum allowable annular space between the roof and shell, as well as the maximum and minimum annular space the proposed roof seal system can accommodate.

W.4.7 Manufacturer shall specify size, number, and type of drains with the quotation (external roof only).

W.4.8 The bid shall state if a wind skirt, a top-shell extension, or overflows will be required for proper functioning of the roof seal (external roof only).

W.4.9 The Manufacturer of the external floating roof shall prepare and submit to the Purchaser the following calculations:

• **W.4.9.1** Calculations showing that the roof design complies with the buoyancy requirements of C.3.4.1a, for both single-deck and double-deck roofs using the smaller of the specific gravity in C.3.4.1 (0.7), or the minimum specific gravity of the product specified on the Data Sheet, Line 5.

W.4.9.2 Calculations showing that the roof design complies with the punctured compartment loading condition for single-deck pontoon roofs and for double deck roofs as specified in C.3.4.1b.

W.4.9.3 Calculations showing that the design of the roof and roof supports satisfies C.3.10.2.

W.4.10 The Manufacturer of the internal floating roof shall prepare and submit to the Purchaser the following calculations, considering internal floating roof deflections and stresses for each of the load conditions required by Appendix H. All calculations
07 for the floating condition shall be based upon the design specific gravity (per H.4.2.1.1).

W.4.10.1 Calculations showing that the roof design complies with the buoyancy requirements of H.4.2.1.

W.4.10.2 Calculations showing that the roof design complies with the punctured compartment loading condition for single-deck pontoon roofs and for double deck roofs as specified in H.4.2.3.

W.4.10.3 Calculations showing that the design of the roof and roof supports in the landed condition satisfies H.4.2.2.2.

W.4.11 The internal floating roof Manufacturer shall specify the internal floating roof weight and total flotation displacement provided based on a flotation level for design specific gravity per H.4.2.1.

• W.5 Jobsite Responsibilities

Unless otherwise specified by the Purchaser, the Manufacturer shall furnish all labor, tools, equipment, supplies, materials, utilities (including power for welding), storage, and personnel services necessary for, and reasonably incidental to, the delivery of materials to the site, the construction of the tank(s), and the removal of surplus and scrap materials from the job site. See the Data Sheet (see Line 14) for the Manufacturer's additional post-hydro-test responsibilities. The Purchaser shall furnish and dispose of the water for hydro-testing the tank from the tie-in points as designated on the Data Sheet, Line 14.

APPENDIX X—DUPLEX STAINLESS STEEL STORAGE TANKS

X.1 Scope

X.1.1 This appendix covers materials, design, fabrication, erection, and testing requirements for vertical, cylindrical, aboveground, closed- and open-top, welded, duplex stainless steel storage tanks constructed of material grades 2205 (UNS S31803), 2003 (UNS S32003), 2101 (UNS S32101), 2205 (UNS S32205), 2304 (UNS S32304), 255 (UNS S32550), 255+ (UNS S32520), 2507 (UNS S32750), and Z100 (UNS S32760). This appendix does not cover stainless steel clad plate or strip lined construction. 08

X.1.2 This appendix applies only to tanks in non-refrigerated services with a maximum design temperature not exceeding 260°C (500°F) and a minimum design metal temperature of –40°C(–40°F). Ambient temperature tanks (non-heated) shall have a design temperature of 40°C (100°F). It is cautioned that exothermic reactions occurring inside unheated storage tanks can produce temperatures exceeding 40°C (100°F).

X.1.3 DELETED

X.1.4 The minimum thicknesses specified in this appendix are corroded thicknesses unless otherwise stated. 11

X.1.5 This appendix states only the requirements that differ from the basic rules in this standard. For requirements not stated, the basic rules must be followed.

X.2 Materials

X.2.1 SELECTION AND ORDERING

X.2.1.1 Materials shall be in accordance with Table X-1.

● **X.2.1.2** Selection of the type/grade of duplex stainless steel depends on the service and environment to which it will be exposed. The Purchaser shall specify the type/grade.

X.2.1.3 External structural attachments may be carbon steels meeting the requirements of Section 4 of this standard, providing any permanent attachments are protected from corrosion. (This does not include shell, roof, or bottom openings and their reinforcement.) Carbon steel attachments (e.g. clips for scaffolding) shall not be welded directly to any internal surface of the tank..

