Welded Tanks for Oil Storage

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G is the design specific gravity of the liquid to be stored, as specified by the Purchaser, not greater than 1.0;

Υ is the density factor of water. MPa per meter, (psi per foot) SI: 9.81/1000, USC: 62.4/144.

NOTE Derivation of the equation is from "Structural Analysis and Design of Process Equipment" by Jawad and Farr and L.P. Zick and R.V. McGrath, "Design of Large Diameter Cylindrical Shells."

Alternatively, if thickened annular plates are being solely provided as wind or seismic overturning resistance, the minimum radial distance between the inside of the shell and the edge of the plate in the remainder of the bottom shall be in accordance with 5.11.2.3 or E.6.2.1.1.3, respectively.

5.5.3 The thickness of the annular bottom plates shall not be less than the greater thickness determined using Table 5.1a and Table 5.1b for product design (plus any specified corrosion allowance) or for hydrostatic test design. Table 5.1a and Table 5.1b are applicable for effective product height of $H \times G \leq 23$ m (75 ft). Beyond this height an elastic analysis must be made to determine the annular plate thickness.

Table 5.1a—Annular Bottom-Plate Thicknesses (t_b) (SI)

Plate Thickness[a] of First Shell Course (mm)	Stress[b] in First Shell Course (MPa)			
	≤ 190	≤ 210	≤ 220	≤ 250
$t \leq 19$	6	6	7	9
$19 < t \leq 25$	6	7	10	11
$25 < t \leq 32$	6	9	12	14
$32 < t \leq 40$	8	11	14	17
$40 < t \leq 45$	9	13	16	19

[a] Plate thickness refers to the corroded shell plate thickness for product design and nominal thickness for hydrostatic test design.

[b] The stress to be used is the maximum stress in the first shell course (greater of product or hydrostatic test stress). The stress may be determined using the required thickness divided by the thickness from "a" then multiplied by the applicable allowable stress:

Product Stress = $((t_d - CA) / \text{corroded } t)\ (S_d)$

Hydrostatic Test Stress = $(t_t / \text{nominal } t)\ (S_t)$

NOTE The thicknesses specified in the table, as well as the width specified in 5.5.2, are based on the foundation providing uniform support under the full width of the annular plate. Unless the foundation is properly compacted, particularly at the inside of a concrete ringwall, settlement will produce additional stresses in the annular plate.

5.5.4 The ring of annular plates shall have a circular outside circumference, but may have a regular polygonal shape inside the tank shell, with the number of sides equal to the number of annular plates. These pieces shall be welded in accordance with 5.1.5.6 and 5.1.5.7, Item b.

5.5.5 In lieu of annular plates, the entire bottom may be butt-welded provided that the requirements for annular plate thickness, welding, materials, and inspection are met for the annular distance specified in 5.5.2.

5.6 Shell Design

5.6.1 General

5.6.1.1 The required shell thickness shall be the greater of the design shell thickness, including any corrosion allowance, or the hydrostatic test shell thickness, but the shell thickness shall not be less than the following:

Nominal Tank Diameter		Nominal Plate Thickness	
(m)	(ft)	(mm)	(in.)
< 15	< 50	5	3/16
15 to < 36	50 to < 120	6	1/4
36 to 60	120 to 200	8	5/16
> 60	> 200	10	3/8

● NOTE 1 Unless otherwise specified by the Purchaser, the nominal tank diameter shall be the centerline diameter of the bottom shell-course plates.

NOTE 2 The thicknesses specified are based on erection requirements.

● NOTE 3 When specified by the Purchaser, plate with a nominal thickness of 6 mm may be substituted for 1/4-in. plate.

NOTE 4 For diameters less than 15 m (50 ft) but greater than 3.2 m (10.5 ft), the nominal thickness of the lowest shell course shall not be less than 6 mm (1/4 in.).

Table 5.1b—Annular Bottom-Plate Thicknesses (t_b) (USC)

Plate Thickness[a] of First Shell Course (in.)	Stress[b] in First Shell Course (lbf/in.^{2})			
	≤ 27,000	≤ 30,000	≤ 32,000	≤ 36,000
$t \le 0.75$	0.236	0.236	9/32	11/32
$0.75 < t \le 1.00$	0.236	9/32	3/8	7/16
$1.00 < t \le 1.25$	0.236	11/32	15/32	9/16
$1.25 < t \le 1.50$	5/16	7/16	9/16	11/16
$1.50 < t \le 1.75$	11/32	1/2	5/8	3/4

[a] Plate thickness refers to the corroded shell plate thickness for product design and nominal thickness for hydrostatic test design.

