Annex AL
(normative)

Aluminum Storage Tanks

AL.1 Scope

AL.1.1 Construction

This Annex provides material, design, fabrication, erection, and inspecting requirements for vertical, cylindrical, aboveground, closed- and open top, welded aluminum storage tanks constructed of the alloys specified in AL.4.

AL.1.2 Requirements

This Annex states only the requirements that differ from the rules in this standard. For requirements not stated, follow the rules of this standard.

AL.1.3 Temperature

This Annex applies for maximum design temperatures up to 200 °C (400 °F). Alloys 5083, 5086, 5154, 5183, 5254, 5356, 5456, 5556, and 5654 shall not be used if the maximum design temperature exceeds 65 °C (150 °F). Ambient temperature tanks shall have a maximum design temperature of 40 °C (100 °F).

For maximum design temperatures above 93 °C (200 °F) designers shall consider thermal stresses and fatigue.

AL.1.4 Units

Use consistent units in this Annex's equations. For example, in an equation, use inches for all lengths (stress in lb/in.^{2} and tank diameter in inches) or use mm for all lengths (stress in N/mm^2 and tank diameter in mm).

AL.1.5 Nomenclature

Variables used in this Annex have the following meanings:

A = area of the roof-to-shell joint determined using Figure F.2

A_1 = 0.3 m (1 ft)

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

D = nominal diameter of the tank (see 5.6.1.1)

E = compressive modulus of elasticity (see Table AL.8a and Table AL.8b)

E_j = joint efficiency, 1.0, 0.85, or 0.70 (see Table AL.2)

F_{tu} = minimum tensile ultimate strength

F_{ty} = minimum tensile yield strength

G = design specific gravity of the stored liquid

H = design liquid level (see 5.6.3.2)

p_h = greater of 5.2.2 load combinations (e)(1) and (e)(2)

S_d = allowable stress for the design condition (see Table AL.6a and Table AL.6b)

S_t = allowable stress for hydrostatic test condition (see Table AL.6a and Table AL.6b)

t_b = nominal thickness of the annular bottom plate

t_h = nominal roof thickness

t_s = nominal shell thickness

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

γ_w = density of water

θ = roof slope to horizontal at the shell

ρ_h = density of the roof plate

AL.2 References

The following references are cited in this Annex. The latest edition shall be used.

ASTM B209, *Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate*

ASTM B209M, *Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate [Metric]*

ASTM B210, *Standard Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes*

ASTM B210M, *Standard Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes [Metric]*

ASTM B211, *Standard Specification for Aluminum and Aluminum-Alloy Bar, Rod, and Wire*

ASTM B211M, *Standard Specification for Aluminum and Aluminum-Alloy Bar, Rod, and Wire [Metric]*

ASTM B221, *Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes*

ASTM B221M, *Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes [Metric]*

ASTM B241/B241M, *Standard Specification for Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube*

ASTM B247, *Standard Specification for Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings*

ASTM B247M, *Standard Specification for Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings [Metric]*

ASTM B308/B308M, *Standard Specification for Aluminum-Alloy 6061-T6 Standard Structural Profiles*

ASTM B345/B345M, *Standard Specification for Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube for Gas and Oil Transmission and Distribution Piping Systems*

ASTM B928, *Standard Specification for High Magnesium Aluminum-Alloy Sheet and Plate for Marine Service and Similar Environments*

AWS, A5.10/A5.10M, *Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods*

AL.3 Definitions

For the purposes of this Annex, the following definition applies:

AL.3.1
aluminum
Aluminum and aluminum alloys.

AL.4 Materials

AL.4.1 General

Alloys shall be selected from Table AL.1. Dimensional tolerances shall meet the material specifications given in AL.4. Impact testing and toughness verification are not required.

Table AL.1—Material Specifications

Sheet and Plate		Rod, Bar, and Shapes		Pipe and Tube		Forgings	
Alloy	**Temper**	**Alloy**	**Temper**	**Alloy**	**Temper**	**Alloy**	**Temper**
1060	all	1060	all	1060	all		
1100	all	1100	all	1100	all	1100	H112
3003	all	2024	T4	3003	all	3003	H112
Alclad 3003				Alclad 3003	all		
3004	all	3004	all				
Alclad 3004	all						
5050	all			5050	all		
5052	all	5052	all	5052	all		

Table AL.1—Material Specifications (Continued)

5083	all	5083	all	5083	all	5083	H111, H112
5086	all	5086	all	5086	all		
5154	all	5154	all	5154	all		
5254	all			5254	all		
5454	all	5454	all	5454	all		
5456	all	5456	all	5456	all		
5652	all			5652	all		
6061	(1)	6061	T6	6061	T4, T6	6061	T6
Alclad 6061	(1)	6063	T5, T6	6063	T5, T6		

NOTE 1 Includes T4, T42, T451, T6, T62, T651 tempers.

Table AL.2—Joint Efficiency

Joint Efficiency (E_j)	Shell Radiography Requirements
1.00	Full radiography required for all vertical joints. Horizontal joints per 0.85 joint efficiency requirements.
0.85	Radiography per 8.1.2 except additional random spot radiography in first course vertical seams is not required.
0.70	No shell radiography required.

Table AL.3a—Minimum Mechanical Properties (SI)

Minimum Tensile Yield Strengths F_{ty} (MPa) at Temperatures (°C)								
Alloy	**Temper**	**40**	**65**	**90**	**120**	**150**	**175**	**200**
1060	all	17	17	17	15	13	12	11
1100	all	24	24	24	23	22	19	17
3003	all	34	34	34	34	32	30	26
Alclad 3003	all	31	31	31	30	28	27	23
3004	all	59	59	59	59	59	55	51
Alclad 3004	all	55	55	55	55	55	50	46
5050	all	41	41	41	41	41	40	39
5052, 5652	all	66	66	66	66	66	66	58
5083 (1)	all	124	123	do not use above 65 °C				
5083 (2)	all	117	117	do not use above 65 °C				
5086	all	97	96	do not use above 65 °C				
5154, 5254	all	76	76	do not use above 65 °C				

Table AL.3a—Minimum Mechanical Properties (SI) (Continued)

5454	all	93	83	83	83	82	80	77
5456 (1)	all	131	130	do not use above 65 °C				
5456 (2)	all	124	123	do not use above 65 °C				
6061, Alclad 6061	T4, T6 welded	103	103	103	103	101	91	72
6061	T6 extrusions	240	240	232	201	163	103	54
6063	T5, T6 welded	55	55	55	55	52	31	23
6063	T6	172	172	159	137	111	61	36
Minimum Tensile Ultimate Strengths F_{tu} (MPa) at Temperatures (°C)								
Alloy	**Temper**	**40**	**65**	**90**	**120**	**150**	**175**	**200**
1060	all	55	55					
1100	all	76	76					
3003	all	95	95					
Alclad 3003	all	90	90					
3004	all	150	150					
Alclad 3004	all	145	145					
5050	all	125	125					
5052, 5652	all	175	175					
5083 (1)	all	275	275	do not use above 65 °C				
5083 (2)	all	270	270	do not use above 65 °C				
5086	all	240	240	do not use above 65 °C				
5154, 5254	all	205	205	do not use above 65 °C				
5454	all	215	215					
5456 (1)	all	290	290	do not use above 65 °C				
5456 (2)	all	285	285	do not use above 65 °C				
6061, Alclad 6061	T4, T6 welded	165	165					
6061	T6 extrusions	260	260	243	208	169	117	76
6063	T5, T6 welded	115	115					
6063	T6	205	205	188	160	130	83	53

NOTE 1 Up to 40 mm thick.