Table X-1—ASTM Materials for Duplex Stainless Steel Components

	UNS S31803 2205	UNS S32003 2003	UNS S32101 2101	UNS S32205 2205	UNS S32304 2304	UNS S32550 255	UNS S32520 255+	UNS S32750 2507	UNS S32760 Z100
Plates and Structural Members									
A240	X	X	X	X	X	X	X	X	X
A276	X		X	X	X	X			X
Tube or Pipe Seamless and Welded									
A789	X			X	X	X		X	X
A790	X			X	X	X		X	X
A928	X			X	X	X	X	X	X
Forgings and Fittings									
A182	X			X				X	X
A815	X			X					X
Bolting and Bars									
A479	X		X	X		X		X	X

08

Notes:
1. Unless otherwise specified by the Purchaser, plate, sheet, or strip shall be furnished with a No. 1 finish and shall be hot-rolled, annealed, and descaled.
2. Carbon steel flanges and/or stub ends may be used by agreement between the Purchaser and Manufacturer providing, the design and details consider the dissimilar properties of the materials used and are suitable for the intended service.
3. Castings shall not be used unless specified by the Purchaser. If specified, castings shall meet ASTM A890 and shall be inspected in accordance with ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1, Appendix 7.
4. All bars in contact with the product shall be furnished in the hot-rolled, annealed, and descaled condition.
5. Other bolting materials may be used by agreement between the Purchaser and Manufacturer.

X.2.2 PACKAGING

11 Packaging duplex stainless steel for shipment is important to maintain its corrosion resistance. Precautions to protect the surface of the material depend on the surface finish supplied and may vary among Manufacturers. Standard packaging methods may not be sufficient to protect the material from normal shipping damage. If the intended service requires special precautions, the Purchaser shall specify special instructions.

X.2.3 QUALIFICATION TESTING

● **X.2.3.1** Tests for detecting detrimental intermetallic phases for ASTM A923 are required from one plate per heat treat lot as follows:

UNS S32205/S31803	Methods B & C
UNS S32304	Method B*
UNS S32101	Method B*
UNS S32003	Method B*
UNS S32750	Method B* & C
UNS S32550/S32520	Method B* & C**
UNS S32760	Method B* & C**

08 *B test values to be agreed upon between Purchaser and Manufacturer but not less than 54J (40 ft-lbf).
**C test values to be agreed upon between Purchaser and Manufacturer.

X.2.3.2 Charpy Impact testing per ASME UHA-51 at minimum design metal temperature is required for:

a. components named in 4.2.9.1 in all thicknesses, when the minimum design temperature is between –29°C and –40°C (–20°F and –40°F), and
b. components named in 4.2.9.1 that have thickness greater than 10 mm ($^3/_8$ in.) for all temperatures.

ASTM A 923 Practice B test results may be used to fulfill these requirements provided the lateral expansion is measured and reported.

X.3 Design

● X.3.1 BOTTOM PLATES

11 All bottom plates shall have a nominal corroded thickness of not less than 5 mm ($^3/_{16}$ in.). Unless otherwise approved by the Purchaser, all rectangular and sketch plates (bottom plates on which the shell rests that have one end rectangular) shall have a nominal width of not less than1200 mm (48 in.).

X.3.2 ANNULAR BOTTOM PLATES

Butt-welded annular bottom plates meeting the requirements of 5.5.2 through 5.5.5 are required when either the bottom shell course maximum product stress is greater than 160 MPa (23,200 lbf/in.^{2}) or the bottom shell course maximum test stress is greater than 172 MPa (24,900 lbf/in.^{2}).

X.3.3 SHELL DESIGN

X.3.3.1 Shell Minimum Thickness

11 The required nominal shell thickness shall shall not be less than the greatest of the design shell thickness plus corrosion allowance, hydrostatic test shell thickness, or the nominal thickness listed in 5.6.1.1 (note 4 does not apply).

● X.3.3.2 Minimum Plate Widths

08 Unless otherwise approved by the Purchaser, the shell plates shall have a minimum width of 1200 mm (48 in.).

X.3.3.3 Shell Thickness Calculation

The requirements of 5.6 shall be followed except as modified in X.3.3.3.1 through X.3.3.3.3.

X.3.3.3.1 Allowable stresses for all shell thickness calculation methods are provided in Tables X-2a and X-2b.