[b] The stress to be used is the maximum stress in the first shell course (greater of product or hydrostatic test stress). The stress may be determined using the required thickness divided by the thickness from "a" then multiplied by the applicable allowable stress:

Product Stress = ((t_d – CA)/ corroded t) (S_d)

Hydrostatic Test Stress = (t_t / nominal t) (S_t)

NOTE The thicknesses specified in the table, as well as the width specified in 5.5.2, are based on the foundation providing uniform support under the full width of the annular plate. Unless the foundation is properly compacted, particularly at the inside of a concrete ringwall, settlement will produce additional stresses in the annular plate.

5.6.1.2 Unless otherwise agreed to by the Purchaser, the shell plates shall have a minimum nominal width of 1800 mm (72 in.). Plates that are to be butt-welded shall be properly squared.

5.6.1.3 The calculated stress for each shell course shall not be greater than the stress permitted for the particular material used for the course. When the allowable stress for an upper shell course is lower than the allowable stress of the next lower shell course, then either a or b shall be satisfied.

a) The lower shell course thickness shall be no less than the thickness required of the upper shell course for product and hydrostatic test loads by 5.6.3 or 5.6.4.

b) The thickness of all shell courses shall be that determined from an elastic analysis per 5.6.5 using final plate thicknesses.

The inside of an upper shell course shall not project beyond the inside surface of the shell course below (except within tolerances provided in 7.2.3.2).

5.6.1.4 The tank shell shall be checked for stability against buckling from the design wind speed in accordance with 5.9.6. If required for stability, intermediate girders, increased shell-plate thicknesses, or both shall be used.

5.6.1.5 Isolated radial loads on the tank shell, such as those caused by heavy loads on platforms and elevated walkways between tanks, shall be distributed by rolled structural sections, plate ribs, or built-up members.

5.6.2 Allowable Stress

5.6.2.1 The maximum allowable product design stress, S_d, shall be as shown in Table 5.2a and Table 5.2b. The corroded plate thicknesses shall be used in the calculation. The design stress basis, S_d, shall be either two-thirds the yield strength or two-fifths the tensile strength, whichever is less.

5.6.2.2 The maximum allowable hydrostatic test stress, S_t, shall be as shown in Table 5.2a and Table 5.2b. The nominal plate thicknesses shall be used in the calculation. The hydrostatic test basis shall be either three-fourths the yield strength or three-sevenths the tensile strength, whichever is less.

Table 5.2a—Permissible Plate Materials and Allowable Stresses (SI)

Plate Specification	Grade	Nominal Plate Thickness t mm	Minimum Yield Strength MPa	Minimum Tensile Strength MPa	Product Design Stress S_d MPa	Hydrostatic Test Stress S_t MPa
ASTM Specifications						
A283M	C		205	380	137	154
A285M	C		205	380	137	154
A131M	A, B		235	400	157	171
A36M	—		250	400	160	171
A131M	EH 36		360	490[a]	196	210
A573M	400		220	400	147	165
A573M	450		240	450	160	180
A573M	485		290	485[a]	193	208
A516M	380		205	380	137	154
A516M	415		220	415	147	165
A516M	450		240	450	160	180
A516M	485		260	485	173	195
A662M	B		275	450	180	193

Table 5.2a—Permissible Plate Materials and Allowable Stresses (SI) (Continued)

Plate Specification	Grade	Nominal Plate Thickness t mm	Minimum Yield Strength MPa	Minimum Tensile Strength MPa	Product Design Stress S_d MPa	Hydrostatic Test Stress S_t MPa
ISO Specifications						
ISO 630	S275C, D	$t \le 16$	275	410	164	176
		$16 < t \le 40$	265	410	164	176
	S355C, D	$t \le 16$	355	470[a]	188	201
		$16 < t \le 40$	345	470[a]	188	201
		$40 < t \le 50$	335	470[a]	188	201
EN Specifications						
EN 10025	S 275J0, J2	$t \le 16$	275	410	164	176
		$16 < t \le 40$	265	410	164	176
	S 355J0, J2, K2	$t \le 16$	355	470[a]	188	201
		$16 < t \le 40$	345	470[a]	188	201
		$40 < t \le 50$	335	470[a]	188	201

[a] By agreement between the Purchaser and the Manufacturer, the tensile strength of ASTM A537M, Class 2, and A841M, Class 2 materials may be increased to 585 MPa minimum and 690 MPa maximum. The tensile strength of the other listed materials may be increased to 515 MPa minimum and 620 MPa maximum. When this is done, the allowable stresses shall be determined as stated in 5.6.2.1 and 5.6.2.2.