NOTE 2 > 40 mm and ≤ 75mm thick.

NOTE 3 Strengths are for the –O temper for all alloys except 6061, Alclad 6061, and 6063 which are as noted.

Table AL.3b—Minimum Mechanical Properties (USC)

Minimum Tensile Yield Strengths F_{ty} (ksi) at Temperatures (°F)								
Alloy	**Temper**	**100**	**150**	**200**	**250**	**300**	**350**	**400**
1060	all	2.5	2.5	2.4	2.2	1.9	1.8	1.6
1100	all	3.5	3.5	3.5	3.4	3.2	2.8	2.4
3003	all	5.0	5.0	5.0	4.9	4.6	4.3	3.7
Alclad 3003	all	4.5	4.5	4.5	4.4	4.1	3.9	3.3
3004	all	8.5	8.5	8.5	8.5	8.5	8.0	7.4
Alclad 3004	all	8.0	8.0	8.0	8.0	8.0	7.2	6.7
5050	all	6.0	6.0	6.0	6.0	6.0	5.8	5.6
5052, 5652	all	9.5	9.5	9.5	9.5	9.5	9.5	8.4
5083 (1)	all	18	17.9	do not use above 150 °F				
5083 (2)	all	17	16.9	do not use above 150 °F				
5086	all	14	13.9	do not use above 150 °F				

Table AL.3b—Minimum Mechanical Properties (USC) (Continued)

5154, 5254	all	11	11	do not use above 150 °F				
5454	all	12	12	12	12	11.9	11.6	11.1
5456 (1)	all	19	18.8	do not use above 150 °F				
5456 (2)	all	18	17.9	do not use above 150 °F				
6061, Alclad 6061	T4, T6 welded	15	15	15	15	14.7	13.2	10.5
6061	T6 extrusions	35	35	33.6	29.1	23.6	14.9	7.9
6063	T5, T6 welded	8	8	8	8	7.5	4.5	3.4
6063	T6	25	25	23	19.8	16.1	8.9	5.2
Minimum Tensile Ultimate Strengths F_{tu} (ksi) at Temperatures (°F)								
Alloy	**Temper**	**100**	**150**	**200**	**250**	**300**	**350**	**400**
1060	all	8.0	8.0					
1100	all	11	11					
3003	all	14	14					
Alclad 3003	all	13	13					
3004	all	22	22					
Alclad 3004	all	21	21					
5050	all	18	18					
5052, 5652	all	25	25					
5083 (1)	all	40	40	do not use above 150 °F				
5083 (2)	all	39	39	do not use above 150 °F				
5086	all	35	35	do not use above 150 °F				
5154, 5254	all	30	30	do not use above 150 °F				
5454	all	31	31					
5456 (1)	all	42	42	do not use above 150 °F				
5456 (2)	all	41	41	do not use above 150 °F				
6061, Alclad 6061	T4, T6 welded	24	24					
6061	T6 extrusions	38	38	35.3	30.2	24.5	16.9	11.0
6063	T5, T6 welded	17	17					
6063	T6	30	30	27.2	23.2	18.9	12.0	7.7

NOTE 1 Up to 1.500 in. thick.

NOTE 2 > 1.500 in. thick, ≤ 3.000 in. thick.

NOTE 3 Strengths are for the –O temper for all alloys except 6061, Alclad 6061, and 6063 which are as noted.

AL.4.2 Sheet and Plate

Sheet and plate shall meet ASTM B209 or B928. Tapered thickness plate may be used.

AL.4.3 Rod, Bar, and Structural Shapes

Rod, bar, and shapes shall meet ASTM B211, ASTM B221, or ASTM B308.

AL.4.4 Pipe and Tube

Pipe and tube shall meet ASTM B210, ASTM B241, or ASTM B345.

AL.4.5 Forgings

Forgings shall meet ASTM B247.

AL.4.6 Flanges

AL.4.6.1 Aluminum

Flanges shall meet ASTM B247 and be 6061-T6. Flange dimensions shall meet ASME B16.5 or B16.47.

AL.4.6.2 Composite Lap Joint Flanges

For composite lap joint flanges, the aluminum stub ends shall be one of the alloys listed in Table AL.1 for sheet and plate or pipe and tube, and the steel, stainless steel, or galvanized steel flanges shall meet ASME B16.5.

AL.4.7 Bolting

AL.4.7.1 Aluminum

Aluminum bolts shall meet ASTM F468. Aluminum nuts shall meet ASTM F467. Bolts and nuts of 2024 alloy shall have an anodic coating at least 0.005 mm [0.0002 in.] thick. Bolts shall not be welded. Aluminum threads tend to gall, so aluminum threaded parts shall not be used where they must be reinstalled.

AL.4.7.2 Stainless Steel

Stainless steel bolts shall meet ASTM F593 alloy group 1 or 2, or ASTM A193 B8. Stainless steel nuts shall meet ASTM F594 alloy group 1 or 2 or ASTM A194 Grade 8.

AL.4.7.3 Carbon Steel

Carbon steel bolts shall be galvanized.

AL.4.8 Welding Electrodes

Welding electrodes shall meet AWS A5.10/A5.10M and shall be chosen in accordance with AWS D1.2.

AL.5 Design

AL.5.1 Joints

Joints shall be as prescribed in 5.1.5 unless otherwise specified below.

AL.5.1.1 Bottom Joints

a) Bottom plates under the shell thicker than 8 mm ($^{5}/_{16}$ in.) shall be butt welded.

b) *Butt-Welded Bottom Joints*. The butt welds may be made from both sides or from one side and shall have full penetration and full fusion. In the latter case, a backing strip 5 mm ($^{3}/_{16}$ in.) or thicker, of an aluminum alloy compatible with the bottom plate, shall be tacked to one of the plates, and the intersection joints of the strips shall be welded with full penetration and full fusion.

AL.5.1.2 Roof and Top Angle Joints

The moment of inertia of the top angle and contributing portion of the shell (see AL.5.5) shall equal or exceed that provided by the sizes listed below:

In SI units:

Diameter (m)	Size (mm)
$D < 11$	$65 \times 65 \times 6$
$11 < D < 18$	$65 \times 65 \times 8$
$18 < D$	$75 \times 75 \times 10$

In USC units:

Diameter (ft)	Size (in.)
$D < 35$	$2\ ^1/_2 \times 2\ ^1/_2 \times\ ^1/_4$
$35 < D \leq 61$	$2\ ^1/_2 \times 2\ ^1/_2 \times\ ^5/_{16}$
$61 < D$	$3 \times 3 \times\ ^3/_8$

AL.5.2 Bottoms

AL.5.2.1 Annular Bottom Plate Width

Annular bottom plates shall have a radial width that meets the requirements of 5.5.2 except that the width must equal or exceed:

$$2t_b\sqrt{\frac{F_{ty}}{2\gamma_w GH}}$$

AL.5.2.2 Annular Bottom Plate Thickness

The nominal thickness of annular bottom plates shall equal or exceed the requirements given in Table AL.4a and Table AL.4b.