X.3.3.3.2 Appendix A is not applicable.

● **X.3.3.3.3** The following formulas for design shell thickness and test shell thickness may alternatively be used for tanks 60 m (200 ft) in diameter and smaller.

In SI units:

$$t_d = (4.9D(H - 0.3)G)/((S_d)(E)) + CA$$

$$t_t = 4.9D(H - 0.3))/((S_t)(E))$$

where

t_d = design shell thickness (mm);

t_t = hydrostatic test shell thickness (mm);

D = nominal diameter of tank (m) (see 5.6.1.1);

H = design liquid level (m) (see 5.6.3.2);

● G = specific gravity of the liquid to be stored, as specified by the Purchaser;

E = joint efficiency, 1.0, 0.85, or 0.70 (see Table X-3);

● CA = corrosion allowance (mm), as specified by the Purchaser (see 5.3.2);

S_d = allowable stress for the design condition (MPa) (see Tables X-2a and X-2b); 08

S_t = allowable stress for hydrostatic test condition (MPa) (see Tables X-2a and X-2b).

In US Customary units:

$$t_d = (2.6D(H - 1)G)/((S_d)(E)) + CA$$

$$t_t = (2.6D(H - 1))/((S_t)(E))$$

where

t_d = design shell thickness (in.).

t_t = hydrostatic test shell thickness (in.).

D = nominal diameter of tank (ft) (see 5.6.1.1).

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

● G = specific gravity of the liquid to be stored, as specified by the Purchaser.

E = joint efficiency, 1.0, 0.85, or 0.70 (see Table X-3).

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

S_d = allowable stress for the design condition (lbf/in.^{2}) (see Tables X-2a and X-2b).

S_t = allowable stress for hydrostatic test condition (lbf/in.^{2}) (see Tables X-2a and X-2b).

Table X-2a—(SI) Allowable Stresses for Tank Shells

Alloy	Min Yld MPa	Min Ten MPa	Allowable Stress MPa for Design Temp Not Exceeding (S_d) 40°C	90°C	150°C	200°C	260°C	S_t ambient
S31803	450	620	248	248	239	230	225	266
S32003	450	655	262	231	218	215	212	281
S32101	450	650	260	234	223	215	212	278
S32205	450	655	262	234	225	208	198	281
S32304	400	600	240	229	213	205	200	257
S32550	550	760	303	302	285	279	272	325
S32520	550	770	308	270	265	256	251	331
S32750	550	795	318	319	298	279	268	343
S32760	550	750	298	314	259	256	256	319

08 Notes:
1. S_d may be interpolated between temperatures.
2. The design stress shall be the lesser of $^2/_5$ of the minimum tensile strength or $^2/_3$ of the minimum yield strength.
3. The hydrotest stress shall be the lesser of $^3/_7$ of the minimum tensile strength or $^3/_4$ of the minimum yield strength.
4. For dual certified materials, S31803/S32205 and S32550/S32520, use the allowable stress of the grade specified by the Purchaser.

Table X-2b—(USC) Allowable Stresses for Tank Shells

Alloy	Min Yld psi	Min Ten psi	Allowable Stress psi for Design Temp Not Exceeding (S_d) 100°F	200°F	300°F	400°F	500°F	S_t ambient
S31803	65,000	90,000	36,000	36,000	34,700	33,400	32,600	38,600
S32003	65,000	95,000	38,000	33,600	3,600	31,200	30,700	40,800
S32101	65,000	94,000	37,600	34,000	32,400	31,200	30,700	40,300
S32205	65,000	95,000	38,000	34,000	32,700	30,000	28,700	40,800
S32304	58,000	87,000	34,800	33,200	30,900	29,700	29,000	37,300
S32550	80,000	110,000	44,000	43,800	41,400	40,400	39,400	47,200
S32520	80,000	112,000	44,800	39,200	38,400	37,200	36,400	48,000
S32750	80,000	116,000	46,400	46,200	43,200	40,500	38,900	49,800
S32760	80,000	108,000	43,200	39,200	37,600	37,200	37,200	46,300

Notes:
1. S_d may be interpolated between temperatures.
2. The design stress shall be the lesser of $^2/_5$ of the minimum tensile strength or $^2/_3$ of the minimum yield strength.
3. The hydrotest stress shall be the lesser of $^3/_7$ of the minimum tensile strength or $^3/_4$ of the minimum yield strength.
4. For dual certified materials, S31803/S32205 and S32550/S32520, use the allowable stress of the grade specified by the Purchaser.