[b] By agreement between the Purchaser and the Manufacturer, the tensile strength of ASTM A537M, Class 2 materials may be increased to 550 MPa minimum and 690 MPa maximum. The tensile strength of the other listed materials may be increased to 485 MPa minimum and 620 MPa maximum. When this is done, the allowable stresses shall be determined as stated in 5.6.2.1 and 5.6.2.2.

5.6.2.3 Annex A permits an alternative shell design with a fixed allowable stress of 145 MPa (21,000 lbf/in.^{2}) and a joint efficiency factor of 0.85 or 0.70. This design may only be used for tanks with shell thicknesses less than or equal to 13 mm ($^1/_2$ in.).

5.6.2.4 Structural design stresses shall conform to the allowable working stresses given in 5.10.3.

5.6.3 Calculation of Thickness by the 1-Foot Method

5.6.3.1 The 1-foot method calculates the thicknesses required at design points 0.3 m (1 ft) above the bottom of each shell course. Annex A permits only this design method. This method shall not be used for tanks larger than 61 m (200 ft) in diameter.

• **5.6.3.2** The required minimum thickness of shell plates shall be the greater of the values computed by the following formulas:

In SI units:

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

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

Table 5.2b—Permissible Plate Materials and Allowable Stresses (USC)

Plate Specification	Grade	Nominal Plate Thickness t in.	Minimum Yield Strength psi	Minimum Tensile Strength psi	Product Design Stress S_d psi	Hydrostatic Test Stress S_t psi
ASTM Specifications						
A283	C		30,000	55,000	20,000	22,500
A285	C		30,000	55,000	20,000	22,500
A131	A, B		34,000	58,000	22,700	24,900
A36	—		36,000	58,000	23,200	24,900
A131	EH 36		51,000	71,000[a]	28,400	30,400
A573	58		32,000	58,000	21,300	24,000
A573	65		35,000	65,000	23,300	26,300
A573	70		42,000	70,000[a]	28,000	30,000
A516	55		30,000	55,000	20,000	22,500
A516	60		32,000	60,000	21,300	24,000
A516	65		35,000	65,000	23,300	26,300
A516	70		38,000	70,000	25,300	28,500
A662	B		40,000	65,000	26,000	27,900
A662	C		43,000	70,000[a]	28,000	30,000
A537	1	$t \leq 2\tfrac{1}{2}$ $2\tfrac{1}{2} < t \leq 4$	50,000 45,000	70,000[a] 65,000[b]	28,000 26,000	30,000 27,900
A537	2	$t \leq 2\tfrac{1}{2}$ $2\tfrac{1}{2} < t \leq 4$	60,000 55,000	80,000[a] 75,000[b]	32,000 30,000	34,300 32,100
A633	C, D	$t \leq 2\tfrac{1}{2}$ $2\tfrac{1}{2} < t \leq 4$	50,000 46.000	70,000[a] 65,000[b]	28,000 26,000	30,000 27,900
A737	B		50,000	70,000[a]	28,000	30,000
A841	Class 1, Grades A and B		50,000	70,000[a]	28,000	30,000
A841	Class 2, Grades A and B		60,000	80,000[a]	32,000	34,300
CSA Specifications						
G40.21	38W		38,000	60,000	24,000	25,700
G40.21	38WT		38,000	60,000	24,000	25,700

Table 5.2b—Permissible Plate Materials and Allowable Stresses (USC) (Continued)