Table AL.4a—Annular Bottom Plate Thickness (SI)

Nominal Thickness of First Shell Course (mm)	Hydrostatic Test Stress in First Shell Course (MPa)						
	14	28	41	55	69	83	97
$t \leq 12.7$	6	6	6	6	6	6	7
$12.7 < t \leq 19$	6	6	6	6	7	9	10
$19 < t \leq 25$	6	6	6	7	10	12	15
$25 < t \leq 32$	6	6	7	10	13	16	19
$32 < t \leq 38$	6	6	10	12	16	19	27
$38 < t \leq 51$	6	10	11	16	21	25	31

Table AL.4b—Annular Bottom Plate Thickness (USC)

Nominal Thickness of First Shell Course (in.)	Hydrostatic Test Stress in First Shell Course (ksi)						
	2.0	4.0	6.0	8.0	10.0	12.0	14.0
$t \le 0.50$	1/4	1/4	1/4	1/4	1/4	1/4	9/32
$0.50 < t \le 0.75$	1/4	1/4	1/4	1/4	9/32	11/32	13/32
$0.75 < t \le 1.00$	1/4	1/4	1/4	9/32	3/8	15/32	19/32
$1.00 < t \le 1.25$	1/4	1/4	9/32	3/8	1/2	5/8	3/4
$1.25 < t \le 1.50$	1/4	1/4	3/8	15/32	5/8	3/4	1 1/16
$1.50 < t \le 2.00$	1/4	3/8	7/16	5/8	13/16	1	1 7/32

AL.5.3 Shells

The nominal thickness of the shell plates shall be no less than the greatest of the calculated design shell thickness t_d including any corrosion allowance, the hydrostatic test shell thickness t_t, and the thickness required by Table AL.5a and Table AL.5b:

$$t_d = \frac{\gamma_w G D (H - A_1)}{2 E_j S_d} + CA$$

$$t_t = \frac{\gamma_w D (H - A_1)}{2 E_j S_t}$$

Table AL.5a—Minimum Shell Thickness (SI)

Nominal Tank Diameter (m)	Nominal Plate Thickness (mm)
$D < 6$	5
$6 \le D < 36$	6
$36 \le D \le 60$	8
$D > 60$	10

Table AL.5b—Minimum Shell Thickness (USC)

Nominal Tank Diameter (ft)	Nominal Plate Thickness (in.)
$D < 20$	3/16
$20 \le D < 120$	1/4
$120 \le D \le 200$	5/16
$D > 200$	3/8

AL.5.4 Shell Openings

AL.5.4.1 Thermal Stress Relief

Thermal stress relief requirements of 5.7.4 do not apply.

AL.5.4.2 Shell Manholes

Shell manholes shall meet 5.7.5 except the following.

a) *Cover Plate and Flange Thickness*. The cover plate and flange thickness shall comply with Figure AL.1 and Figure AL.2. As an alternative to Figure AL.1 and Figure AL.2, plate flanges may be designed in accordance with API 620 rules using the allowable stresses from Table AL.6a and Table AL.6b.

b) *Neck Thickness*. Where manhole neck thickness is controlled by thickness of the bolting flange (see note b of Table 5.4a and Table 5.4b), the flange thickness determined in item 1 above shall be used.

c) *Weld Sizes*: Fillet weld A shall comply with Table AL.9a and Table AL.9b.

AL.5.4.3 Nozzles

Shell nozzles shall meet 5.7.6 except fillet weld A shall comply with Table AL.9a and Table AL.9b.

AL.5.4.4 Flush Type Cleanouts

Flush-type cleanout fittings shall comply with Figure AL.1, Figure AL.2, and Figure AL.3.

AL.5.5 Wind Girders

The length of the shell included in the area of wind girders shall be $0.424\sqrt{Dt_s}$ except for unstiffened shell above top wind girders, the length shall be $56t_s\sqrt{F_{ty}}$.

AL.5.5.1 Wind Girders

The section modulus of wind girders shall equal or exceed:

$$Z = \frac{pH_wD^3}{12Ec}$$

where

p equals (1.48 kPa) (V/[190 km/hr])^2;

p equals (31 lb/ft^2) (V/[120 mph])^2;

V is the 3-sec gust design wind speed (see 5.2.1[k]);

H_w is for top wind girders on tanks with no intermediate wind girder, the tank height; for tanks with intermediate wind girders, the vertical distance between the intermediate wind girder and the top angle of the shell or the top wind girder of an open-top tank;

c is the lesser of the distances from the neutral axis to the extreme fibers of the wind girder.

Table AL.6a—Allowable Tensile Stresses for Tank Shell (for Design and Test) (SI)

Allowable Stress (MPa) (5) S_d for Maximum Design Temperature Not Exceeding											
Alloy	**Temper**	**Minimum Yield Strength MPa (4)**	**Minimum Tensile Strength MPa (4)**	**40 °C**	**65 °C**	**90 °C**	**120 °C**	**150 °C**	**175 °C**	**200 °C**	**S_t Ambient (6)**
1060	all	17	55	14	14	13	12	10	7	6	15
1100	all	24	76	19	19	19	19	12	9	7	21
3003	all	34	97	28	28	28	22	17	12	10	29
Alclad 3003	all	31	90	25	25	25	20	15	11	9	26
3004	all	59	152	47	47	47	47	40	26	16	50
Alclad 3004	all	55	145	44	44	44	44	40	26	16	47
5050	all	41	124	33	33	33	33	33	19	10	35
5052, 5652	all	66	172	52	52	52	52	39	28	16	56
5083 (1)	all	124	276	90	90	do not use above 65 °C					91
5083 (2)	all	117	269	88	88	do not use above 65 °C					89
5086	all	97	241	77	77	do not use above 65 °C					80
5154, 5254	all	76	207	61	60	do not use above 65 °C					64
5454	all	83	214	66	66	66	51	38	28	21	70
5456 (1)	all	131	290	96	96	do not use above 65 °C					96
5456 (2)	all	124	283	93	93	do not use above 65 °C					93
6061, Alclad 6061 (3)	T4, T6, T451, T651		165	55	55	55	54	51	42	30	55

NOTE 1 Up to 40 mm thick.

NOTE 2 > 40 mm and ≤ 80 mm thick

NOTE 3 Tempers T4 and T6 apply for thickness < 6 mm, T451 and T651 apply for thickness ≥ 6 mm.

NOTE 4 Strengths are for the –O temper for all alloys except 6061, Alclad 6061, and 6063.

NOTE 5 The design stress shall be the lesser of 1/3 of the minimum tensile strength, 0.8 of the minimum yield strength, the stress producing a secondary creep rate of 0.1 % in 1000 hr, or 67 % of the average stress for rupture at the end of 100,000 hr.

NOTE 6 The allowable test stress shall be the lesser of 1/3 of the minimum tensile strength or 0.85 of the minimum yield strength at ambient temperature.