X.3.4 SHELL OPENINGS

X.3.4.1 The minimum nominal thickness of connections and openings shall be as follows:

Size of Nozzle	Minimum Nominal Neck Thickness
NPS 2 and less	Schedule 80S
NPS 3 and NPS 4	Schedule 40S
Over NPS 4	Schedule 40S but need not be greater than the shell thickness

08

Note: Reinforcement requirements of 5.7 must be maintained.

X.3.4.2 Thermal stress relief requirements of 5.7.4 are not applicable.

X.3.4.3 Shell manholes shall be in conformance with 5.7.5.

X.3.4.4 As an alternative to X.3.4.3, plate ring flanges may be designed in accordance with API 620 rules using the allowable stresses given in Tables X-2a and X-2b.

X.3.4.5 Allowable weld stresses for shell openings shall conform to 5.7.2.7 except S_d = the maximum allowable design stress (the lesser value of the base materials joined) permitted by Tables X-2a and X-2b.

X.3.5 ROOF MANHOLES

All duplex stainless steel components of the roof manhole shall have a nominal thickness of not less than 5 mm (3/16 in.). 11

X.3.6 APPENDIX F—MODIFICATIONS

In F.7.1, the shell thickness shall be as specified in X.3.3 except that the pressure P [in kPa (in. of water)] divided by 9.8G (12G) shall be added to the design liquid height in meters (ft).

X.3.7 APPENDIX M—MODIFICATIONS 11

X.3.7.1 Appendix M requirements shall be met for duplex stainless steel tanks with design temperatures over 40°C (100°F) as modified by X.3.7.2 through X.3.7.7.

X.3.7.2 Allowable shell stress shall be in accordance with Tables X-2a and X-2b.

X.3.7.3 In M.3.6, the duplex stainless steel structural allowable stress shall be multiplied by the ratio of the material yield strength at the design temperature to the material yield strength at 40°C (100°F). (See Tables X-4a and X-4bfor yield strength.)

X.3.7.4 In M.5.1, the requirements of 5.10.5.1 and 5.10.6.1 which are applicable to self supporting roof plate thickness shall be multiplied by the ratio of the material modulus of elasticity at 40°C (100°F) to the material modulus of elasticity at the design temperature. (See Tables X-5a and X-5b for modulus of elasticity.) 11

X.3.7.5 In M.6 (the equation for the maximum height of unstiffened shell in 5.9.7.1), the maximum height shall be multiplied by the ratio of the material modulus of elasticity at the design temperature to the material modulus of elasticity at 40°C (100°F).

X.4 Fabrication and Construction 08

X.4.1 GENERAL

Special precautions must be observed to minimize the risk of loss of the corrosion resistance and toughness of duplex stainless steel. Duplex stainless steel shall be handled so as to minimize contact with iron or other types of steel during all phases of fabrication, shipping, and construction. The thermal history of the material must also be controlled. The following sections describe 11
the major precautions that should be observed during fabrication, and handling.

Table X-3—Joint Efficiencies

Joint Efficiency	Radiographic Requirements
1	Radiograph per 8.1.2
0.85	Radiograph per X.4.14.1.1
0.7	No radiography required

Table X-4a—(SI) Yield Strength Values in MPa

Alloy	Yield Strength MPa for Design Temp Not Exceeding				
	40°C	90°C	150°C	200°C	260°C
S31803	450	396	370	353	342
S32003	450	386	352	331	317
S32101	450	379	351	324	317
S32205	450	358	338	319	296
S32304	400	343	319	307	299
S32550	550	484	443	421	407
S32520	550	448	421	400	379
S32750	550	486	446	418	402
S32760	550	455	428	414	400

Notes: 1. Interpolate between temperatures.
2. Reference: Table Y-1 of ASME Section II, Part D or Manufacturers' data sheets.