Plate Specification	Grade	Nominal Plate Thickness t in.	Minimum Yield Strength psi	Minimum Tensile Strength psi	Product Design Stress S_d psi	Hydrostatic Test Stress S_t psi
G40.21	44W		44,000	64,000	25,600	27,400
G40.21	44WT		44,000	64,000	25,600	27,400
G40.21	50W		50,000	65,000	26,000	27,900
G40.21	50WT	$t \leq 2^1/_2$	50,000	65,000[a]	26,000	27,900
		$2^1/_2 < t \leq 4$	46,000	65,000[a]	26,000	27,900
National Standards						
	235		34,000	52,600	20,000	22,500
	250		36,000	58,300	22,700	25,000
	275		40,000	62,600	24,000	26,800
ISO Specifications						
ISO 630	S275C, D	$t \leq {}^5/_8$	39,900	59,500	23,800	25,500
		${}^5/_8 < t \leq 1^1/_2$	38,400	59,500	23,800	25,500
	S355C, D	$t \leq {}^5/_8$	51,500	68,100[a]	27,200	29,200
		${}^5/_8 < t \leq 1^1/_2$	50,000	68,100[a]	27,200	29,200
		$1^1/_2 < t \leq 2$	48,600	68,100[a]	27,200	29,200
EN Specifications						
EN 10025	S 275J0, J2	$t \leq {}^5/_8$	39,900	59,500	23,800	25,500
		${}^5/_8 < t \leq 1^1/_2$	38,400	59,500	23,800	25,500
	S 355J0, J2, K2	$t \leq {}^5/_8$	51,500	68,100[a]	27,200	29,200
		${}^5/_8 < t \leq 1^1/_2$	50,000	68,100[a]	27,200	29,200
		$1^1/_2 < t \leq 2$	48,600	68,100[a]	27,200	29,200

• [a] By agreement between the Purchaser and the Manufacturer, the tensile strength of ASTM A537M, Class 2, and A841M, Class 2 materials may be increased to 85,000 psi minimum and 100,000 psi maximum. The tensile strength of the other listed materials may be increased to 75,000 psi minimum and 90,000 psi maximum. When this is done, the allowable stresses shall be determined as stated in 5.6.2.1 and 5.6.2.2.

• [b] By agreement between the Purchaser and the Manufacturer, the tensile strength of ASTM A537M, Class 2 materials may be increased to 80,000 psi minimum and 100,000 psi maximum. The tensile strength of the other listed materials may be increased to 70,000 psi minimum and 90,000 psi maximum. When this is done, the allowable stresses shall be determined as stated in 5.6.2.1 and 5.6.2.2.

where

t_d is the design shell thickness, in mm;

t_t is the hydrostatic test shell thickness, in mm;

D is the nominal tank diameter, in m (see 5.6.1.1, Note 1);

• H is the design liquid level, in m:

is the height from the bottom of the course under consideration to the top of the shell including the top angle, if any; to the bottom of any overflow that limits the tank filling height; or to any other level specified by the Purchaser, restricted by an internal floating roof, or controlled to allow for seismic wave action;

• G is the design specific gravity of the liquid to be stored, as specified by the Purchaser;

• CA is the corrosion allowance, in mm, as specified by the Purchaser (see 5.3.2);

S_d is the allowable stress for the design condition, in MPa (see 5.6.2.1);

S_t is the allowable stress for the hydrostatic test condition, in MPa (see 5.6.2.2).

In USC units:

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

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

where

t_d is the design shell thickness, in inches;

t_t is the hydrostatic test shell thickness, in inches;

D is the nominal tank diameter, in ft (see 5.6.1.1, Note 1);

• H is the design liquid level, in ft:

is the height from the bottom of the course under consideration to the top of the shell including the top angle, if any; to the bottom of any overflow that limits the tank filling height; or to any other level specified by the Purchaser, restricted by an internal floating roof, or controlled to allow for seismic wave action;

• G is the design specific gravity of the liquid to be stored, as specified by the Purchaser;

• CA is the corrosion allowance, in inches, as specified by the Purchaser (see 5.3.2);

S_d is the allowable stress for the design condition, in lbf/in.^{2} (see 5.6.2.1);

S_t is the allowable stress for the hydrostatic test condition, in lbf/in.^{2} (see 5.6.2.2).

5.6.4 Calculation of Thickness by the Variable-Design-Point Method

NOTE This procedure normally provides a reduction in shell-course thicknesses and total material weight, but more important is its potential to permit construction of larger diameter tanks within the maximum plate thickness limitation. For background information, see L.P. Zick and R.V. McGrath, "Design of Large Diameter Cylindrical Shells."[15]