Table AL.6b—Allowable Tensile Stresses for Tank Shell (for Design and Test) (USC)

Allowable Stress (psi) (5) S_d for Maximum Design Temperature Not Exceeding											
Alloy	**Temper**	**Minimum Yield Strength (psi) (4)**	**Minimum Tensile Strength (psi) (4)**	**100 °F**	**150 °F**	**200 °F**	**250 °F**	**300 °F**	**350 °F**	**400 °F**	**S_t Ambient (6)**
1060	all	2,500	8,000	2,000	2,000	1,900	1,750	1,450	1,050	800	2,100
1100	all	3,500	11,000	2,800	2,800	2,800	2,700	1,750	1,350	1,000	3,000
3003	all	5,000	14,000	4,000	4,000	4,000	3,150	2,400	1,800	1,400	4,300
Alc 3003	all	4,500	13,000	3,600	3,600	3,600	2,850	2,150	1,600	1,250	3,800
3004	all	8,500	22,000	6,800	6,800	6,800	6,800	5,750	3,800	2,350	7,200
Alc 3004	all	8,000	21,000	6,400	6,400	6,400	6,400	5,750	3,800	2,350	6,800
5050	all	6,000	18,000	4,800	4,800	4,800	4,800	4,800	2,800	1,400	5,100
5052, 5652	all	9,500	25,000	7,600	7,600	7,600	7,500	5,600	4,100	2,350	8,100
5083 (1)	all	18,000	40,000	13,000	13,000	do not use above 150 °F					13,200
5083 (2)	all	17,000	39,000	12,800	12,800	do not use above 150 °F					12,900
5086	all	14,000	35,000	11,200	11,100	do not use above 150 °F					11,600
5154, 5254	all	11,000	30,000	8,800	8,700	do not use above 150 °F					9,400
5454	all	12,000	31,000	9,600	9,600	9,600	7,400	5,500	4,100	3,000	10,200
5456 (1)	all	19,000	42,000	13,900	13,900	do not use above 150 °F					13,900
5456 (2)	all	18,000	41,000	13,500	13,500	do not use above 150 °F					13,500
6061, Alc 6061 (3)	T4, T6, T451, T651		24,000	8,000	8,000	8,000	7,900	7,400	6,100	4,300	8,000

NOTE 1 Up to 1.500 in. thick.

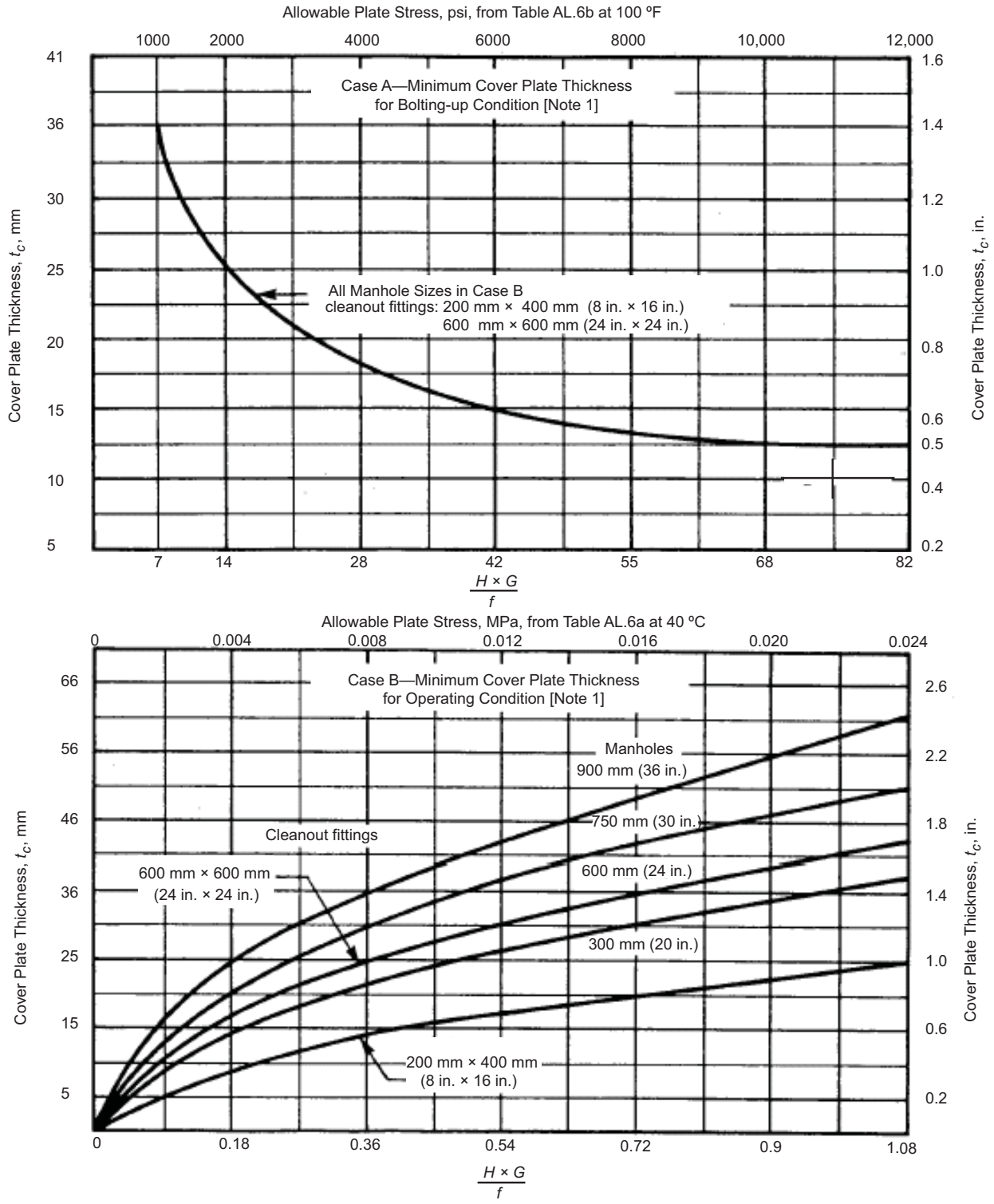
NOTE 2 > 1.500 in. and ≤ 3.000 in. thick.

NOTE 3 Temper T4 and T6 apply for thickness < 6 mm (0.25 in.), T451 and T651 apply for thickness ≥ 0.25 in.

NOTE 4 Strengths are for the – O temper for all alloys except 6061, Alclad 6061, and 6063.

NOTE 5 The design stress shall be the lesser of 1/3 of the minimum tensile strength, 0.8 of the minimum yield strength, the stress producing a secondary creep rate of 0.1 % in 1000 hr, or 67 % of the average stress for rupture at the end of 100,000 hr.