Table X-4b—(USC) Yield Strength Values in psi

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Alloy	Yield Strength psi for Design Temp Not Exceeding				
	100°F	200°F	300°F	400°F	500°F
S31803	65,000	57,500	53,700	51,200	49,600
S32003	65,000	56,000	51,000	48,000	46,000
S32101	65,000	55,000	51,000	47,000	46,000
S32205	65,000	52,000	49,000	45,000	43,000
S32304	58,000	49,800	46,300	44,500	43,400
S32550	80,000	70,200	64,300	61,000	59,000
S32520	80,000	65,000	61,000	58,000	55,000
S32750	80,000	70,500	64,700	60,700	58,300
S32760	80,000	66,000	62,000	60,000	58,000

Notes: 1. Interpolate between temperatures.
2. Reference: Table Y-1 of ASME Section II, Part D or Manufacturers' data sheets.

X.4.2 STORAGE

Storage should be under cover and well removed from shop dirt and fumes from pickling operations. If outside storage is necessary, provisions should be made for rainwater to drain and allow the material to dry. Duplex stainless steel should not be stored in contact with carbon steel. Materials containing chlorides, including foods, beverages, oils, cleaners and greases, should not come in contact with duplex stainless steel.

X.4.3 THERMAL CUTTING

X.4.3.1 Thermal cutting of duplex stainless steel shall be by the plasma-arc method or by laser cutting.

• **X.4.3.2** Thermal cutting of duplex stainless steel may leave a heat-affected zone with intermetallic precipitates. This heat-affected zone may have reduced corrosion resistance and toughness unless removed by machining or grinding. Normally the

Table X-5a—(SI) Modulus of Elasticity at the Maximum Operating Temperature

11

Alloy	40°C	90°C	150°C	200°C	260°C
	Modulus of Elasticity in Mpa for Design Temperatures Not Exceeding				
S31803	198,000	190,000	185,000	180,000	174,000
S32003	203,000	205,000	201,000	197,000	192,000
S32101	198,000	194,000	190,000	185,000	182,000
S32205	198,000	190,000	185,000	180,000	174,000
S32304	198,000	190,000	185,000	180,000	174,000
S32550	203,000	206,000	202,000	198,000	194,000
S32520	203,000	206,000	202,000	198,000	180,000
S32750	202,000	194,000	188,000	180,000	175,000
S32760	198,000	193,000	190,000	185,000	182,000

Note: 1. Interpolate between temperatures.

Table X-5b—(USC) Modulus of Elasticity at the Maximum Operating Temperature 08

Alloy	100°F	200°F	300°F	400°F	500°F
	Modulus of Elasticity in psi for Design Temperatures Not Exceeding				
S31803	28,700	27,600	26,800	26,100	25,300
S32003	30,300	29,800	29,200	28,600	27,900
S32101	28,700	28,100	27,500	26,900	26,400
S32205	28,700	27,600	26,800	26,100	25,300
S32304	28,700	27,600	26,800	26,100	25,300
S32550	30,300	29,900	29,300	28,700	28,100
S32520	30,300	29,900	29,300	28,700	26,100
S32750	29,300	28,100	27,200	26,200	25,400
S32760	28,800	28,000	27,600	26,900	26,400

Note: 1. Interpolate between temperatures.

HAZ from thermal cutting is thin enough to be removed by edge preparation machining and adjacent base metal melting during welding. The Purchaser shall specify if the heat-affected zone is to be removed.

X.4.4 FORMING

X.4.4.1 Duplex stainless steels shall be formed by a cold or hot forming procedure that is not injurious to the material.

X.4.4.2 Duplex stainless steels may be cold formed. The maximum strain produced by such cold forming shall not exceed 10% and control of forming spring-back is provided in the forming procedure.

X.4.4.3 Hot forming, if required, may be performed within a temperature range shown in Tables X-6a and X-6b.

X.4.4.4 Forming at temperatures between 600°F (315°C) and the minimum temperature shown in Tables X-6a and X-6b is not permitted.

Table X-6a—(SI) Hot Form Temperatures

Alloy	°C Max	°C Min	°C Min Soaking Temp
S31803	1230	950	1040
S32003	1100	950	1010
S32101	1100	900	980
S32205	1230	950	1040
S32304	1100	950	980
S32550	1230	1000	1080
S32520	1230	1000	1080
S32750	1230	1025	1050
S32760	1230	1000	1100

Table X-6b—(USC) Hot Form Temperatures

Alloy	°F Max	°F Min	°F Min Soaking Temp
S31803	2250	1740	1900
S32003	2010	1740	1850
S32101	2010	1650	1800
S32205	2250	1740	1900
S32304	2010	1740	1800
S32550	2250	1830	1975
S32520	2250	1830	1975
S32750	2250	1875	1920
S32760	2250	1830	2010

X.4.5 CLEANING

• **X.4.5.1** When the Purchaser requires cleaning to remove surface contaminants that may impair the normal corrosion resistance; it shall be done in accordance with ASTM A380, unless otherwise specified. The Purchaser shall specify any additional cleanliness requirements for the intended service.

