APPENDIX E—SEISMIC DESIGN OF STORAGE TANKS

Part I—Provisions

E.1 Scope

This appendix provides minimum requirements for the design of welded steel storage tanks that may be subject to seismic ground motion. These requirements represent accepted practice for application to welded steel flat-bottom tanks supported at grade.

The fundamental performance goal for seismic design in this appendix is the protection of life and prevention of catastrophic collapse of the tank. Application of this Standard does not imply that damage to the tank and related components will not occur during seismic events.

This appendix is based on the allowable stress design (ASD) methods with the specific load combinations given herein. Application of load combinations from other design documents or codes is not recommended, and may require the design methods in this appendix be modified to produce practical, realistic solutions. The methods use an equivalent lateral force analysis that applies equivalent static lateral forces to a linear mathematical model of the tank based on a rigid wall, fixed based model.

The ground motion requirements in this appendix are derived from ASCE 7, which is based on a maximum considered earthquake ground motion defined as the motion due to an event with a 2% probability of exceedance within a 50-year period (a recurrence interval of approximately 2,500 years). Application of these provisions as written is deemed to meet the intent and requirements of ASCE 7. Accepted techniques for applying these provisions in regions or jurisdictions where the regulatory requirements differ from ASCE 7 are also included.

The pseudo-dynamic design procedures contained in this appendix are based on response spectra analysis methods and consider two response modes of the tank and its contents—impulsive and convective. Dynamic analysis is not required nor included within the scope of this appendix. The equivalent lateral seismic force and overturning moment applied to the shell as a result of the response of the masses to lateral ground motion are determined. Provisions are included to assure stability of the tank shell with respect to overturning and to resist buckling of the tank shell as a result of longitudinal compression.

The design procedures contained in this appendix are based on a 5% damped response spectra for the impulsive mode and 0.5% damped spectra for the convective mode supported at grade with adjustments for site-specific soil characteristics. Application to tanks supported on a framework elevated above grade is beyond the scope of this appendix. Seismic design of floating roofs is beyond the scope of this appendix.

Optional design procedures are included for the consideration of the increased damping and increase in natural period of vibration due to soil-structure interaction for mechanically-anchored tanks.

Tanks located in regions where S_1 is less than or equal to 0.04 and S_S less than or equal to 0.15, or the peak ground acceleration for the ground motion defined by the regulatory requirements is less than or equal to 0.05*g*, need not be designed for seismic forces; however, in these regions, tanks in SUG III shall comply with the freeboard requirements of this appendix. 07

• Dynamic analysis methods incorporating fluid-structure and soil-structure interaction are permitted to be used in lieu of the procedures contained in this appendix with Purchaser approval and provided the design and construction details are as safe as otherwise provided in this appendix.

E.2 Definitions and Notations

E.2.1 DEFINITIONS

E.2.1.1 active fault: A fault for which there is an average historic slip rate of 1 mm (0.4 in.) per year or more and geologic evidence of seismic activity within Holocene times (past 11,000 years).

E.2.1.2 characteristic earthquake: An earthquake assessed for an active fault having a magnitude equal to the best-estimate of the maximum magnitude capable of occurring on the fault, but not less than the largest magnitude that has occurred historically on the fault.

E.2.1.3 maximum considered earthquake (MCE): The most severe earthquake ground motion considered in this appendix.

E.2.1.4 mechanically-anchored tank: Tanks that have anchor bolts, straps or other mechanical devices to anchor the tank to the foundation.

E.2.1.5 self-anchored tank: Tanks that use the inherent stability of the self-weight of the tank and the stored product to resist overturning forces.

E.2.1.6 site class: A classification assigned to a site based on the types of soils present and their engineering properties as defined in this appendix.

07 E.2.2 NOTATIONS

	A	Lateral acceleration coefficient, %g
	A_c	Convective design response spectrum acceleration coefficient, %g
07	A_f	Acceleration coefficient for sloshing wave height calculation, %g
	A_i	Impulsive design response spectrum acceleration coefficient, %g
	A_v	Vertical earthquake acceleration coefficient, %g
07	C_d	Deflection amplification factor, $C_d = 2$
	C_i	Coefficient for determining impulsive period of tank system
	D	Nominal tank diameter, m (ft)
07	d_c	Total thickness ($100 - d_s$) of cohesive soil layers in the top 30 m (100 ft)
	d_i	Thickness of any soil layer i (between 0 and 30 m [100 ft])
	d_s	Total thickness of cohesionless soil layers in the top 30 m (100 ft)
08	E	Elastic Modulus of tank material, MPa (lbf/in.^{2})
	F_a	Acceleration-based site coefficient (at 0.2 sec period)
08	F_c	Allowable longitudinal shell-membrane compression stress, MPa (lbf/in.^{2})
07	F_{ty}	Minimum specified yield strength of shell course, MPa (lbf/in.^{2})
	F_v	Velocity-based site coefficient (at 1.0 sec period)
08	F_y	Minimum specified yield strength of bottom annulus, MPa (lbf/in.^{2})
	G	Specific gravity
	g	Acceleration due to gravity in consistent units, m/sec^2 (ft/sec^2)
	G_e	Effective specific gravity including vertical seismic effects = $G(1 - 0.4A_v)$
	H	Maximum design product level, m (ft)
	H_S	Thickness of soil, m (ft)
	I	Importance factor coefficient set by seismic use group
	J	Anchorage ratio
	K	Coefficient to adjust the spectral acceleration from 5% – 0.5% damping = 1.5 unless otherwise specified
	L	Required minimum width of thickened bottom annular ring measured from the inside of the shell m (ft)
08	L_s	Selected width of annulus (bottom or thickened annular ring) to provide the resisting force for self anchorage, measured from the inside of the shell m (ft)
	t_a	Thickness, excluding corrosion allowance, mm (in.) of the bottom annulus under the shell required to provide the resisting force for self anchorage. The bottom plate for this thickness shall extend radially at least the distance, L, from the inside of the shell. This term applies for self-anchored tanks only.
	M_{rw}	Ringwall moment—Portion of the total overturning moment that acts at the base of the tank shell perimeter, Nm (ft-lb)
07	M_s	Slab moment (used for slab and pile cap design), Nm (ft-lb)
08	N	Standard penetration resistance, ASTM D 1586
	$\overline{N}$	Average field standard penetration test for the top 30 m (100 ft)

n_A	Number of equally-spaced anchors around the tank circumference
N_c	Convective hoop membrane force in tank shell, N/mm (lbf/in.)
N_{ch}	Average standard penetration of cohesionless soil layers for the top 30 m (100 ft)
N_h	Product hydrostatic membrane force, N/mm (lbf/in.)
N_i	Impulsive hoop membrane force in tank shell, N/mm (lbf/in.)
P_A	Anchorage attachment design load, N (lbf) 07
P_{AB}	Anchor design load, N (lbf)
Pf	Overturning bearing force based on the maximum longitudinal shell compression at the base of shell, N/m (lbf/ft) 08
PI	Plasticity index, ASTM D 4318
Q	Scaling factor from the MCE to the design level spectral accelerations; equals $^2/_3$ for ASCE 7
R	Force reduction coefficient for strength level design methods
R_{wc}	Force reduction coefficient for the convective mode using allowable stress design methods
R_{wi}	Force reduction factor for the impulsive mode using allowable stress design methods
S_0	Mapped, maximum considered earthquake, 5% damped, spectral response acceleration parameter at a period of zero seconds (peak ground acceleration for a rigid structure), %g
S_1	Mapped, maximum considered earthquake, 5% damped, spectral response acceleration parameter at a period of one second, %g
S_a	The 5% damped, design spectral response acceleration parameter at any period based on mapped, probabilistic procedures, %g
$S_a{}^*$	The 5% damped, design spectral response acceleration parameter at any period based on site-specific procedures, %g
$S_{a0}{}^*$	The 5% damped, design spectral response acceleration parameter at zero period based on site-specific procedures, %g
S_{D1}	The design, 5% damped, spectral response acceleration parameter at one second based on the ASCE 7 methods, equals $Q\,F_v\,S_1$, %g 11
S_{DS}	The design, 5% damped, spectral response acceleration parameter at short periods (T = 0.2 seconds) based on ASCE 7 methods, equals $Q\,F_a\,S_s$, %g
S_P	Design level peak ground acceleration parameter for sites not addressed by ASCE methods. [See EC Example Problem 2 when using "Z" factor from earlier editions of API 650 and UBC. Since 475 year recurrence interval is basis of this peak ground acceleration, Q = 1.0 (no scaling).] 11
S_S	Mapped, maximum considered earthquake, 5% damped, spectral response acceleration parameter at short periods (0.2 sec), %g
s_u	Undrained shear strength, ASTM D 2166 or ASTM D 2850
$\bar{s}_u$	Average undrained shear strength in top 30 m (100 ft)
t	Thickness of the shell ring under consideration, mm (in.)
t_a	Thickness, excluding corrosion allowance, mm (in.) of the bottom annulus under the shell required to provide the resisting force for self anchorage. The bottom plate for this thickness shall extend radially at least the distance, L, from the inside of the shell. this term applies for self-anchored tanks only. 08
t_b	Thickness of tank bottom less corrosion allowance, mm (in.)
t_s	Thickness of bottom shell course less corrosion allowance, mm (in.)
t_u	Equivalent uniform thickness of tank shell, mm (in.)
T	Natural period of vibration of the tank and contents, seconds

	T_C	Natural period of the convective (sloshing) mode of behavior of the liquid, seconds
	T_i	Natural period of vibration for impulsive mode of behavior, seconds
	T_L	Regional-dependent transition period for longer period ground motion, seconds
	T_0	$0.2\, F_v S_1 / F_a S_S$
	T_S	$F_v S_1 / F_a S_S$
	V	Total design base shear, N (lbf)
	V_c	Design base shear due to the convective component of the effective sloshing weight, N (lbf)
	v_s	Average shear wave velocity at large strain levels for the soils beneath the foundation, m/s (ft/s)
	$\bar{v}_s$	Average shear wave velocity in top one 30 m (100 ft), m/s (ft/s)
	V_i	Design base shear due to impulsive component from effective weight of tank and contents, N (lbf)
	w	Moisture content (in %), ASTM D 2216
08	w_a	Force resisting uplift in annular region, N/m (lbf/ft)
	w_{AB}	Calculated design uplift load on anchors per unit circumferential length, $^{N}/_{m}$ (lbf/ft)
	W_c	Effective convective (sloshing) portion of the liquid weight, N (lbf)
	W_{eff}	Effective weight contributing to seismic response
	W_f	Weight of the tank bottom, N (lbf)
	W_{fd}	Total weight of tank foundation, N (lbf)
	W_g	Weight of soil directly over tank foundation footing, N (lbf)
	W_i	Effective impulsive portion of the liquid weight, N (lbf)
	w_{int}	Calculated design uplift load due to product pressure per unit circumferential length, N/m (lbf/ft)
	W_p	Total weight of the tank contents based on the design specific gravity of the product, N (lbf)
	W_r	Total weight of fixed tank roof including framing, knuckles, any permanent attachments and 10% of the roof design snow load, N (lbf)
	W_{rs}	Roof load acting on the tank shell including 10% of the roof design snow load, N (lbf)
	w_{rs}	Roof load acting on the shell, including 10% of the specified snow load N/m (lbf/ft)
	W_s	Total weight of tank shell and appurtenances, N (lbf)
08	W_T	Total weight of tank shell, roof, framing, knuckles, product, bottom, attachments, appurtenances, participating snow load, if specified, and appurtenances, N (lbf)
	w_t	Tank and roof weight acting at base of shell, N/m (lbf/ft)
	X_c	Height from the bottom of the tank shell to the center of action of lateral seismic force related to the convective liquid force for ringwall moment, m (ft)
	X_{cs}	Height from the bottom of the tank shell to the center of action of lateral seismic force related to the convective liquid force for the slab moment, m (ft)
	X_i	Height from the bottom of the tank shell to the center of action of the lateral seismic force related to the impulsive liquid force for ringwall moment, m (ft)
	X_{is}	Height from the bottom of the tank shell to the center of action of the lateral seismic force related to the impulsive liquid force for the slab moment, m (ft)
	X_r	Height from the bottom of the tank shell to the roof and roof appurtenances center of gravity, m (ft)

X_s	Height from the bottom of the tank shell to the shell's center of gravity, m (ft)
Y	Distance from liquid surface to analysis point, (positive down), m (ft)
y_u	Estimated uplift displacement for self-anchored tank, mm (in.)
σ_c	Maximum longitudinal shell compression stress, MPa (lbf/in.^{2})
σ_h	Product hydrostatic hoop stress in the shell, Mpa (lbf/in.^{2})
σ_s	Hoop stress in the shell due to impulsive and convective forces of the stored liquid, MPa (lbf/in.^{2}) 08
σ_T	Total combined hoop stress in the shell, MPa (lbf/in.^{2})
μ	Friction coefficient for tank sliding
ρ	Density of fluid, kg/m^3 (lb/ft^3) 07

E.3 Performance Basis

E.3.1 SEISMIC USE GROUP

● The Seismic Use Group (SUG) for the tank shall be specified by the Purchaser. If it is not specified, the SUG shall be assigned to be SUG I.

E.3.1.1 Seismic Use Group III

SUG III tanks are those providing necessary service to facilities that are essential for post-earthquake recovery and essential to the life and health of the public; or, tanks containing substantial quantities of hazardous substances that do not have adequate control to prevent public exposure.

E.3.1.2 Seismic Use Group II

SUG II tanks are those storing material that may pose a substantial public hazard and lack secondary controls to prevent public exposure, or those tanks providing direct service to major facilities.

E.3.1.3 Seismic Use Group I

SUG I tanks are those not assigned to SUGs III or II.

E.3.1.4 Multiple Use

Tanks serving multiple use facilities shall be assigned the classification of the use having the highest SUG.

E.4 Site Ground Motion

Spectral lateral accelerations to be used for design may be based on either "mapped" seismic parameters (zones or contours), "site-specific" procedures, or probabilistic methods as defined by the design response spectra method contained in this appendix. A method for regions outside the USA where ASCE 7 methods for defining the ground motion may not be applicable is also included.

A methodology for defining the design spectrum is given in the following sections.

E.4.1 MAPPED ASCE 7 METHOD

● For sites located in the USA, or where the ASCE 7 method is the regulatory requirement, the maximum considered earthquake ground motion shall be defined as the motion due to an event with a 2% probability of exceedance within a 50-year period. The following definitions apply:

- S_S is the mapped, maximum considered earthquake, 5% damped, spectral response acceleration parameter at short periods (0.2 seconds).
- S_1 is the mapped, maximum considered earthquake, 5% damped, spectral response acceleration parameter at a period of 1 second.

- S_0 is the mapped, maximum considered earthquake, 5% damped, spectral response acceleration parameter at zero seconds (usually referred to as the peak ground acceleration). Unless otherwise specified or determined, S_0 shall be defined as $0.4S_S$ when using the mapped methods.

E.4.2 SITE-SPECIFIC SPECTRAL RESPONSE ACCELERATIONS

The design method for a site-specific spectral response is based on the provisions of ASCE 7. Design using site-specific ground motions should be considered where any of the following apply:

- The tank is located within 10 km (6 miles) of a known active fault.
- The structure is designed using base isolation or energy dissipation systems, which is beyond the scope of this appendix.
- The performance requirements desired by the owner or regulatory body exceed the goal of this appendix.

Site-specific determination of the ground motion is required when the tank is located on Site Class F type soils.

● If design for an MCE site-specific ground motion is desired, or required, the site–specific study and response spectrum shall be provided by the Purchaser as defined this section.

However, in no case shall the ordinates of the site-specific MCE response spectrum defined be less than 80% of the ordinates of the mapped MCE response spectra defined in this appendix.

E.4.2.1 Site-Specific Study

A site-specific study shall account for the regional tectonic setting, geology, and seismicity. This includes the expected recurrence rates and maximum magnitudes of earthquakes on known faults and source zones, the characteristics of ground motion attenuation, near source effects, if any, on ground motions, and the effects of subsurface site conditions on ground motions. The study shall incorporate current scientific interpretations, including uncertainties, for models and parameter values for seismic sources and ground motions.

If there are known active faults identified, the maximum considered seismic spectral response acceleration at any period, $S_a{}^*$, shall be determined using both probabilistic and deterministic methods.

E.4.2.2 Probabilistic Site-Specific MCE Ground Motion

The probabilistic site-specific MCE ground motion shall be taken as that motion represented by a 5% damped acceleration response spectrum having a 2% probability of exceedance in a 50-year period.

E.4.2.3 Deterministic Site-Specific MCE Ground Motion

The deterministic site-specific MCE spectral response acceleration at each period shall be taken as 150% of the largest median 5% damped spectral response acceleration computed at that period for characteristic earthquakes individually acting on all known active faults within the region.

However, the ordinates of the deterministic site-specific MCE ground motion response spectrum shall not be taken lower than the
08 corresponding ordinates of the response spectrum where the value of S_S is equal to $1.5F_a$ and the value of S_1 is equal to $0.6F_v/T$.

● E.4.2.4 Site-Specific MCE Ground Motions

07 The 5% damped site-specific MCE spectral response acceleration at any period, $S_a{}^*$, shall be defined as the lesser of the probabilistic MCE ground motion spectral response accelerations determined in E.4.2.2 and the deterministic MCE ground motion spectral response accelerations defined in E.4.2.3.

The response spectrum values for 0.5% damping for the convective behavior shall be 1.5 times the 5% spectral values unless otherwise specified by the Purchaser.

The values for sites classified as F may not be less than 80% of the values for a Site Class E site.

E.4.3 SITES NOT DEFINED BY ASCE 7 METHODS

In regions outside the USA, where the regulatory requirements for determining design ground motion differ from the ASCE 7 methods prescribed in this appendix, the following methods may be utilized:

1. A response spectrum complying with the regulatory requirements may be used providing it is based on, or adjusted to, a basis of 5% and 0.5% damping as required in this appendix. The values of the design spectral acceleration coefficients, A_i and A_c, which include the effects of site amplification, importance factor and response modification may be determined directly. A_i shall be based on the calculated impulsive period of the tank (see E.4.5.1) using the 5% damped spectra, or the period may be assumed to be 0.2 seconds. A_c shall be based on the calculated convective period (see E.4.5.2) using the 0.5% spectra. 07
2. If no response spectra shape is prescribed and only the peak ground acceleration, S_P, is defined, then the following substitutions shall apply:

$$S_S = 2.5\ S_P \qquad \text{(E.4.3-1)}$$

$$S_1 = 1.25\ S_P \qquad \text{(E.4.3-2)}$$

E.4.4 MODIFICATIONS FOR SITE SOIL CONDITIONS

The maximum considered earthquake spectral response accelerations for peak ground acceleration, shall be modified by the appropriate site coefficients, F_a and F_v from Tables E-1 and E-2.

● Where the soil properties are not known in sufficient detail to determine the site class, Site Class D shall be assumed unless the authority having jurisdiction determines that Site Class E or F should apply at the site.

Table E-1—Value of F_a as a Function of Site Class

	Mapped Maximum Considered Earthquake Spectral Response Accelerations at Short Periods				
Site Class	$S_s \le 0.25$	$S_s = 0.50$	$S_s = 0.75$	$S_s = 1.0$	$S_s \ge 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	a	a	a	a	a

[a]Site-specific geotechnical investigation and dynamic site response analysis is required. 07

Table E-2—Value of F_v as a Function of Site Class

	Mapped Maximum Considered Earthquake Spectral Response Accelerations at 1 Sec Periods				
Site Class	$S_1 \le 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \ge 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	a	a	a	a	a

[a]Site-specific geotechnical investigation and dynamic site response analysis is required. 07

SITE CLASS DEFINITIONS

The Site Classes are defined as follows:

A Hard rock with measured shear wave velocity, $\bar{v}_s > 1500$ m/s (5,000 ft/sec)

B Rock with 760 m/s $< \bar{v}_s \leq 1500$ m/s (2,500 ft/sec $< \bar{v}_s \leq$ 5,000 ft/sec)

C Very dense soil and soft rock with 360 m/s $< \bar{v}_s \leq 760$ m/s (1,200 ft/sec $< \bar{v}_s \leq$ 2,500 ft/sec) or with either $\bar{N} > 50$ or $\bar{s}_u > 100$ kPa (2,000 psf)

D Stiff soil with 180 m/s $\leq \bar{v}_s \leq 360$ m/s (600 ft/sec $\leq \bar{v}_s \leq$ 1,200 ft/sec) or with either $15 \leq \bar{N} \leq 50$ or 50 kPa $\leq \bar{s}_u \leq$ 100 kPa (1,000 psf $\leq \bar{s}_u \leq$ 2,000 psf)

E A soil profile with $\bar{v}_s < 180$ m/s (600 ft/sec) or with either $\bar{N} < 15$, $\bar{s}_u < 50$ kPa (1,000 psf), or any profile with more than 3 m (10 ft) of soft clay defined as soil with $PI > 20$, $w \geq 40\%$, and $\bar{s}_u < 25$ kPa (500 psf)

F Soils requiring site-specific evaluations:

1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils. However, since tanks typically have an impulsive period of 0.5 secs or less, site-specific evaluations are not required but recommended to determine spectral accelerations for liquefiable soils. The Site Class may be determined as noted below, assuming liquefaction does not occur, and the corresponding values of F_a and F_v determined from Tables E-1 and E-2. 07
2. Peats and/or highly organic clays ($H_S > 3$ m [10 ft] of peat and/or highly organic clay, where H = thickness of soil).
3. Very high plasticity clays ($H_S > 8$ m [25 ft] with $PI > 75$).
4. Very thick, soft/medium stiff clays ($H_S > 36$ m [120 ft])

07 The parameters used to define the Site Class are based on the upper 30 m (100 ft) of the site profile. Profiles containing distinctly different soil layers shall be subdivided into those layers designated by a number that ranges from 1 to n at the bottom where there are a total of n distinct layers in the upper 30 m (100 ft). The symbol i then refers to any one of the layers between 1 and n.

where

v_{si} = the shear wave velocity in m/s (ft/sec),

d_i = the *thickness* of any layer (between 0 and 30 m [100 ft]).

$$\bar{v} = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{v_{si}}} \qquad \text{(E.4.4-1)}$$

where

$\sum_{i=1} d_i$ = 30 m (100 ft),

N_i = the Standard Penetration Resistance determined in accordance with ASTM D 1586, as directly measured in the field without corrections, and shall not be taken greater than 100 blows/ft.

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$$\bar{N} = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{N_i}} \qquad \text{(E.4.4-2)}$$

$$\bar{N}_{ch} = \frac{d_s}{\sum_{i=1}^{m} \frac{d_i}{N_i}} \qquad \text{(E.4.4-3)}$$

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where $\sum_{i=1}^{m} d_i = d_s$.

Use only d_i and N_i for cohesionless soils.

d_s = the total thickness of cohesionless soil layers in the top 30 m (100 ft),

s_{ui} = the undrained shear strength in kPa (psf), determined in accordance with ASTM D 2166 or D 2850, and shall not be taken greater than 240 kPa (5,000 psf).

$$\bar{s}_u = \frac{d_c}{\sum_{i=1}^{k} \frac{d_i}{s_{ui}}} \qquad \text{(E.4.4-4)}$$

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where $\sum_{i=1}^{k} d_i = d_c$.

d_c = the total thickness ($100 - d_s$) of cohesive soil layers in the top 30 m (100 ft),

PI = the plasticity index, determined in accordance with ASTM D 4318,

w = the moisture content in %, determined in accordance with ASTM D 2216.

STEPS FOR CLASSIFYING A SITE:

Step 1: Check for the four categories of Site Class F requiring site-specific evaluation. If the site corresponds to any of these categories, classify the site as Site Class F and conduct a site-specific evaluation.

Step 2: Check for the existence of a total thickness of soft clay > 3 m (10 ft) where a soft clay layer is defined by: $s_u < 25$ kPa (500 psf) $w \geq 40\%$, and $PI > 20$. If these criteria are satisfied, classify the site as Site Class E.

Step 3: Categorize the site using one of the following three methods with $\bar{v}_s$, $\bar{N}$, and $\bar{s}_u$ computed in all cases see Table E-3:

a. $\bar{v}_s$ for the top 30 m (100 ft) ($\bar{v}_s$ method).

b. $\bar{N}$ for the top 30 m (100 ft) ($\bar{N}$ method).

c. $\bar{N}$ for cohesionless soil layers ($PI < 20$) in the top 30 m (100 ft) and average $\bar{s}_u$ for cohesive soil layers ($PI > 20$) in the top 30 m (100 ft) ($\bar{s}_u$ method).

Table E-3—Site Classification

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Site Class	$\bar{v}_s$	$\bar{N}$ or $\bar{N}_{ch}$	$\bar{s}_u$
E	(< 180 m/s) (< 600 fps)	< 15	< 50 kPa (< 1,000 psf)
D	180 m/s – 360 m/s (600 to 1,200 fps)	15 to 50	50 kPa – 100 kPa (1,000 psf – 2,000 psf)
C	360 m/s – 760 m/s (1,200 fps – 2,500 fps)	> 50	100 kPa (> 2,000 psf)
B	760 m/s – 1500 m/s (2,500 fps – 5,000 fps)		
A	> 1500 m/s (5,000 fps)		

Note: [a] If the $\bar{s}_u$ method is used and the $\bar{N}_{ch}$ and $\bar{s}_u$ criteria differ, select the category with the softer soils (for example, use Site Class E instead of D).

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Assignment of Site Class B shall be based on the shear wave velocity for rock. For competent rock with moderate fracturing and weathering, estimation of this shear wave velocity shall be permitted. For more highly fractured and weathered rock, the shear wave velocity shall be directly measured or the site shall be assigned to Site Class C.

Assignment of Site Class A shall be supported by either shear wave velocity measurements on site or shear wave velocity measurements on profiles of the same rock type in the same formation with an equal or greater degree of weathering and fracturing. Where hard rock conditions are known to be continuous to a depth of 30 m (100 ft), surficial shear wave velocity measurements may be extrapolated to assess $\overline{v}_s$.

Site Classes A and B shall not be used where there is more than 3 m (10 ft) of soil between the rock surface and the bottom of the tank foundation.

E.4.5 STRUCTURAL PERIOD OF VIBRATION

The pseudo-dynamic modal analysis method utilized in this appendix is based on the natural period of the structure and contents as defined in this section.

E.4.5.1 Impulsive Natural Period

The design methods in this appendix are independent of impulsive period of the tank. However, the impulsive period of the tank system may be estimated by Equation E.4.5.1-1.

In SI units:

$$T_i = \left(\frac{1}{\sqrt{2000}}\right)\left(\frac{C_i H}{\sqrt{\frac{t_u}{D}}}\right)\left(\frac{\sqrt{\rho}}{\sqrt{E}}\right) \qquad \text{(E.4.5.1-1a)}$$

Substituting the SI units specified above: $T_i = 0.128$ sec.

09 In US Customary units:

$$T_i = \left(\frac{1}{27.8}\right)\left(\frac{C_i H}{\sqrt{\frac{t_u}{D}}}\right)\left(\frac{\sqrt{\rho}}{\sqrt{E}}\right) \qquad \text{(E.4.5.1-1b)}$$

Substituting the US Customary units specified above: $T_i = 0.128$ sec.

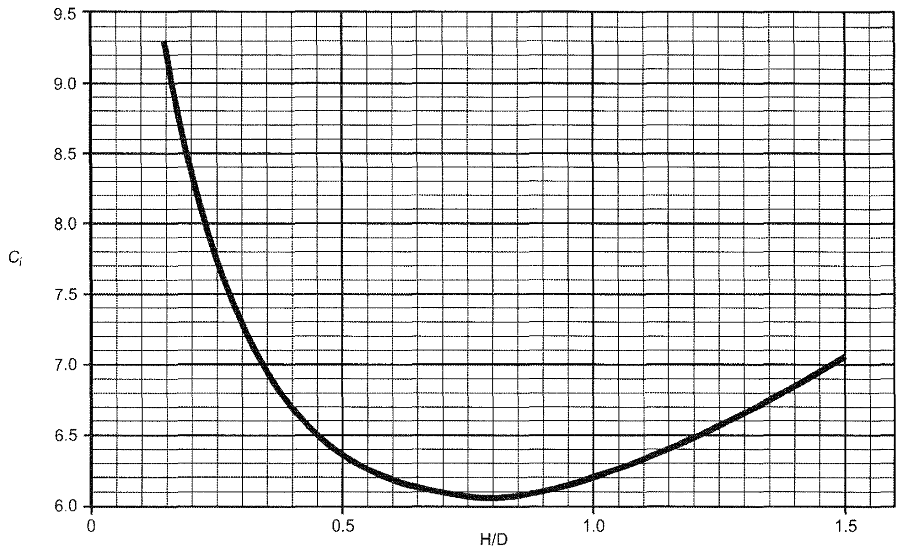

Figure E-1—Coefficient C_i

E.4.5.2 Convective (Sloshing) Period

The first mode sloshing wave period, in seconds, shall be calculated by Equation E.4.5.2 where K_s is the sloshing period coefficient defined in Equation E.4.5.2-c:

In SI units:

$$T_c = 1.8K_s\sqrt{D} \qquad \text{(E.4.5.2-a)}$$

or, in US Customary units:

$$T_c = K_s\sqrt{D} \qquad \text{(E.4.5.2-b)}$$

$$K_s = \frac{0.578}{\sqrt{\tanh\left(\frac{3.68H}{D}\right)}} \qquad \text{(E.4.5.2-c)}$$

E.4.6 DESIGN SPECTRAL RESPONSE ACCELERATIONS

The design response spectrum for ground supported, flat-bottom tanks is defined by the following parameters:

E.4.6.1 Spectral Acceleration Coefficients

When probabilistic or mapped design methods are utilized, the spectral acceleration parameters for the design response spectrum are given in Equations E.4.6.1-1 through E.4.6.1-5. Unless otherwise specified by the Purchaser, T_L shall be taken as the mapped value found in ASCE 7. For tanks falling in SUG I or SUG II, the mapped value of T_L shall be used to determine convective forces except that a value of T_L equal to 4 seconds shall be permitted to be used to determine the sloshing wave height. For tanks falling in SUG III, the mapped value of T_L shall be used to determine both convective forces and sloshing wave height except that the importance factor, I, shall be set equal to 1.0 in the determination of sloshing wave height. In regions outside the USA, where the regulatory requirements for determining design ground motion differ from the ASCE 7 methods prescribed in this appendix, T_L shall be taken as 4 seconds. 07

For sites where only the peak ground acceleration is defined, substitute S_P for S_0 in Equations E.4.6.1-1 through E.4.6.2-1. The scaling factor, Q, is defined as $^2/_3$ for the ASCE 7 methods. Q may be taken equal to 1.0 unless otherwise defined in the regulatory requirements where ASCE 7 does not apply. Soil amplification coefficients, F_a and F_v; the value of the importance factor, I; and the ASD response modification factors, R_{wi} and R_{wc}, shall be as defined by the local regulatory requirements. If these values are not defined by the regulations, the values in this appendix shall be used. 07

Impulsive spectral acceleration parameter, A_i:

$$A_i = S_{DS}\left(\frac{I}{R_{wi}}\right) = 2.5QF_aS_0\left(\frac{I}{R_{wi}}\right) \qquad \text{(E.4.6.1-1)}$$

However,

$$A_i \geq 0.007 \qquad \text{(E.4.6.1-2)}$$

and, for seismic site Classes E and F only:

$$A_i \geq 0.5S_1\left(\frac{I}{R_{wi}}\right) = 0.625S_P\left(\frac{I}{R_{wi}}\right) \qquad \text{(E.4.6.1-3)}$$

Convective spectral acceleration parameter, A_c:

08

When, $T_C \leq T_L$

$$A_c = KS_{D1}\left(\frac{1}{T_c}\right)\left(\frac{I}{R_{wc}}\right) = 2.5KQF_aS_0\left(\frac{T_s}{T_c}\right)\left(\frac{I}{R_{wc}}\right) \leq A_i \qquad \text{(E.4.6.1-4)}$$

When, $T_C > T_L$

$$A_c = KS_{D1}\left(\frac{T_L}{T_c^2}\right)\left(\frac{I}{R_{wc}}\right) = 2.5KQF_aS_0\left(\frac{T_sT_L}{T_c^2}\right)\left(\frac{I}{R_{wc}}\right) \leq A_i \qquad \text{(E.4.6.1-5)}$$

E.4.6.2 Site-Specific Response Spectra

07 When site-specific design methods are specified, the seismic parameters shall be defined by Equations E.4.6.2-1 through E.4.6.2-3.