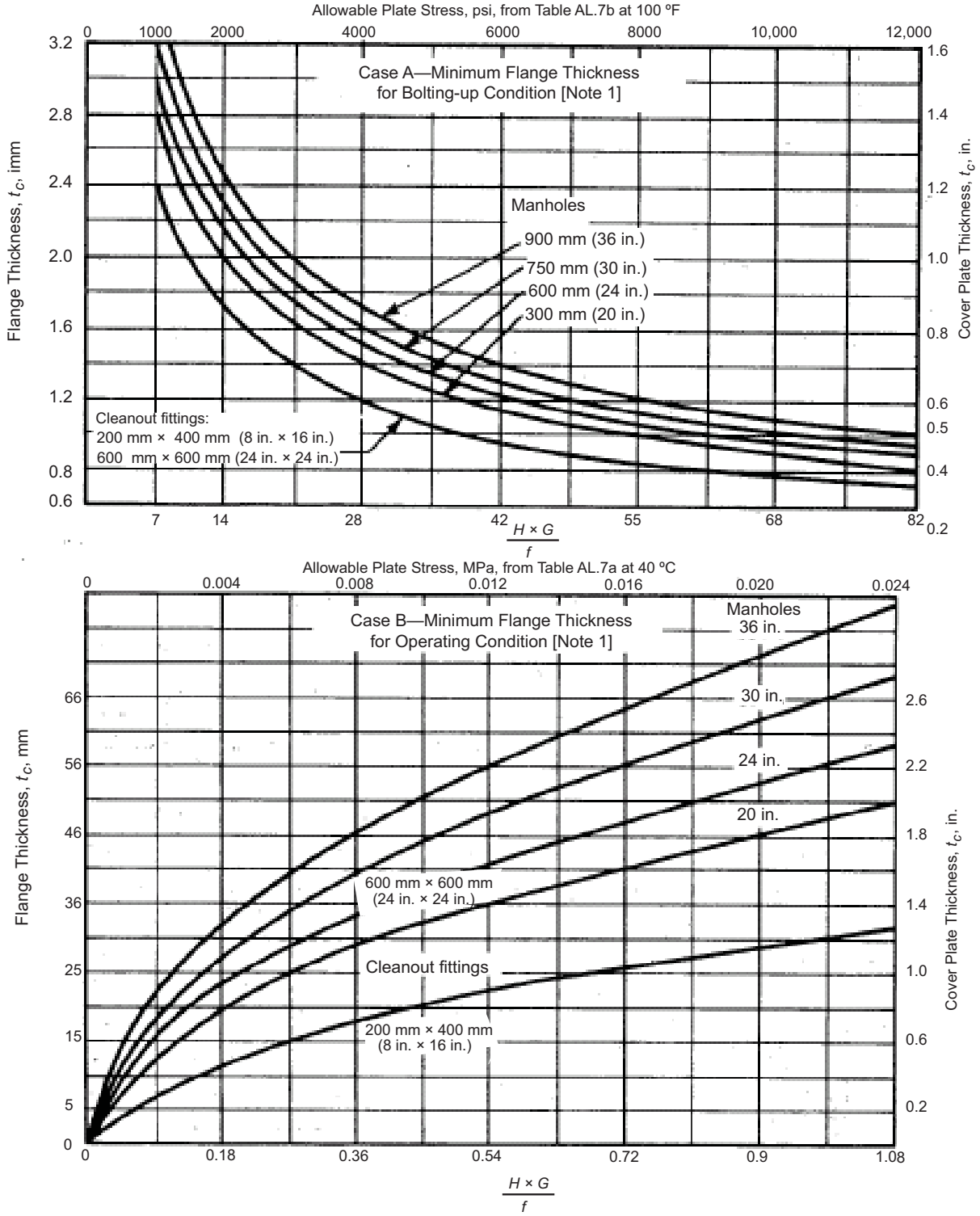
NOTE 6 The allowable test stress shall be the lesser of 1/3 of the minimum tensile strength or 0.85 of the minimum yield strength at ambient temperature.



G is the specific gravity of liquid that determines the shell thickness;
H is the height of design liquid level above centerline of manhole m (ft);
f is the allowable tensile stress (S_d or S_b) from Table AL.6a and Table AL.6b at the temperature coincident with *G*, MPa (psi).

NOTE 1 The minimum cover plate thickness shall be a maximum of Case A or B values.

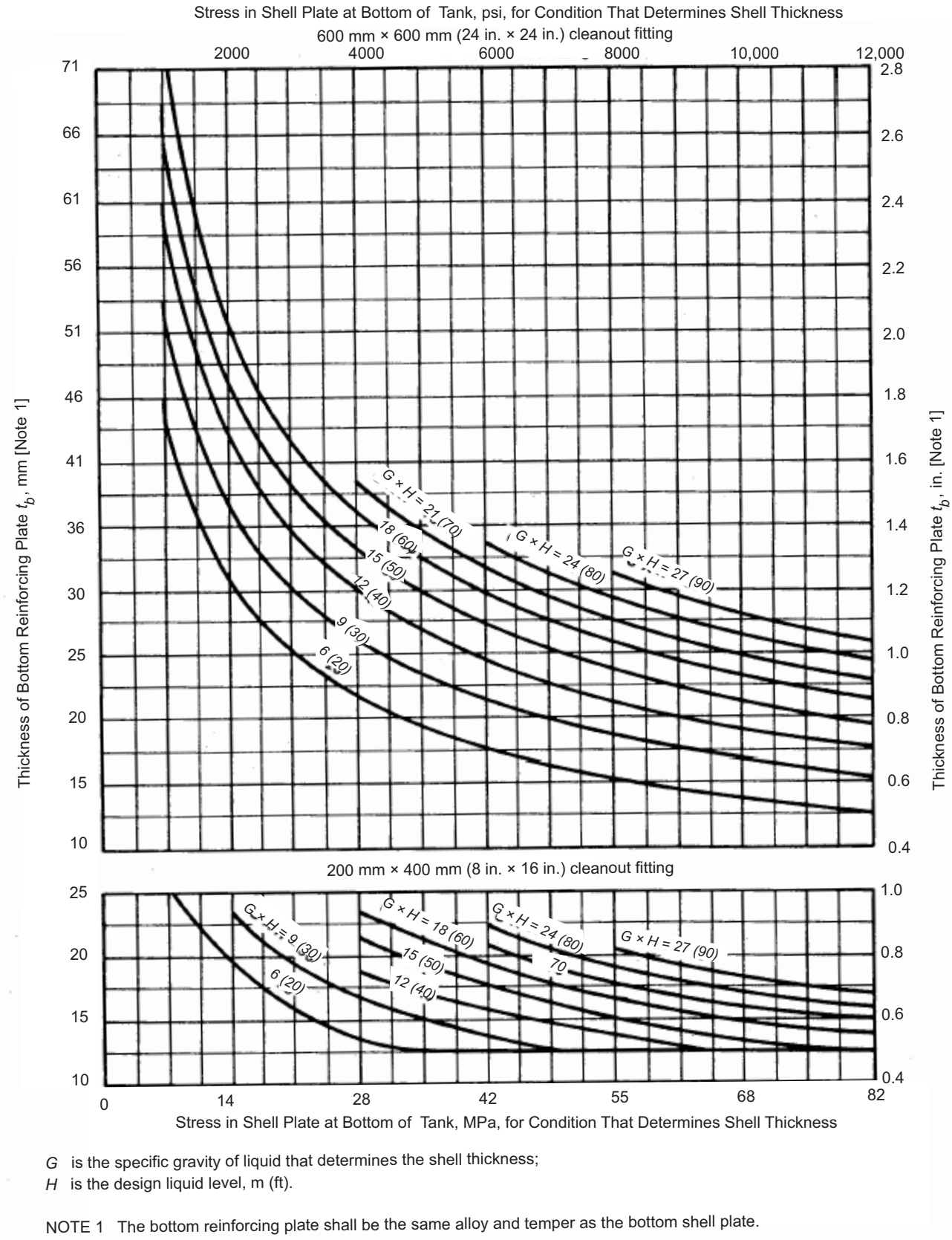
Figure AL.1—Cover Plate Thickness for Shell Manholes and Cleanout Fittings



G is the specific gravity of liquid that determines the shell thickness;
H is the height of design liquid level above centerline of manhole, m (ft);
f is the allowable tensile stress (S_d or S_b) from Table AL.6a and Table AL.6b at the temperature coincident with G, MPa (psi).