X.4.5.2 When welding is completed; flux residues and weld spatter shall be removed mechanically using stainless steel tools.

X.4.5.3 Removal of excess weld metal, if required, shall be done with a grinding wheel or belt that has not been previously used on other metals.

X.4.5.4 Removal of weld heat tint, if required, shall be done using an appropriate pickling product and pickling procedure.

X.4.5.5 Chemical cleaners and pickling solutions used shall not have a detrimental effect on the duplex stainless steel or welded joints and shall be disposed of in accordance with laws and regulations governing the disposal of such chemicals. Thorough rinsing with water and drying shall always follow the use of any chemical cleaners or pickling solutions (see X.4.9).

X.4.6 BLAST CLEANING

If blast cleaning is necessary, it shall be done with sharp acicular grains of sand or grit containing not more than 1% by weight iron as free iron or iron oxide. Steel shot or sand previously used to clean non stainless steel materials is not permitted.

X.4.7 PICKLING

If pickling of a duplex stainless steel is necessary, an acid mixture of nitric and hydrofluoric acids shall be used. After pickling, the stainless steel shall be thoroughly rinsed with water and dried.

• X.4.8 PASSIVATION OR SURFACE IRON REMOVAL

When the Purchaser specifies passivation or surface iron removal, cleaning may be achieved by treatment with nitric or citric acid. Nitric hydrofluoric acid shall be used to remove embedded iron.

X.4.9 RINSING

X.4.9.1 When cleaning, pickling or passivation is required, these operations shall be followed immediately by rinsing, not allowing the surfaces to dry between operations. Pickling solutions may require a neutralization treatment before rinsing.

• **X.4.9.2** Rinse water shall be potable and shall not contain more than 200 parts per million chloride at temperatures below 40°C (100°F), or no more than 100 parts per million chloride at temperatures above 40°C (100°F) and below 65°C (150°F), unless specifically allowed by the Purchaser.

X.4.9.3 Following final rinsing, the equipment shall be completely dried.

X.4.10 HYDROSTATIC TESTING

X.4.10.1 The rules of 7.3.5 apply to hydrostatic testing except that the penetrating oil test in 7.3.5(2) shall be replaced with liquid penetrant examination conducted by applying the penetrant on one side and developer on the opposite side of the welds. The penetrant dwell time must be at least one hour.

• **X.4.10.2** The materials used in the construction of duplex stainless steel tanks may be subject to pitting, or general corrosion if they are exposed to contaminated test water for extended periods of time. The Purchaser shall specify a minimum quality of test water that conforms to the following requirements: 08

a. Unless otherwise specified by the Purchaser, water used for hydrostatic testing of tanks shall be potable and treated, containing at least 0.2 parts per million free chlorine.
b. Water shall be substantially clean and clear.
c. Water shall have no objectionable odor (that is, no hydrogen sulfide).
d. Water pH shall be between 6 and 8.3.
e. Water temperature shall be below 50°C (120°F).
f. The chloride content of the water shall be below 50 parts per million, unless otherwise allowed by the Purchaser.

• **X.4.10.3** When testing with potable water, the exposure time shall not exceed 21 days, unless otherwise specified by the Purchaser.

X.4.10.4 When testing with other fresh waters, the exposure time shall not exceed 7 days.

X.4.10.5 Upon completion of the hydrostatic test, water shall be completely drained. Wetted surfaces shall be washed with potable water when non-potable water is used for the test, and completely dried. Particular attention shall be given to low spots, crevices, and similar areas. Hot air drying is not permitted.

X.4.11 WELDING

X.4.11.1 Tanks and their structural attachments shall be welded by any of the processes permitted in 7.2.1.1. Galvanized components or components coated with zinc-rich coating shall not be welded directly to duplex stainless steel.

• **X.4.11.2** Filler metal chemistry shall be as specified by the Purchaser. Proper filler metal selection may be discussed with the materials manufacturer. Dissimilar welds to carbon steels shall use filler metals of E309L or higher alloy content.