Impulsive spectral acceleration parameter:

$$A_i = 2.5Q\left(\frac{I}{R_{wi}}\right)S_{a0}^* \qquad \text{(E.4.6.2-1)}$$

Alternatively, A_i, may be determined using either (1) the impulsive period of the tank system, or (2) assuming the impulsive period = 0.2 sec;

$$A_i = Q\left(\frac{I}{R_{wi}}\right)S_a^* \qquad \text{(E.4.6.2-2)}$$

where, S_a^* is the ordinate of the 5% damped, site-specific MCE response spectra at the calculated impulsive period including site
07 soil effects. See E.4.5.1.

Exception:

● Unless otherwise specified by the Purchaser, the value of the impulsive spectral acceleration, S_a*, for flat-bottom tanks with $H/D \leq 0.8$ need not exceed 150%*g* when the tanks are:

- self-anchored, or
- mechanically-anchored tanks that are equipped with traditional anchor bolt and chairs at least 450 mm (18 in.) high and are not otherwise prevented from sliding laterally at least 25 mm (1 in.).

Convective spectral acceleration:

08

$$A_c = QK\left(\frac{I}{R_{wc}}\right)S_a^* < A_i \qquad \text{(E.4.6.2-3)}$$

where, S_a^* is the ordinate of the 5% damped, site-specific MCE response spectra at the calculated convective period including site
07 soil effects (see E.4.5.2).

Alternatively, the ordinate of a site-specific spectrum based on the procedures of E.4.2 for 0.5% damping may be used to determine the value S_a^* with K set equal to 1.0.

E.5 Seismic Design Factors

E.5.1 DESIGN FORCES

The equivalent lateral seismic design force shall be determined by the general relationship

$$F = AW_{\text{eff}} \qquad \text{(E.5.1-1)}$$

where

A = lateral acceleration coefficient, %g,
W_{eff} = effective weight.

E.5.1.1 Response Modification Factor

The response modification factor for ground supported, liquid storage tanks designed and detailed to these provisions shall be less than or equal to the values shown in Table E-4.

Table E-4—Response Modification Factors for ASD Methods

Anchorage system	R_{wi}, (impulsive)	R_{wc}, (convective)
Self-anchored	3.5	2
Mechanically-anchored	4	2

E.5.1.2 Importance Factor

● The importance factor (I) is defined by the SUG and shall be specified by the Purchaser. See E.3 and Table E-5.

Table E-5—Importance Factor (I) and Seismic Use Group Classification

Seismic Use Group	I
I	1.0
II	1.25
III	1.5

08

E.6 Design

E.6.1 DESIGN LOADS

Ground-supported, flat-bottom tanks, storing liquids shall be designed to resist the seismic forces calculated by considering the effective mass and dynamic liquid pressures in determining the equivalent lateral forces and lateral force distribution. This is the default method for this appendix. The equivalent lateral force base shear shall be determined as defined in the following sections. The seismic base shear shall be defined as the square root of the sum of the squares (SRSS) combination of the impulsive and convective components unless the applicable regulations require direct sum. For the purposes of this appendix, an alternate method using the direct sum of the effects in one direction combined with 40% of the effect in the orthogonal direction is deemed to be equivalent to the SRSS summation.

$$V = \sqrt{V_i^2 + V_c^2} \qquad \text{(E.6.1-1)}$$

where

$$V_i = A_i(W_s + W_r + W_f + W_i) \qquad \text{(E.6.1-2)}$$

$$V_c = A_c W_c \qquad \text{(E.6.1-3)}$$

E.6.1.1 Effective Weight of Product

The effective weights W_i and W_c shall be determined by multiplying the total product weight, W_p, by the ratios W_i/W_p and W_c/W_p, respectively, Equations E.6.1.1-1 through E.6.1.1-3.

When D/H is greater than or equal to 1.333, the effective impulsive weight is defined in Equation E.6.1.1-1:

$$W_i = \frac{\tanh\left(0.866\frac{D}{H}\right)}{0.866\frac{D}{H}} W_p \qquad \text{(E.6.1.1-1)}$$

When D/H is less than 1.333, the effective impulsive weight is defined in Equation E.6.1.1-2:

$$W_i = \left[1.0 - 0.218\frac{D}{H}\right] W_p \qquad \text{(E.6.1.1-2)}$$

The effective convective weight is defined in Equation E.6.1.1-3:

08 $$W_c = 0.230\frac{D}{H}\tanh\left(\frac{3.67H}{D}\right)W_p \qquad \text{(E.6.1.1-3)}$$

E.6.1.2 Center of Action for Effective Lateral Forces

The moment arm from the base of the tank to the center of action for the equivalent lateral forces from the liquid is defined by
07 Equations E.6.1.2.1-1 through E.6.1.2.2-3.

The center of action for the impulsive lateral forces for the tank shell, roof and appurtenances is assumed to act through the center of gravity of the component.

E.6.1.2.1 Center of Action for Ringwall Overturning Moment

The ringwall moment, M_{rw}, is the portion of the total overturning moment that acts at the base of the tank shell perimeter. This moment is used to determine loads on a ringwall foundation, the tank anchorage forces, and to check the longitudinal shell compression.

The heights from the bottom of the tank shell to the center of action of the lateral seismic forces applied to W_i and W_c, X_i and X_c, may be determined by multiplying H by the ratios X_i/H and X_c/H, respectively, obtained for the ratio D/H by using Equations
08 E.6.1.2.1-1 through E.6.1.2.2-3.

When D/H is greater than or equal to 1.3333, the height X_i is determined by Equation E.6.1.2.1-1:

$$X_i = 0.375H \qquad \text{(E.6.1.2.1-1)}$$

When D/H is less than 1.3333, the height X_i is determined by Equation E.6.1.2.1-2:

$$X_i = \left[0.5 - 0.094\frac{D}{H}\right]H \qquad \text{(E.6.1.2.1-2)}$$

The height X_c is determined by Equation E.6.1.2.1-3:

07 $$X_c = \left[1.0 - \frac{\cosh\left(\frac{3.67H}{D}\right) - 1}{\frac{3.67H}{D}\sinh\left(\frac{3.67H}{D}\right)}\right]H \qquad \text{(E.6.1.2.1-3)}$$

E.6.1.2.2 Center of Action for Slab Overturning Moment

The "slab" moment, M_s, is the total overturning moment acting across the entire tank base cross-section. This overturning moment is used to design slab and pile cap foundations.

When D/H is greater than or equal to 1.333, the height X_{is} is determined by Equation E.6.1.2.2-1:

$$X_{is} = 0.375\left[1.0 + 1.333\left(\frac{0.866\frac{D}{H}}{\tanh\left(0.866\frac{D}{H}\right)} - 1.0\right)\right]H \qquad \text{(E.6.1.2.2-1)}$$

When D/H is less than 1.333, the height X_{is} is determined by Equation E.6.1.2.2-2:

07 $$X_{is} = \left[0.500 + 0.060\frac{D}{H}\right]H \qquad \text{(E.6.1.2.2-2)}$$

The height, X_{cs}, is determined by Equation E.6.1.2.2-3:

$$X_{cs} = \left[1.0 - \frac{\cosh\left(\frac{3.67H}{D}\right) - 1.937}{\frac{3.67H}{D}\sinh\left(\frac{3.67H}{D}\right)} \right] H \qquad \text{(E.6.1.2.2-3)}$$

07

E.6.1.3 Vertical Seismic Effects

● When specified (see Line 8 in the Data Sheet), vertical acceleration effects shall be considered as acting in both upward and downward directions and combined with lateral acceleration effects by the SRSS method unless a direct sum combination is required by the applicable regulations. Vertical acceleration effects for hydrodynamic hoop stresses shall be combined as shown in E.6.1.4. Vertical acceleration effects need not be combined concurrently for determining loads, forces, and resistance to overturning in the tank shell. 09 07

● The maximum vertical seismic acceleration parameter shall be taken as $0.14S_{DS}$ or greater for the ASCE 7 method unless otherwise specified by the Purchaser. Alternatively, the Purchaser may specify the vertical ground motion acceleration parameter, A_v. The total vertical seismic force shall be:

$$F_v = \pm A_v W_{\text{eff}} \qquad \text{(E.6.1.3-1)}$$

Vertical seismic effects shall be considered in the following when specified:

- Shell hoop tensile stresses (see E.6.1.4).
- Shell-membrane compression (see E.6.2.2).
- Anchorage design (see E.6.2.1).
- Fixed roof components (see E.7.5).
- Sliding (see E.7.6).
- Foundation design (see E.6.2.3).

● In regions outside the USA where the regulatory requirements differ from the methods prescribed in this appendix, the vertical acceleration parameter and combination with lateral effects may be applied as defined by the governing regulatory requirements.

E.6.1.4 Dynamic Liquid Hoop Forces

Dynamic hoop tensile stresses due to the seismic motion of the liquid shall be determined by the following formulas:

For $D/H \geq 1.333$:

In SI units:

$$N_i = 8.48A_iGDH\left[\frac{Y}{H} - 0.5\left(\frac{Y}{H}\right)^2\right]\tanh\left(0.866\frac{D}{H}\right) \qquad \text{(E.6.1.4-1a)}$$

or, in US Customary units:

$$N_i = 4.5A_iGDH\left[\frac{Y}{H} - 0.5\left(\frac{Y}{H}\right)^2\right]\tanh\left(0.866\frac{D}{H}\right) \qquad \text{(E.6.1.4-1b)}$$

08

For $D/H < 1.33$ and $Y < 0.75D$:

In SI units:

$$N_i = 5.22A_iGD^2\left[\frac{Y}{0.75D} - 0.5\left(\frac{Y}{0.75D}\right)^2\right] \qquad \text{(E.6.1.4-2a)}$$

or, in US Customary units:

$$N_i = 2.77A_iGD^2\left[\frac{Y}{0.75D} - 0.5\left(\frac{Y}{0.75D}\right)^2\right] \qquad \text{(E.6.1.4-2b)}$$

For $D/H < 1.333$ and $Y \geq 0.75D$:

In SI units:

$$N_i = 2.6A_iGD^2 \qquad \text{(E.6.1.4-3a)}$$

or, in US Customary units:

08

$$N_i = 1.39A_iGD^2 \qquad \text{(E.6.1.4-3b)}$$

For all proportions of D/H:

In SI units:

$$N_c = \frac{1.85A_cGD^2\cosh\left[\frac{3.68(H-Y)}{D}\right]}{\cosh\left[\frac{3.68H}{D}\right]} \qquad \text{(E.6.1.4-4a)}$$

or, in US Customary units:

$$N_c = \frac{0.98A_cGD^2\cosh\left[\frac{3.68(H-Y)}{D}\right]}{\cosh\left[\frac{3.68H}{D}\right]} \qquad \text{(E.6.1.4-4b)}$$

07 When the Purchaser specifies that vertical acceleration need not be considered (i.e., $A_v = 0$), the combined hoop stress shall be defined by Equation E.6.1.4-5. The dynamic hoop tensile stress shall be directly combined with the product hydrostatic design stress in determining the total stress.

$$\sigma_T = \sigma_h \pm \sigma_s = \frac{N_h \pm \sqrt{N_i^2 + N_c^2}}{t} \qquad \text{(E.6.1.4-5)}$$

07 When vertical acceleration is specified.

$$\sigma_T = \sigma_h \pm \sigma_s = \frac{N_h \pm \sqrt{N_i^2 + N_c^2 + (A_vN_h)^2}}{t} \qquad \text{(E.6.1.4-6)}$$

E.6.1.5 Overturning Moment

- The seismic overturning moment at the base of the tank shell shall be the SRSS summation of the impulsive and convective components multiplied by the respective moment arms to the center of action of the forces unless otherwise specified.

Ringwall Moment, M_{rw}:

$$M_{rw} = \sqrt{[A_i(W_iX_i + W_sX_s + W_rX_r)]^2 + [A_c(W_cX_c)]^2} \qquad \text{(E.6.1.5-1)}$$

Slab Moment, M_s:

$$M_s = \sqrt{[A_i(W_iX_{is} + W_sX_s + W_rX_r)]^2 + [A_c(W_cX_{cs})]^2} \qquad \text{(E.6.1.5-2)}$$

Unless a more rigorous determination is used, the overturning moment at the bottom of each shell ring shall be defined by linear approximation using the following:

1. If the tank is equipped with a fixed roof, the impulsive shear and overturning moment is applied at the top of the shell.
2. The impulsive shear and overturning moment for each shell course is included based on the weight and centroid of each course.
3. The overturning moment due to the liquid is approximated by a linear variation that is equal to the ringwall moment, M_{rw} at the base of the shell to zero at the maximum liquid level. 07

E.6.1.6 Soil-Structure Interaction 07

● If specified by the Purchaser, the effects of soil-structure interaction on the effective damping and period of vibration may be considered for tanks in accordance with ASCE 7 with the following limitations:

- Tanks shall be equipped with a reinforced concrete ringwall, mat or similar type foundation supported on grade. Soil structure interaction effects for tanks supported on granular berm or pile type foundation are outside the scope of this appendix.
- The tanks shall be mechanically anchored to the foundation.
- The value of the base shear and overturning moments for the impulsive mode including the effects of soil-structure interaction shall not be less than 80% of the values determined without consideration of soil-structure interaction.
- The effective damping factor for the structure-foundation system shall not exceed 20%.

E.6.2 RESISTANCE TO DESIGN LOADS

The allowable stress design (ASD) method is utilized in this appendix. Allowable stresses in structural elements applicable to normal operating conditions may be increased by 33% when the effects of the design earthquake are included unless otherwise specified in this appendix.

E.6.2.1 Anchorage

Resistance to the design overturning (ringwall) moment at the base of the shell may be provided by:

- The weight of the tank shell, weight of roof reaction on shell W_{rs}, and by the weight of a portion of the tank contents adjacent to the shell for unanchored tanks.
- Mechanical anchorage devices.

E.6.2.1.1 Self-Anchored

For self-anchored tanks, a portion of the contents may be used to resist overturning. The anchorage provided is dependent on the assumed width of a bottom annulus uplifted by the overturning moment. The resisting annulus may be a portion of the tank bottom or a separate butt-welded annular ring. The overturning resisting force of the annulus that lifts off the foundation shall be determined by Equation E.6.2.1.1-1 except as noted below:

In SI units:

$$v_a = 99t_a\sqrt{F_yHG_e} \le 201.1\ HDG_e \qquad \text{(E.6.2.1.1-1a)}$$

or, in US Customary units:

$$w_a = 7.9t_a\sqrt{F_yHG_e} \le 1.28\ HDG_e \qquad \text{(E.6.2.1.1-1b)}$$

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Equation E.6.2.1.1-1 for w_a applies whether or not a thickened bottom annulus is used. If w_a exceeds the limit of 201.1 HDG_e, (1.28 HDG_e) the value of L shall be set to 0.035D and the value of w_a shall be set equal to 201.1 HDG_e, (1.28 HDG_e). A value of L defined as L_s that is less than that determined by the equation found in E.6.2.1.1.2-1 may be used. If a reduced value L_s is used, a reduced value of w_a shall be used as determined below:

In SI units:

$$w_a = 5742\ HG_eL_s \qquad \text{(E.6.2.1.1-2a)}$$

In US Customary units

$$w_a = 36.5\ HG_eL_s \qquad \text{(E.6.2.1.1-2b)}$$

The tank is self-anchored providing the following conditions are met:

1. The resisting force is adequate for tank stability (i.e., the anchorage ratio, $J \leq 1.54$).
2. The maximum width of annulus for determining the resisting force is 3.5% of the tank diameter.
3. The shell compression satisfies E.6.2.2.
4. 08 The required annulus plate thickness does not exceed the thickness of the bottom shell course.
5. Piping flexibility requirements are satisfied.

E.6.2.1.1.1 Anchorage Ratio, *J*

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$$J = \frac{M_{rw}}{D^2[w_t(1-0.4A_v)+w_a-0.4w_{int}]} \qquad \text{(E.6.2.1.1.1-1)}$$

where

$$w_t = \left[\frac{W_s}{\pi D}+w_{rs}\right] \qquad \text{(E.6.2.1.1.1-2)}$$

Table E-6—Anchorage Ratio Criteria

Anchorage Ratio *J*	Criteria
$J \leq 0.785$	No calculated uplift under the design seismic overturning moment. The tank is self-anchored.
$0.785 < J \leq 1.54$	Tank is uplifting, but the tank is stable for the design load providing the shell compression requirements are satisfied. Tank is self-anchored.
$J > 1.54$	Tank is not stable and cannot be self-anchored for the design load. Modify the annular ring if $L < 0.035D$ is not controlling or add mechanical anchorage.

E.6.2.1.1.2 Annular Ring Requirements

The thickness of the tank bottom plate provided under the shell may be greater than or equal to the thickness of the general tank bottom plate with the following restrictions.

Note: In thickening the bottom annulus, the intent is not to force a thickening of the lowest shell course, thereby inducing an abrupt thickness change in the shell, but rather to impose a limit on the bottom annulus thickness based on the shell design.

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1. The thickness, t_a, corresponding with the final w_a in Equations E.6.2.1.1.1-1 and E.6.2.1.1.1-2 shall not exceed the first shell course thickness, t_s, less the shell corrosion allowance.
2. Nor shall the thickness, t_a, used in Equation E.6.2.1.1.1-1 and E.6.2.1.1.1-2 exceed the actual thickness of the plate under the shell less the corrosion allowance for tank bottom.
3. When the bottom plate under the shell is thicker than the remainder of the tank bottom, the minimum projection, L, of the supplied thicker annular ring inside the tank wall shall be the greater of 0.45 m (1.5 ft) or as determined in equation (E.6.2.1.1.2-1); however, L need not be greater than 0.035 D: 09

In SI units:

08

$$L = 0.01723t_a\sqrt{F_y/(HG_e)} \qquad \text{(E.6.2.1.1.2-1a)}$$

or, in US Customary units:

$$L = 0.216t_a\sqrt{F_y/(HG_e)} \qquad \text{(E.6.2.1.1.2-1b)}$$

E.6.2.1.2 Mechanically-Anchored

• If the tank configuration is such that the self-anchored requirements can not be met, the tank must be anchored with mechanical devices such as anchor bolts or straps.

When tanks are anchored, the resisting weight of the product shall not be used to reduce the calculated uplift load on the anchors. The anchors shall be sized to provide for at least the following minimum anchorage resistance:

$$w_{AB} = \left(\frac{1.273M_{rw}}{D^2} - w_t(1-0.4A_v)\right) \qquad \text{(E.6.2.1.2-1)}$$

plus the uplift, in N/m (lbf/ft) of shell circumference, due to design internal pressure. See Appendix R for load combinations. Wind loading need not be considered in combination with seismic loading. 11

The anchor seismic design load, P_{AB}, is defined in Equation E.6.2.1.2-2:

$$P_{AB} = w_{AB}\left(\frac{\pi D}{n_A}\right) \qquad \text{(E.6.2.1.2-2)}$$

where, n_A is the number of equally-spaced anchors around the tank circumference. P_{AB} shall be increased to account for unequal spacing.

When mechanical anchorage is required, the anchor embedment or attachment to the foundation, the anchor attachment assembly and the attachment to the shell shall be designed for P_A. The anchor attachment design load, P_A, shall be the lesser of the load equal to the minimum specified yield strength multiplied by the nominal root area of the anchor or three times P_{AB}. 11

The maximum allowable stress for the anchorage parts shall not exceed the following values for anchors designed for the seismic loading alone or in combination with other load cases:

- An allowable tensile stress for anchor bolts and straps equal to 80% of the published minimum yield stress.
- For other parts, 133% of the allowable stress in accordance with 5.12.8. 11
- The maximum allowable design stress in the shell at the anchor attachment shall be limited to 170 MPa (25,000 lbf/in.^{2}) with no increase for seismic loading. These stresses can be used in conjunction with other loads for seismic loading when the combined loading governs. 08

E.6.2.2 Maximum Longitudinal Shell-Membrane Compression Stress

E.6.2.2.1 Shell Compression in Self-Anchored Tanks

The maximum longitudinal shell compression stress at the bottom of the shell when there is no calculated uplift, $J < 0.785$, shall be determined by the formula

In SI units:

$$\sigma_c = \left(w_t(1+0.4A_v) + \frac{1.273M_{rw}}{D^2}\right)\frac{1}{1000t_s} \qquad \text{(E.6.2.2.1-1a)}$$

or, in US Customary units:

$$\sigma_c = \left(w_t(1+0.4A_v) + \frac{1.273M_{rw}}{D^2}\right)\frac{1}{12t_s} \qquad \text{(E.6.2.2.1-1b)}$$

The maximum longitudinal shell compression stress at the bottom of the shell when there is calculated uplift, $J > 0.785$, shall be determined by the formula:

In SI units:

$$\sigma_c = \left(\frac{w_t(1+0.4A_v)+w_a}{0.607-0.18667[J]^{2.3}} - w_a\right)\frac{1}{1000t_s} \qquad \text{(E.6.2.2.1-2a)}$$

or, in US Customary units:

$$\sigma_c = \left(\frac{w_t(1+0.4A_v)+w_a}{0.607-0.18667[J]^{2.3}} - w_a\right)\frac{1}{12t_s} \qquad \text{(E.6.2.2.1-2b)}$$

E.6.2.2.2 Shell Compression in Mechanically-Anchored Tanks

The maximum longitudinal shell compression stress at the bottom of the shell for mechanically-anchored tanks shall be determined by the formula

In SI units:

$$\sigma_c = \left(w_t(1+0.4A_v) + \frac{1.273M_{rw}}{D^2}\right)\frac{1}{1000t_s} \qquad \text{(E.6.2.2.2-1a)}$$

or, in US Customary units:

$$\sigma_c = \left(w_t(1+0.4A_v) + \frac{1.273M_{rw}}{D^2}\right)\frac{1}{12t_s} \qquad \text{(E.6.2.2.2-1b)}$$

E.6.2.2.3 Allowable Longitudinal Shell-Membrane Compression Stress in Tank Shell

The maximum longitudinal shell compression stress s_c must be less than the seismic allowable stress F_C, which is determined by the following formulas and includes the 33% increase for ASD. These formulas for F_C, consider the effect of internal pressure due to the liquid contents.

08 When GHD^2/t^2 is ≥44 (SI units) (10^6 US Customary units),

In SI units:

$$F_C = 83\, t_s/D \qquad \text{(E.6.2.2.3-1a)}$$

or, in US Customary units:

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$$F_C = 10^6\, t_s/D \qquad \text{(E.6.2.2.3-1b)}$$

In SI units:

When GHD^2/t^2 is <44:

08

$$F_C = 83t_s/(2.5D) + 7.5\sqrt{(GH)} < 0.5F_{ty} \qquad \text{(E.6.2.2.3-2a)}$$

or, in US Customary units:

When GHD^2/t^2 is less than 1×10^6:

07

$$F_C = 10^6\, t_s/(2.5D) + 600\sqrt{(GH)} < 0.5F_{ty} \qquad \text{(E.6.2.2.3-2b)}$$

If the thickness of the bottom shell course calculated to resist the seismic overturning moment is greater than the thickness required for hydrostatic pressure, both excluding any corrosion allowance, then the calculated thickness of each upper shell course for hydrostatic pressure shall be increased in the same proportion, unless a special analysis is made to determine the seismic overturning moment and corresponding stresses at the bottom of each upper shell course (see E.6.1.5).

E.6.2.3 Foundation

Foundations and footings for mechanically-anchored flat-bottom tanks shall be proportioned to resist peak anchor uplift and overturning bearing pressure. Product and soil load directly over the ringwall and footing may be used to resist the maximum anchor uplift on the foundation, provided the ringwall and footing are designed to carry this eccentric loading.

Product load shall not be used to reduce the anchor load.

When vertical seismic accelerations are applicable, the product load directly over the ringwall and footing:

1. When used to resist the maximum anchor uplift on the foundation, the product pressure shall be multiplied by a factor of $(1 - 0.4A_v)$ and the foundation ringwall and footing shall be designed to resist the eccentric loads with or without the vertical seismic accelerations.

2. When used to evaluate the bearing (downward) load, the product pressure over the ringwall shall be multiplied by a factor of $(1 + 0.4A_v)$ and the foundation ringwall and footing shall be designed to resist the eccentric loads with or without the vertical seismic accelerations.

The overturning stability ratio for mechanically-anchored tank system excluding vertical seismic effects shall be 2.0 or greater as defined in Equation E.6.2.3-1.

$$\frac{0.5D[W_p + W_f + W_T + W_{fd} + W_g]}{M_s} \geq 2.0 \qquad \text{(E.6.2.3-1)}$$

Ringwalls for self-anchored flat-bottom tanks shall be proportioned to resist overturning bearing pressure based on the maximum longitudinal shell compression force at the base of the shell in Equation E.6.2.3-2. Slabs and pile caps for self-anchored tanks shall be designed for the peak loads determined in E.6.2.2.1.

$$P_f = \left(w_t(1 + 0.4A_v) + \frac{1.273M_{rw}}{D^2}\right) \qquad \text{(E.6.2.3-2)}$$

E.6.2.4 Hoop Stresses

The maximum allowable hoop tension membrane stress for the combination of hydrostatic product and dynamic membrane hoop effects shall be the lesser of:

- The basic allowable membrane in this Standard for the shell plate material increased by 33%; or,
- $0.9F_y$ times the joint efficiency where F_y is the lesser of the published minimum yield strength of the shell material or weld material.

E.7 Detailing Requirements

E.7.1 ANCHORAGE

Tanks at grade are permitted to be designed without anchorage when they meet the requirements for self-anchored tanks in this appendix.

The following special detailing requirements shall apply to steel tank mechanical anchors in seismic regions where $S_{DS} > 0.05g$.

E.7.1.1 Self-Anchored

For tanks in SUG III and located where $S_{DS} = 0.5g$ or greater, butt-welded annular plates shall be required. Annular plates exceeding 10 mm ($^3/_8$ in.) thickness shall be butt-welded. The weld of the shell to the bottom annular plate shall be checked for the design uplift load.

E.7.1.2 Mechanically-Anchored

When mechanical-anchorage is required, at least six anchors shall be provided. The spacing between anchors shall not exceed 3 m (10 ft).

When anchor bolts are used, they shall have a corroded shank diameter of no less than 25 mm (1 in.). Carbon steel anchor straps shall have a nominal thickness of not less than 6 mm ($^1/_4$ in.) and shall have a minimum corrosion allowance of 1.5 mm ($^1/_{16}$ in.) on each surface for a distance at least 75 mm (3 in.) but not more than 300 mm (12 in.) above the surface of the concrete. 11

Hooked anchor bolts (L- or J-shaped embedded bolts) or other anchorage systems based solely on bond or mechanical friction shall not be used when seismic design is required by this appendix. Post-installed anchors may be used provided that testing validates their ability to develop yield load in the anchor under cyclic loads in cracked concrete and meet the requirements of ACI 355.

E.7.2 FREEBOARD

- Sloshing of the liquid within the tank or vessel shall be considered in determining the freeboard required above the top capacity liquid level. A minimum freeboard shall be provided per Table E-7. See E.4.6.1. Purchaser shall specify whether freeboard is desired for SUG I tanks. Freeboard is required for SUG II and SUG III tanks. The height of the sloshing wave above the product design height can be estimated by:

07 $$\delta_s = 0.5DA_f \text{ (see Note c in Table E-7)} \qquad \text{(E.7.2-1)}$$

For SUG I and II,

When, $T_C \leq 4$ $$A_f = KS_{D1}I\left(\frac{1}{T_C}\right) = 2.5KQF_aS_0I\left(\frac{T_S}{T_C}\right) \qquad \text{(E.7.2-2)}$$

08

When, $T_C > 4$ $$A_f = KS_{D1}I\left(\frac{4}{T_C^2}\right) = 2.5KQF_aS_0I\left(\frac{4T_S}{T_C^2}\right) \qquad \text{(E.7.2-3)}$$

For SUG III,

When, $T_C \leq T_L$ $$A_f = KS_{D1}\left(\frac{1}{T_C}\right) = 2.5KQF_aS_0\left(\frac{T_S}{T_C}\right) \qquad \text{(E.7.2-4)}$$

08

When, $T_C > T_L$ $$A_f = KS_{D1}\left(\frac{T_L}{T_C^2}\right) = 2.5KQF_aS_0\left(\frac{T_ST_L}{T_C^2}\right) \qquad \text{(E.7.2-5)}$$

Table E-7—Minimum Required Freeboard

Value of S_{DS}	SUG I	SUG II	SUG III
08 $S_{DS} < 0.33g$	*(a)*	*(a)*	δ_s *(c)*
08 $S_{DS} \geq 0.33g$	*(a)*	$0.7\delta_s$ *(b)*	δ_s *(c)*

a. A freeboard of $0.7\delta_s$ is recommended for economic considerations but not required.
b. A freeboard equal to $0.7\delta_s$ is required unless one of the following alternatives are provided:
  1. Secondary containment is provided to control the product spill.
  2. The roof and tank shell are designed to contain the sloshing liquid.
c. Freeboard equal to the calculated wave height, δ_s, is required unless one of the following alternatives are provided:
  1. Secondary containment is provided to control the product spill.
  2. The roof and tank shell are designed to contain the sloshing liquid.

E.7.3 PIPING FLEXIBILITY

Piping systems connected to tanks shall consider the potential movement of the connection points during earthquakes and provide sufficient flexibility to avoid release of the product by failure of the piping system. The piping system and supports shall be designed so as to not impart significant mechanical loading on the attachment to the tank shell. Local loads at piping connections shall be considered in the design of the tank shell. Mechanical devices which add flexibility such as bellows, expansion joints, and other flexible apparatus may be used when they are designed for seismic loads and displacements.

Unless otherwise calculated, piping systems shall provide for the minimum displacements in Table E-8 at working stress levels (with the 33% increase for seismic loads) in the piping, supports and tank connection. The piping system and tank connection 07 shall also be designed to tolerate $1.4C_d$ times the working stress displacements given in Table E-8 without rupture, although permanent deformations and inelastic behavior in the piping supports and tank shell is permitted. For attachment points located above the support or foundation elevation, the displacements in Table E-8 shall be increased to account for drift of the tank or vessel.

Table E-8—Design Displacements for Piping Attachments

Condition	ASD Design Displacement mm (in.)
Mechanically-anchored tanks	
Upward vertical displacement relative to support or foundation:	25 (1)
Downward vertical displacement relative to support or foundation:	13 (0.5)
Range of horizontal displacement (radial and tangential) relative to support or foundation:	13 (0.5)
Self-anchored tanks	
Upward vertical displacement relative to support or foundation:	
Anchorage ratio less than or equal to 0.785:	25 (1)
Anchorage ratio greater than 0.785:	100 (4)
Downward vertical displacement relative to support or foundation:	
For tanks with a ringwall/mat foundation:	13 (0.5)
For tanks with a berm foundation:	25 (1)
Range of horizontal displacement (radial and tangential) relative to support or foundation	50 (2)

The values given in Table E-8 do not include the influence of relative movements of the foundation and piping anchorage points due to foundation movements (such as settlement or seismic displacements). The effects of foundation movements shall be included in the design of the piping system design, including the determination of the mechanical loading on the tank or vessel consideration of the total displacement capacity of the mechanical devices intended to add flexibility.

When $S_{DS} < 0.1$, the values in Table E-7 may be reduced to 70% of the values shown.