NOTE 1 The minimum cover plate thickness shall be a maximum of Case A or B values.

Figure AL.2—Flange Plate Thickness for Shell Manholes and Cleanout Fittings



G is the specific gravity of liquid that determines the shell thickness;
H is the design liquid level, m (ft).

NOTE 1 The bottom reinforcing plate shall be the same alloy and temper as the bottom shell plate.

Figure AL.3—Bottom Reinforcing Plate Thickness for Cleanout Fittings

AL.5.5.2 Intermediate Wind Girders

The height of the unstiffened shell shall not exceed:

$$H_1 = 2400t\sqrt{\left(\frac{1200t}{D}\right)^3}\left(\frac{E_{MDT}}{E_{40}}\right)$$

where

H_1 is the vertical distance between the intermediate wind girder and the top angle of the shell or the top wind girder of an open-top tank;

t is the nominal thickness, unless otherwise specified, of the top shell course;

E_{MDT} is the modulus of elasticity at the maximum design temperature;

E_{40} is the modulus of elasticity at 40 °C (100 °F).

AL.5.6 Roofs

AL.5.6.1 Structural Members

The minimum nominal thickness of structural members shall be 4 mm (0.15 in.).

AL.5.6.2 Frangible Roofs

Roofs required to be frangible shall meet the requirements of 5.10.2.6 except that the cross sectional area *A* of the roof-to-shell joint shall not exceed $0.159W/(F_{ty}\tan\theta)$ where F_{ty} = the greatest tensile yield strength of the materials in the joint.

AL.5.6.3 Allowable Stresses

Roofs shall be proportioned so that stresses from the load combinations specified in 5.10.2.1 do not exceed the allowable stresses given in the *Aluminum Design Manual (ADM) Specification for Aluminum Structures—Allowable Stress Design for building type structures.* Allowable stresses for ambient temperature service shall be calculated using the minimum mechanical properties given in the ADM. Allowable stresses for elevated temperature service shall be calculated using the minimum mechanical properties given in Table AL.8a and Table AL.8b. Section 5.10.3.4 does not apply.

AL.5.6.4 Supported Cone Roofs

a) The stresses determined from Figure AL.4 for dead load and dead and live loads for the thickness and span of roof plates shall not exceed the allowable stresses given in Table AL.7a and Table AL.7b.

b) The roof supporting structure shall be of 6061-T6 or 6063-T6 and proportioned so stresses do not exceed allowable stresses. Dead load stresses for temperatures over 120 °C (250 °F) shall not exceed 25 % of allowable stresses.

c) Low cycle fatigue failures may occur at the roof-to-top-angle weld and at roof lap welds for roofs designed to the minimum requirements of this standard when:

   1) the internal pressure exceeds the weight of the roof plates; or

   2) tanks larger than 15 m (50 ft) in diameter are subjected to steady wind speeds of 40 to 50 km/hr (25 to 30 mph) or greater.

Table AL.7a—Allowable Stresses for Roof Plates (SI)

Allowable Tensile Stresses (MPa) at Maximum Design Temperatures (°C) Not Exceeding									
Alloy	**Temper**		**40**	**65**	**90**	**120**	**150**	**175**	**200**
3003	all	(dead load)				22	16	12	9.6
		(dead + live load)	34	34	34	34	32	30	26
Alclad 3003	all	(dead load)				20	15	11	8.6
		(dead + live load)	31	31	31	30	29	27	23
3004	all	(dead load)					40	26	16
		(dead + live load)	59	59	59	59	59	55	51
Alclad 3004	all	(dead load)					36	23	17
		(dead + live load)	55	55	55	55	55	50	46
5050	all	(dead load)					37	19	9.6
		(dead + live load)	41	41	41	41	41	40	39
5052, 5652	all	(dead load)					43	28	16
		(dead + live load)	66	66	66	66	66	66	58
5083	all	(dead + live load)	124	123	do not use above 65 °C				
5086	all	(dead + live load)	97	96	do not use above 65 °C				
5154, 5254	all	(dead + live load)	76	76	do not use above 65 °C				
5454	all	(dead load)			81	51	38	28	21
		(dead + live load)	83	83	83	83	82	80	77
5456	all	(dead + live load)	131	130	do not use above 65°C				
6061, Alclad 6061	T4, T6	(dead load)					57	42	30
		(dead + live load)	66	66	66	65	61	51	39

NOTE For non-heat treatable alloys, allowable stresses for dead + live loads are the lesser of the yield strength, the stress producing a secondary creep rate of 0.1 % in 10,000 hr, 67 % of the average stress for rupture after 100,000 hr. For heat treatable alloys, allowable stresses are 40 % of the minimum strength of groove welds.