X.4.12 WELDING PROCEDURE AND WELDER QUALIFICATIONS

• **X.4.12.1** Welding Procedure and Welder Qualification requirements shall be as specified in Section 9. In addition, procedures shall meet the requirements of ASTM A923 Method B and when specified by Purchaser also Method C. Welding Procedure Qualification Records shall document the results of tests required both by Section 9 and by ASTM A923.

X.4.12.2 For any material that has not been assigned a P-number in Table QW-422 of Section IX of the ASME Code, the Welding Procedure and the Welder Qualification shall be developed for that specific material.

X.4.13 POSTWELD HEAT TREATMENT

Post weld heat treatment of duplex stainless steel materials shall not be performed.

X.4.14 INSPECTION OF WELDS

X.4.14.1 Radiographic Inspection of Butt-Welds

X.4.14.1.1 Radiographic examination of butt-welds shall be in accordance with 6.1 and Table X-3.

X.4.14.1.2 When shell designs use joint efficiency = 0.85, spot radiographs of vertical joints shall conform to 8.1.2.2, Item a, excluding the 10 mm (3/8 in.) shell-thickness limitation in Item a and excluding the additional random spot radiograph required by Item a.

X.4.14.2 Inspection of Welds by Liquid Penetrant Method

08 The following component welds shall be examined by the liquid penetrant method before the hydrostatic test of the tank:

a. The shell-to-bottom inside attachment weld.

b. All welds of opening connections in tank shell that are not completely radiographed, including nozzle and manhole neck welds and neck-to-flange welds.

c. All welds of attachments to shells, such as stiffeners, compression rings, clips, and other nonpressure parts for which the thickness of both parts joined is greater than 19 mm (3/4 in.).

d. All butt-welded joints in tank annular plates on which backing strips are to remain.

X.5 Marking

Brazing shall be deleted from 10.1.2.

• X.6 Appendices

The following appendices are modified for use with duplex stainless steel storage tanks:

a. Appendix A is not applicable to tanks built to this appendix.

b. Appendix C may be used; however, the Purchaser shall identify all materials of construction. The nominal deck thickness using duplex stainless steel shall not be less than 2.5 mm (0.094 in.).

c. Appendix F is modified as outlined in X.3.5 of this appendix.

d. Appendix H may be used: however the Purchaser shall identify all materials of construction. The nominal deck thickness using
11 duplex stainless steel shall not be less than 2.5 mm (0.094 in.).

e. Appendix J may be used, except the nominal shell thickness for all tank diameters shall not be less than 5 mm (3/16 in.).

f. Appendix K is not applicable to tanks built to this appendix.

g. Appendix M is modified as outlined in X.3.6 of this appendix.

h. Appendix N is not applicable.

i. Appendix O may be used; however, the structural members of Tables O-1a and O-1b shall be of an acceptable grade of material.

j. All other appendices may be used without modifications.

APPENDIX Y—API MONOGRAM
(informative)

Y.1 Introduction

The API Monogram Program allows an API Licensee to apply the API Monogram to products.

The use of the Monogram on products constitutes a representation and warranty by the Licensee to purchasers of the products that, on the date indicated, the products were produced in accordance with a verified quality management system and in accordance with an API product specification. The API Monogram Program delivers significant value to the international oil and gas industry by linking the verification of an organization's quality management system with the demonstrated ability to meet specific product specification requirements.

When used in conjunction with the requirements of the API License Agreement, API Specification Q1, including Annex A, defines the requirements for those organizations who wish to voluntarily obtain an API license to provide API monogrammed products in accordance with an API product specification. 09

API Monogram Program licenses are issued only after an on-site audit has verified that the Licensee conforms to the requirements described in API Q1 in total.

For information on becoming an API Monogram Licensee, please contact API, Certification Programs, 1220 L Street, NW, Washington, DC 20005 or call 202-682-8000 or by email at certification@api.org.

Y.2 API Monogram Marking Requirements

The following marking requirements apply only to those API Licensees wishing to mark their products with the API Monogram.

The complete API Monogram marking consists of the following:

— the letters "API 650,"

— the manufacturer's API license number,

— the API Monogram,

— the date of manufacture (defined as the month and year when the Monogram is applied by the manufacturer).