E.7.3.1 Method for Estimating Tank Uplift

The maximum uplift at the base of the tank shell for a self-anchored tank constructed to the criteria for annular plates (see E.6.2.1) may be approximated by Equation E.7.3.1-1:

In SI units:

$$y_u = \frac{12.10 F_y L^2}{t_b} \qquad \text{(E.7.3.1-1a)}$$

Or, in US Customary units:

$$y_u = \frac{F_y L^2}{83300 t_b} \qquad \text{(E.7.3.1-1b)}$$ 07

where

t_b = calculated annular ring t holdown. 08

E.7.4 CONNECTIONS

Connections and attachments for anchorage and other lateral force resisting components shall be designed to develop the strength of the anchor (e.g., minimum published yield strength, F_y in direct tension, plastic bending moment), or 4 times the calculated element design load.

Penetrations, manholes, and openings in shell components shall be designed to maintain the strength and stability of the shell to carry tensile and compressive membrane shell forces.

The bottom connection on an unanchored flat-bottom tank shall be located inside the shell a sufficient distance to minimize damage by uplift. As a minimum, the distance measured to the edge of the connection reinforcement shall be the width of the calculated unanchored bottom hold-down plus 300 mm (12 in.)

E.7.5 INTERNAL COMPONENTS

The attachments of internal equipment and accessories which are attached to the primary liquid- or pressure-retaining shell or bottom, or provide structural support for major components shall be designed for the lateral loads due to the sloshing liquid in addition to the inertial forces.

• Seismic design of roof framing and columns shall be made if specified by the Purchaser. The Purchaser shall specify live loads and amount of vertical acceleration to be used in seismic design of the roof members. Columns shall be designed for lateral liquid inertia loads and acceleration as specified by the Purchaser. Seismic beam-column design shall be based upon the primary member allowable stresses set forth in AISC (ASD), increased by one-third for seismic loading.

Internal columns shall be guided or supported to resist lateral loads (remain stable) even if the roof components are not specified to be designed for the seismic loads, including tanks that need not be designed for seismic ground motion in this appendix (see E.1).

E.7.6 SLIDING RESISTANCE

The transfer of the total lateral shear force between the tank and the subgrade shall be considered.

For self-anchored flat-bottom steel tanks, the overall horizontal seismic shear force shall be resisted by friction between the tank bottom and the foundation or subgrade. Self-anchored storage tanks shall be proportioned such that the calculated seismic base shear, V, does not exceed V_S:

08 The friction coefficient, μ, shall not exceed 0.4. Lower values of the friction coefficient should be used if the interface of the bottom to supporting foundation does not justify the friction value above (e.g., leak detection membrane beneath the bottom with a lower friction factor, smooth bottoms, etc.).

$$V_s = \mu(W_s + W_r + W_f + W_p)(1.0 - 0.4A_v) \qquad \text{(E.7.6-1)}$$

No additional lateral anchorage is required for mechanically-anchored steel tanks designed in accordance with this appendix even though small movements of approximately 25 mm (1 in.) are possible.

The lateral shear transfer behavior for special tank configurations (e.g., shovel bottoms, highly crowned tank bottoms, tanks on grillage) can be unique and are beyond the scope of this appendix.

E.7.7 LOCAL SHEAR TRANSFER

Local transfer of the shear from the roof to the shell and the shell of the tank into the base shall be considered. For cylindrical tanks, the peak local tangential shear per unit length shall be calculated by:

$$V_{\max} = \frac{2V}{\pi D} \qquad \text{(E.7.7-1)}$$

Tangential shear in flat-bottom steel tanks shall be transferred through the welded connection to the steel bottom. The shear stress in the weld shall not exceed 80% of the weld or base metal yield stress. This transfer mechanism is deemed acceptable for steel tanks designed in accordance with the provisions and $S_{DS} < 1.0g$.

E.7.8 CONNECTIONS WITH ADJACENT STRUCTURES

Equipment, piping, and walkways or other appurtenances attached to the tank or adjacent structures shall be designed to accommodate the elastic displacements of the tank imposed by design seismic forces amplified by a factor of 3.0 plus the amplified displacement of the other structure.

E.7.9 SHELL SUPPORT

Self-anchored tanks resting on concrete ringwalls or slabs shall have a uniformly supported annulus under the shell. The foundation must be supplied to the tolerances required in 7.5.5 in to provide the required uniform support for Items b, c, and d below. Uniform support shall be provided by one of the following methods:

a. Shimming and grouting the annulus,

b. Using fiberboard or other suitable padding

c. Using double butt-welded bottom or annular plates resting directly on the foundation, Annular plates or bottom plates under the shell may utilize back-up bars welds if the foundation is notched to prevent the back-up bar from bearing on the foundation.

07 d. Using closely spaced shims (without structural grout) provided that the localized bearing loads are considered in the tank wall and foundation to prevent local crippling and spalling.

Mechanically-anchored tanks shall be shimmed and grouted.

APPENDIX EC—COMMENTARY ON APPENDIX E

Acknowledgement

The development of this extensive revision to Appendix E and preparation of this Commentary was funded jointly by API and the Federal Emergency Management Agency through the American Lifelines Alliance. The development of this appendix and Commentary was directed by the API Seismic Task Group with technical review by the Dynamic Analysis and Testing Committee of the Pressure Vessel Research Council.

EC.1 Scope

API 650, Appendix E has been revised in it's entirety to accomplish the following:

- incorporate the newer definitions of ground motion used in the US model building codes and ASCE 7,
- add a procedure to address regions outside the US where ground motions may be defined differently by local regulations,
- expand and generalize the equations to improve programming applications and reduce reliance on plots and equations where terms were combined and lacked the clarity needed to adapt to changing requirements,
- include additional requirements for hydrodynamic hoop stresses and vertical earthquake,
- include, for the convenience of the users, information and equations previously found in outside reference materials,
- revise the combination of impulsive and convective forces to use the SRSS method instead of direct sum method,
- introduce the concept of an "anchorage ratio" for clarity,
- add a foundation stability ratio requirement,
- permit the use of soil structure interaction for mechanically-anchored tanks,
- add detailing requirements for freeboard, pipe flexibility, and other components,
- and, improve maintainability.

EC.2 Definitions and Notations 08

For additional definitions and background information, the user is referred to the following documents:

1. *National Earthquake Hazard Reduction Program Provisions and Commentary*, FEMA Publications 302, 303, 368 and 369.
2. ASCE 7, *Minimum Design Loads for Buildings and Other Structures*, American Society of Civil Engineers.
3. *International Building Code*, 2000 and 2003.

EC.3 Performance Basis

EC.3.1 SEISMIC USE GROUP

Tanks are classified in the appropriate Seismic Use Group based on the function and hazard to the public. Tank owner/operators may elect to specify a higher SUG as part of their risk management approach for a tank or facility. Specifying a higher SUG increases the Importance Factor, I, used to define the design acceleration parameters and indirectly influences the performance level expected of the tank. Selection of the appropriate SUG is by the owner or specifying engineer who is familiar with the risk management goals, the surrounding environment, the spill prevention, control and countermeasures plans and other factors.

SUG I is the default classification.

EC.3.1.1 Seismic Use Group III

Tanks assigned the SUG III designation are those whose function are deemed essential (i.e., critical) in nature for public safety, or those tanks that store materials that may pose a very serious risk to the public if released and lack secondary control or protection. For example, tanks serving these types of applications may be assigned SUG III unless an alternative or redundant source is available:

1. fire, rescue, and police stations;
2. hospitals and emergency treatment facilities;
3. power generating stations or other utilities required as emergency backup facilities for Seismic Use Group III facilities;
4. designated essential communication centers;

5. structures containing sufficient quantities of toxic or explosive substances deemed to be hazardous to the public but lack secondary safeguards to prevent widespread public exposure;

6. water production, distribution, or treatment facilities required to maintain water pressure for fire suppression within the municipal or public domain (not industrial).

It is unlikely that petroleum storage tanks in terminals, pipeline storage facilities and other industrial sites would be classified as SUG III unless there are extenuating circumstances.

EC.3.1.2 Seismic Use Group II

Tanks assigned the SUG II designation are those that should continue to function, after a seismic event, for public welfare, or those tanks that store materials that may pose a moderate risk to the public if released and lack secondary containment or other protection. For example, tanks serving the following types of applications may be assigned SUG II unless an alternative or redundant source is available:

1. power generating stations and other public utility facilities not included in Seismic Use Group III and required for continued operation;
2. water and wastewater treatment facilities required for primary treatment and disinfection for potable water.

EC.3.1.3 Seismic Use Group I

SUG I is the most common classification. For example, tanks serving the following types of applications may be assigned SUG I unless an alternative or redundant source is available:

08 1. storage tanks in a terminal or industrial area isolated from public access that has secondary spill prevention and control;
2. storage tanks without secondary spill prevention and control systems that are sufficiently removed from areas of public access such that the hazard is minimal.

EC.4 Site Ground Motion

The definition of the considered ground motion at the site is the first step in defining acceleration parameters and loads. The philosophy for defining the considered ground motion in the US began changing about 1997. This new approach, which began with the evolution of the 1997 UBC and advanced through the efforts of the National Earthquake Hazard Reduction Program, was the basic resource for the new model building codes. Subsequent to the *International Building Code* 2000, ASCE 7 adopted the methods and is presently the basis for the US model building codes.

However, regulations governing seismic design for tank sites outside the US may not follow this ASCE 7 approach. Therefore, this revision was written to be adaptable to these regulations. Consequently, there is no longer a definition of the "minimum" design ground motion based on US standards that applies to all sites regardless of the local regulations.

Historically, this appendix (and the US standards) was based on ground motion associated with an event having a 10% probability of exceedance in 50 years. This is an event that has a recurrence interval of 475 years. In seismically active areas where earthquakes are more frequent, such as the west coast of the US, this was a reasonable approach. In regions where earthquakes are less frequent, engineers and seismologists concluded that the hazard was under-predicted by the 475 year event. Thus, the maximum considered ground motion definition was revised to a 2% probability of exceedance in 50 years, or a recurrence interval of about 2500 years. The economic consequences of designing to this more severe ground motion was impractical so a scaling factor was introduced based on over-strength inherently present in structures built to today's standards. See the NEHRP Provisions for a more extensive discussion of this rationale.

The API Seismic Task Group considered setting the 475 year event as the "minimum" for application of this standard. Given the variations worldwide in defining the ground motion, it was decided that the local regulation should set the requirements. However, the owner/specifying engineer for the tank should carefully consider the risk in selecting the appropriate design motion in areas outside the US. The API Seismic Task Group suggests that the 475 year event be the minimum basis for defining the site ground motion for tanks.

EC.4.1 MAPPED ASCE 7 METHODS

The ASCE 7 maximum considered earthquake response spectrum is shown in Figure EC-1 and also illustrates the notations used in developing the response spectrum for the maximum considered ground motion.

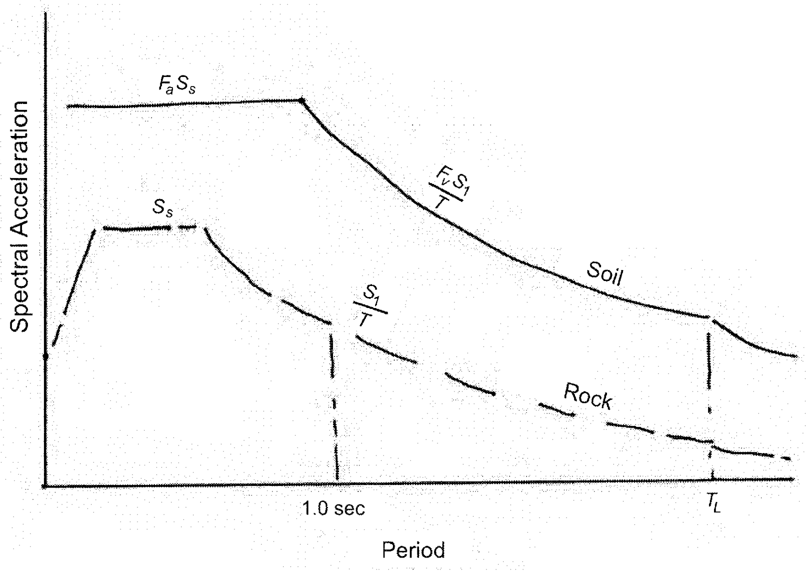

Figure EC-1—Maximum Earthquake Response Spectrum 11

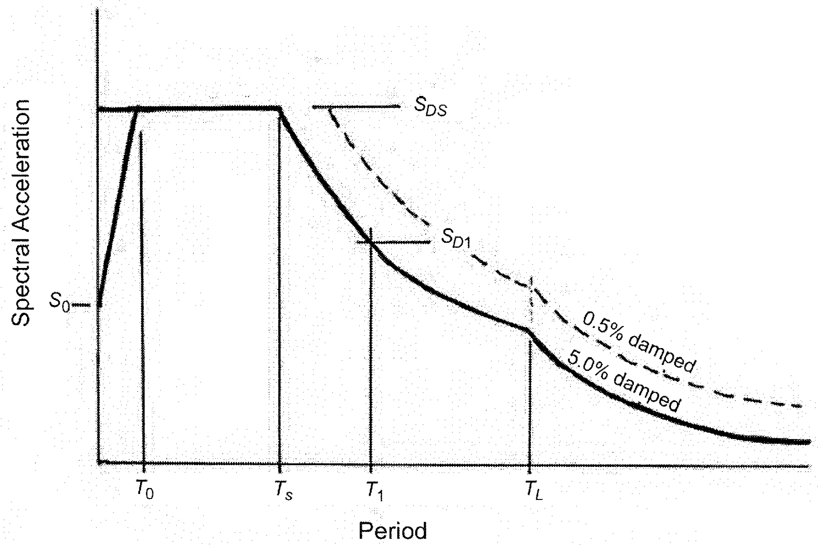

Figure EC-2—Earthquake Response Spectrum Notation

EC.4.2 SITE-SPECIFIC SPECTRAL RESPONSE ACCELERATIONS

In most situations, a site-specific response spectrum approach is not required. In the rare cases that a site-specific approach is necessary, the ASCE 7 approach was adopted into the appendix. To utilize this procedure, both a probabilistic and deterministic response spectrum is developed. The site specific value is then the *lesser* of the two values.

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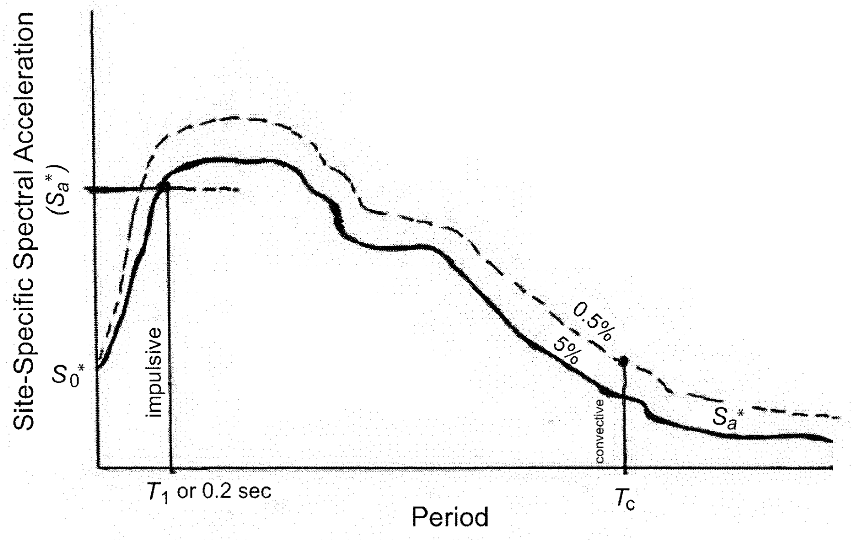

11 Figure EC-3—Site Specific Response Spectrum

EC.4.2.1 Site-Specific Study

<none>

EC.4.2.2 Probabilistic Site-Specific MCE Ground Motion

<none>

EC.4.2.3 Deterministic Site-Specific MCE Ground Motion

In addition to the value determined for the characteristic earthquake acting on the known active faults, the deterministic values also have a lower bound limit as shown in Figure EC-4.

08

EC.4.2.4 Site-Specific MCE Ground Motions

Figure EC-5 illustrates conceptually how these requirements might relate to define the site specific response spectrum.

EC.4.3 SITES NOT DEFINED BY ASCE 7 METHODS

The methods and equations in this appendix are best illustrated by a response spectrum curve. When the only definition of ground motion is the peak ground acceleration, the shape of the response spectrum is approximated to determine the spectral accelerations parameters. Consequently, the API Seismic Task Group recommended the relationship of S_1 and S_p defined in Equation (E.4.3-2) as an approximation based on typical response spectrum curves encountered in design.

$$S_1 = 1.25 S_p \qquad \text{(E.4.3-2)}$$

Alternatively, if the applicable regulations have a means of determining the spectral response at the appropriate periods and damping values, those values (i.e., response spectrum) can be used, assuming that the other requirements of the appendix are met.

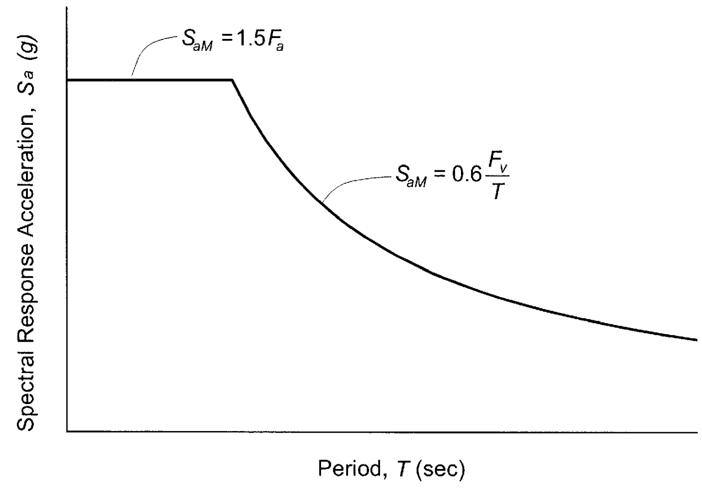

Figure EC-4—Deterministic Lower Limit on MCE Response Spectrum

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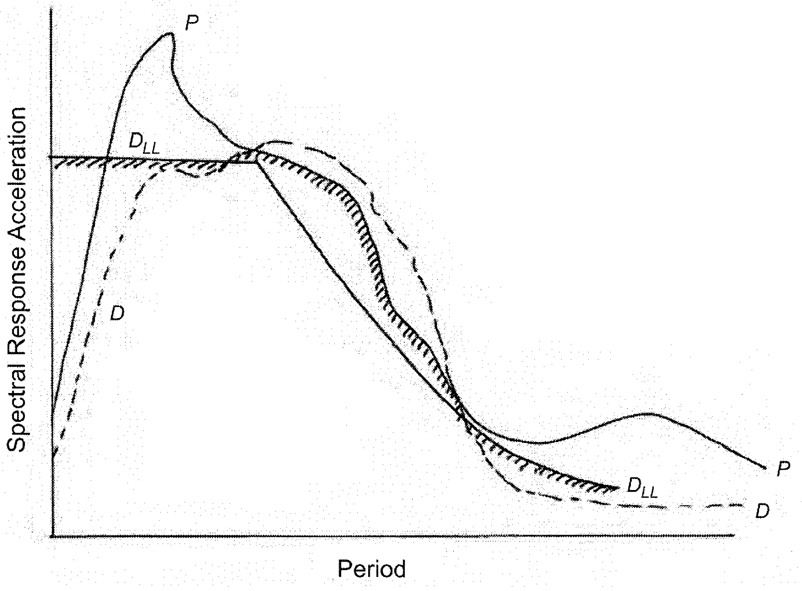


Figure EC-5—Relationship of Probabilistic and Deterministic Response Spectra

EC.4.4 MODIFICATIONS FOR SITE SOIL CONDITIONS

The ground motions must be amplified when the founding soils are not rock. In previous editions of the appendix, these adjustments only applied to the constant velocity and acceleration portions of the response. Since the mid-1990s, there have been dual site factors as found in ASCE 7 to define the influence of the soil on the shape and values of the ground motions. The appendix utilizes this ASCE 7 approach. 08

Outside the US, local regulations may have alternate methods of defining the influence of the soil. Such alternate methods may be used; however, if no site amplifications are defined in the local regulations, then the ASCE 7 method of addressing site amplification is required.

EC.4.5 STRUCTURAL PERIOD OF VIBRATION

EC.4.5.1 Impulsive Natural Period

To use the methods in this appendix, the impulsive seismic acceleration parameter is independent of tank system period unless a site-specific analysis or soil structure interaction evaluation is performed. The impulsive period of the tank is nearly always less than T_S, placing it on the plateau of the response spectra. Thus, the impulsive acceleration parameter is based directly on SDS. For special circumstances, a simplified procedure was included in the appendix to determine the impulsive period which was taken from the following reference:

"Simplified Procedure for Seismic Analysis of Liquid-Storage Tanks," Malhotra, P; Wenk, T; and Wieland, M. *Structural Engineering International,* March 2000.

EC.4.5.2 Convective (Sloshing) Period

For convenience, the graphical procedure for determining the sloshing period, T_C, is included here. See Equation (E.4.5.2-b) and Figure EC-5.

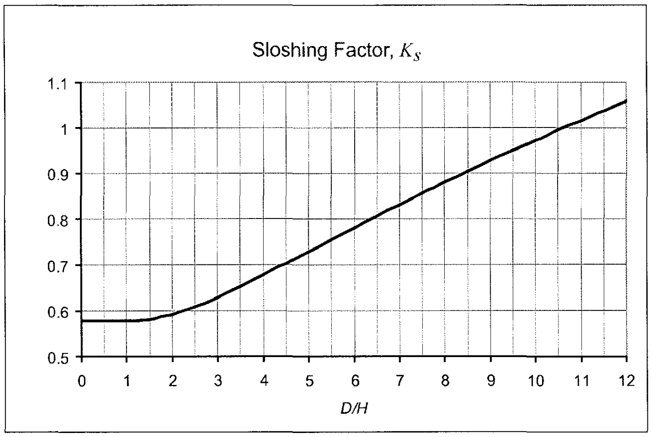
$$T_c = K_s\sqrt{D} \qquad \text{(E.4.5.2-b)}$$

where

D = nominal tank diameter in ft,

K_S = factor obtained from Figure EC-6 for the ratio *D/H.*

08



11 Figure EC-6—Sloshing Factor, K_S

EC.4.6 DESIGN SPECTRAL RESPONSE ACCELERATIONS

EC.4.6.1 Spectral Acceleration Coefficients

The acceleration parameters equations are based on the response spectrum pictured in Figure EC-7.

A "Q" term not included in the ASCE 7 is introduced in this appendix. "Q" is the scaling factor from the MCE, which is equal to
08 2/3 for the ASCE 7 method. When using a recurrence interval of other than 2500 years, or another regulatory basis, "Q" should be set to the appropriate value; for most cases this is 1.0. For example, in a region outside the US using the 475 year event, $Q = 1.0$.

For site-specific analysis, the impulsive spectral acceleration is limited to 1.5*g*. This is based on practical experience and observations of tank behavior. When tanks are lower profile, i.e., $H/D < 0.8$ and are either self- anchored or have long anchor bolt projections, the tanks can slide at the high impulsive accelerations. This sliding effectively limits the amount of force transferred into the tank. This limitation should not apply if the tank is prevented from sliding.

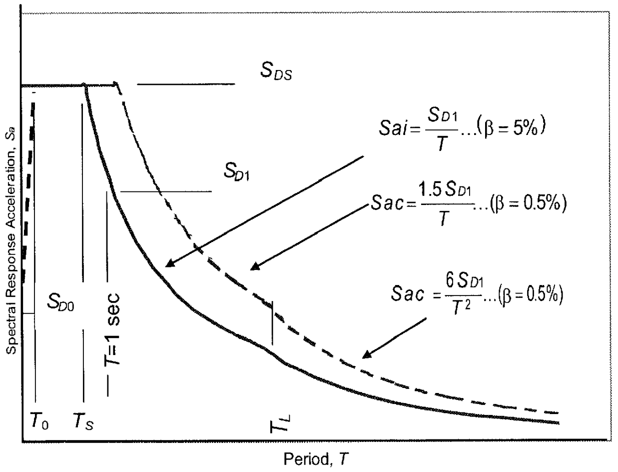


Figure EC-7—Design Response Spectra for Ground-Supported Liquid Storage Tanks

EC.5 Seismic Design Factors

EC.5.1 DESIGN FORCES

EC.5.1.1 Response Modification Factor

This appendix differentiates the response modification factors for impulsive and convective forces. The force reduction factor mimics the nonlinear response of the tank. There are three components to the force reduction factor R: (1) ductility R_μ, (2) damping R_β, and (3) over-strength R_Ω. 08

$$R = R_\mu \times R_\beta \times R_\Omega \qquad \text{(EC.5.1.1-1)}$$

The ductility reduction is to account for the force reduction associated with a more flexible response. The damping reduction is to account for the force reduction associated with increased system damping. The over-strength reduction is to account for the fact that the actual strength is higher than the calculated strength.

The convective response is generally so flexible (period between 2 and 10 seconds) that any increased flexibility due to non-linearity has negligible influence on the period and damping of the convective response. It is, therefore, not justified to apply the ductility and damping reductions to the convective response—however, the over-strength reduction can still be applied. In the absence of raw data, NEHRP Technical Subcommittee 13—Non-building Structures proposed a reduction in R_W for the convective forces. After additional discussion in the ASCE Seismic Task Group, $R = 1.5$ (or R_{WC} of approximately 2.0) was accepted.

EC.5.1.2 Importance Factor

<none>

EC.6 Design

EC.6.1 DESIGN LOADS

Historically, steel tank standards in the US have used the direct sum of the impulsive and convective forces. Other standards do not. For example, the SRSS method of combining the impulsive and convective components is used the New Zealand Standard NZS 3106. Here is what C2.2.9.4 (Commentary) of that standard says:

"The periods of the inertia (ed. note: impulsive) and convective responses are generally widely separated, the impulsive period being much shorter than the convective period. When responses are widely separated, near-simultaneous occurrence of peak values could occur. However, the convective response takes much longer to build up than the impulsive response, consequently the impulsive component is likely to be subsiding by the time the convective component reaches its peak. It is thus recommended that the combined impulsive and convective responses be taken as the square root of the sum of the squares of the separate components."

A numerical study was undertaken by the NEHRP Technical Subcommittee 13—Non-building Structures to investigate the relative accuracy of "direct sum" and SRSS methods for combining the impulsive and convective responses. In this study: (1) the impulsive period was varied between 0.05 seconds and 1 second, (2) the convective period was varied between 1 second and 20 seconds; (3) the impulsive and convective masses were assumed equal, and (4) eight different ground motions from Northridge and Landers earthquake data were used.

While, the SRSS modal combination rule does not provide the worst possible loading, it does provide the most likely loading. It has been shown that this rule is suitable for combining the impulsive and convective (sloshing) responses in tanks.

Furthermore, it should be remembered that different portions of a site response spectrum are not controlled by the same seismic event. Whereas, the short-period spectral values, which determine the impulsive response, are controlled by the closer earthquakes, the long-period spectral values, which determine the convective response, are controlled by distant, larger earthquakes. Therefore, there is already some conservatism inherent in assuming that the impulsive and convective responses will occur simultaneously.

EC.6.1.1 Effective Weight of Product

For convenience, the relationships defined in the appendix equations are graphically illustrated in Figure EC-8.

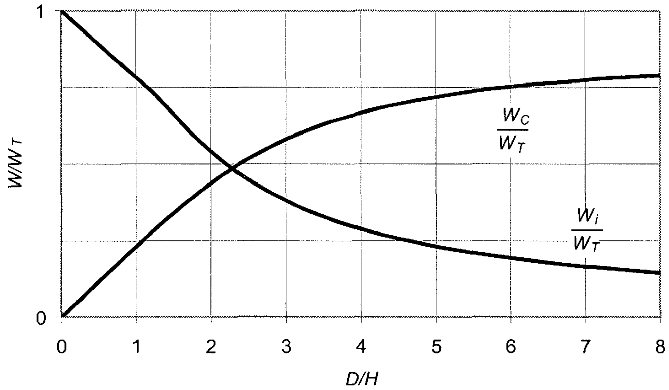


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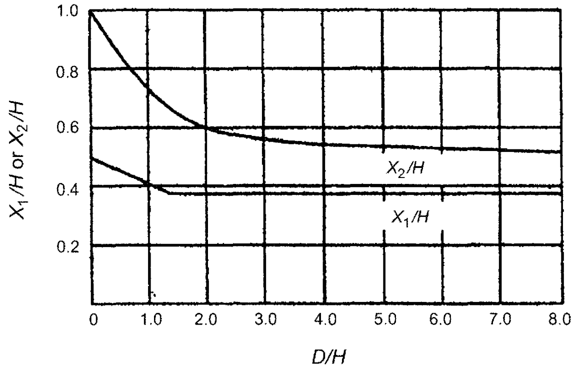
Figure EC-8—Effective Weight of Liquid Ratio

EC.6.1.2 Center of Action for Effective Forces

For convenience, the relationships defined in the appendix equations are graphically illustrated in Figure EC-9.



11 Figure EC-9—Center of Action of Effective Forces

EC.6.1.3 Vertical Seismic Effects

<none>

EC.6.1.4 Dynamic Liquid Hoop Forces

Calculations of hydrodynamic hoop forces were not included in previous editions of the appendix since it was not usually a governing condition for the typical petroleum storage tank. However, with larger diameter tanks, products with higher specific gravity, and vertical seismic effects, this additional check for hoop stresses was deemed to be necessary.

EC.6.1.5 Overturning Moment

<none>

EC.6.1.6 Soil-Structure Interaction

See the NEHRP Provisions, Chapter 5 for additional information. This is applicable to mechanically anchored tanks in this appendix. The complexity and state of technology for soil structure interaction evaluations of uplifting tanks and tanks with berm foundations was considered as beyond the scope of this appendix.

EC.6.2 RESISTANCE TO DESIGN LOADS

EC.6.2.1 Anchorage

Anchorage for overturning loads may be accomplished by the inherent tank configuration and product weight (self-anchored) or by adding mechanical devices (mechanically-anchored) such as anchor bolts or straps. If a tank satisfies the requirements for self anchorage, it should not be anchored.

The methods and load combinations used to design tank anchorage have proven to be satisfactory. Alternative methods for predicting annular plate behavior and anchor bolt loads have been proposed by various researchers. The API Seismic task Group believes that while some of these methods may more accurately depict the actual behavior of the tank, the added complexity does not significantly alter the anchorage design for the tanks usually constructed to API standards. Consequently, the simplified, but proven, method is retained. 08

EC.6.2.2 Maximum Longitudinal Shell Membrane Compression Stress

EC.6.2.3 Foundation

Using the calculated maximum toe pressure in the tank shell to satisfy equilibrium on self anchored flatbottom tanks produces impractical ringwall dimensions. Some yielding of soil (settlement) may occur under the shell requiring re-leveling of the tank after a seismic event. The foundations under flatbottom tanks, even tanks resting directly on earth foundations, have fared well under seismic loadings. Therefore, the seismic loading does not alter the foundation design criteria or provide justification for increased foundations for ringbearing plates.

A requirement for a mechanically-anchored tank stability check was added. This check assumes that the tank, product and foundation behave as a rigid body and is over-turning about the toe (i.e., base of the tank). This is not the actual behavior of the tank system but is a convenient model to use for checking the gross stability of the foundation. See Figure EC-10. The required factor of safety is 2.0 for this model.

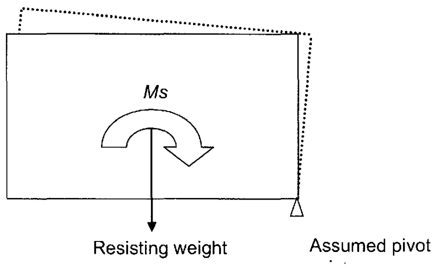


Figure EC-10—Overturning Moment

EC.6.2.4 Hoop Stress

EC.7 Detailing Requirements

EC.7.1 ANCHORAGE

EC.7.1.1 Self-Anchored

EC.7.1.1.1 Mechanically-Anchored

Although not the preferred solution for mechanical anchors, straps are permitted. However, if straps are utilized, proper details are vital to achieve the performance objective. The anchorage into the foundation should be mechanical, and not rely on bond strength alone. Since there are no direct technical testing methods for validation as exist for anchor bolts, the ability of the detail selected to yield the anchor strap should be demonstrated preferably by test or, at a minimum, by calculation.