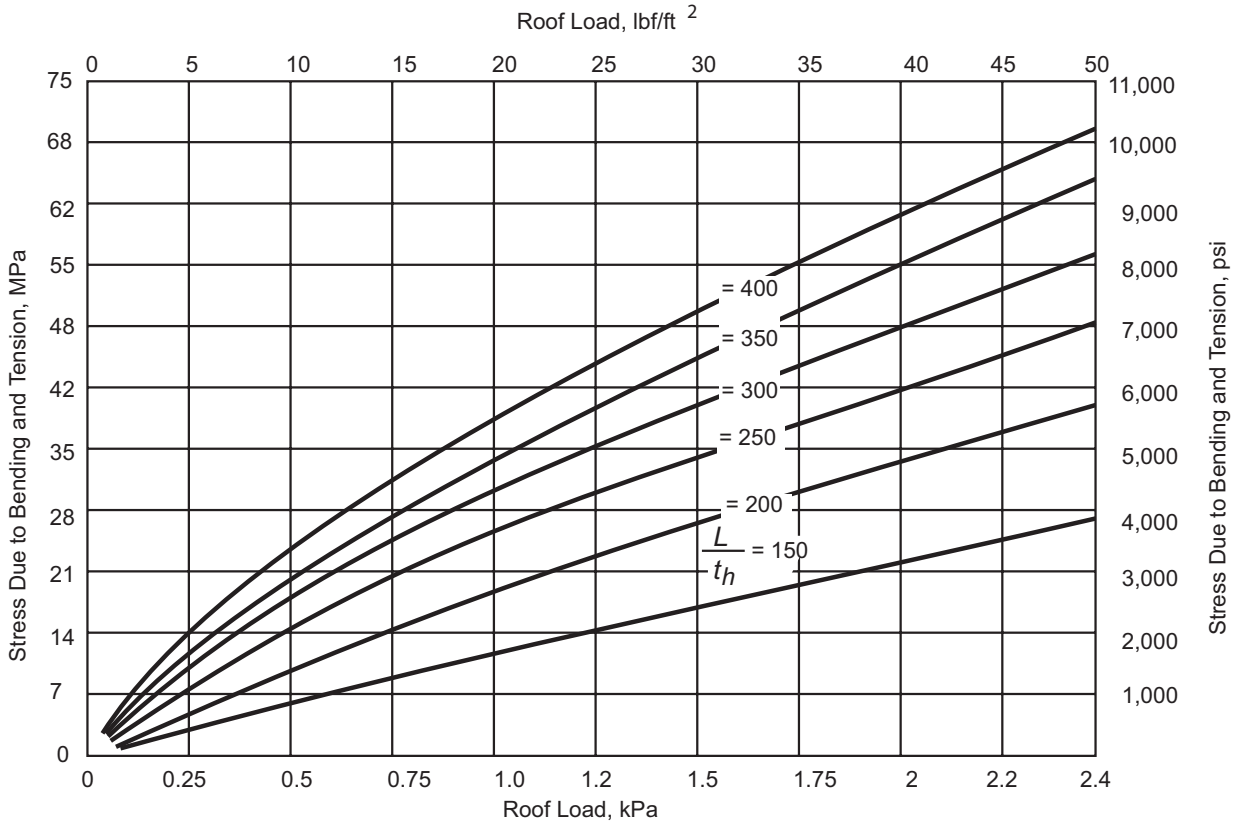
Table AL.7b—Allowable Stresses for Roof Plates (USC)

Allowable Tensile Stresses (ksi) at Maximum Design Temperatures (°F) Not Exceeding									
Alloy	**Temper**		**100**	**150**	**200**	**250**	**300**	**350**	**400**
3003	all	(dead load)				3.15	2.4	1.8	1.4
		(dead + live load)	5.0	5.0	5.0	4.9	4.6	4.3	3.7
Alclad 3003	all	(dead load)				2.85	2.15	1.6	1.25
		(dead + live load)	4.5	4.5	4.5	4.4	4.15	3.85	3.35
3004	all	(dead load)					5.75	3.8	2.35
		(dead + live load)	8.5	8.5	8.5	8.5	8.5	8.0	7.4
Alclad 3004	all	(dead load)					5.15	3.4	2.4
		(dead + live load)	8.0	8.0	8.0	8.0	8.0	7.2	6.65
5050	all	(dead load)					5.35	2.8	1.4
		(dead + live load)	6.0	6.0	6.0	6.0	6.0	5.8	5.6

Table AL.7b—Allowable Stresses for Roof Plates (USC) (Continued)

Allowable Tensile Stresses (ksi) at Maximum Design Temperatures (°F) Not Exceeding									
Alloy	**Temper**		**100**	**150**	**200**	**250**	**300**	**350**	**400**
5052, 5652	all	(dead load)					6.25	4.1	2.35
		(dead + live load)	9.5	9.5	9.5	9.5	9.5	9.5	8.4
5083	all	(dead + live load)	18	17.9	do not use above 150 °F				
5086	all	(dead + live load)	14	13.9	do not use above 150 °F				
5154, 5254	all	(dead + live load)	11	11	do not use above 150 °F				
5454	all	(dead load)			11.7	7.4	5.5	4.1	3.0
		(dead + live load)	12	12	12	12	11.9	11.6	11.1
5456	all	(dead + live load)	19	18.8	do not use above 150 °F				
6061, Alclad 6061	T4, T6	(dead load)					8.2	6.1	4.3
		(dead + live load)	9.6	9.6	9.6	9.45	8.85	7.45	5.65

NOTE For non-heat treatable alloys, allowable stresses for dead + live loads are the lesser of the yield strength, the stress producing a secondary creep rate of 0.1 % in 10,000 hr, 67 % of the average stress for rupture after 100,000 hr. For heat treatable alloys, allowable stresses are 40 % of the minimum strength of groove welds.



L is the maximum rafter spacing, mm (in.);
t_h is the thickness of roof, mm (in.).

Figure AL.4—Stresses in Roof Plates

Table AL.8a—Compressive Moduli of Elasticity *E* (MPa) at Temperature (°C) (SI)

Alloy	40	65	90	120	150	175	200
1060	69,600	68,300	66,900	64,800	63,400	60,700	57,900
1100	69,600	68,300	66,900	64,800	63,400	60,700	57,900
3003, Alclad 3003	69,600	68,300	66,900	64,800	63,400	60,700	57,900
3004, Alclad 3004	69,600	68,300	66,900	64,800	63,400	60,700	57,900
5050	69,600						
5052, 5652	71,000	68,900	67,600	64,800	62,700	59,300	55,800
5083	71,700	70,300	do not use above 65 °C				
5086	71,700	70,300	do not use above 65 °C				
5154, 5254	71,000		do not use above 65 °C				
5454	71,000	68,900	67,600	64,800	62,700	59,300	55,800
5456	71,700	70,300	do not use above 65 °C				
6061	69,600	68,300	66,900	65,500	64,100	62,700	60,700
6063	69,600	68,300	66,900	65,500	64,100	62,700	60,700

NOTE 1 Tensile moduli = (compressive moduli)/1.02.

Table AL.8b—Compressive Moduli of Elasticity *E* (ksi) at Temperature (°F) (USC)

Alloy	100	150	200	250	300	350	400
1060	10,100	9900	9700	9400	9200	8800	8400
1100	10,100	9900	9700	9400	9200	8800	8400
3003, Alclad 3003	10,100	9900	9700	9400	9200	8800	8400
3004, Alclad 3004	10,100	9900	9700	9400	9200	8800	8400
5050	10,100						
5052, 5652	10,300	10,000	9800	9400	9100	8600	8100
5083	10,400	10,200	do not use above 150 °F				
5086	10,400	10,200	do not use above 150 °F				
5154, 5254	10,300		do not use above 150 °F				
5454	10,300	10,000	9800	9400	9100	8600	8100
5456	10,400	10,200	do not use above 150 °F				
6061	10,100	9900	9700	9500	9300	9100	8800
6063	10,100	9900	9700	9500	9300	9100	8800

NOTE 1 Tensile moduli = (compressive moduli)/1.02.