The design and detailing of the strap should also allow for the commonly occurring corrosion of the strap near the foundation, while not providing too much steel area that reduces the desirable ductile stretching of the strap under overload. One solution is to contour the strap to produce reduced area over a portion of the strap length. See Figure EC-11.

The connection to the shell is also often poorly detailed and stresses the attachment weld in the weak direction. Attaching the strap with a single horizontal fillet weld is not recommended. Attaching the strap to a thicker reinforcing plate may also be necessary to avoid over-stressing the shell. One method of detailing a strap is shown is Figure EC-11.

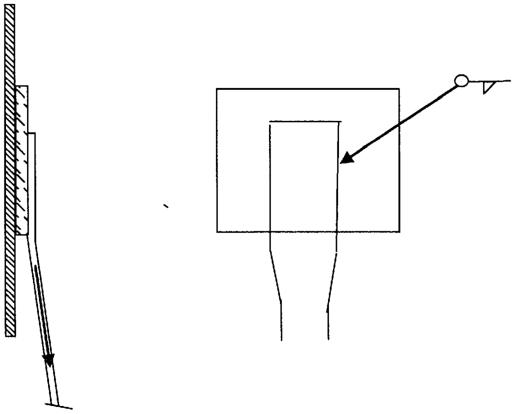


Figure EC-11—Anchor Strap Attachment to Shell

EC.7.2 FREEBOARD

Freeboard is provided to reduce potential operational damage to the upper shell and roof by the impingement of the sloshing wave. In some circumstances, this damage may include tearing of the roof to shell connection and release a small amount of product. However, in almost all cases, this damage is not a structural collapse mechanism but rather an issue of operational risk and repair cost. Designing the typical API style roof and shell to resist the sloshing wave is impractical.

In the rare situation that the these provisions are applied to a tank that is completely filled and no sloshing space is provided above the maximum operating level, the entire contents of the tank should be considered an impulsive mass.

EC.7.3 PIPING FLEXIBILITY

Lack of sufficient piping flexibility has been one of the leading causes of product loss observed after an earthquake. Piping designers may not recognize the movements that the tank and foundation may experience and may not provide sufficient flexibility in the piping system and supports. This overstresses the pipe and tank shell, usually causing a piping break.

Piping designers should not assume that the tank is an anchor point to resist piping loads without carefully evaluating the mechanical loads on the tank, including the compatibility of displacement. While the tank shell is relatively stiff in reacting to loads applied in the vertical direction, in most cases it is not stiff relative to the piping for radial or rotational loads.

A table of design displacements is included in the appendix. See Table E-8. These values are a compromise of practical design considerations, economics and the probability that the piping connection will be at the point of maximum uplift. If one "estimated" the tank uplift using the simplified model in the appendix, the uplift will often exceed the values in Table E-8 unless the tank is in lower ground motion regions.

Mechanically anchoring the tank to reduce piping flexibility demands should be a "last resort." The cost of anchoring a tank that otherwise need not be anchored will often be larger than altering the piping configuration. The cost of the anchors, the foundation, and the attachment details to the shell must be weighed against piping flexibility devices or configuration changes.

Some tank designers incorporate under-bottom connections attached to the bottom out of the uplift zone. This is potentially problematic in areas where high lateral impulsive ground motion may cause the tank to slide. The tank sliding may cause a bottom failure. Properly detailed connections though the cylindrical shell are preferred.

EC.7.3.1 Method for Estimating Tank Uplift

EC.7.4 CONNECTIONS

EC.7.5 INTERNAL COMPONENTS

Buckling of the roof rafters perpendicular to the primary direction of the lateral ground motion has been observed after some events. Initially, this damage was thought to be impingement damage to the rafter from the sloshing of the liquid. Presently, this buckling behavior is believed to be the result of the tendency of the flexible tank wall to oval, creating a compressive force perpendicular to the direction of the ground motion. Allowing these rafter to slip, or including an "accidental" compression load in the design of the rafter is recommended.

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EC.7.6 SLIDING RESISTANCE

EC.7.7 LOCAL SHEAR TRANSFER

EC.7.8 CONNECTIONS WITH ADJACENT STRUCTURES

EC.7.9 SHELL SUPPORT

EC.7.10 REPAIR, MODIFICATION OR RECONSTRUCTION

EC.8 Additional Reading

The following references are part of a large body of work addressing the behavior of tanks exposed to seismic ground motion.

1. Hanson, R.D., *Behavior of Liquid Storage Tanks,* Report, National Academy of Sciences, Washington D.C., 1973, pp. 331 - 339.

2. Haroun, M.A., and Housner, G.W., "Seismic Design of Liquid Storage Tanks," *Journal of Technical Councils,* ASCE, Vol. 107, April 1981, pp. 191 - 207.

3. Housner, G.W. 1954, *Earthquake Pressures on Fluid Containers,* California Institute of Technology.

4. Malhotra, P.K., and Veletsos, A.S., "Uplifting Analysis of Base Plates in Cylindrical Tanks," *Journal of Structural Division,* ASCE, Vol. 120, No. 12, 1994, pp. 3489 - 3505.

5. Malhotra, P.K., and Veletsos, A.S., *Seismic response of unanchored and partially anchored liquid-storage tanks,* Report TR-105809. Electric Power Research Institute. Palo Alto. 1995.

6. Malhotra, P; Wenk, T; and Wieland, M., "Simplified Procedure for Seismic Analysis of Liquid-Storage Tanks," *Structural Engineering International,* March 2000.

7. Manos, G. C.; Clough, R. W., *Further study of the earthquake response of a broad cylindrical liquid-storage tank model,* Report EERC 82-07, University of California, Berkeley, 1982.

8. New Zealand Standard NZS 3106.

9. Peek, R., and Jennings, P.C., "Simplified Analysis of Unanchored Tanks," *Journal of Earthquake Engineering and Structural Dynamics*, Vol. 16, No. 7, October 1988, pp. 1073 - 1085.

10. Technical Information Document (TID) 7024, *Nuclear Reactors and Earthquakes*, Chap. 6 and Appendix F. Published by Lockheed Aircraft Corporation under a grant from the US Dept. of Energy (formerly US Atomic Energy Commission), 1963.

11. Veletsos, A.S., *Seismic Effects in Flexible Liquid Storage Tanks*, Proceedings of the 5th World Conference on Earthquake Engineering, Rome, Italy, Vol. 1, 1974, pp. 630 - 639.

12. Veletsos, A.S.; Yang. J. Y., *Earthquake response of liquid storage tanks*, Proceedings of the Second Engineering Mechanics Specialty Conference. ASCE. Raleigh. 1977. pp. 1 - 24.

13. Veletsos, A.S., "Seismic response and design of liquid storage tanks," *Guidelines for the Seismic Design of Oil and Gas Pipeline Systems*, ASCE. New York. 1984 pp. 255 - 370.

14. Wozniak, R.S., and W.W. Mitchell. 1978, *Basis of Seismic Design Provisions for Welded Steel Oil Storage Tanks*, 1978 Proceedings—Refining Dept., Washington, D.C.: American Petroleum Institute. 57:485 - 501.

EC.9 Example Problems

1. Determining Spectral Acceleration Parameters Using ASCE 7 Method
2. Determining Spectral Acceleration Parameters Using Peak Ground Acceleration
3. Determining Spectral Acceleration Parameters Using Site-specific Response Spectrum
4. Calculating Impulsive, Convective and Combined Overturning Moment and Base Shear
5. Calculating Anchorage Ratio "*J*" and Self-Anchored Annular Plate 08
6. Calculating Hydrodynamic Hoop Stresses
7. Calculating the Overturning Stability Ratio

EXAMPLE PROBLEM #1

Determining Spectral Acceleration Parameters Using ASCE 7 Method

Required for US Locations

Seismic ground motion parameters may be determined from the ASCE 7 maps (this may be difficult in some locations due to scale); or, using digital data from USGS or IBC CD-ROM.

The results from the USGS web site for an assumed location, using the 2002 values: http://eqhazmaps.usgs.gov/index.html

The ground motion values for the requested point:			
LOCATION	35 Lat. - 118 Long.		
DISTANCE TO			
NEAREST GRID POINT	0.00 kms		
NEAREST GRID POINT	35.00 Lat. - 118.00 Long.		
Probabilistic ground motion values, in %*g*, at the Nearest Grid point are:			
10%PE in 50 yr		2%PE in 50 yr	
PGA	23.00	38.22	<< S_0
0.2 sec SA	54.56	92.65	<< S_S
1.0 sec SA	25.35	42.09	<< S_1

Similarly, using the IBC 2000 CD-ROM *

Selecting S_S and S_1

API 650 Appendix EC Example Problem
MCE Parameters—Conterminous 48 States
Latitude = 35.0000, Longitude = –118.0000
Data are based on the 0.01 deg grid set

Period	SA
(sec)	(%g)
0.2	102.7 Map Value, Soil Factor of 1.0
1.0	42.0 Map Value, Soil Factor of 1.0

Comparing to ASCE 7-02 Map, Figure 9.4.1.1(c) *

$S_S = 100\%\ g$

$S_1 = 42\%\ g$

* The ABC 2000 and ASCE 7 values are based on the USGS 1996 values. These values will be used for the example problems. The user should note that these maps are likely being revised in the later editions of these documents.

Therefore, use $S_S = 103\%\ g$, $S_1 = 42\%\ g$ and $S_0 = 38\%\ g$

$S_S = 103\%\ g$

$S_1 = 42\%\ g$ 08

$S_0 = 38\%\ g$

For this site, (from ASCE 7 maps)

$T_L = 12$ seconds

Assuming Site Class D, and interpolating

$F_a = 1.09$

(See E.4.4)

$F_v = 1.58$

$Q = 0.67$ for ASCE methods

Therefore

$S_{DS} = QF_aS_S = 75\%\ g$

$S_{D1} = QF_vS_1 = 44\%\ g$

$S_{D0} = QS_0 = 25\%\ g$

$T_S = S_{D1}/S_{DS} = 0.59$ seconds

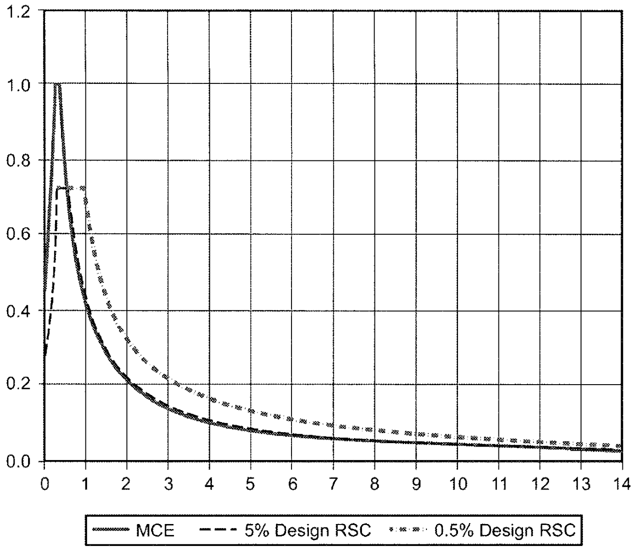
$T_o = 0.2S_{D1}/S_{DS} = 0.12$ seconds

The response spectrum can now be constructed (does not include I/R_w)

Determine Spectral Acceleration Coefficients (See E.4.6.1)

Given:

Assume tank is self-anchored, $R_w = 3.5$ (see E.5.1.1)



SUG I applies, I = 1.0

Tank Diameter, D = 100 ft

Product Height, H = 40 ft

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Impulsive

$$A_i = S_{DS}\left(\frac{I}{R_{wi}}\right) = 0.75\left(\frac{1.0}{3.5}\right) = 0.21 > 0.007 \quad \text{(E.4.6.1-1)}$$

Convective

Per E.4.5.2,

$$T_c = 6.09 \text{ seconds} < T_L$$

$$A_c = KS_{D1}\left(\frac{1}{T_c}\right)\left(\frac{I}{R_{wc}}\right) = 1.5(0.44)\left(\frac{1}{6.09}\right)\left(\frac{1.0}{2}\right) = 0.054 \leq .21 \quad \text{(E.4.6.1-4)}$$

EXAMPLE PROBLEM #2

Determining Spectral Acceleration Parameters Using Peak Ground Acceleration

For regions outside the US where applicable

For the same tank in Example #1, located outside the US.

See E.4.3.

Assuming the only parameter given is the 475 year peak ground acceleration (damping = 5%).

This is comparable to the 'Z' used in the earlier editions of the UBC.

Assume that regulations do not provide response spectrum.

Since 475 year recurrence interval is basis of peak ground acceleration, Q = 1.0 (no scaling).

Determine parameters:

S_p = 0.23% g << given See Ex #1, USGS PGA for 10% PE
S_s = 2.5 S_p = 0.58% g
S_1 = 1.25 S_p = 0.29% g

Assuming Site Class D, and interpolating

No soil or site class parameters were given in the local regulations, use same as Example #1

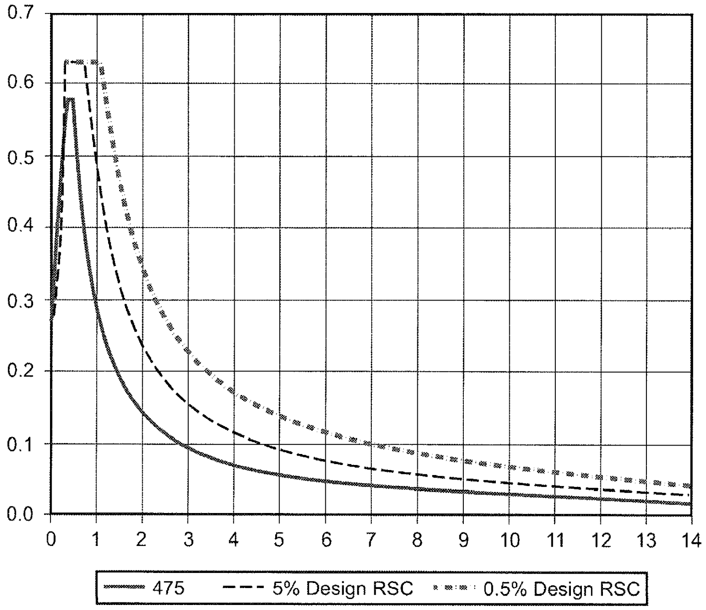
F_a = 1.09 (See E.4.4)
F_v = 1.58
Q = 1.00

S_0 is 475 year value

Therefore

$SDS = QF_aS_sS$ = 63% g
$S_{D1} = QF_vS_1$ = 46% g
$SD_0 = QS_0$ = 23% g
$T_s = S_{D1}/S_{DS}$ = 0.73 seconds 08
$T_o = 0.2S_{D1}/S_{DS}$ = 0.15 seconds

The response spectrum can now be constructed (does not include I/R_w)



The remaining calculations are similar to those shown in Example #1.

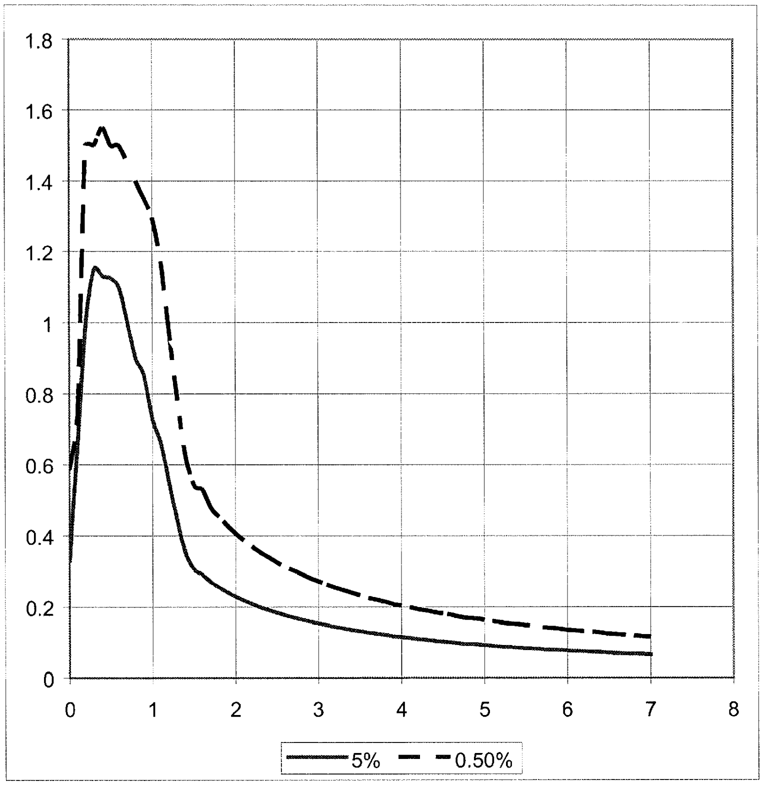
EXAMPLE PROBLEM #3

Determining Spectral Acceleration Parameters Using Site-Specific Response Spectrum

Given the following 2500 year recurrence interval site specific response spectrum.

Assume that the spectrum was developed according to the requirements of Appendix E.

Also, assume that the soil/site class influences are included in the spectrum (i.e., F_a and $F_v = 1.0$)



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From this response spectrum select the peak ground acceleration, S_{a0}^* (the * denotes site-specific in Appendix E nomenclature)

Using the 5% curve,

$$S_{a0}^* = 0.33g$$

Select the Impulsive Spectral Acceleration

There are two methods: 1) calculate the impulsive period per E.4.5.1, or Section 2) the more traditional approach—simply use the maximum value in the short period region of the curve. Using this second approach, and the 5% spectrum:

$$S_{ai}^* = 1.15g$$

Select the Convective Spectral Acceleration

Using the sloshing period form Example Problem #1, and reading from the 0.5% curve, the convective spectral acceleration is:

$$S_{ac}^* = 0.13g$$

Assuming that the project specifications do not require designing for the 2500 year event, but follow Appendix E:

Using Equation (E.4.6.2-1)

$$A_i = 2.5QS_{a0}{}^{*}0.550g \qquad \text{(E.4.6.2-1)}$$

Alliteratively, scale $S_{ai}{}^{*}$ by the factor $Q = 0.77g$ << USE

Similarly,

$A_c = QS_{ac}{}^{*} = 0.087g$ << USE

These values of A_i and A_c may be substituted into the equations in Appendix E.

EXAMPLE PROBLEM #4

Calculating Impulsive, Convective and Combined Overturning Moment and Base Shear

This problem illustrates the determination of the seismic base shear and overturning forces.

Known information about the tank:

H = 40 ft
D = 100 ft
G = 0.7
W_p = 13,722,000 lb, weight of product
W_s = 213,500 lb, weight of the shell 08
W_r = 102,100 lb, weight of the roof (an allowance for a snow load is not required for this site)
W_f = 80,900 lb, weight of the bottom
t_s = 0.5625 in., thickness of the bottom shell course
F_y = 30,000 psi for ASTM A 283, Grade C material for the bottom plate welded to the shell
S_d = 20,000 psi for ASTM A 283, Grade C material for the lowest shell course
X_s = 18.0 ft (this value was assumed to be $0.45 \times H_t$ for this sample problem)
X_r = 41.0 ft (this value was assumed to be $H_t + 1$ for this sample problem)
I = 1.00 Seismic Use Group I for a self-anchored tank
R_w = 3.5

Problem Solution

Per E.5.1 and E.6.1.6, the equivalent lateral seismic force is given by the square root sum of the squares combination impulsive and convective forces.

The seismic base shear is determined by Equation (E.6.1-1):

$$V = \sqrt{V_i^2 + V_c^2} \qquad \text{(E.6.1-1)}$$

The seismic overturning moment at the base of the tank shell ringwall) is determined by Equation (E.6.1.5-1):

$$M_{rw} = \sqrt{[A_i(W_iX_i + W_sX_s + W_rX_r)]^2 + [A_c(W_cX_c)]^2} \qquad \text{(E.6.1.5-1)}$$

Determine the Impulsive Water Parameters

W_i, the impulsive weight

$D/H = 2.50 >= 1.33$ Use Equation (E.6.1.1-1)

$$W_i = \frac{\tanh\left(0.866\frac{D}{H}\right)}{0.866\frac{D}{H}} W_p \qquad \text{(E.6.1.1-1)}$$

$$= 0.450 \times 13{,}722{,}000$$

$$= 6{,}173{,}000 \text{ lb}$$

X_i, the moment arm for the impulsive product mass, see Equation (E.6.1.2.1-1)

$$X_i = 0.375H = 15.0 \text{ ft} \qquad \text{(E.6.1.2.1-1)}$$

A_i, the impulsive spectral acceleration parameter was determined in Example Problem #1

$A_i = 0.21g$

Determine the Convective Water Parameters

08 Determine W_i, the convective water weight using Equation (E.6.1.1-3)

$$W_c = 0.230\frac{D}{H}\tanh\left(\frac{3.67H}{D}\right) W_p \qquad \text{(E.6.1.1-3)}$$

$$= 0.517 \times 13{,}722{,}000$$

$$= 7{,}095{,}000 \text{ lb}$$

The sloshing period was determined in Example Problem #1

$T_C = 6.08 \text{ seconds} < T_L = 12 \text{ seconds}$

A_C was determined in Example Problem #1

$A_C = 0.054g$

X_c, the moment arm for the convective water mass is determined by Equation (E.6.1.2.1-3)

$$X_c = \left[1.0 - \frac{\cosh\left(\frac{3.67H}{D}\right) - 1}{\frac{3.67H}{D}\sinh\left(\frac{3.67H}{D}\right)}\right] H \qquad \text{(E.6.1.2.1-3)}$$

$$= 0.574 \times 40$$

$$= 23.0 \text{ ft}$$

Determine the Seismic Base Shear

The impulsive component is determined by Equation (E.6.1-2)

$$V_i = A_i(W_s + W_r + W_f + W_i) \tag{E.6.1-2}$$

$$= 0.21 \times 6{,}569{,}500$$

$$= 1{,}379{,}600 \text{ lb}$$

A_i = $0.21g$

W_S = 213,500 lb

W_r = 102,100 lb

W_f = 80,900 lb

W_i = 6,173,000 lb

The convective component is determined by Equation (E.6.1-3)

$$V_c = A_c W_c \tag{E.6.1-3}$$

$$= 0.054 \times 7{,}095{,}000$$

$$= 383{,}100 \text{ lb}$$

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A_c = $0.054g$

W_c = 7,095,000 lb

The seismic base shear is

$$V = \sqrt{V_i^2 + V_c^2}$$

$$= 1{,}431{,}800 \text{ lb}$$

Determine the Seismic Overturning Moment

The ringwall moment is determined by Equation (E.6.1.5-1)

$$M_{rw} = \sqrt{[A_i(W_iX_i + W_sX_s + W_rX_r)]^2 + [A_c(W_cX_c)]^2} \tag{E.6.1.5-1}$$

A_i = $0.21g$

W_i = 6,173,000 lb

X_i = 15.0 ft

W_S = 213,500 lb

X_S = 18.0 ft

W_r = 102,100 lb

X_r = 41.0 ft

= $0.21 \times 100{,}624{,}100$

= 21,131,100 ft-lb

A_c = 0.054g

W_c = 7,095,000 lb

X_c = 23.0 ft

= $0.054 \times 162{,}874{,}400$

= 8,795,200 ft-lb

The seismic overturning moment at the base of the tank shell, M_{rw}, is 22,888,400 ft-lb

EXAMPLE PROBLEM #5

Calculating Anchorage Ratio "*J*" and Self-Anchored Annular Plate

Determine if the tank is suitable for the seismic overturning forces without the need for anchors.

Consideration of vertical seismic accelerations are not considered for this problem ($A_v = 0$).

08 Known information for this tank:

D = 100 ft, diameter

t = 0.5625 in., the thickness of the lowest shell course

t_a = 0.25 in., the thickness of the bottom plate welded to the shell ft

H = 40 ft

G = 0.7

S_d = 20,000 psi for ASTM A 283, Grade C material for the lowest shell course

F_y = 30,000 psi for ASTM A 283, Grade C material for the bottom plate welded to the shell

M_{rw} = 22,888,400 ft-lb, the seismic overturning moment at the base of the tank

W_s = 213,500 lb, the weight of the shell

W_{rs} = 61,300 lb, weight of the roof supported by the shell (assumed 60% of W_r without snow)

w_{rs} = 195 lb/ft, the weight of the roof supported by the shell

The resisting force for a self-anchored tank is determined by Equation (E.6.2.1.1-1b)

$$w_a = 7.9 t_a \sqrt{F_y H G_e} \leq 1.28\ HDG(1 - A_v) \qquad \text{(E.6.2.1.1-1b)}$$

$$= 3584 \text{ lb/ft}$$

11 $$w_a = 1810 \text{ lb/ft}$$

The anchorage ratio, J is:

Using Equation (E.6.2.1.1.1-2)

$$w_t = \frac{W_s}{\pi D} + w_{rs} \qquad \text{(E.6.2.1.1.1-2)}$$

$$= 680 + 195$$

$$= 875 \text{ lb/ft}$$

Applying this to Equation (E.6.2.1.1.1-1)

$$J = \frac{M_{rw}}{D^2[w_t(1 - 0.4A_v) + w_a - 0.4w_{int}]} \qquad \text{(E.6.2.1.1.1-1)}$$

$$= 0.853 < 1.54, \text{ therefore tank is stable}$$

For purposes of demonstration, assume M_{rw} is doubled and J is = 1.71 > 1.54, therefore tank is not stable

With this increased load, this tank does not meet the stability requirements with a 1/4 in. thick bottom plate under the shell. Try a thickened annular plate

Determine the required bottom thickness in order to avoid the addition of tank anchorage.

By trial-and-error, a 0.4375 in. thick annular ring will be used. 08

Recalculating:

t_a = 0.4375 in.

w_a = 3168 lb/ft

J = 0.566 < 1.54, therefore tank is now stable

The minimum width of the butt welded annular ring to be provided (inside the tank) is calculated by Equation (E.6.2.1.1.2-1b)

$$L = 0.216 t_a \sqrt{F_y / HG} \qquad \text{(E.6.2.1.1.2-1b)}$$

$$= 3.09 \text{ ft} = 37.1 \text{ in.}$$

but, L to exceed 0.035D = 3.50 ft = OK

A 0.4375 in. thickened annular plate projecting at least 37.1 in. inside the tank shell is OK providing, the check the vertical shell compression due to seismic overturning forces is met.

J = 0.566, no calculated uplift

$$\sigma_c = \left(w_t(1 + 0.4A_v) + \frac{1.273 M_{rw}}{D^2}\right)\frac{1}{12 t_s}$$

$$= 993 \text{ psi}$$

The allowable shell compression is calculated by the following equation:

$$GHD^2/t^2 = 884,938 < 1,000,000$$

The allowable compression is given by Equation (E.6.2.2.3-2b)

$$F_C = 10^6\ t_s/(2.5D) + 600\sqrt{(GH)} \qquad \text{(E.6.2.2.3-2b)}$$

$$= 4925 \text{ psi} > 993 \text{ psi} = \text{OK}$$

EXAMPLE PROBLEM #6

Calculating Hydrodynamic Hoop Stresses

See E.6.1.4.

Consider both lateral and vertical accelerations.

The owner has specified a vertical acceleration of 12.5% g.

Known information about the tank:

H = 40 ft

D = 100 ft

G = 0.7

t_s = 0.5625 in., thickness of the bottom shell course

F_y = 30,000 psi for ASTM A 283, Grade C material for the bottom plate welded to the shell

08 S_d = 20,000 psi for ASTM A 283, Grade C material for the lowest shell course

E = 1.0 weld joint efficiency

A_i = 0.210 g

A_c = 0.054 g

A_v = 0.125 g

The product hydrostatic membrane hoop load at the base of the tank is

$$N_h = 2.6(H-1)DG$$

$$= 7098 \text{ lb/in.}$$

The impulsive hoop membrane hoop force at the base of the tank is calculated by Equation (E.6.1.4-1b)

D/H = 2.5

$Y = H$ = 40 ft

$$N_i = 4.5A_iGDH\left[\frac{Y}{H} - 0.5\left(\frac{Y}{H}\right)^2\right]\tanh\left(0.866\frac{D}{H}\right) \qquad \text{(E.6.1.4-1b)}$$

09 $$= 1312 \text{ lb/in.}$$

The convective hoop membrane hoop load at the base of the tank is Equation (E.6.1.4-4b)

08 D/H = 2.5

$Y = H$ = 40 ft

$$N_c = \frac{0.98 A_c G D^2 \cosh\left[\frac{3.68(H-Y)}{D}\right]}{\cosh\left[\frac{3.68H}{D}\right]} \qquad \text{(E.6.1.4-4b)}$$ 08

$$= 163 \text{ lb/in}$$ 09

The total hoop stress, including lateral and vertical seismic accelerations per Equation (E.6.1.4-b)

$$\sigma_T = \sigma_h \pm \sigma_s = \frac{N_h \pm \sqrt{N_i^2 + N_c^2 + (A_v N_h)^2}}{t} \qquad \text{(E.6.1.4-b)}$$ 08

$$= 15{,}449 \text{ psi (max)}$$ 09

The allowable seismic hoop stress is the lesser of

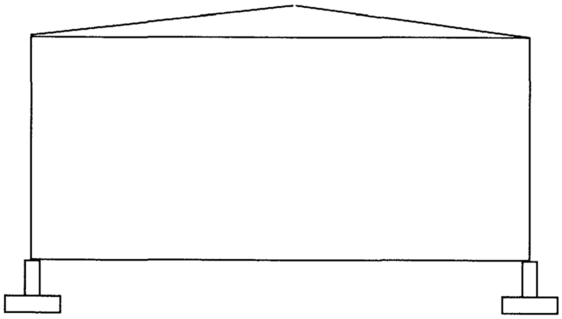
$$1.333 \times S_d = 26{,}660 \text{ psi (GOVERNS)} < 22{,}924 \text{ psi} = \text{OK}$$

$$0.9F_y = 27{,}000 \text{ psi}$$

EXAMPLE PROBLEM #7

Calculating the Overturning Stability Ratio

See E.6.2.3.



08

See Example Problem #4

D = 100 ft

H = 40 ft

W_p = 13,722,000 lb weight of product

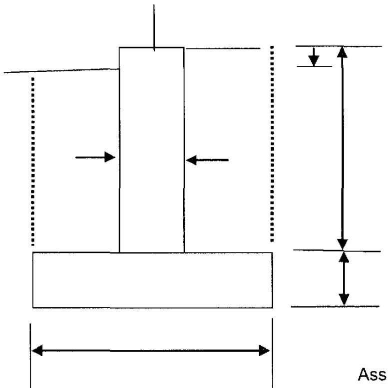
W_f = 80,900 lb weight of floor

W_T = 315,600 lb weight of tank

W_{fd} = 1,413,716 lb weight of foundation

W_g = 721,300 lb weight of soil over foundation

Assume $M_s = 75{,}000{,}000$ lb-ft



Assume concrete weighs 150 lbs/cf
Assume soil weighs 100 lbs/cf

08 Compute weight of foundation:

$$W_{fd} = 150\pi D A_{fd} = 150\pi(100)[(2x6)+(3x6)] = 1,413,716 \text{ lb}$$

Compute weight of soil over footing

Outside ringwall:

$$W_{go} = 100\pi(D+4 \text{ ft})(2x5.5) = 359,400 \text{ lb}$$

$$W_{gi} = 100\pi(D-4 \text{ ft})(2x6) = 361,900 \text{ lb}$$

Summing

W_g = 721,300 lbs

Sum moments about toe of the tank, Equation (E.6.2.3-1)

$$\frac{0.5D[W_p + W_f + W_T + W_{fd} + W_g]}{M_s} \geq 2.0 \qquad \text{(E.6.2.3-1)}$$

$$= 10.8 > 2 = \text{OK}$$

APPENDIX F—DESIGN OF TANKS FOR SMALL INTERNAL PRESSURES

F.1 Scope

F.1.1 The maximum internal pressure for closed-top API Std 650 tanks may be increased to the maximum internal pressure permitted when the additional requirements of this appendix are met. This appendix applies to the storage of nonrefrigerated liquids (see also API Std 620, Appendices Q and R). For maximum design temperatures above 93°C (200°F), see Appendix M.

F.1.2 When the internal pressure multiplied by the cross-sectional area of the nominal tank diameter does not exceed the nominal weight of the metal in the shell, roof, and any framing supported by the shell or roof, see the design requirements in F.3 through F.6. Overturning stability with respect to seismic conditions shall be determined independently of internal pressure uplift. Seismic design shall meet the requirements of Appendix E. 07

F.1.3 Internal pressures that exceed the weight of the shell, roof, and framing but do not exceed 18 kPa ($2^1/_2$ lbf/in.^{2}) gauge when the shell is anchored to a counterbalancing weight, such as a concrete ringwall, are covered in F.7.

F.1.4 Tanks designed according to this appendix shall comply with all the applicable rules of this Standard unless the rules are superseded by the requirements of F.7.

F.1.5 The tank nameplate (see Figure 10-1) shall indicate whether the tank has been designed in accordance with F.1.2 or F.1.3.

F.1.6 Figure F-1 is provided to aid in the determination of the applicability of various sections of this appendix.

F.2 Venting (Deleted)

F.3 Roof Details

The details of the roof-to-shell junction shall be in accordance with Figure F-2, in which the participating area resisting the compressive force is shaded with diagonal lines.

F.4 Maximum Design Pressure and Test Procedure

F.4.1 The maximum design pressure, P, for a tank that has been constructed or that has had its design details established may be calculated from the following equation (subject to the limitations of P_{max} in F.4.2): 08

In SI units:

$$P = \frac{AF_y \tan\theta}{200D^2} + \frac{0.00127\ D_{LR}}{D^2}$$ 11

where

P = internal design pressure (kPa),

A = area resisting the compressive force, as illustrated in Figure F-1 (mm^2),

F_y = lowest minimum specified yield strength (modified for design temperature) of the materials in the roof-to-shell junction (MPa), 09

θ = angle between the roof and a horizontal plane at the roof-to-shell junction (degrees),

$\tan\theta$ = slope of the roof, expressed as a decimal quantity,

D_{LR} = nominal weight of roof plate plus any attached structural (N). 11

DELETED

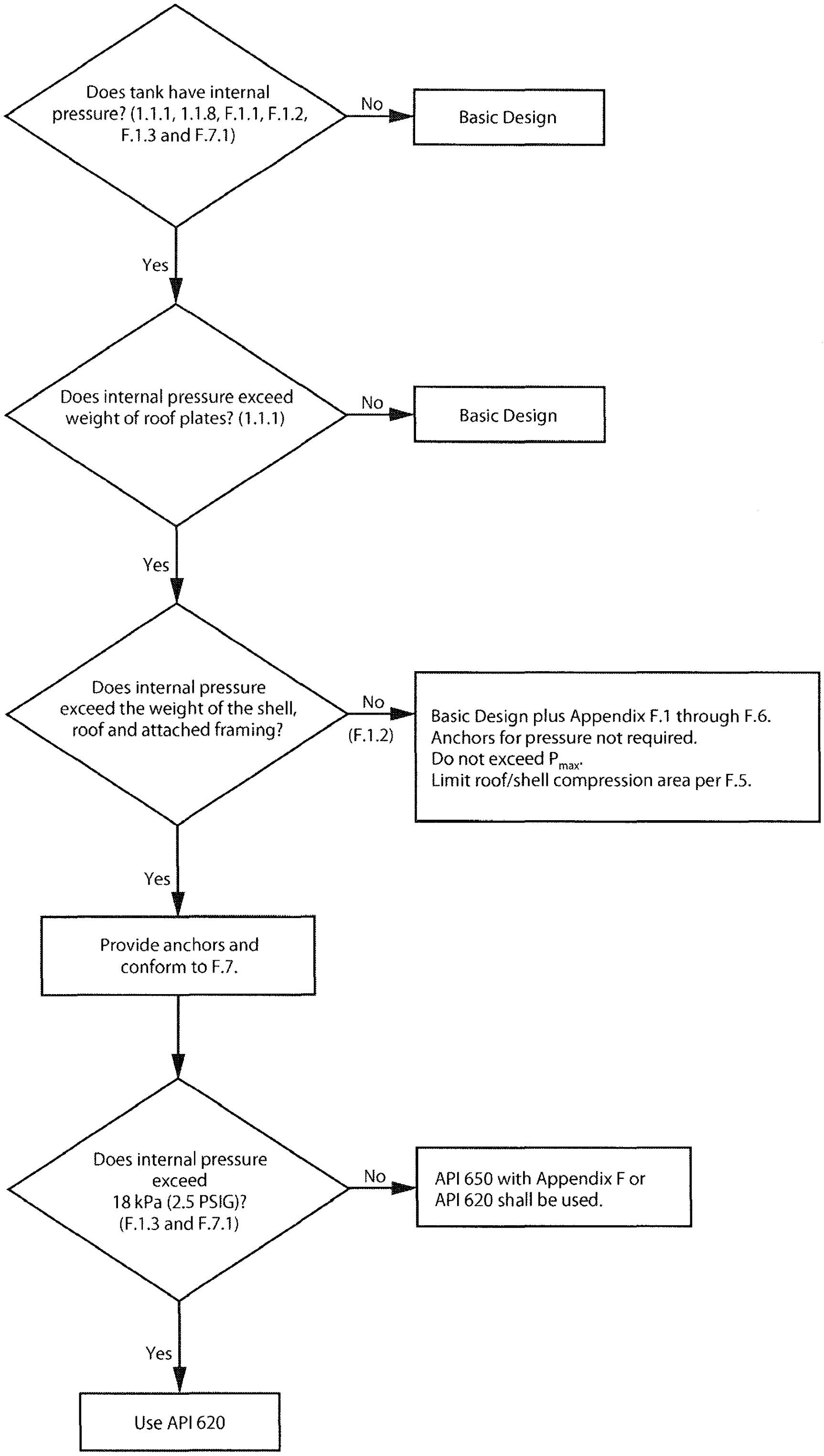
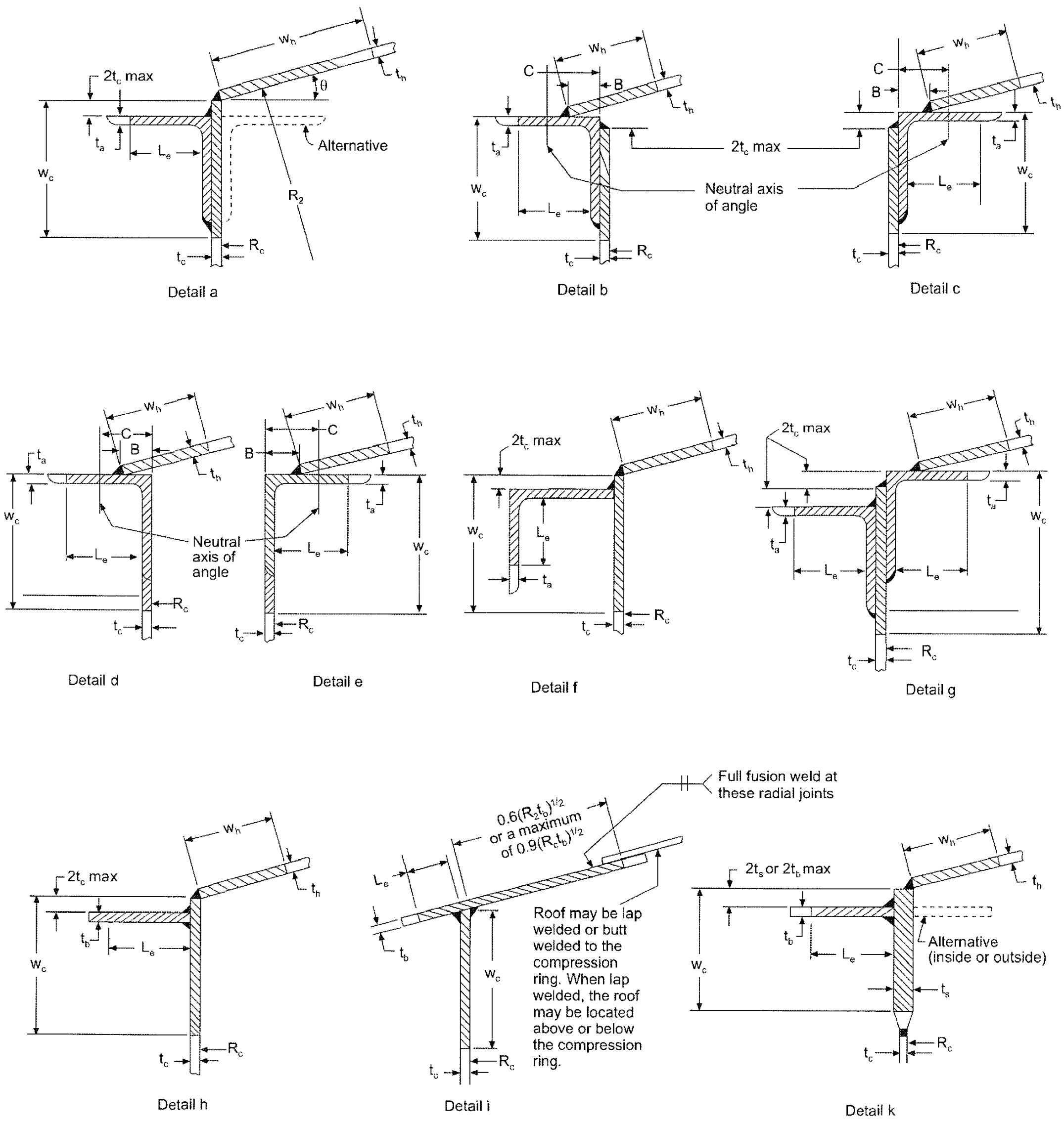


Figure F-1—Appendix F Decision Tree



11

t_a = thickness of angle leg
t_b = thickness of bar
t_c = thickness of shell plate
t_h = thickness of roof plate
t_s = thickness of thickened plate in shell
t_f = t_a plus t_c (see note 4)
w_c = maximum width of participating shell = $0.6\,(R_c\,t)^{1/2}$, where $t = t_a, t_c, t_s$, or t_f as applicable.

w_h = maximum width of participating roof = $0.3(R_2\,t_h)^{1/2}$ or 300 mm (12 in.) whichever is less.
R_c = inside radius of tank shell
R_2 = length of the normal to the roof, measured from the vertical centerline of the tank = R_c / (sin θ)
θ = angle between roof and horizontal

Notes:

1. All dimensions and thicknesses are in mm (in.).
2. Dimension B in details b, c, d, and e is: $0 \le B \le C$. C is the dimension to the neutral axis of the angle.
3. The unstiffened length of the angle or bar, L_e, shall be limited to $250t/(F_y)^{1/2}$ mm $[3000t/(F_y)^{1/2}$ in.] where F_y is the minimum specified yield strength, MPa (lbf/in.^{2}) and $t = t_a$ or t_b, as applicable.
4. Where members are lap welded onto the shell (refer to details a, b, c, and g), t_f may be used in w_c formula only for the extent of the overlap.

Figure F-2—Permissible Details of Compression Rings

In US Customary units:

11

$$P = \frac{(0.962)(AF_y)(\tan\theta)}{D^2} + \frac{0.245\ D_{LR}}{D^2}$$

where

P = internal design pressure (in. of water),

A = area resisting the compressive force, as illustrated in Figure F-2 (in.^{2}),

09 F_y = lowest minimum specified yield strength (modified for design temperature) of the materials in the roof-to-shell junction (lb/in.^{2}),

θ = angle between the roof and a horizontal plane at the roof-to-shell junction (degrees),

$\tan\theta$ = slope of the roof, expressed as a decimal quantity,

11 D_{LR} = nominal weight of roof plate plus any attached structural (lbf).

F.4.2 The maximum design pressure, limited by uplift at the base of the shell, shall not exceed the value calculated from the following equation unless further limited by F.4.3:

In SI units:

11

$$P_{\max} = \frac{0.000849\ D_{LS}}{D^2} + \frac{0.00127\ D_{LR}}{D^2} - \frac{0.00153\ M_w}{D^3}$$

where

$P_{\max}$ = maximum design internal pressure (kPa),

D_{LS} = nominal weight of the shell and any framing (but not roof plates) supported by the shell and roof (N),

11 M_W = wind moment (N-m).

D_{LR} = nominal weight of roof plate plus any attached structural (N).

In US Customary units:

11

$$P_{\max} = \frac{0.1632 D_{LS}}{D^2} + \frac{0.245\ D_{LR}}{D^2} - \frac{0.2938 M_w}{D^3}$$

where

$P_{\max}$ = maximum design internal pressure (in. of water),

D_{LS} = nominal weight of the shell and any framing (but not roof plates) supported by the shell and roof (lbf),

11 M_W = wind moment (ft-lbf).

D_{LR} = nominal weight of roof plate plus any attached structural (lbf).

F.4.3 As top angle size and roof slope decrease and tank diameter increases, the design pressure permitted by F.4.1 and F.4.2 approaches the failure pressure of F.6 for the roof-to-shell junction. In order to provide a safe margin between the maximum operating pressure and the calculated failure pressure, a suggested further limitation on the maximum design pressure for tanks with a weak roof-to-shell attachment (frangible joint) is:

$$P_{\max} \leq 0.8 P_f$$

F.4.4 When the entire tank is completed, it shall be filled with water to the top angle or the design liquid level, and the design internal air pressure shall be applied to the enclosed space above the water level and held for 15 minutes. The air pressure shall then be reduced to one-half the design pressure, and all welded joints above the liquid level shall be checked for leaks by means of a soap film, linseed oil, or another suitable material. Tank vents shall be tested during or after this test.

F.5 Required Compression Area at the Roof-to-Shell Junction

● **F.5.1** Where the maximum design pressure has already been established (not higher than that permitted by F.4.2 or F.4.3, whenever applicable), the total required compression area at the roof-to-shell junction shall be calculated from the following equation: 09

In SI units:

$$A = \frac{200D^2\left(P_i - \frac{0.00127\ D_{LR}}{D^2}\right)}{F_y(\tan\theta)}$$

11

where

A = total required compression area at the roof-to-shell junction (mm^2),
P_i = design internal pressure (kPa).
D_{LR} = nominal weight of roof plate plus any attached structural (N). 11

In US Customary units:

$$A = \frac{D^2\left(P_i - \frac{0.245\ D_{LR}}{D^2}\right)}{0.962F_y\ (\tan\theta)}$$

11

where

A = total required compression area at the roof-to-shell junction (in.^{2}),
P_i = design internal pressure (in. of water),
D_{LR} = nominal weight of roof plate plus any attached structural (lbf). 11

A is based on the nominal material thickness less any corrosion allowance.

F.5.2 For self-supporting roofs, the compression area shall not be less than the cross-sectional area calculated in 5.10.5 and 5.10.6.

F.6 Calculated Failure Pressure

Failure of the roof-to-shell junction can be expected to occur when the stress in the compression ring area reaches the yield point. On this basis, an approximate formula for the pressure at which failure of the top compression ring is expected (using conservative effective areas) to occur can be expressed in terms of the design pressure permitted by F.4.1, as follows: 08

In SI units:

$$P_f = 1.6P - \frac{0.000746\ D_{LR}}{D^2}$$

11

where

P_f = calculated minimum failure pressure (kPa). 08
D_{LR} = nominal weight of roof plate plus any attached structural (N). 11

In US Customary units:

$$P_f = 1.6P - \frac{0.147\ D_{LR}}{D^2}$$

11

where

P_f = calculated minimum failure pressure (in. of water). 08
D_{LR} = nominal weight of roof plate plus any attached structural (lbf). 11

Note: Experience with actual failures indicates that buckling of the roof-to-shell junction is localized and probably occurs when the yield point of the material is exceeded in the compression area. 08

F.7 Anchored Tanks with Design Pressures up to 18 kPa ($2^1/_2$ lbf/in.^{2}) Gauge

F.7.1 In calculating shell thickness for Appendix F tanks that are to be anchored to resist uplift due to internal pressure, and when selecting shell manhole thicknesses in Tables 5-3a and 5-3b and flush-type cleanout fitting thicknesses in Tables 5-10a and 5-10b, H shall be increased by the quantity $P/(9.8G)$ $[P/(12G)]$—where H is the design liquid height, in m (ft), P is the design pressure kPa (in. of water), and G is the design specific gravity.

F.7.2 The required compression area at the roof-to-shell junction shall be calculated as in F.5.1, and the participating compression area at the junction shall be determined by Figure F-2. Full penetration butt welds shall be used to connect sections of the compression ring. For self-supporting roofs, the compression area shall not be less than the cross sectional area calculated in 5.10.5 or 5.10.6 as applicable. Materials for compression areas may be selected from API 650, Section 4, and need not meet toughness criteria of 4.2.9.

F.7.3 The design and welding of roofs and the design, reinforcement, and welding of roof manholes and nozzles shall be completed with consideration of both API 650 and API 620. The design rules shall be as follows:

1. The thickness of self supporting roofs shall not be less than required by API 620, 5.10.2 and 5.10.3, using API 650, Table 5-2, for allowable stresses and API 620, Table 5-2, for joint efficiency and radiography requirements. The thickness of self supporting roofs shall not be less than required by API 650, 5.10.5 or 5.10.6, as applicable.
2. Roof plate, manway and nozzle materials shall be selected from API 650, Section 4. Materials need not meet toughness criteria of 4.2.9.
3. Roof manways and roof nozzles shall meet the requirements of API 650, 5.7.1 through 5.7.6, for shell manways and nozzles. Where designed details for API 650 vary by height of liquid level, the values for the lowest liquid level may be used. Alternatively, roof manways and nozzles may be designed per API 620 using all the rules for API 620 roof manways and nozzles, including the 250°F maximum design temperature limitation.

● **F.7.4** The design of the anchorage and its attachment to the tank shall be a matter of agreement between the Manufacturer and the Purchaser and shall meet the requirements of 5.12.

F.7.5 The counterbalancing weight, in addition to the requirements in 5.12, shall be designed so that the resistance to uplift at the bottom of the shell will be the greatest of the following:

a. The uplift produced by 1.5 times the design pressure of the corroded empty tank plus the uplift from the design wind velocity on the tank.

b. The uplift produced by 1.25 times the test pressure applied to the empty tank (with the nominal thicknesses).

c. The uplift produced by 1.5 times the calculated failure pressure (P_f in F.6) applied to the tank filled with the design liquid. The effective weight of the liquid shall be limited to the inside projection of the ringwall (Appendix B type) from the tank shell. Friction between the soil and the ringwall may be included as resistance. When a footing is included in the ringwall design, the effective weight of the soil may be included.

F.7.6 After the tank is filled with water, the shell and the anchorage shall be visually inspected for tightness. Air pressure of 1.25 times the design pressure shall be applied to the tank filled with water to the design liquid height. The air pressure shall be reduced to the design pressure, and the tank shall be checked for tightness. In addition, all seams above the water level shall be tested using a soap film or another material suitable for the detection of leaks. After the test water has been emptied from the tank (and the tank is at atmospheric pressure), the anchorage shall be checked for tightness. The design air pressure shall then be applied to the tank for a final check of the anchorage.

APPENDIX G—STRUCTURALLY-SUPPORTED ALUMINUM DOME ROOFS

G.1 General

G.1.1 PURPOSE

This appendix establishes minimum criteria for the design, fabrication, and erection of structurally-supported aluminum dome roofs. When this appendix is applicable, the requirements of 5.10 and the paragraphs in Appendix F that deal with roof design are superseded. All other requirements of API Std 650 shall apply, except that the maximum design temperature shall not exceed 90°C (200°F).

G.1.2 DEFINITION

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

G.1.3 GENERAL APPLICATION

G.1.3.1 New Tanks

When this appendix is specified for a new tank, the tank shall be designed to support the aluminum dome roof. The roof Manufacturer shall supply the magnitude and direction of all the forces acting on the tank as a result of the roof loads, together with details of the roof-to-shell attachment. The tank shall be designed as an open-top tank, and its wind girder shall meet the requirements of 5.9. The top of the tank shell shall be structurally suitable for attachment of the dome roof structure. The tank Manufacturer and the foundation designer shall be responsible for designing the tank and foundation, respectively, for the loads and moments transmitted from the roof, as provided by the roof manufacturer. If the Purchaser specifies a roof with fixed supports, the supports shall be rigidly attached directly to the tank and the top of the tank shall be designed to sustain the horizontal thrust transferred from the roof (see G.5.2). The as-built minimum and maximum diameter at the top of the tank shall be reported to the roof manufacturer by the Purchaser or the tank Manufacturer. 11

● G.1.3.2 Existing Tanks

When this appendix is specified for an aluminum dome roof to be added to an existing tank (with or without an existing roof), the roof Manufacturer shall verify that the tank has sufficient strength to support a new roof and meet the applicable requirements of Section 5.11. Information on the existing tank shall be provided by the Purchaser including minimum tank shell course thicknesses, tank shell course heights, design corrosion allowance, and existing anchorage details. The Purchaser shall specify the existing or new appurtenances to be accommodated by the roof Manufacturer. The roof Manufacturer shall supply the values of the forces acting on the tank as a result of the roof loads. The Purchaser shall verify the adequacy of the foundations. Unless otherwise specified, any reinforcement required to enable the tank to support the roof shall be the responsibility of the Purchaser. The design and erection of the roof shall accommodate the actual tank shape. The responsibility for determining the tank shape shall be specified by the Purchaser. The existing tank shall be equipped with a wind girder that meets the requirements of 5.9 for an open-top tank. 11

● G.1.3.3 Existing Tank Data Sheet

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

G.1.4 SPECIAL FEATURES

● G.1.4.1 Self-Supporting Structure

The aluminum dome roof shall be supported only from the rim of the tank. The design of the connection between the roof and the tank rim shall allow for thermal expansion. A minimum temperature range of ±70°C (120°F) shall be used for design unless a wider range is specified by the Purchaser. 11

● G.1.4.2 Finish

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

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

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

(INFORMATION TO BE COMPLETED BY THE PURCHASER)

1. PURCHASER/AGENT ____________
ADDRESS ____________
CITY ____________ STATE ____________ ZIP ____________
PHONE ____________ FAX ____________
2. USER ____________
3. ERECTION SITE:NAME OF PLANT ____________
LOCATION ____________
4. TANK NO. ____________
5. PUMPING RATES: IN ____________ m^3/h (bbl/h) OUT ____________ m^3/h (bbl/h)
6. MAXIMUM DESIGN TEMPERATURE ____________ (NOT TO EXCEED 90°C [200°F])
7. DESIGN PRESSURE: ○ ATMOSPHERIC OR ____________ kPa (in.) OF WATER (INDICATE WHETHER POSITIVE OR NEGATIVE)
8. ROOF LOADS: UNIFORM LIVE ____________ kPa (lbf/ft^2)
SPECIAL (PROVIDE SKETCH) ____________ kPa (lbf/ft^2)
9. SEISMIC DESIGN? ○ YES ○ NO ○ APPENDIX E ○ OR ALTERNATE SEISMIC CRITERIA ____________
IF APPENDIX E, CONTINUE HERE: SEISMIC USE GROUP ____________; MBE SITE CLASS ____________
BASIS OF LATERAL ACCELERATIONS (SELECT ONE):
○ MAPPED SEISMIC PARAMETERS, %g (E.4.1) S_S ________ S_1 ________ S_0 ________
○ SITE-SPECIFIC SPECTRAL RESPONSE ACCELERATIONS (E.4.2); MCE DESIGN REQUIRED? ○ YES ○ NO
○ OTHER (NON-ASCE) METHODS ____________
VERTICAL SEISMIC DESIGN? ○ YES ○ NO; VERTICAL EARTHQUAKE ACCELERATION COEFFICIENT A_v, %g: ________
GROUND SNOW LOAD (IF NOT FROM ASCE 7): ____________ kPa (lbf/ft^2)
10. DESIGN WIND SPEED: (SELECT ONE) ○ 190 Km/h (120 mph)
○ PURCHASER SPECIFIED WIND SPEED (50-YR MIN. 3-SEC. GUST) ________ Km/h (mph)
○ 3-SEC. GUST FROM ASCE 7, FIGURE 6-1 ____________ Km/h (mph)
IMPORTANCE FACTOR (IF OTHER THAN 1.0) ____________
11 EXPOSURE CATEGORY PER ASCE 7 ____________
11. MAXIMUM HEIGHT FROM TOP OF SHELL TO TOP OF DOME ____________ m (ft)
12. TANK SHELL THICKNESS (ACTUAL)

COURSE NUMBER	MINIMUM THICKNESS	TYPICAL THICKNESS	PLATE WIDTH

13. ACTUAL TANK STIFFENER DETAILS, POSITION AND DIMENSIONS (PROVIDE SKETCH)
14. GASES EXPECTED IN THE VAPOR SPACE ____________
15. REQUIRED FREEBOARD ABOVE TOP OF TANK ____________ mm (in.)
16. ACTUAL MINIMUM TANK DIAMETER AT THE TOP OF THE TANK ____________ m (ft)
ACTUAL MAXIMUM TANK DIAMETER AT THE TOP OF THE TANK ____________ m (ft)
17. ELEVATION OF TOP OF TANK: MAXIMUM ____________ MINIMUM
18. BOTTOM THICKNESS AT THE TANK SHELL ____________ mm (in.)
19. MAXIMUM LIQUID LEVEL ____________ m (ft)
20. EXISTING ANCHORAGE DETAILS IF ANY: ____________
21. LIST ALL APPURTENANCES, OTHER THAN THOSE TO BE REMOVED BY THE PURCHASER, AND INDICATE ACTION REQUIRED OF CONTRACTOR

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

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

G.1.4.3 Maintenance and Inspection

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

● G.1.4.4 Jurisdictional Requirements

The Purchaser is required to provide all applicable jurisdictional requirements that apply to the aluminum dome roof (see 1.3). | 07

G.2 Materials

● G.2.1 GENERAL

Materials furnished to meet the requirements of this appendix shall be new. A complete material specification shall be submitted by the roof Manufacturer for approval by the Purchaser. The materials shall be compatible with the product specified to be stored in the tank and the surrounding environment. No aluminum alloy with a magnesium content greater than 3% shall be used when the maximum design temperature exceeds 65°C (150°F). Properties and tolerances of aluminum alloys shall conform to *Aluminum Standards and Data*, as published by the Aluminum Association (Washington, D.C.).

G.2.2 STRUCTURAL FRAME

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

G.2.3 ROOF PANELS

Roof panels shall be fabricated from Series 3000 or 5000 aluminum with a minimum nominal thickness of 1.20 mm (0.050 in.).

● G.2.4 BOLTS AND FASTENERS

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

G.2.5 SEALANT AND GASKET MATERIAL

G.2.5.1 Sealants shall be silicone or urea urethane compounds that conform to Federal Spec TT-S-00230C unless another material is required for compatibility with stored materials. Sealants shall remain flexible over a temperature range of –60°C to +150°C (–80°F to +300°F) without tearing, cracking, or becoming brittle. Elongation, tensile strength, hardness, and adhesion shall not change significantly with aging or exposure to ozone, ultraviolet light, or vapors from the product stored in the tank.

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

G.2.6 SKYLIGHT PANELS

Skylight panels shall be clear acrylic or polycarbonate with a minimum nominal thickness of 6 mm (0.25 in.).

G.3 Allowable Stresses

G.3.1 ALUMINUM STRUCTURAL MEMBERS

Aluminum structural members and connections shall be designed in accordance with the *Aluminum Design Manual*, as published by the Aluminum Association, Inc. (Washington, D.C.), except as modified by this appendix.

G.3.2 ALUMINUM PANELS

Aluminum panels shall be designed in accordance with *Specifications for Aluminum Sheet Metal Work in Building Construction*, as published by the Aluminum Association, Inc. (Washington, D.C.) and this appendix. Attachment fasteners shall not penetrate both the panel and the flange of the structural member.

G.3.3 BOLTS AND FASTENERS

G.3.3.1 The maximum stress in bolts and fasteners for any design condition shall not exceed the allowable stress given in Tables G-1a and G-1b. 08

Table G-1a—(SI) Bolts and Fasteners

Materials	Allowable Tensile Stress[a,b] (MPa)	Allowable Shear Stress[a,b,c] (MPa)
Austenitic stainless steel[d]	172	124
Austenitic stainless steel[e]	234	172
2024-T4 aluminum	182	109
7075-T73 aluminum	201	120

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

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

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

[d] For bolts with a minimum tensile strength of 620 MPa.

[e] For bolts with a minimum tensile strength of 860 MPa.

[f] For fasteners not shown, design shall be in accordance with the *Aluminum Design Manual*, as published by the Aluminum Association, Inc. (Washington, D.C.).

08 Table G-1b—(USC) Bolts and Fasteners

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

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

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

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

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

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

[f] For fasteners not shown, design shall be in accordance with the *Aluminum Design Manual*, as published by the Aluminum Association, Inc. (Washington, D.C.).

G.3.3.2 The hole diameter for a fastener shall not exceed the diameter of the fastener plus 1.5 mm ($^1/_{16}$ in.).

G.4 Design

G.4.1 DESIGN PRINCIPLES

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

G.4.1.2 The actual stresses in the framing members and panels under all design load conditions shall be less than or equal to the allowable stresses per the *Aluminum Design Manual*, as published by the Aluminum Association, Inc. (Washington, D.C.).

G.4.1.3 The allowable general buckling pressure p_a shall equal or exceed the maximum pressure given in R.1 (e).

$$p_a = \frac{1.6E\sqrt{I_x A}}{LR^2(SF)} \qquad \text{(G.4.1.3-1)}$$

where

E = modulus of elasticity of the dome frame members,

I_x = moment of inertia of frame members for bending in a plane normal to the dome surface,

A = cross-sectional area of frame members,

R = spherical radius of the dome,

L = average length of the frame members,

SF = safety factor = 1.65.

Alternatively, p_a shall be determined by a non-linear finite element analysis with a safety factor of 1.65.

G.4.1.4 The net tension ring area (exclusive of bolt holes and top flange protrusions) shall not be less than:

$$A_n = \frac{D^2 p}{8F_t \tan\theta} \qquad \text{(G.4.1.4-1)}$$

where 09

A_n = net area of tension ring,

D = nominal tank diameter,

p = maximum pressure given in R.1 (e),

θ = $^1/_2$ the central angle of the dome or roof slope at the tank shell,

F_t = least allowable stress for components of the tension ring.

Note: This formula does not include bending stresses due to loads from the panel attached to the beam. These stresses must also be considered in the tension ring design per G.3.1.

G.4.2 DESIGN LOADS

G.4.2.1 Loads on Dome Roofs

Dome roofs shall be designed for:

a. the loads in 5.2.1,
b. the load combinations in Appendix R.1(a), (b), (c), (e), and (f).

G.4.2.2 Seismic Load

If the tank is designed for seismic loads, the roof shall be designed for:

a. a horizontal seismic force $F_h = A_i W_r$
b. a vertical seismic force $F_v = \pm A_v W_r$

where A_i, A_v, and W_r are as defined in Appendix E. Forces shall be uniformly applied over the surface of the roof. Horizontal and vertical forces need not be applied simultaneously

G.4.2.3 Panel Loads

G.4.2.3.1 Roof panels shall be of one-piece aluminum sheet (except for skylights as allowed by G.8.4). The roof shall be 09 designed to support a uniform load of 3 kPa (60 lbf/ft^2) over the full area of the panel.

G.4.2.3.2 The roof shall be designed to support two concentrated loads 1100 N (250 lbf), each distributed over two separate 0.1 m^2 (1 ft^2) areas of any panel.

G.4.2.3.3 The loads specified in G.4.2.3.1 and G.4.2.3.2 shall not be applied simultaneously or in combination with any other loads.