Table AL.9a and Table AL.9b are the same as Table 5.7a and Table 5.7b, respectively, with the following modifications:

Table AL.9a—Shell Nozzle Welding Schedule (SI)

Dimensions in mm

Column 1	Column 5
Thickness of Shell and Reinforcing Plate t and T	**Size of Fillet Weld A Nozzles Larger Than NPS 2**
5	6
6	6
8	6
10	6
11	6
13	6
14	6
16	8
17	8
20	10
21	11
22	11
24	13
25	13
27	14
28	14
30	14
32	16
33	16
35	17
36	17
38	20
40	21
41	21
43	22
45	22

Table AL.9b—Shell Nozzle Welding Schedule (USC)

Dimensions in inches

Column 1	Column 5
Thickness of Shell and Reinforcing Plate t and T	**Size of Fillet Weld A Nozzles Larger Than NPS 2**
3/16	1/4
1/4	1/4
5/16	1/4
3/8	1/4
7/16	1/4
1/2	1/4
9/16	1/4
5/8	5/16
11/16	5/16
3/4	3/8
13/16	7/16
7/8	7/16
15/16	1/2
1	1/2
1 1/16	9/16
1 1/8	9/16
1 3/16	9/16
1 1/4	5/8
1 5/16	5/8
1 3/8	11/16
1 7/16	11/16
1 1/2	3/4
1 9/16	13/16
1 5/8	13/16
1 11/16	7/8
1 3/4	7/8

AL.5.6.5 Self-Supporting Cone Roofs

a) The minimum nominal roof thickness is t_h.

$$t_h = \frac{2D}{\sin\theta}\sqrt{\frac{p_h}{E}}$$

b) The minimum area of the roof-to-shell joint is A.

$$A = p_h D^2/(8f\tan\theta)$$

where

f is the lesser of (0.5 F_{tu}, or 0.6 F_{ty}), the least allowable tensile stress of the materials in the roof-to-shell joint;

F_{tu} is the Least Ultimate Strength of roof-to-shell joint material at maximum design temperature;

F_{ty} is the Least Yield Strength of roof-to-shell joint material at maximum design temperature.

AL.5.6.6 Self-Supporting Dome and Umbrella Roofs

a) The minimum nominal roof thickness is t_h.

$$t_h = 4.0 r_h \sqrt{\frac{p_h}{E}}$$

where

r_h is the roof radius

b) The minimum area of the roof-to-shell joint *is* A.

$$A = p_h D^2/(8f\tan\theta)$$

where

f is the lesser of (0.5 F_{tu}, or 0.6 F_{ty}), the least allowable tensile stress of the materials in the roof-to-shell joint;

F_{tu} is the Least Ultimate Strength of roof-to-shell joint material at maximum design temperature;

F_{ty} is the Least Yield Strength of roof-to-shell joint material at maximum design temperature.

AL.5.6.7 Structurally Supported Aluminum Dome Roofs

Structurally supported aluminum dome roofs shall meet Annex G.

AL.6 Fabrication

AL.6.1 Finish of Plate Edges

At least 3 mm ($^1/_8$ in.) shall be mechanically removed from edges of heat treatable alloys that have been plasma arc cut. Oxygen cutting shall not be used.

AL.6.2 Marking Materials

Marking materials shall not contain carbon or heavy metal compounds.

AL.7 Erection

AL.7.1 Welding Methods

Welding shall be gas metal arc welding, gas tungsten arc welding, plasma arc welding without using flux, or friction stir welding. The welding may be performed by the manual, machine, automatic, or semiautomatic welding processes according to procedures by welders or welding operators qualified in accordance with ASME Section IX or AWS D1.2.

AL.7.2 Preheating

Parts to be welded shall not be preheated except to the extent needed to drive off moisture or bring base metal temperature up to minimum welding temperature per 7.2.1.2.

AL.7.3 Plumbness

The plumbness requirements shall be per 7.5.2 except the out-of-plumbness in any shell course shall not exceed the flatness tolerance in ASTM B209M (B209).

AL.7.4 Storage

Aluminum parts shall not be stored in contact with one another when moisture is present. Aluminum shall not be stored or erected in contact with carbon steel or the ground.

AL.7.5 Quality of Test Water

- **AL.7.5.1** The materials used in the construction of aluminum tanks and materials used for tank components that 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 AL.7.5.1.1 through AL.7.5.1.8.

AL.7.5.1.1 Water shall be substantially clean and clear.

AL.7.5.1.2 Water shall have no objectionable odor (i.e. no hydrogen sulfide).

AL.7.5.1.3 Water pH shall be between 6 and 8.3.

AL.7.5.1.4 Water temperature shall be below 50 °C (120 °F).

AL.7.5.1.5 Water mercury content shall be less than 0.005 ppm.

AL.7.5.1.6 Water copper content shall be less than 0.02 ppm.

AL.7.5.1.7 Water shall have chloride content not exceeding 200 ppm.

AL.7.5.1.8 The water used to test the tank shall either:

1) be potable water with a free residual chlorine of at least 0.2 ppm, or

2) be tested for harmful microorganism content and found acceptable in accordance with parameters set by the owner.

AL.7.5.2 After the hydrostatic test is completed, the tank shall be promptly drained, cleaned, and dried.

AL.8 Examination of Welds

AL.8.1 Liquid Penetrant Examination

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

a) shell opening reinforcement and structural attachment plates, excluding lightly loaded attachments, that intersect a shell weld shall be examined for a distance of 150 mm (6 in.) on each side of the intersection and the butt weld for a distance of 50 mm (2 in.) beyond the pad weld;

b) all welds of openings in the shell that are not completely radiographed, including nozzle and manhole neck welds and neck-to-flange welds;

c) all butt-welded joints in tank shell and annular plate on which backing strips are to remain.

AL.8.2 Magnetic Particle Examination

Section 8.2 does not apply.

AL.9 Welding Procedures and Welder Qualifications

Weld procedures and welder qualifications shall meet Section 9 except that impact tests are not required.

AL.10 Marking

AL.10.1 Material

In addition to the requirements of Section 10, the bottom and roof alloys shall be shown on the nameplate.

AL.11 Foundations

AL.11.1 Concrete

Aluminum shall not be placed in direct contact with concrete.

AL.12 Internal Pressure

AL.12.1 General

Annex F shall be met with the following exceptions.

AL.12.2 Design Pressure

The design internal pressure P in F.4.1:

$$P = \frac{8AF_{ty}\tan\theta}{(SF)D^2} + \rho_h t_h$$

where

F_{ty} is the tensile yield strength of the materials in the roof-to-shell joint;

SF is the safety factor = 1.6;

A is the area resisting the compressive force as illustrated in Figure F.2 except that 16t shall be replaced by $56t_s\sqrt{F_{ty}}$.

AL.12.3 Maximum Design Pressure

For maximum design pressure, reference Annex F.4.2.

AL.12.4 Required Compression Area at the Roof-to-Shell Junction

The required area at the roof-to-shell joint in F.5.1 shall be:

$$A = \frac{(SF)D^2(P - \rho_h t_h)}{8F_{ty}\tan\theta}$$

AL.12.5 Calculated Failure Pressure

The calculated failure pressure in F.7 shall be:

$$P_f = 1.6P - 0.6\rho_h t_h$$

AL.12.6 Mechanically-anchored Tanks

The allowable compressive stress in F.7.2 shall be F_{ty}/1.6.

AL.13 Seismic Design

AL.13.1 General

Annex E shall be met with the following exceptions.

AL.13.2 Allowable Longitudinal Membrane Compression Stress in Shell

The allowable compressive stress in E.6.2.2.3 shall be determined in accordance with the ASME *Boiler and Pressure Vessel Code,* Section VIII, Division 1.

AL.14 External Pressure

AL.14.1 General

Annex V does not apply to aluminum tanks.