• G.4.3 INTERNAL PRESSURE

Unless otherwise specified by the Purchaser, the internal design pressure shall not exceed the weight of the roof. In no case shall the internal design pressure exceed 2.2 kPa (9 in. of water) water column. When the design pressure, P_{max}, for a tank with an aluminum dome roof is being calculated, the weight of the roof, including structure, shall be used for the D_{LR} term in F.4.2. 11

G.5 Roof Attachment

G.5.1 LOAD TRANSFER

Structural supports for the roof shall be bolted or welded to the tank. To preclude overloading of the shell, the number of attachment points shall be determined by the roof Manufacturer in consultation with the tank Manufacturer. The attachment detail shall be suitable to transfer all roof loads to the tank shell and keep local stresses within allowable limits.

G.5.2 ROOF SUPPORTS

G.5.2.1 Sliding Supports

The roof attachment points may incorporate a slide bearing with low-friction bearing pads to minimize the horizontal radial forces transferred to the tank. The primary horizontal thrust transferred from the dome shall be resisted by an integral tension ring.

11 G.5.2.2 Fixed Supports

The roof may have fixed supports attached directly to the tank, and the top of the tank shall be analyzed and designed to sustain the horizontal thrust transferred from the roof, including that from differential thermal expansion and contraction. For roofs with fixed supports on a new tank, the maximum acceptable radial tank deflections at the top of the tank shall be coordinated between the tank Manufacturer and roof manufacturer. For roofs with fixed supports on an existing tank, the maximum acceptable radial tank deflections at the top of the tank shall be coordinated between the Purchaser and roof manufacturer.

• G.5.3 SEPARATION OF CARBON STEEL AND ALUMINUM

Unless another method is specified by the Purchaser, aluminum shall be isolated from carbon steel by an austenitic stainless steel spacer or an elastomeric isolator bearing pad.

G.5.4 ELECTRICAL GROUNDING

The aluminum dome roof shall be electrically interconnected with and bonded to the steel tank shell or rim. As a minimum, stainless steel cable conductors 3 mm ($^1/_8$ in.) in diameter shall be installed at every third support point. The choice of cable shall take into account strength, corrosion resistance, conductivity, joint reliability, flexibility, and service life.

G.6 Physical Characteristics

G.6.1 SIZES

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

● G.6.2 DOME RADIUS

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

● G.7 Platforms, Walkways, and Handrails

Platforms, walkways, and handrails shall conform to 5.8.10 except that the maximum concentrated load on walkways or stairways supported by the roof structure shall be 4450 N (1000 lbf). When walkways are specified to go across the exterior of the roof (to the apex, for example), stairways shall be provided on portions of walkways whose slope is greater than 20 degrees. Walkways and stairways may be curved or straight segments. | 11

G.8 Appurtenances

G.8.1 ROOF HATCHES

If roof hatches are required, each hatch shall be furnished with a curb 100 mm (4 in.) or higher and a positive latching device to hold the hatch in the open position. The minimum size of opening shall not be less than 600 mm (24 in.). The axis of the opening may be perpendicular to the slope of the roof, but the minimum clearance projected on a horizontal plane shall be 500 mm (20 in.).

G.8.2 ROOF NOZZLES AND GAUGE HATCHES

Roof nozzles and gauge hatches shall be flanged at the base and bolted to the roof panels with an aluminum reinforcing plate on the underside of the panels. The axis of a nozzle or gauge hatch shall be vertical. If the nozzle is used for venting purposes, it shall not project below the underside of the roof panel. Aluminum or stainless steel flanges may be bolted directly to the roof panel, with the joint caulked with sealant. Steel flanges shall be separated from the aluminum panel by a gasket (see Figure G-2 for a typical nozzle detail).

● G.8.3 SKYLIGHTS | 07

G.8.3.1 If skylights are specified by the Purchaser, each skylight shall be furnished with a curb 100 mm (4 in.) or higher and shall be designed for the live and wind loads specified in G.4.2.5. The Purchaser shall specify the total skylight area to be provided.

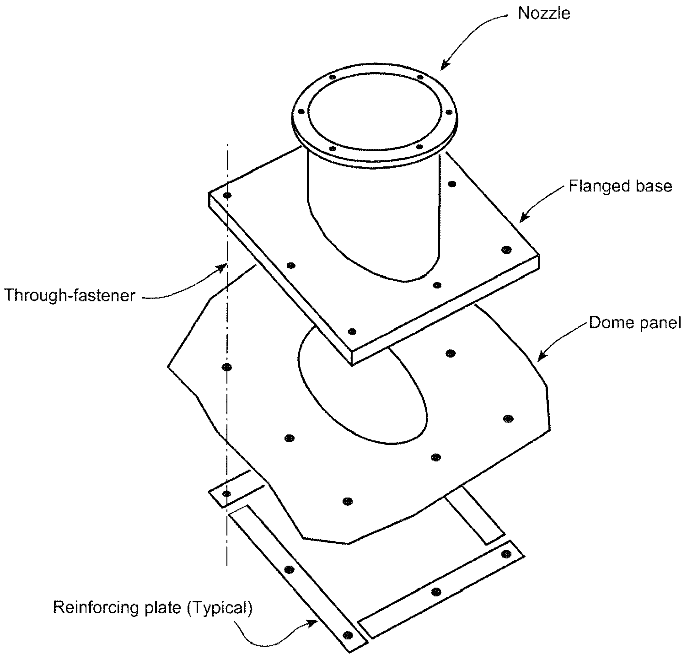

Figure G-2—Typical Roof Nozzle

G.8.3.2 When skylights are specified for tanks without floating roofs or for floating roof tanks which are sealed and gas-blanketed (not provided with circulation venting per H.5.2.2.1 and H.5.2.2.2), the Purchaser shall consider skylight material compatibility with exposure to elevated concentrations of the stored product.

• G.9 Sealing at the Shell

The roof need not be sealed to the tank shell unless specified by the Purchaser or required to contain internal pressure. The bottom of the flashing shall extend at least 50 mm (2 in.) below the top of the tank. Corrosion-resistant coarse-mesh screen (13 mm [$^1/_2$ in.] openings) shall be provided to prevent the entrance of birds.

G.10 Testing

G.10.1 LEAK TESTING

• **G.10.1.1** After completion, the roof seams shall be leak tested by spraying the outside of the seams with water from a hose with a minimum static head pressure 350 kPa (50 lbf/in.^{2}) gauge at the nozzle. Because of possible corrosive effects, consideration shall be given to the quality of the water used and the duration of the test. Potable water shall be used unless otherwise specified. The water shall not be sprayed directly on roof vents. Any water on the inside of the roof shall constitute evidence of leakage.

• **G.10.1.2** Where gas-tight roofs are required, leak testing may be accomplished in accordance with F.4.4 or F.7.6 or by another means acceptable to the roof Manufacturer and the Purchaser.

G.10.1.3 Any leaks discovered during testing shall be sealed, and the roof shall be retested until all leaks are sealed.

G.11 Fabrication and Erection

G.11.1 GENERAL

The dome contractor shall perform the work described in this appendix using qualified supervisors who are skilled and experienced in the fabrication and erection of aluminum structures.

G.11.2 FABRICATION

07 All roof parts shall be prefabricated for field assembly. Fabrication procedures shall be in accordance with Section 6 of the *Aluminum Design Manual.* All structural shapes used to make the roof shall be punched or drilled before any shop coating is applied.

• G.11.3 WELDING

The design and fabrication of welded aluminum parts shall be in accordance with the *Aluminum Design Manual: Specifications for Aluminum Structures* and AWS D1.2. All aluminum structural welds and components joined by welding shall be visually inspected and tested by dye-penetrant examination in accordance with Section 5, Part D, of AWS D1.2. All structural welding of aluminum shall be performed before the dome is erected in the field. A full set of satisfactory examination records shall be delivered to the owner before field erection.

G.11.4 SHIPPING AND HANDLING

Materials shall be handled, shipped, and stored in a manner that does not damage the surface of aluminum or the surface coating of steel.

G.11.5 ERECTION

The erection supervisor shall be experienced in the construction of aluminum dome roofs and shall follow the Manufacturer's instructions and drawings furnished for that purpose.

G.11.6 WORKMANSHIP

To minimize internal stresses on the structure when fasteners are tightened, the roof shall be installed on supports that are in good horizontal alignment. The components of the structure shall be erected with precise fit and alignment. Field cutting and trimming, relocation of holes, or the application of force to the parts to achieve fit-up is not acceptable.

APPENDIX H—INTERNAL FLOATING ROOFS

H.1 Scope

- **H.1.1** This appendix provides minimum requirements that apply to a tank with an internal floating roof and a fixed roof at the top of the tank shell, and to the tank appurtenances. This appendix is intended to limit only those factors that affect the safety and durability of the installation and that are considered to be consistent with the quality and safety requirements of this Standard. Types of internal floating roofs (listed under H.2) and materials (listed under H.3) are provided as a basic guide and shall not be considered to restrict the Purchaser option of employing other commonly accepted or alternative designs, as long as all design loading is documented to meet the minimum requirements herein, and all other criteria are met (except alternative materials and thicknesses as permitted by H.3.1). The requirements apply to the internal floating roof of a new tank and may be applied to an existing fixed-roof tank. Section 5.10 of this Standard is applicable, except as modified in this appendix.

- **H.1.2** The Purchaser is required to provide all applicable jurisdictional requirements that apply to internal floating roofs (see 1.3). 07

- **H.1.3** See Appendix W for bid requirements pertaining to internal floating roofs.

H.2 Types of Internal Floating Roofs

H.2.1 The internal floating roof type shall be selected by the Purchaser after consideration of both proposed and future product service, operating conditions, maintenance requirements, regulatory compliance, service life expectancy, ambient temperature, maximum design temperature, product vapor pressure, corrosion conditions and other compatibility factors. Other operating conditions requiring consideration include (but are not limited to) anticipated pumping rates, roof landing cycles, and the potential for turbulence resulting from upsets, such as vapor slugs injected into the tank. Safety and risk factors associated with the roof types shall also be evaluated[24]. The type of roof, which shall be designated by the Purchaser on the Data Sheet, Line 30, shall be one of the types described in H.2.2.

H.2.2 The following types of internal floating roofs are described in this appendix:

a. Metallic pan internal floating roofs[25,26,27] have a peripheral rim above the liquid for buoyancy. These roofs are in full contact with the liquid surface and are typically constructed of steel.

b. Metallic open-top bulk-headed internal floating roofs[26,27] have peripheral open-top bulk-headed compartments for buoyancy. Distributed open-top bulk-headed compartments shall be used as required. These roofs are in full contact with the liquid surface and are typically constructed of steel.

c. Metallic pontoon internal floating roofs have peripheral closed-top bulk-headed compartments for buoyancy. Distributed closed-top bulk-headed compartments shall be used as required. These roofs are in full contact with the liquid surface and are typically constructed of steel.

d. Metallic double-deck internal floating roofs have continuous closed top and bottom decks, which contain bulk-headed compartments for buoyancy. These roofs are in full contact with the liquid surface and are typically constructed of steel.

e. Metallic internal floating roofs on floats have their deck above the liquid, supported by closed pontoon compartments for buoyancy. These roof decks are not in full contact with the liquid surface and are typically constructed of aluminum alloys or stainless steel.

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[24] Internal floating roof tanks generally have reduced fire risk, and the use of fixed fire suppression systems is often not mandatory. Various internal floating roof materials will have unique flammability characteristics, melting points and weights (perhaps with reduced buoyancy being required). If fire suppression systems are used, certain roof types need to be evaluated for full surface protection. NFPA 11 *Standard for Low-Expansion Foam* can provide guidance for this evaluation.

[25] The Purchaser is cautioned that this design does not have multiple flotation compartments necessary to meet the requirements of H.4.2.1.3.

[26] These designs contain no closed buoyancy compartments, and are subject to flooding during sloshing or during application of fire-fighting foam/water solution. Also, without bracing of the rim being provided by the pontoon top plate, design to resist buckling of the rim must be evaluated. 07

[27] If the floating roof is a) a metallic pan roof with or without bulkheads, or b) a non-metallic roof with or without closed buoyancy compartments, then the tank is considered a fixed-roof tank (i.e., having no internal floating roof) for the requirements of NFPA 30. See NFPA 30 for spacing restrictions on floating roof tanks.

07 ● f. Metallic sandwich-panel/composite internal floating roofs have metallic or composite material panel modules for buoyancy compartments. Panel modules may include a honeycomb or closed cell foam core; however, cell walls within the panel module are not considered "compartments" for purposes of inspection and design buoyancy requirements (see H.4.1.7 and H.4.2.1)[28]. These roofs are in full contact with the liquid surface and are typically constructed of aluminum alloys or Purchaser approved composite materials.[27]

● g. Hybrid internal floating roofs shall, upon agreement between the Purchaser and the Manufacturer, be a design combination of roof types described in H.2.2.b and H.2.2.c, having bulkhead compartments with closed-top perimeter pontoon and open-top center compartments for buoyancy. These roofs are in full contact with the liquid surface and are typically constructed of steel.

07 ● h. Other roof materials or designs if specified and described in detail by the Purchaser on the Data Sheet.

● H.3 Material

H.3.1 SELECTION

Internal floating roof materials shall be selected by the Purchaser after consideration of items listed under H.2.1. The Manufacturer shall submit a complete material specification in his proposal. The choice of materials should be governed by compatibility with the specified liquid. Material produced to specifications other than those listed in this appendix (alternative materials) may be used. Material shall be certified to meet all the requirements of a material specification listed in this appendix, and approved by the Purchaser or shall comply with requirements as specified by the Purchaser. When specified by the Purchaser, a corrosion allowance shall be added to the minimum nominal thickness indicated below. The "nominal thickness" is the purchased thickness with allowance for the permissible mill tolerance.

H.3.2 STEEL

08 Steel shall conform to the requirements of Section 4 of this Standard. Steel in contact with vapor or liquid shall be 4.8 mm ($^3/_{16}$ in.) minimum nominal thickness. Other steel shall be 2.5 mm (0.094 in.) minimum nominal thickness.

H.3.3 ALUMINUM

08 Aluminum shall conform to the requirements of Apendix AL. Aluminum skin shall be 0.50 mm (0.020 in.) minimum nominal thickness. Aluminum floats shall be 1.2 mm (0.050 in.) minimum nominal thickness. For a sandwich panel flotation unit, core material shall be at least 25 mm (1.0 in.) thick, and metallic skin (except carbon steel) shall be 0.41 mm (0.016 in.) minimum nominal thickness.

H.3.4 STAINLESS STEEL

Stainless steel shall conform to the requirements of ASTM A 240/A 240M (austenitic type only). Stainless steel skin shall be 0.46 mm (0.018 in.) minimum nominal thickness. Stainless steel floats shall be 1.2 mm (0.048 in.) minimum nominal thickness.

H.4 Requirements for All Types

H.4.1 GENERAL

H.4.1.1 An internal floating roof and its accessories shall be designed and constructed to allow the roof to operate throughout its normal travel without manual attention and without damage to any part of the fixed roof, the internal floating roof, internal floating roof seals (except for normal wear), the tank, or their appurtenances. The internal floating roof and seals shall be designed to operate in a tank constructed within the dimensional limits defined in 7.5 of this Standard.

H.4.1.2 The internal floating roof shall be designed and built to float and rest in a uniform horizontal plane (no drainage slope required).

H.4.1.3 All seams in the internal floating roof that are exposed to product vapor or liquid shall be vapor-tight in accordance with H.4.3.1.

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[28] A single inspection opening per panel module is permitted, regardless of core material; however, core materials producing enclosed spaces within a module may result in undetectable combustible gas in areas isolated from the inspection opening. Design buoyancy shall be based on the loss of any two full panel modules (not cells within modules).

H.4.1.4 A vapor-tight rim (or skirt), extending at least 150 mm (6 in.) above the liquid at the design flotation level, shall be provided around both the internal floating roof periphery and around all internal floating roof penetrations (columns, ladders, stilling wells, manways, open deck drains and other roof openings) except for drains designed to avoid product backflow onto the roof. 09

H.4.1.5 The non-contact type (see H.2.2e) internal floating roof shall have a vapor-tight rim (or skirt), extending at least 100 mm (4 in.) into the liquid at the design flotation level, around both the internal floating roof periphery and around all internal floating roof penetrations (columns, ladders, stilling wells, manways, open deck drains and other roof openings), with the exception of penetrations for pressure-vacuum (bleeder) vents (per H.5.2.1).

● **H.4.1.6** All conductive parts of the internal floating roof shall be electrically interconnected and bonded to the outer tank structure. This shall be accomplished by electric bonding shunts in the seal area (a minimum of four, uniformly distributed) or flexible multi-strand cables from the external tank roof to the internal floating roof (a minimum of two, uniformly distributed). The choice of bonding devices shall be specified by the Purchaser on the Data Sheet, Line 32, considering strength, corrosion resistance, joint reliability, flexibility, and service life. All movable cover accessories (hatches, manholes, pressure relief devices, and other openings) on the internal floating roof shall be electrically bonded to the internal floating roof to prevent static electricity sparking when they are opened. 07

● **H.4.1.7** Each closed flotation compartment shall be capable of being field-inspected for the presence of combustible gas. Inspection openings shall be located above the liquid level and closed compartments shall be capable of being resealed in the field after periodic inspection (to prevent liquid or vapor entry). Closed-top compartments (types H.2.2c, d, and g) shall be accessible from the top of the internal floating roof and provided with a secured and gasketed manhole for visual internal inspection and the manhole cover shall be provided with a suitable vent. The top edge of the manhole shall extend a minimum of 25 mm (1 in.) above the top of the pontoon rim/skirt. With agreement by the Purchaser, type H.2.2c, d, and g floating roofs 6 m (20 ft) in diameter or less may be provided with an inspection port in place of a manhole. The inspection ports must meet the sealing, securing and extension requirements listed here for manholes in internal floating roof closed compartments.

● **H.4.1.8** All closed flotation compartments shall be seal welded to prevent liquid or vapor entry, unless otherwise specified by the Purchaser. For pontoon, double-deck and hybrid internal floating roofs (types H.2.2c, d, and g), each bulkhead in a closed flotation compartment shall also be provided with a continuous seal weld all around so that the bulkhead is liquid and vapor-tight.

● **H.4.1.9** For metallic/composite sandwich-panel roofs (type H.2.2f), if the use of adhesives is allowed by the Purchaser (per H.4.3.4) to seal the flotation panels (in lieu of welding), all exposed adhesives shall be compatible with the product service and flotation test water (Purchaser shall consider future product service, the hydrostatic test condition, and design condition changes to specify adhesive compatibility.)

● **H.4.1.10** When specified by the Purchaser for deck surfaces above the liquid level, deck drains shall be provided to return any spillage or condensate to the product. Such drains shall close automatically or extend at least 100 mm (4 in.) into the product to minimize vapor loss.

H.4.1.11 Internal floating roofs classified as full-contact types (see H.2.2) shall be designed to minimize trapped vapor space beneath the internal floating roof.

H.4.2 INTERNAL FLOATING ROOF DESIGN

H.4.2.1 Buoyancy Requirements

● **H.4.2.1.1** All internal floating roof design calculations shall be based on the lower of the product specific gravity or 0.7 (to allow for operation in a range of hydrocarbon service), regardless of any higher specific gravity that might be specified by the Purchaser.

H.4.2.1.2 All internal floating roofs shall include buoyancy required to support at least twice its dead weight (including the weight of the flotation compartments, seal and all other floating roof and attached components), plus additional buoyancy to offset the calculated friction exerted by peripheral and penetration seals during filling. 07

● **H.4.2.1.3** All internal floating roofs with multiple flotation compartments shall be capable of floating without additional damage after any two compartments are punctured and flooded. Designs which employ an open center deck in contact with the liquid (types H.2.2b, c, and g) shall be capable of floating without additional damage after any two compartments and the center deck are punctured and flooded. With agreement by the Purchaser, any floating roof 6 m (20 ft) in diameter or less with multiple flotation compartments may be designed to be capable of floating without additional damage after any one compartment is punctured and flooded.

08 **H.4.2.1.4** The internal floating roof shall be designed to meet the requirements of H.4.2.1.3 and to safely support at least two men walking anywhere on the roof while it is floating without damaging the floating roof and without allowing product on the roof. One applied load of 2.2 kN (500 lbf) over 0.1 m^2 (1 ft^2) applied anywhere on the roof addresses two men walking. With agreement by the Purchaser, the concentrated load design criteria may be modified for roofs less than 9 m (30 ft) diameter (where internal floating roofs may become unstable), to account for access needs, and expected concentrated live loads.

H.4.2.2 Internal Floating Roof Support Design Loads

11 **H.4.2.2.1** Internal floating roof supports and deck structural attachments (such as reinforcing pads and pontoon end gussets) shall be designed to support the load combinations listed in H.4.2.2.2 without exceeding allowable stresses. Consideration shall also be made for non-uniform support settlement or other non-uniform load distribution, based on anticipated conditions specified by the Purchaser. Application of non-uniform loads is by agreement between the Purchaser and Manufacturer.

• H.4.2.2.2 Load Combination for Floating Roof Supports

Floating roof support loading (legs or cables) shall be as follows:

$$D_{f} + \text{(the greater of) } P_{fe} \text{ or } L_{f1} \text{ or } L_{f2}$$

where

D_f = dead load of internal floating roof, including the weight of the flotation compartments, seal and all other floating roof and attached components,

08 L_{f1} = internal floating roof uniform live load (0.6 kPa [12.5 lbf/ft^2] if not automatic drains are provided, 0.24 kPa [5 lbf/ft^2] if automatic drains are provided),

L_{f2} = internal floating roof point load of at least two men walking anywhere on the roof. One applied load of 2.2 kN [500 lbf] over 0.1 m^2 [1 ft^2] applied anywhere on the roof addresses two men walking,

P_{fe} = internal floating roof design external pressure (0.24 kPa [5 lbf/ft^2] minimum).

Note: With agreement by the Purchaser, L_{f2} may be modified for roofs less than 9 m (30 ft) diameter (where internal floating roofs may be come unstable), to account for access needs, and expected concentrated live loads.

H.4.2.2.3 The allowable load on support cables shall be determined using a factor of safety of 5 on the ultimate strength of cables and their connections. Cables and their connections shall be de designed for the load combination listed in H.4.2.2.2.

H.4.2.3 Other Design Requirements

H.4.2.3.1 Aluminum load carrying members, assemblies and connections shall comply with the design requirements of the latest edition of the Aluminum Design Manual.

07 • **H.4.2.3.2** Steel structural components shall be proportioned so that the maximum stresses shall not exceed the limitations specified in the latest edition of the *Manual of Steel Construction, Allowable Stress Design*, as published by the American Institute of Steel Construction (Chicago, IL). For other steel components, the allowable stress and stability requirements shall be jointly established by the Purchaser and the Manufacturer, as part of the inquiry. Alternatively, a proof test (simulating the conditions of H.4.2) may be performed on the roof or on one of similar design.

H.4.3 JOINT DESIGN

H.4.3.1 All seams in the floating roof exposed directly to product vapor or liquid shall be welded, bolted, screwed, riveted, clamped, or sealed and checked for vapor-tightness per H.6.2.

H.4.3.2 Welded joints between stainless steel members and welded joints between carbon steel members shall conform to 5.1 of this Standard. Welded joints between aluminum members shall conform to AL.5.1. 08

H.4.3.2.1 Single-welded butt joints without backing are acceptable for flotation units where one side is inaccessible.

08 **H.4.3.2.2** The thickness of fillet welds on material less than 4.8 mm ($^3/_{16}$ in.) thick shall not be less than that of the. thinner member of the joint. 07

• **H.4.3.3** Bolted, threaded, and riveted joints are acceptable when mutually agreed upon by the Purchaser and the Manufacturer.

● **H.4.3.3.1** Only austenitic type stainless steel hardware shall be used to join aluminum and/or stainless steel components to each other or to carbon steel. Where acceptable to the Purchaser and the Manufacturer, aluminum hardware may be used to join aluminum components. Aluminum shall be isolated from carbon steel by an austenitic stainless steel spacer, an elastomeric pad, or equivalent protection. The use of plated fasteners shall be permitted only when connecting steel components, if specified by the Purchaser. 07

● **H.4.3.4** Use of any joint sealing compound, insulating material, polymer, elastomer or adhesive must be pre-approved by the Purchaser. The joining procedure along with test results demonstrating the properties required by this paragraph shall be described completely. Where such joints are permitted, any joint sealing compound, insulating material, elastomeric or adhesive shall be compatible with the product stored, specified service conditions, and with materials joined. Resulting joints shall be equivalent in serviceability (with the basic floating roof components), of a size and strength that will accept the roof design loads without failure or leakage, and shall have an expected life equal to the service life of the roof. Any non-metallic component shall be selected and fabricated to preclude absorption (under design conditions specified and permitted by this Standard) of hydrocarbons, hydro-test water and specified product to be stored.

● **H.4.3.5** If specified by the Purchaser, all steel plate seams exposed to the product liquid or vapor shall be seal welded (for corrosive service conditions).

H.4.4 PERIPHERAL SEALS

● In addition to the required floating roof primary peripheral seal, secondary-peripheral seals shall be provided if specified on the Data Sheet, Line 31. Floating roof primary and secondary peripheral seal types and configurations shall be provided as specified on the Data Sheet, Line 31. 07

H.4.4.1 A peripheral seal (also referred to as "rim seal") that spans the annular space between the internal floating roof deck and the shell shall be provided. When an internal floating roof has two such devices, one mounted above the other, the lower is the primary peripheral seal and the upper is the secondary peripheral seal. When there is only one such device, it is a primary peripheral seal, regardless of its mounting position.

● **H.4.4.2** The peripheral seal type and material shall be selected by the Purchaser after consideration of both proposed and future product service, tank shell construction/condition, maintenance requirements, regulatory compliance, service life expectancy, ambient temperature, design metal temperature, maximum design temperature, permeability, abrasion resistance, discoloration, aging, embrittlement, flammability, and other compatibility factors. The various seal types (listed H.4.4.4) will have variable life expectancy and service limitations. 07

The following non-mandatory table provides guidance on frequently used materials for selected products. Each material must be evaluated for the specific product and temperature.

Fluid Stored	Seal Material
Crude oil	Fluoropolymers, urethane, nitrile
Refined products	Fluoropolymers, urethane, urethane laminate, fluoroelastomers, or Buna-N-Vinyl
Gasoline/MTBE blend	Fluoropolymers or nitrile

H.4.4.3 All peripheral seals and their attachment to the floating roof shall be designed to accommodate ±100 mm (±4 in.) of local deviation between the floating roof and the shell.

H.4.4.4 Types of Primary Seals 07

a. Liquid-mounted rim seal: Means a resilient foam-filled or liquid-filled primary rim seal mounted in a position resulting in the bottom of the seal being normally in contact with the stored liquid surface. This seal may be a flexible foam (such as polyurethane foam in accordance with ASTM D 3453) or liquid contained in a coated fabric envelope. Circumferential joints on liquid-mounted peripheral seals shall be liquid-tight and shall overlap at least 75 mm (3 in.). The material and thickness of the envelope fabric shall be determined after the factors given in H.4.4.2 are considered.

b. Vapor-mounted rim seal: Means a peripheral seal positioned such that it does not normally contact the surface of the stored liquid. Vapor-mounted peripheral seals may include, but are not limited to, resilient-filled seals (similar in design to liquid-mounted 07 rim seals per H.4.4.4a), and flexible-wiper seals. Flexible-wiper seal means a rim seal utilizing a blade or tip of a flexible material (such as extruded rubber or synthetic rubber) with or without a reinforcing cloth or mesh.

c. Mechanical shoe (metallic shoe): Means a peripheral seal that utilizes a light-gauge metallic band as the sliding contact with the shell and a fabric seal to close the annular space between the metallic band and the rim of the floating roof deck. The band is 07 typically formed as a series of sheets (shoes) that are overlapped or joined together to form a ring and held against the shell by a series of mechanical devices.

Galvanized shoes shall conform to ASTM A 924 and shall have a minimum nominal thickness of 1.5 mm (16 gauge) and a G90 coating. Stainless steel shoes shall conform to H.3.3, and shall have a minimum nominal thickness of 1.2 mm (18 gauge). For internal floating roofs the primary shoes shall extend at least 150 mm (6 in.) above and at least 100 mm (4 in.) into the liquid at the design flotation level. If necessary, bottom shell course accessories (e.g., side mixers) and other assemblies shall be modified or relocated to eliminate interference between lower portions of metallic seal assemblies.

● Unless specified otherwise by the Purchaser, the seal shoe and compression mechanism shall be installed before hydrostatic testing. It may be necessary to remove the seal shoe after the hydro-test to accommodate cleaning, application of interior lin- 11 ings, or any situation where the installed shoe might interfere with the process. The fabric seal may be installed after the hydrostatic testing.

H.4.4.5 The specific requirements for all floating roof peripheral seals are:

1. All fasteners and washers for installation of seal joints, including fabric seal joints, shall be austenitic stainless steel. (See restrictions on contact between galvanizing and stainless steel in S.2.1.3.)
2. The seals shall be designed for a temperature range extending from design metal temperature less 8°C (15°F) to the maximum operating temperature.
3. 07 Lengths of seal sections shall be as long as practical. No holes or openings shall be permitted in the completed seal. The seal material may be fabricated in sections resulting in seams, but any such seam shall be joined or otherwise held tightly together along the entire seam. For peripheral seals that use a fabric material to effect the seal, the requirement in the preceding sentence applies only to the fabric and not to any support devises. An adequate but minimum number of expansion joints shall be provided.
4. Provisions shall be made to prevent damage to the seal due to any overflow openings in the shell.
5. Rough spots on the shell that could damage the seal assembly shall be ground smooth. See H.6.1.
6. All metallic components shall be electrically bonded. See H.4.1.6 or C.3.1.6 for electrical bonding requirements.

H.4.4.6 If wax scrapers are specified on the Data Sheet, Line 31, they shall be located such that the scraping action occurs below the liquid surface. Design of wax scrapers shall not interfere with bottom shell course accessories.

H.4.5 ROOF PENETRATIONS

Columns, ladders, and other rigid vertical appurtenances that penetrate the deck shall be provided with a seal that will permit a local deviation of ±125 mm (±5 in.). Appurtenances shall be plumb within a tolerance of ±75 mm (±3 in.).

H.4.6 ROOF SUPPORTS

● **H.4.6.1** The floating roof shall be provided with adjustable supports, unless the Purchaser specifies fixed supports.

● **H.4.6.2** Unless specified otherwise, the height of the floating roof shall be adjustable to two positions with the tank in service. The design of the supports shall prevent damage to the fixed roof and floating roof when the tank is in an overflow condition.

● **H.4.6.3** The Purchaser shall specify clearance requirements to establish the low (operating) and high (maintenance) levels of the roof supports. The low roof position shall be the lowest permitted by the internal components of the tank including shell nozzles with internal projections. If specified, a single position support height shall be based on the Purchaser-specified clearance dimension. The Purchaser shall provide data to enable the Manufacturer to ensure that all tank appurtenances (such as mixers, 07 interior piping, and fill nozzles) are cleared by the roof in its lowest position. In addition to fitting elevations, such data shall include minimum mixer operation level and low level alarm settings (if applicable). If not specified otherwise by the Purchaser, the following apply:

H.4.6.3.1 The high roof position shall provide a 2-m (78-in.) minimum clearance throughout the bottom, between the roof and the tank bottom.

H.4.6.3.2 Where propeller-type mixers are used, the support legs shall provide a minimum clearance of 75 mm (3 in.) from the underside of the internal floating roof (or roof notch) to the tip of the mixer propeller. 07

H.4.6.4 Support attachments in the deck area shall be designed to prevent failure at the point of attachment. On the bottom of the steel welded deck plates (used on types H.2.2a, b, c, d, and g), where flexure is anticipated adjacent to supports or other relatively rigid members, full-fillet welds not less than 50 mm (2 in.) long on 250 mm (10 in.) centers shall be used on any plate laps that occur within 300 mm (12 in.) of any such support or member.

● **H.4.6.5** Supports shall be fabricated from pipe, unless cable or another type is specified on the Data Sheet, Line 34 and approved by the Purchaser. Supports fabricated from pipe shall be notched or otherwise constructed at the bottom to provide complete liquid drainage. Cable supports shall be adjustable externally and shall not have an open penetration at the floating roof surface. Fixed roofs shall be designed or verified suitable for cable support loads, when used, per agreement between the Purchaser and tank/roof Manufacturers. 07

● **H.4.6.6** Steel pads or other means shall be used to distribute the loads on the bottom of the tank and provide a wear surface. With the Purchaser's approval, pads may be omitted if the tank bottom will support the live load plus the dead load of the floating roof. If pads are used, they shall be continuously welded to the tank bottom.

● **H.4.6.7** Aluminum supports shall be isolated from carbon steel by an austenitic stainless steel spacer, an elastomeric bearing pad, or equivalent protection, unless specified otherwise by the Purchaser.

● **H.4.6.8** Special protective measures (corrosion allowance, material selection, linings) are to be evaluated for supports that interface with stratified product bottoms, which may include corrosive contaminant combinations not found in the normal product. The Purchaser shall specify if any protective measures are required. 11

● **H.4.6.9** For tanks with internal linings, the Purchaser shall specify on Line 23 of the Data Sheet any special requirements for minimizing corrosion where the leg contacts the tank bottom, such as a flat plate or bull nose on the leg base, a thicker base plate, or other means. 11

H.4.6.10 Consideration shall be given to the use of fixed supports for the operating position (low level) of internal floating roofs, which utilize cable supports suspended from a fixed roof. These supports are typically not adjustable, are sealed to prevent emissions, and are for the operating position (low level) set at a level as specified by the Purchaser. The use of fixed supports for the low level position are intended to reduce the frequency of fixed roof loading. The operating position (low level) and length of the cables shall be such that sinking and/or collapse of the internal floating roof will not apply loads to the support cables.

H.4.6.11 If cable supports are used, the supports shall be adjustable from the fixed roof while the floating roof is floating and with the cables unloaded. 08

H.4.6.12 Cables, cable segments, or cable connections which support the floating roof are prohibited from using a fusible link or other devices which are designed to fail at a specified load limit.

H.4.6.13 Cables used to support internal floating roofs shall be 300 series stainless steel and shall be flexible to facilitate repeatable lay down patterns on the floating roof as it travels up and down within the tank. Lay down patterns shall be positioned to avoid rim seals and floating roof appurtenances that could prevent the cable from freely extending as the floating roof lowers.

H.5 Openings and Appurtenances

H.5.1 LADDER

● **H.5.1.1** The tank interior is considered a confined space environment with restricted access (see API RP 2026). If specified by the Purchaser, the tank shall be supplied with a ladder for internal floating roof deck access. If a ladder is not supplied and the floating roof is not steel, a ladder landing pad shall be provided on the floating roof.

H.5.1.2 The ladder shall be designed to allow for the full travel of the internal floating roof, regardless of any settling of the roof supports.

H.5.1.3 The ladder shall be installed within a fixed-roof manhole, per H.5.5.1. 07

• **H.5.1.4** If a level-gauge stilling well is provided, the well may form one or both legs of the ladder, as specified by the Purchaser.

H.5.1.5 The ladder shall not be attached to the tank bottom unless provision is made for vertical movement at the upper connection.

H.5.2 VENTS

08 • **H.5.2.1 Internal Floating Roof Pressure-Relieving Vents**

H.5.2.1.1 Vents suitable to prevent overstressing of the roof deck or seal membrane shall be provided on the floating roof. These vents shall be adequate to evacuate air and gases from underneath the roof such that the internal floating roof is not lifted from resting on its supports during filling operations, until floating on the stored liquid. The vents shall also be adequate to release any vacuum generated underneath the roof after it settles on its supports during emptying operations to limit the floating roof external pressure to P_{fe}. The Purchaser shall specify filling and emptying rates. The manufacturer shall size the vents.

H.5.2.1.2 Internal floating roofs which utilize support legs shall be equipped with leg- or pressure-vacuum-activated vents. The Purchaser may specifiy the type of vent and the associated design conditions (see Line 33 of the Data Sheet). Leg activated vents shall be adjustable as required per H.4.6.

H.5.2.1.3 Internal floating roofs, which utilize cable supports and mechanical activiated vents shall have a leg or cable activated vent(s) for the operating position (low level) and a cable activated vent(s) for the maintenance position (high level). Alternatively, internal floating roofs which utilize cable supports shall use a pressure vacuum vent(s) to provide the required venting for all floating roof support levels. 08

H.5.2.1.4 Leg or cable activated vents shall be designed to open automatically when the roof lowers to 150 mm (6 in.) above its lowest operating position and to close automatically when the roof raises more than 150 mm (6 in.) above its lowest position. Float-activated vents shall be designed to remain closed while the roof is floating. Pressure-vacuum activated vents shall be designed to open and achieve required flow rates within the design capacities of the floating roof and floating roof support system as described in H.5.2.1.1.

H.5.2.2 Tank Circulation Vents

• **H.5.2.2.1** Peripheral circulation vents shall be located on the tank roof (unless otherwise specified by the Purchaser) and meet the requirements of H.5.3.3, so that they are above the seal of the internal floating roof when the tank is full. The maximum spacing between vents shall be 10 m (32 ft), based on an arc measured at the tank shell, but there shall not be fewer than four equally-spaced vents. The venting shall be distributed such that the sum of the open areas of the vents located within any 10 m (32 ft) interval is at least 0.2 m^2 (2.0 ft^2). The total net open area of these vents shall be greater than or equal to 0.06 m^2/m (0.2 ft^2/ft) of tank diameter. These vents shall be covered with a corrosion-resistant coarse-mesh screen (13 mm [$^1/_2$ in.] openings, unless specified otherwise by the Purchaser) and shall be provided with weather shields (the closed area of the screen must be deducted to determine the net open vent area).

H.5.2.2.2 A center circulation vent with a minimum net open area of 30,000 mm^2 (50 $in.^2$) shall be provided at the center of the fixed roof or at the highest elevation possible on the fixed roof. It shall have a weather cover and shall be provided with a corrosion-resistant coarse-mesh screen (the closed area of the screen must be deducted to determine the net open vent area).

• **H.5.2.2.3** If circulation vents (per H.5.2.2.1 and H.5.2.2.2) are not installed, gas blanketing or another acceptable method to prevent the development of a combustible gas mixture within the tank is required. Additionally, the tank shall be protected by pressure-vacuum vents in accordance with 5.8.5, based on information provided by the Purchaser. 07

H.5.3 LIQUID-LEVEL INDICATION, OVERFILL PROTECTION, AND OVERFLOW SLOTS

• **H.5.3.1** The Purchaser shall provide appropriate alarm devices to indicate a rise of the liquid in the tank to a level above the normal and overfill protection levels (see NFPA 30 and API RP 2350). Overflow slots shall not be used as a primary means of detecting an overfill incident.

• **H.5.3.2** The internal floating roof Manufacturer shall provide information defining the internal floating roof and seal dimensional profile for the Purchasers' determination of the maximum normal operating and overfill protection liquid levels (considering tank fixed-roof support, overflow slots or any other top of shell obstructions). The floating roof Manufacturer shall provide the design flotation level (liquid surface elevation) of the internal floating roof at which the pressure/vacuum relief vents will begin to open (to facilitate the Purchasers' determination of minimum operating levels).

● **H.5.3.3** The use of emergency overflow slots shall only be permitted if specified by the Purchaser. When emergency overflow slots are used, they shall be sized to discharge at the pump-in rates for the tank. The greater of the product specific gravity or 1.0 shall be used to determine the overflow slot position so that accidental overfilling will not damage the tank or roof or interrupt the continuous operation of the floating roof. Overflow discharge rates shall be determined by using the net open area (less screen) and using a product level (for determining head pressure) not exceeding the top of the overflow opening. The overflow slots shall be covered with a corrosion-resistant coarse-mesh screen (13 mm [$^1/_2$ in.] openings) and shall be provided with weather shields (the closed area of the screen must be deducted to determine the net open area). The open area of emergency overflow slots may contribute to the peripheral venting requirement of H.5.2.2.1 provided that at least 50% of the circulation-vent area remains unobstructed during emergency overflow conditions. The floating-roof seal shall not interfere with the operation of the emergency overflow openings. Overflow slots shall not be placed over the stairway or nozzles unless restricted by tank diameter/height or unless overflow piping, collection headers, or troughs are specified by the Purchaser to divert flow.

H.5.4 ANTI-ROTATION AND CENTERING DEVICES

The internal floating roof shall be centered and restrained from rotating. A guide pole with rollers, two or more seal centering cables or other suitable device(s) shall be provided as required for this purpose. The internal floating roof shall not depend solely on the peripheral seals or vertical penetration wells to maintain the centered position or to resist rotation. Any device used for either purpose shall not interfere with the ability of the internal floating roof to travel within the full operating elevations in accordance with H.4.1.1.

H.5.5 MANHOLES AND INSPECTION HATCHES

H.5.5.1 Fixed-Roof Manholes

At least one fixed-roof manhole complying with this Standard, with a nominal opening of 600 mm (24 in.) or larger, shall be provided in the fixed roof for maintenance ventilation purposes. If used for access to the tank interior, the minimum clear opening shall be 750 mm (30 in.). 07

H.5.5.2 Floating-Roof Manholes

At least one internal floating roof deck manhole shall be provided for access to and ventilation of the tank when the floating roof is on its supports and the tank is empty. The manhole shall have a nominal opening of 600 mm (24 in.) or larger and shall be provided with a bolted or secured and gasketed manhole cover. The manhole neck dimensions shall meet the requirements of H.4.1.4 and H.4.1.5.

● H.5.5.3 Inspection Hatches

When specified by the Purchaser, inspection hatches shall be located on the fixed roof to permit visual inspection of the seal region. The maximum spacing between inspection hatches shall be 23 m (75 ft), but there shall not be fewer than four equally-spaced hatches. Designs that combine inspection hatches with tank-shell circulation vents (located on the tank roof) are acceptable.

● H.5.6 INLET DIFFUSER

Purchaser shall specify the need for an inlet diffuser sized to reduce the inlet velocity to less than 1 m (3 ft) per second during initial fill per API RP 2003. Purchaser shall provide pumping rates and any blending, pigging and recirculation data along with the inlet diameter, for Manufacturer's determination of the diffuser design and size.

● H.5.7 GAUGING AND SAMPLING DEVICES

When specified by the Purchaser, the fixed roof and the internal floating roof shall be provided with and/or accommodate gauging and sampling devices. Sampling devices on the deck of the floating roof shall be installed beneath the fixed-roof hatch (as specified for this purpose) and, unless designed as a gauge pole (extending up to the fixed roof), shall have a funneled (tapered) cover to facilitate use from the roof of the tank. All such devices on the floating roof shall be installed within the plumbness tolerance of H.4.5. See C.3.14 for additional requirements applicable to gauge wells and poles. 07

● H.5.8 CORROSION GAUGE

When specified by the Purchaser, a corrosion gauge for the internal floating roof shall be provided adjacent to the ladder to indicate the general corrosion rate.

07 ● **H.5.9 FOAM DAMS**

A foam dam, if specified on the Data Sheet, Line 32, shall be fabricated and installed in compliance with NFPA 11.

H.6 Fabrication, Erection, Welding, Inspection, and Testing

● **H.6.1** The applicable fabrication, erection, welding, inspection, and testing requirements of this Standard shall be met. Upon the start of internal floating roof installation, or concurrent with assembly within a tank under construction, the tank (interior shell and vertical components) shall be inspected by the floating roof erector, unless otherwise specified. The purpose of this inspection shall be to confirm plumbness of all interior components, along with roundness and the condition of the shell (for the presence of damage, projections, or obstructions) to verify that the floating roof and seals will operate properly. Any defects, projections, obstructions or tank tolerance limits (exceeding those defined in 7.5 of this Standard), which would inhibit proper internal floating roof and seal operation, that are identified by the internal floating roof erector shall be reported to the Purchaser.

● **H.6.2** Deck seams and other joints that are required to be or vapor-tight per H.4.1.3 shall be tested for leaks by the shop or field joint assembler. Joint testing shall be performed by means of penetrating oil or another method consistent with those described in this Standard for testing cone-roof and/or tank-bottom seams, or by any other method mutually agreed upon by the Purchaser and the roof Manufacturer.

H.6.3 The floating roof Manufacturer shall supply all floating roof closures required for testing per H.4.1.3, H.4.1.7, H.4.3.1, and H.6.2. Rivets, self-tapping screws, and removable sections are not acceptable for test plugs.

● **H.6.4** Any flotation compartment that is completely shop-fabricated or assembled in such a manner as to permit leak testing at the fabricating shop shall be leak tested at the shop as well as retested in the field by the floating roof erector for all accessible seams. In the field assembly yard or in the erected position, the erector shall spot leak test 10% of the flotation compartments, whether shop- or field-fabricated. The Purchaser may select the specific compartments to test and the test location, based on his visual inspections for indications of damage or potential leaks (see the Data Sheet, Line 34). Any leaking compartments shall be‘ repaired and re-tested by the roof Manufacturer. If the testing finds any leaks in compartments tested, except for those damaged by shipping, then 100% of the roof compartments shall be leak tested. Unless prohibited by safety concerns, leak testing shall be at an internal pressure of 20 kPa – 55 kPa (3 lbf/in.^{2} – 8 lbf/in.^{2}) gauge using a soap solution or commercial leak detection solution. 07

● Note: Special contract terms may be required to cover the costs of the field testing.

H.6.5 Upon assembly and prior to a flotation test, the erector shall inspect to verify that the peripheral seal produces an acceptable fit against the tank shell.

09 ● **H.6.6 INITIAL FLOTATION**

A flotation test and initial fill inspection shall be conducted by the Purchaser. This test may be performed or witnessed by the erector, as subject to agreement with the Purchaser. The party performing the flotation test shall make water connections and supply all tank closures required for testing and remove all water connections and temporary closures (including gaskets, fasteners, test blanks, etc.) after completion of the test, unless otherwise specified by the Purchaser.

● **H.6.6.1** Internal floating roofs in accordance with types H.2.2a, b, c, d, and g shall be given a flotation test on water. Internal floating roofs in accordance with types H.2.2e and H.2.2f shall be given a flotation test on water or product at the option of the Purchaser. During this test, the roof and all accessible compartments shall be checked to confirm that they are free from leaks. The appearance of a damp spot on the upper side of the part in contact with the liquid shall be considered evidence of leakage. 11 07

H.6.6.2 During initial fill the internal floating roof should be checked to confirm that it travels freely to its full height. The peripheral seal shall be checked for proper operation throughout the entire travel of the internal floating roof. During the first event of lowering the level from full height, particular attention shall be given for tanks that contain a floating suction to ensure proper operation. 11

H.6.6.3 Because of possible corrosive effects, consideration shall be given to the quality of water used and the duration of the test. Potable water is recommended. For aluminum or stainless steel floating roofs, S.4.10 shall be followed.

H.6.6.4 The high flotation level shall be evaluated for clearance and the floating suction (if existing) shall be compensated for the excess buoyancy that will be encountered during hydrostatic testing of the floating roof system.

APPENDIX I—UNDERTANK LEAK DETECTION AND SUBGRADE PROTECTION

I.1 Scope and Background

I.1.1 This appendix provides acceptable construction details for the detection of product leaks through the bottoms of aboveground storage tanks, and provides guidelines for tanks supported by grillage.

Note: API supports a general position of installation of a Release Prevention Barrier (RPB) under new tanks during initial construction. An RPB includes steel bottoms, synthetic materials, clay liners, and all other barriers or combination of barriers placed in the bottom of or under an aboveground storage tank, which have the following functions: (a) preventing the escape of contaminated material, and (b) containing or channeling released material for leak detection.

● **I.1.2** Several acceptable construction details are provided for detection of leaks through the tank bottom and details for tanks supported by grillage (see Figures I-1 through I-11). Alternative details or methods may be used if agreed upon by the tank owner and Manufacturer, provided the details or methods satisfy the requirements of I.2.

● **I.1.3** The tank owner shall determine whether the undertank area is to be constructed for leak detection. If leak detection is required, the owner shall specify the method or methods to be employed.

I.1.4 The bottoms of aboveground storage tanks may leak as a result of product side corrosion, soil side corrosion, or a combination of both. The extent of product side corrosion can be detected using standard inspection techniques during an internal inspection, but determining the nature and extent of soil side corrosion is more difficult. Therefore, in certain services and tank locations, it may be desirable to provide for undertank monitoring of leakage through the tank bottom plates.

I.1.5 For additional information on the use of internal linings to prevent internal bottom corrosion, see API RP 652. Similarly, see API RP 651 for guidelines and requirements relating to preventing corrosion from the soil side of the bottom plate. 11

I.1.6 When the appropriate tank foundation design is being selected, it is important to consider the environmental and safety regulatory implications of leakage of tank contents into the containment space below the tank bottom. Specifically, the contamination of permeable material such as sand used as a floor support may constitute the generation of a hazardous waste. The treatment or disposal costs of such contaminated material must be determined.

I.1.7 The requirements for secondary containment as it relates to diked areas and impoundments are not within the scope of this appendix.

I.2 Performance Requirements

The following general requirements shall be satisfied for all leak detection systems:

a. Leaks through the tank bottom shall be detectable by observation at the tank perimeter. If a leak is detected, it shall be collected.

b. The use of electronic sensors for the detection of vapors and liquids is acceptable; however, the requirements of Item a above shall be satisfied. Any such sensor shall be fail-safe or have provision for calibration.

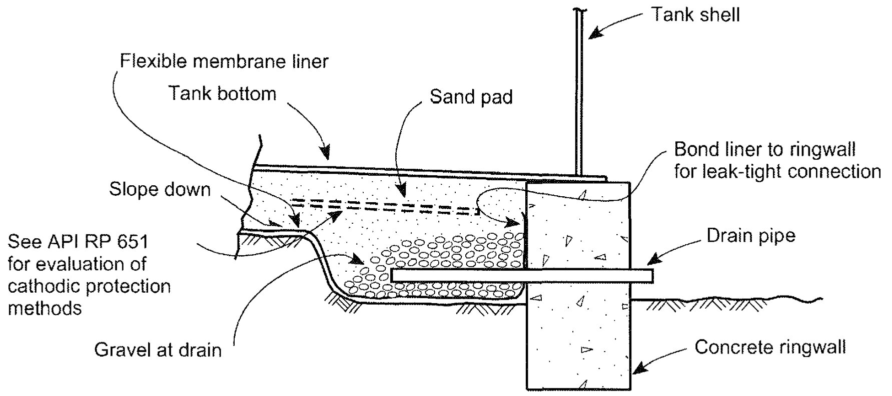


Figure I-1—Concrete Ringwall with Undertank Leak Detection at the Tank Perimeter (Typical Arrangement)

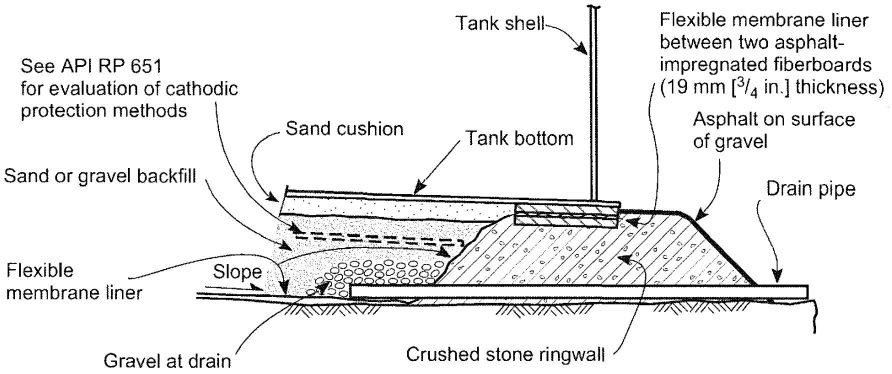


Figure I-2—Crushed Stone Ringwall with Undertank Leak Detection at the Tank Perimeter (Typical Arrangement)

- c. The materials of construction shall be chemically resistant to the range of products to be stored at the temperature range expected in service. Other physical properties shall be specified by the tank owner.

d. The permeability of the leak detection barrier shall not exceed 1×10^{-7} cm (4×10^{-5} mils) per second.

e. The material in contact with the subgrade shall be suitable for below-grade service or be protected against degradation.

f. The leak barrier shall be of one-piece construction, or the joints shall satisfy the leak tightness, permeability, and chemical resistance requirements for the base leak-barrier material. The Manufacturer and a complete description of the leak barrier material shall be identified to the tank owner.

g. The installation of sumps and pipes below the tank bottom is acceptable; however, the required leak detection and leak tightness shall be maintained. See Figures I-8 and I-9 for typical details.

I.3 Cathodic Protection

Cathodic protection systems may be installed in conjunction with undertank leak detection systems. See API RP 651 for guidelines on the use of cathodic protection methods.

I.4 Double Steel Bottom Construction

I.4.1 If a double steel bottom is used, the details of construction shall provide for the proper support of the primary bottom and shell for all operating conditions. The design shall be evaluated to verify that the primary bottom and shell are not overstressed. The evaluation shall consider all anticipated operating conditions such as design metal temperature, maximum design temperature, fill height, hydrostatic testing, seismic conditions, and tank settlement. The evaluation is not required if the primary bottom is uniformly supported on both sides of the shell and is not structurally attached to the secondary bottom or primary bottom support.

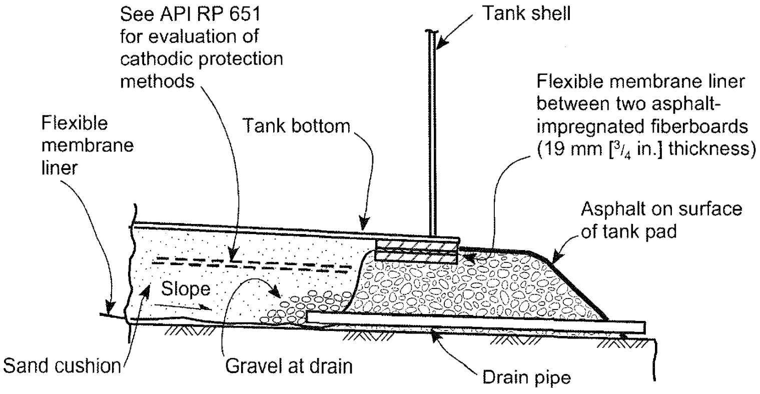


Figure I-3—Earthen Foundation with Undertank Leak Detection at the Tank Perimeter (Typical Arrangement)

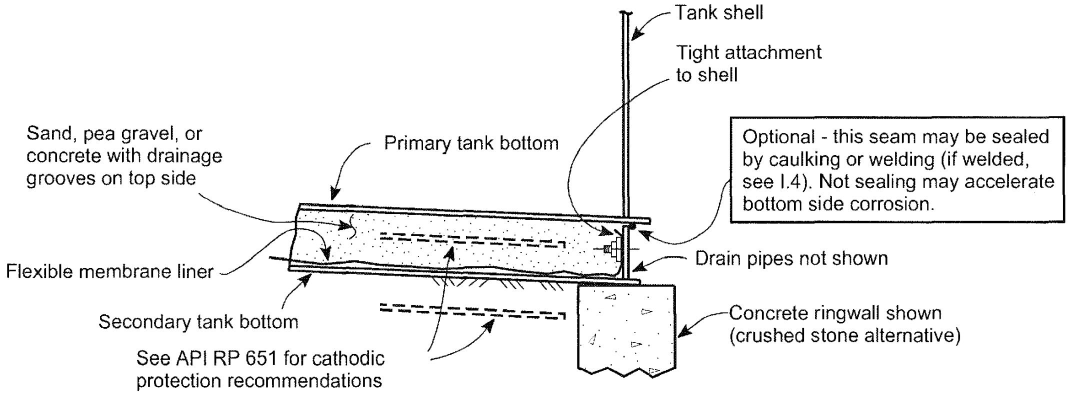


Figure I-4—Double Steel Bottom with Leak Detection at the Tank Perimeter (Typical Arrangement)

I.4.2 For double steel bottom systems that use steel members (such as grating, structural shapes, or wire mesh) to separate the bottoms, ingress of water between the bottoms will result in local accelerated corrosion rates. If the perimeter of the bottoms is not sealed, corrosion protection of the tank bottoms shall be provided.

I.5 Material Requirements and Construction Details

I.5.1 The minimum thickness of flexible-membrane leak barriers shall be 800 millimicrons (30 mils) for fiber-reinforced membranes and 1000 millimicrons (40 mils) for unreinforced membranes. If clay liners are used, they shall be thick enough to meet the permeability requirements of I.2, Item d.

I.5.2 The leak barrier shall be protected as required to prevent damage during construction. If the foundation fill or tank pad material is likely to cause a puncture in the leak barrier, a layer of sand or fine gravel or a geotextile material shall be used as a protective cushion.

I.5.3 For a flexible-membrane liner installed over a steel bottom, all nicks, burrs, and sharp edges shall be removed or a layer of fine sand, gravel, or geotextile material shall be used to protect the liner.

I.5.4 The flexible leak barrier shall be covered by at least 100 mm (4 in.) of sand, except as otherwise shown in Figures I-1 through I-10. This dimension may have to be increased if cathodic protection is to be provided in the space between the tank bottom and the leak barrier.

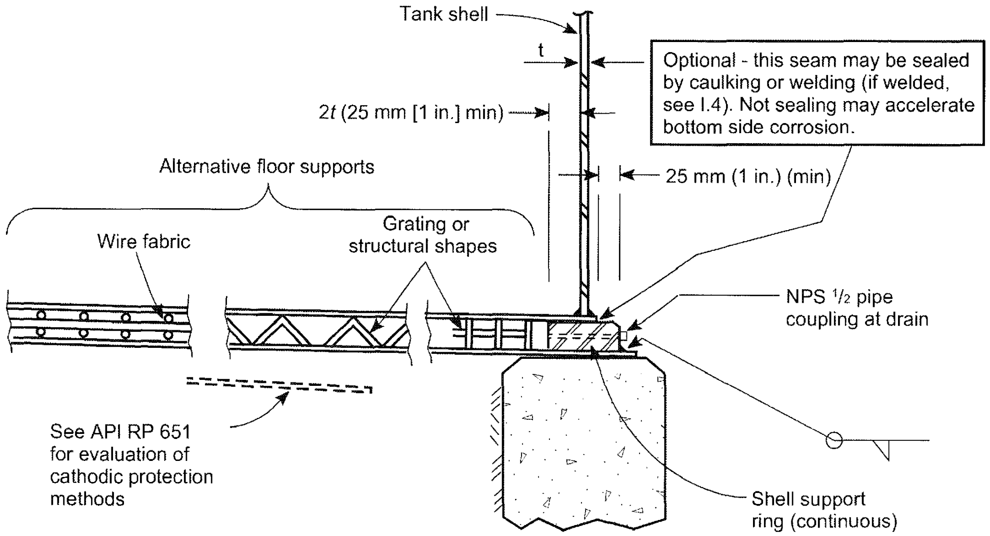


Figure I-5—Double Steel Bottom with Leak Detection at the Tank Perimeter (Typical Arrangement)

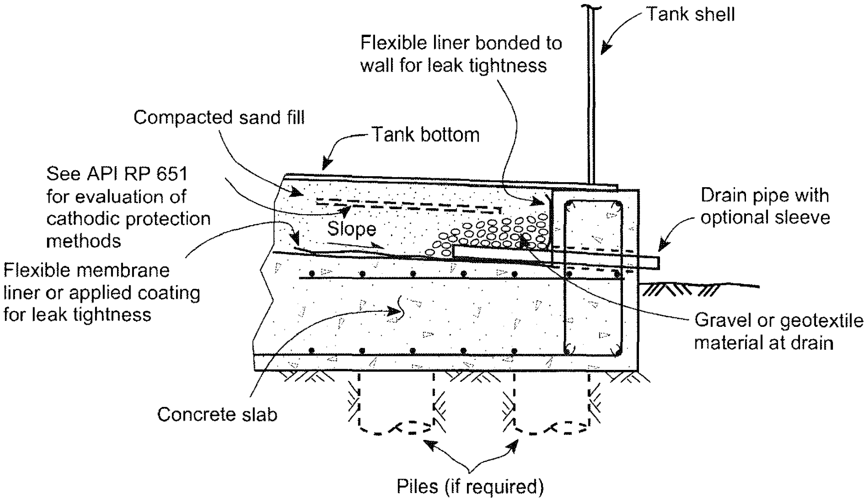


Figure I-6—Reinforced Concrete Slab with Leak Detection at the Perimeter (Typical Arrangement)

- **I.5.5** If drain pipes are used around the tank perimeter, they shall be at least NPS 1 in diameter and have a minimum wall thickness of Schedule 40. The pipes may be perforated in the undertank area to improve their leak detection function. The inner ends and perforations of the drain pipes shall be protected from clogging by the use of gravel, screening, geotextiles, or another method approved by the tank owner. The drain pipes shall exit through the foundation and shall be visible to indicate any leakage. If specified by the owner, the undertank drains shall be fitted with a valve or piped to a leak detection well as shown in Figure I-10. The maximum spacing of drain pipes shall be 15 m (50 ft), with a minimum of four drain pipes per tank; however, two drain pipes may be used for tanks 6 m (20 ft) or less in diameter.

I.5.6 The need for pipe sleeves, expansion joints, or both in conjunction with drain pipes shall be evaluated.

I.5.7 The outlet of the drain pipes and collection sumps, if used, shall be protected from the ingress of water from external sources.

I.5.8 Leak detection systems that use sumps in the liner below the tank bottom shall have a drain line that extends from the sump to the tank perimeter. Consideration shall be given to installation of supplemental perimeter drains.

I.6 Testing and Inspection

I.6.1 The leak barrier, all leak-barrier penetrations, attachments of the leak barrier to the foundation ringwall, and other appurtenances shall be visually inspected for proper construction in accordance with applicable specifications.

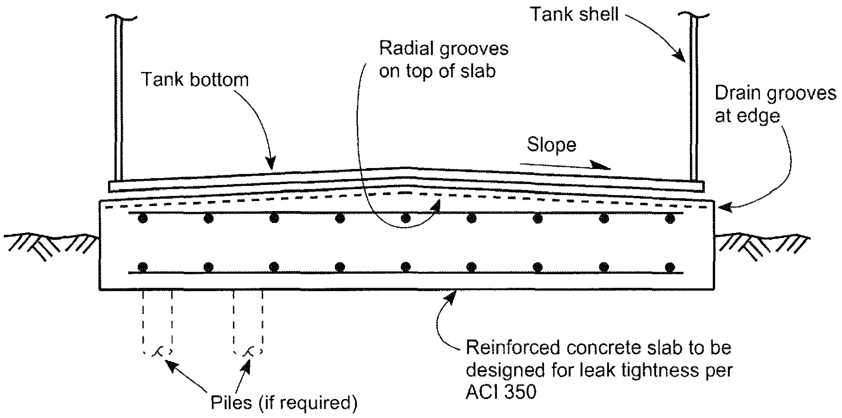


Figure I-7—Reinforced Concrete Slab

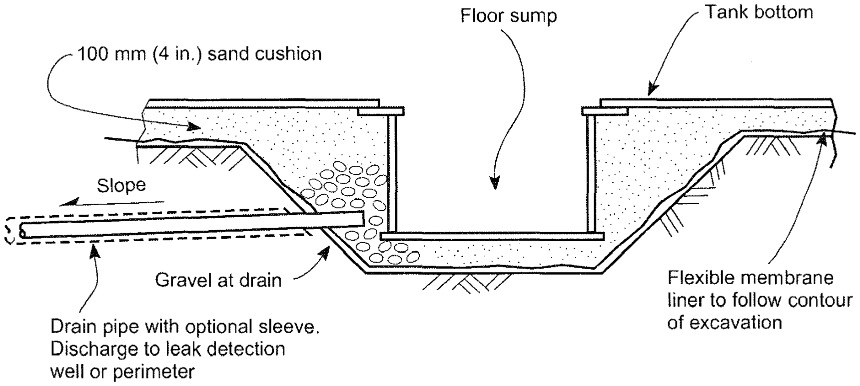


Figure I-8—Typical Drawoff Sump

- **I.6.2** The shop and field seams of flexible-membrane liners shall pass a vacuum-box test. All leaks shall be repaired and retested. Alternative testing methods may be used with the tank owner's approval.

- **I.6.3** Proof testing of samples of the flexible-membrane liner seam shall be performed to verify the seam strength and flexibility and the adequacy of the bonding. The procedure (including testing methods) used to bond or weld the liner seams shall be submitted to the owner for review and shall specify all critical parameters, such as temperature, speed, surface preparation, and curing time, required to achieve liquid-tight seams. The required strength and flexibility of the liner seams shall be agreed upon by the tank owner and Manufacturer. The seam samples shall be produced at the beginning of each shift for each operator and welding machine.

- **I.6.4** All liner penetrations, attachments of the liner to the foundation ringwall, and other appurtenances shall be demonstrated to be leak tight. This may be demonstrated by a mock-up test, prior experience, or other methods acceptable to the owner.

I.7 Tanks Supported by Grillage

- **I.7.1** Tanks designed and constructed in accordance with API Std 650 that have a maximum nominal shell thickness of 13 mm ($^1/_2$ in.), including any customer specified corrosion allowance, and maximum design temperature not exceeding 93°C (200°F) may be supported by steel or concrete grillage. By agreement between the Purchaser and the Manufacturer, these rules may be applied to tanks with shell thickness greater than 13 mm ($^1/_2$ in.). These rules apply to single steel butt-welded bottoms supported by grillage members.

I.7.2 The thickness and design metal temperature of the bottom plate shall be in accordance with Figure 4-1.

I.7.3 The maximum spacing between adjacent or radial grillage members and the bottom plate thickness shall satisfy the requirements of I.7.3.1 and I.7.3.2.

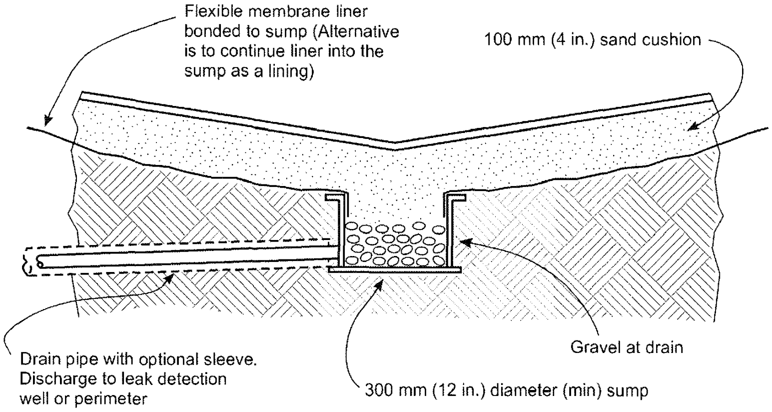
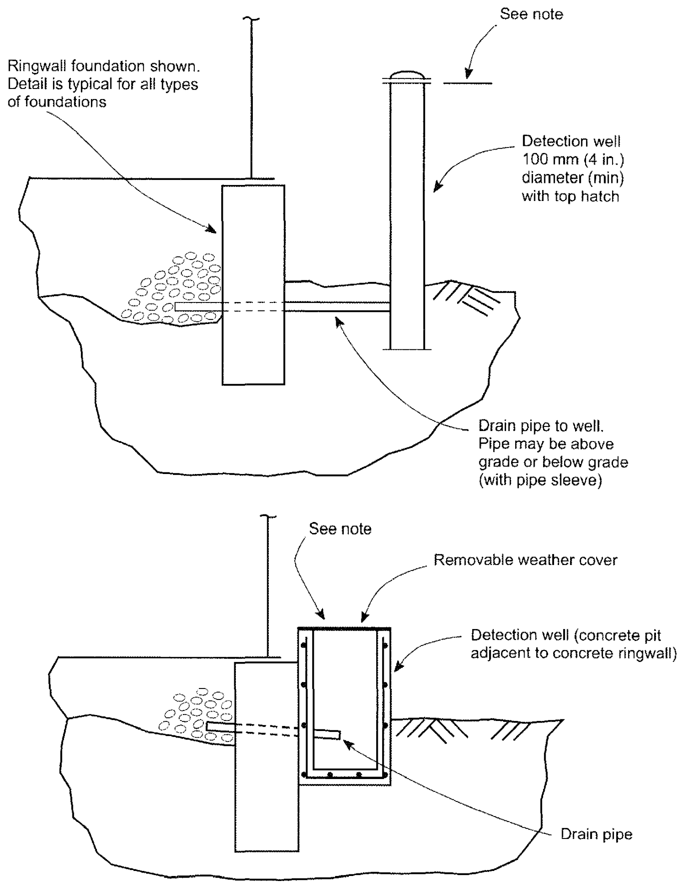


Figure I-9—Center Sump for Downward-Sloped Bottom



Note: Top of well shall be above maximum high water level within dike.

Figure I-10—Typical Leak Detection Wells

I.7.3.1 The maximum spacing between adjacent or radial grillage members shall not exceed:

$$b = \left[\frac{1.5F_y(t_g - CA)^2}{p}\right]^{0.5} \qquad \text{(I.7.3.1-1)}$$

11 **I.7.3.2** The required nominal thickness of the bottom plate supported on grillage shall not be less than that determined by the following equation:

$$t_g = \left[\frac{b^2(p)}{1.5F_y}\right]^{0.5} + CA \qquad \text{(I.7.3.2-1)}$$

where

b = maximum allowable spacing (center-to-center) between adjacent or radial grillage members, in mm (in.),

F_y = specified minimum yield strength of bottom plate material, in MPa (psi),

t_g = nominal thickness (including any corrosion allowance) of the bottom plate supported on grillage, in mm (in.),

● CA = corrosion allowance to be added to the bottom plate, in mm (in.). The Purchaser shall specify the corrosion allowance,

p = uniform pressure (including the weight of the bottom plate) acting on the bottom resulting from the greater of the weight of the product plus any internal pressure, or the weight of the hydrostatic test water, in MPa (psi).

I.7.3.3 The maximum calculated deflection of the bottom plate at mid-span shall not exceed $(t_g - CA) / 2$:

$$d = \frac{0.0284pb^4}{E_s(t_g - CA)^3} \leq (t_g - CA) / 2 \qquad \text{(I.7.3.3-1)}$$

where

d = maximum calculated deflection of the bottom plate at mid-span, in mm (in.),

E_S = modulus of elasticity of the bottom plate material, in MPa (psi).

I.7.4 The bottom plates shall be jointed together by butt-welds having complete penetration and complete fusion. Joints shall be visually inspected prior to welding to ensure the weld gap and fit-up will allow complete penetration. Each weld pass shall be visually inspected. The alignment and spacing of grillage members shall be such that the joints between bottom plates are located approximately above the center of the grillage members to the greatest extent practical. Grillage members shall be arranged to minimize the length of unsupported tank shell spanning between grillage members.

I.7.5 Grillage members shall be symmetrical about their vertical centerline. Steel grillage members shall be designed to prevent web crippling and web buckling as specified in Chapter K of the AISC *Manual of Steel Construction, Allowable Stress Design.* Concrete grillage members may also be used.

● **I.7.6** The Purchaser shall specify the corrosion allowance to be added to steel grillage members. If a corrosion allowance is required, the manner of application (added to webs only, added to webs and flanges, added to one surface, added to all surfaces, and so forth) shall also be specified.

I.7.7 For tanks designed to withstand wind or seismic loads, provisions shall be made to prevent sliding, distortion, and overturning of the grillage members. Lateral bracing between the top and bottom flanges of adjacent steel grillage members may be required to prevent distortion and overturning. The lateral bracing and connections shall be designed to transfer the specified lateral loads. If friction forces between the grillage members and the foundation are not adequate to transfer the specified later load, the grillage members shall be anchored to the foundation.

I.7.8 The tank shall be anchored to resist uplift forces (in excess of the corroded dead load) due to pressure and wind or seismic overturning. Anchors shall be located near the intersection of the tank shell and a grillage member, or near an additional stiffening member.

I.7.9 The tank shell shall be designed to prevent local buckling at the grillage members and consideration shall be given to shell distortion when the spacing of the grillage members is determined.

I.7.10 The bottom plate and grillage members directly beneath roof support columns and other items supported by the bottom shall be designed for the loads imposed. Additional support members are to be furnished if required to adequately support the bottom.

I.7.11 If flush-type cleanouts or flush-type shell connections are furnished, additional support members shall be provided to adequately support the bottom-reinforcing and bottom-transition plates. As a minimum, the additional support members shall consist of a circumferential member (minimum length and location according to Method A of Figure 5-12) and radial support members. The radial support members shall extend from the circumferential member to the inner edge of the bottom reinforcing (for flush-type cleanouts) or bottom-transition plate (for flush-type shell connections). The circumferential spacing of the radial support members shall not exceed 300 mm (12 in.).

I.7.12 For tanks located in a corrosive environment, and where atmospheric corrosion due to wet/dry cycles may occur, consideration shall be given to protecting the soil side of the bottom plates, grillage members, and in particular, the contact surface between the bottom plates and grillage members by utilizing protective coatings or by adding a corrosion allowance to these members.

I.8 Typical Installations

Although it is not the intent of this appendix to provide detailed designs for the construction of undertank leak detection systems and tanks supported by grillage, Figures I-1 through I-11 illustrate the general use and application of the recommendations presented in this appendix.

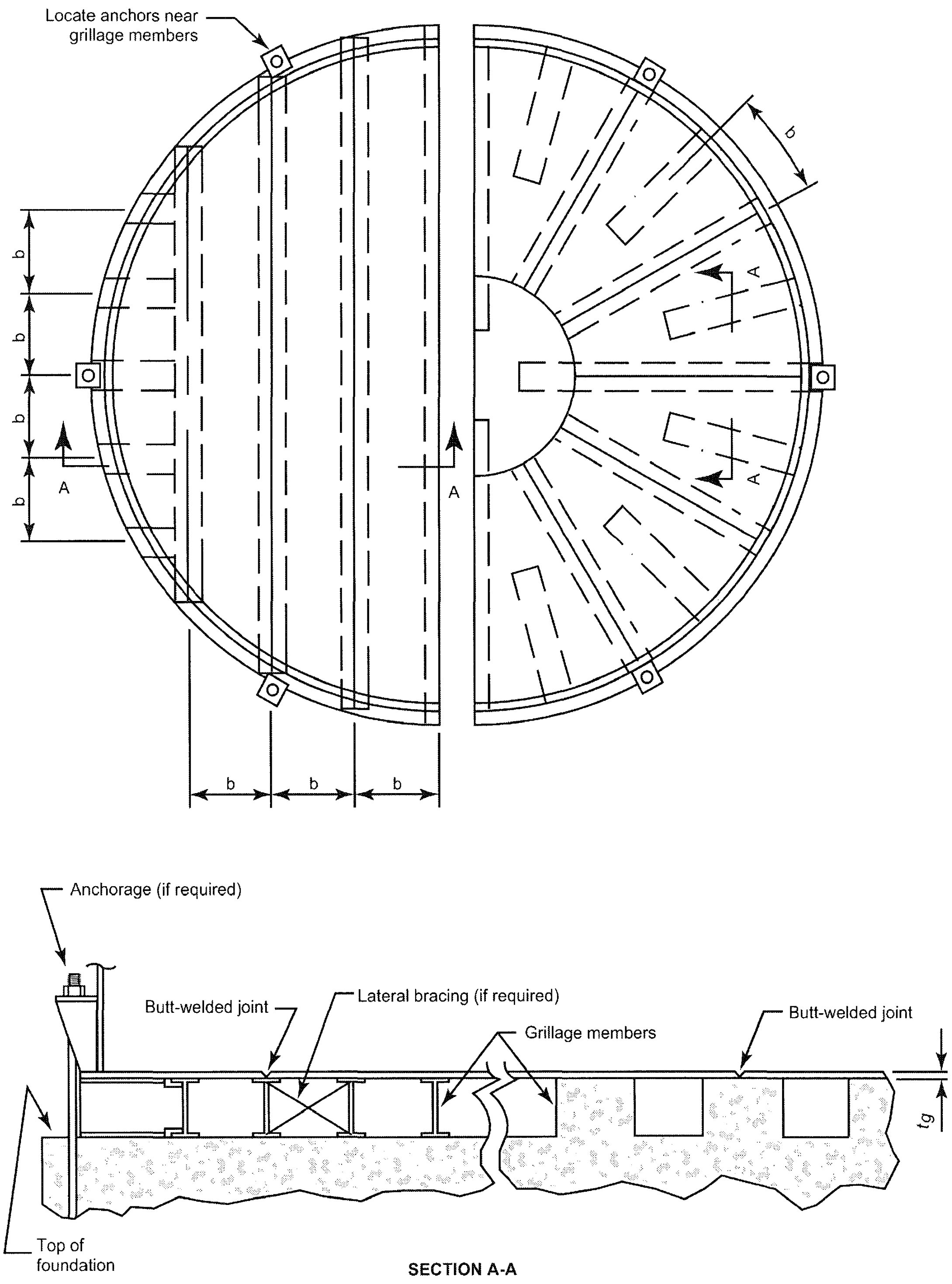


Figure I-11—Tanks Supported by Grillage Members (General Arrangement)

APPENDIX J—SHOP-ASSEMBLED STORAGE TANKS

J.1 Scope

J.1.1 This appendix provides requirements for the design and fabrication of vertical storage tanks in sizes that permit complete shop assembly and delivery to the installation site in one piece. Storage tanks designed according to this appendix shall not exceed 6 m (20 ft) in diameter.

● **J.1.2** The application of this appendix to the design and fabrication of shop-assembled storage tanks shall be mutually agreed upon by the Purchaser and the Manufacturer.

J.2 Materials

J.2.1 The material requirements of Appendix A of this standard are applicable, except as noted in J.2.2.

J.2.2 The selection of shell or bottom plate materials exceeding a nominal thickness of 13 mm ($^1/_2$ in.) shall be based upon the requirements of Section 4 of this standard. 11

J.3 Design

J.3.1 JOINTS

J.3.1.1 Joints shall be designed as specified in 5.1; however, lap-welded joints in bottoms are not permissible. In addition, the modifications given in J.3.1.2 through J.3.1.5 are applicable.

J.3.1.2 All shell joints shall be butt-welded so that full penetration is produced without the use of back-up bars.

J.3.1.3 Shell plates shall be sized to limit the number of plates to the smallest practical number consistent with sound economic practice. Each course should preferably be constructed of one plate.

J.3.1.4 Top angles are not required for flanged-roof tanks.

J.3.1.5 Joints in bottom plates shall be butt-welded. The welding shall produce complete penetration of the parent metal.

J.3.2 BOTTOMS

J.3.2.1 All bottom plates shall have a minimum nominal thickness of 6 mm (0.236 in.) (49.8 kg/m^2 [10.2 lbf/ft^2], see 4.2.1.2 and 5.4.1). 11

J.3.2.2 Bottoms shall be constructed of a minimum number of pieces; wherever feasible they shall be constructed of one piece.

J.3.2.3 Bottoms may be flat or flat flanged. A flat-bottom shall project at least 25 mm (1 in.) beyond the outside diameter of the weld attaching the bottom to the shell plate. A flat-flanged bottom shall have an inside corner radius that is not less than three times the bottom thickness and a straight flange that is a minimum of 19 mm ($^3/_4$ in.).

J.3.2.4 For flat bottoms, the attachment between the bottom edges of the lowest course shell plate and the bottom plate shall be a continuous fillet weld laid on each side of the shell plate. Each fillet weld shall be sized in accordance with 5.1.5.7. A flat-flanged bottom shall be attached to the shell by full-penetration butt-welds.

J.3.3 SHELLS

Shell plates shall be designed in accordance with the formula given in A.4.1, but the nominal thickness of shell plates shall not be less than the following:

a. For tanks with a diameter less than or equal to 3.2 m (10.5 ft) – 4.8 mm ($^3/_{16}$ in.).
b. For tanks with a diameter greater than 3.2 m (10.5 ft) – 6 mm (0.236 in.). 08

J.3.4 WIND GIRDERS FOR OPEN-TOP TANKS

Open-top tanks shall be provided with wind girders as specified in 5.9.

J.3.5 ROOFS

J.3.5.1 General

Roofs for tanks constructed in accordance with this appendix shall be of the self-supporting type and shall conform to either J.3.5.2 or J.3.5.3.

J.3.5.2 Cone Roofs

Self-supporting cone roofs shall be designed as specified in 5.10.5, except they may be provided with a flange that will permit butt-welded attachment to the shell (see J.3.1.4). Flanges shall be formed with a minimum inside corner radius of three times the roof thickness or 19 mm ($^3/_4$ in.), whichever is larger.

J.3.5.3 Dome and Umbrella Roofs

Self-supporting dome and umbrella roofs shall be designed as specified in 5.10.6, except they may be flanged as described in J.3.5.2. For dome roofs that are flanged, the radius of curvature shall not be limited to the maximum requirements given in 5.10.6; instead, the curvature shall be limited by the depth of the roof, including the crown and knuckle depth, as listed in Tables J-1a and J-1b.

Table J-1a—(SI) Minimum Roof Depths for Shop-Assembled Dome-Roof Tanks

Diameter	Depth
m	mm
≤ 1.8	50
≤ 2.4	90
≤ 3.0	140
≤ 3.7	200
≤ 4.3	275
≤ 4.9	375
≤ 6.0	500

Table J-1b—(USC) Minimum Roof Depths for Shop-Assembled Dome-Roof Tanks

Diameter	Depth
ft	in.
6	2
8	$3^1/_2$
10	$5^1/_2$
12	8
14	11
16	15
20	20

J.3.5.4 Top Angles

When top angles are required, they shall be attached as specified in 5.10.7.

J.3.6 TANK CONNECTIONS AND APPURTENANCES

J.3.6.1 Manholes, nozzles, and other connections in the shell shall be constructed and attached as specified in 5.7, but it is unlikely that reinforcing plates will be required for manholes and nozzles in the tank shell. The need for reinforcement shall be checked according to the procedure given in 5.7.2. Since the nominal shell-plate thicknesses required by J.3.3 will normally exceed the calculated thickness, the excess material in the shell should satisfy the reinforcement requirements in nearly all cases.

J.3.6.2 The requirements of 5.7.3 for the spacing of welds do not apply except for the requirement that the spacing between the toes of welds around a connection shall not be less than 2.5 times the shell thickness at the connection.

● **J.3.6.3** The roofs of tanks constructed in accordance with this appendix will be inherently strong because of the limitations in diameter required for shipping clearances. Thus, reinforcement of roof manholes and nozzles is not required unless specifically requested by the Purchaser or unless roof loads exceed 1.2 kPa (25 lbf/ft^2), in which case the amount and type of reinforcement shall be agreed upon by the Purchaser and the Manufacturer. 11

J.3.6.4 For shell manholes and nozzles the radiographic requirements of 5.7.3.4 do not apply.

J.3.6.5 For flush-type cleanout fittings, the provisions for stress relief specified in 5.7.4 and 5.7.7.3 are not required unless any plate in the assembly has a thickness greater than 16 mm ($^5/_8$ in.).

J.3.6.6 For flush-type shell connections, the provisions for stress relief specified in 5.7.4 and 5.7.8.3 are not required unless any plate in the assembly has a thickness greater than 16 mm ($^5/_8$ in.).

J.3.7 CORROSION ALLOWANCE

● **J.3.7.1** If the Purchaser requires that a corrosion allowance be provided, the allowance and the areas to which the allowance is to be added shall be specified. If a corrosion allowance is specified without an indication of the area to which it is to be added, the Manufacturer shall assume that it is to be added only to the calculated shell-plate thickness.

● **J.3.7.2** When a corrosion allowance is specified for the roof and bottom plates, it shall be added to the minimum nominal thicknesses.

J.3.8 LIFTING LUGS

J.3.8.1 Lugs or clips for use in loading and unloading tanks and for use in placing tanks on foundations shall be provided on all tanks constructed in accordance with this appendix.

● **J.3.8.2** There shall be a minimum of two lugs on each tank. The location of the lugs shall be agreed upon by the Purchaser and the Manufacturer. The lugs shall preferably be located at the top of the tank, in pairs, 180 degrees apart.

J.3.8.3 Lugs and their attachment welds shall be designed to carry their share of the applied load (twice the empty weight of the tank) distributed in a reasonable manner and based on a safety factor of 4.

J.3.8.4 Lugs capable of carrying the load described in J.3.8.3 shall be designed and attached in a manner that will not damage the tank.

J.3.9 ANCHORING

Because of the proportions of shop-assembled storage tanks, overturning as a result of wind loading must be considered. If necessary, adequate provisions for anchoring shall be provided.

J.4 Fabrication and Construction

J.4.1 GENERAL

J.4.1.1 Fabrication and construction shall be in accordance with the applicable provisions of Sections 6 and 7 of this Standard. Erection shall be interpreted as assembly, and it shall be understood that the entire vessel is constructed in the shop and not at the field site.

J.4.1.2 Sections 7.2.2 and 7.2.5 of this Standard are not applicable to the bottoms and roofs of shop-assembled tanks.

J.4.2 TESTING, REPAIRS, AND INSPECTION

J.4.2.1 General

For testing of, repairs to, and inspection of shop-assembled tanks, the requirements of J.4.2.2 through J.4.2.4 replace those of 7.3.2 through 7.3.6. 09

● J.4.2.2 Testing

Unless otherwise specified by the Purchaser, as an alternative to the requirements of 7.3.2 through 7.3.7, a tank may be shop tested for leaks by the following method:

a. The tank bottom shall be braced by securely attaching an external stiffening member as required to prevent permanent deformation during the test.

b. All openings shall be closed with plugs or covers as needed. Bolts and gaskets of the size and type required for final installation shall be used during the test.

c. An internal air pressure of 14 kPa – 21 kPa (2 lbf/in.^{2} – 3 lbf/in.^{2}) gauge shall be applied to the tank. For tanks with a diameter of 3.7 m (12 ft) or less, a maximum pressure of 35 kPa (5 lbf/in.^{2}) gauge shall be used.

d. Soap film, linseed oil, or another material suitable for the detection of leaks shall be applied to all shell, bottom, roof, and attachment welds, and the tank shall be carefully examined for leaks.

e. After the air pressure is released, the external stiffening member shall be removed, and any weld scars shall be repaired.

J.4.2.3 Repairs

All weld defects found by the leak test or by radiographic examination shall be repaired as specified in Section 8.

J.4.2.4 Inspection

The Purchaser's inspector shall have free entry to the Manufacturer's shop at all times. The Manufacturer shall afford the Purchaser's inspector reasonable facilities to assure the inspector that the work is being performed in accordance with the requirements of this Standard. All material and workmanship shall be subject to the replacement requirements of 6.2.3.

J.5 Inspection of Shell Joints

J.5.1 The methods of inspecting shell joints described in Section 8 apply to shop-assembled tanks, but spot radiography may be omitted when a joint efficiency of 0.70 is used (see A.3.4).

10 **J.5.2** When radiographic examination is required (joint efficiency = 0.85), the spot radiographs of vertical joints shall conform to 8.1.2.2, Item a only, excluding the 10 mm ($^3/_8$ in.) shell thickness limitation in Item a and excluding the additional random spot radiograph required by Item a. The spot radiographs of horizontal joints shall conform to 8.1.2.3.

J.6 Welding Procedure and Welder Qualifications

The requirements for qualification of welding procedures and welders given in Section 9 apply to shop-assembled tanks.

J.7 Marking

Shop-assembled tanks shall be marked in accordance with Section 10, except that 10.1.4 and 10.2 are not applicable. The nameplate (see Figure 10-1) shall indicate that the tank has been designed in accordance with this appendix.

APPENDIX K—SAMPLE APPLICATIONS OF THE VARIABLE-DESIGN-POINT METHOD TO DETERMINE SHELL-PLATE THICKNESS

11

K.1 Variable-Design-Point, Example #1

K.1.1 DATA

[ ] Design condition [x] Test condition
Specific gravity of liquid, G: 1.0
Corrosion allowance: 0.0 mm (0.0 in.)
Tank diameter, D: 85.0 m (280 ft)
Design Liquid Level (also total height of tank for the examples in this appendix), H: 19.2 m (64 ft) 07
Number of courses: 8.0
Allowable stress for design, S_d: —
Allowable stress for testing, S_t: 208 MPa (30,000 lbf/in.^{2})
Height of bottom course, h_1: 2,400 mm (96 in.)
Nominal tank radius, r: 42,500 mm (1,680 in.)

(See 5.6.4 for definition of nomenclature.)

K.1.2 CALCULATIONS

First Course (t_1)

For the test condition, t_1 is equal to t_{1t} but not greater than t_{pt}.

In SI units:

$$t_{pt} = \frac{4.9D(H-0.3)}{St} = \frac{(4.9)(85)(19.2-0.3)}{208} = 37.85$$

$$t_{1t} = \left[1.06 - \frac{0.0696D}{H}\sqrt{\frac{H}{S_t}}\right]\left[\frac{(4.9HD)}{S_t}\right]$$

$$= \left[1.06 - \frac{0.0696(85)}{19.2}\sqrt{\frac{19.2}{208}}\right]\left[\frac{4.9(19.2)(85)}{208}\right]$$

$$= [1.06 - (0.3081)(0.3038)][38.45]$$

$$= [1.06 - 0.0936][38.45]$$

$$= [0.9664][38.45]$$

$$= 37.15 \text{ mm} = t_1$$

In US Customary units:

$$t_{pt} = \frac{2.6D(H-1)}{St} = \frac{2.6(280)(64-1)}{30{,}000} = 1.529$$

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

$$= \left[1.06 - \frac{0.463(280)}{64}\sqrt{\frac{64}{30{,}000}}\right]\left[\frac{2.6(64)(280)}{30{,}000}\right]$$

$$= [1.06 - (2.026)(0.0462)][1.553]$$

$$= [1.06 - 0.0936][1.553]$$

$$= [0.9664][1.553]$$

$$= 1.501 \text{ in.} = t_1$$

11 K.2 Variable-Design-Point, Example #2

K.2.1 DATA

In US Customary units:

$D = 280$ ft

$H = 40$ ft

$G = 0.85$

Course	Course Height ft	Course Height (h) in.	H ft	CA in.	Material
1	8	96	40	0.125	A573-70
2	8	96	32	0.125	A573-70
3	8	96	24	0.0625	A573-70
4	8	96	16	0	A36
5	8	96	8	0	A36

Material	S_d psi	S_t psi
A573-70	28,000	30,000
A36	23,200	24,900

09 K.2.2 BOTTOM COURSE (COURSE 1)

K.2.2.1 Design Condition

$$t_{pd} = 2.6 \times D \times (H - 1) \times G / S_d + CA = 0.987 \text{ in.}$$

$$t_{1d} = (1.06 - (0.463 \times D/H) \times (HG/S_d)^{0.5}) \times (2.6HDG/S_d) + CA = 0.962 \text{ in.}$$

t_{1d} need not be greater than t_{pd}

t_{1d} = minimum of above thicknesses = 0.962 in.

K.2.2.2 Hydrostatic Test Condition

$$t_{pt} = 2.6 \times D \times (H - 1) / S_t = 0.946 \text{ in.}$$

$$t_{1dt} = (1.06 - (0.463 \times D/H) \times (H/S_t)^{0.5}) \times (2.6HD/S_t) = 0.914 \text{ in.}$$

t_{1t} need not be greater than t_{pt}

t_{1t} = minimum of above thicknesses = 0.914 in.

t_{use} = nominal thickness used

t_{min} = minimum nominal thickness required, the greater of t_d or t_t

t_{min} = 0.962 in. (controlled by t_{1d})

t_{use} = 1.000 in.

Note: $t_{\text{use}} > t_{\text{min}}$ The greater thickness will be used for subsequent calculations and noted as the required thickness, therefore, t_{1d} = 1.000 in.

K.2.2.3 Check $L/H \leq 2$

$L = (6Dt)^{0.5}$

$t = t_{\text{use}} - CA = 0.875$ in.

$L = 38.34$

$L/H = 0.96 \leq 2$

K.2.3 SHELL COURSE 2 11

K.2.3.1 Design Condition

h_1 = 96 in.

r = 1680 in.

t_{1d} = 1.000 in.

CA = 0.125 in. 09

t_1 = 0.875 in.

$h_1/(r \times t_1)^{0.5} = 2.504 > 1.375$ and < 2.625

$t_2 = t_{2a} + (t_1 - t_{2a})(2.1 - h_1/(1.25 \times (rt_1)^{0.5})$

t_{2a} = 0.634 in. (see K.2.4)

t_2 = 0.657 in.

$t_{2d} = t_2 + CA = 0.782$ in.

K.2.3.2 Hydrostatic Test Condition

h_1 = 96 in.

r = 1680 in.

t_{1t} = 1.000 in.

t_1 = 1.000 in.

$h_1/(r \times t_1)^{0.5} = 2.342 > 1.375$ and < 2.625

$t_2 = t_{2a} + (t_1 - t_{2a})(2.1 - h_1/(1.25 \times (rt_1)^{0.5})$

t_{2a} = 0.699 in.(See K.2.4)

t_2 = 0.767 in.

t_{2t} = 0.767 in.

t_{min} = greater of t_{2d} or t_{2t} = 0.782 in.

t_{use} = 0.8125 in.

Note: $t_{use} > t_{min}$, however, the extra thickness will not be used for subsequent calculations, therefore, t_{2d} = 0.782 in.

K.2.4 SECOND COURSE AS UPPER SHELL COURSE

K.2.4.1 Design Condition

D = 280 ft

Material A573-70

S_d = 28,000 psi

S_t = 30,000 psi

CA = 0.125 in.

G = 0.85

H = 32 ft

09 r = 1680 in.

$C = (K^{0.5}(K - 1))/(1+K^{1.5})$

$K = t_L/t_u$

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

$x_2 = 12CH$

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

t_L = 0.875 in. (thickness of bottom shell course less CA)

K.2.4.2 Trials

starting $t_u = 2.6D(H - 1)G/S_d = 0.6851$ in.

	t_u in.	K	C	x_1 in.	x_2 in.	x_3 in.	x in.	$t_d - CA$ in.
1	0.685	1.277	0.128	36.449	49.231	41.390	36.449	0.640
2	0.640	1.367	0.165	40.298	63.420	40.006	40.006	0.634
3	0.634	1.381	0.171	40.885	65.575	39.801	39.801	0.634
4	0.634	1.380	0.170	40.851	65.450	39.813	39.813	0.634

$t_d - CA$ = 0.634 in.

t_d = 0.759 in.

K.2.4.3 Hydrotest Condition

t_L = 0.914 in. (calculated hydrostatic thickness of bottom shell course)

K.2.4.4 Trials

starting $t_u = 2.6D(H - 1)/S_t = 0.752$ in.

	t_u in.	K	C	x_1 in.	x_2 in.	x_3 in.	x in.	t_t in.
1	0.752	1.215	0.101	34.137	38.909	43.371	34.137	0.708
2	0.708	1.292	0.134	37.548	51.616	42.061	37.548	0.701
3	0.701	1.305	0.140	38.098	53.658	41.855	38.098	0.699
4	0.699	1.307	0.141	38.188	53.989	41.822	38.188	0.699

t_t = 0.699 in.

K.2.5 SHELL COURSE 3

K.2.5.1 Design Condition

D = 280 ft

Material A573-70

S_d = 28,000 psi

S_t = 30,000 psi

CA = 0.0625 in. 09

G = 0.85

H = 24 ft

r = 1680 in.

$C = (K^{0.5}(K - 1))/(1 + K^{1.5})$

$K = t_L/t_u$

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

$x_2 = 12CH$

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

t_L = 0.657 in. (t_d of lower shell course less CA)

K.2.5.2 Trials

starting $t_u = 2.6D(H - 1)\,G/S_d = 0.508$ in.

	t_u in.	K	C	x_1 in.	x_2 in.	x_3 in.	x in.	$t_d - CA$ in.
1	0.508	1.293	0.135	30.256	38.846	35.651	30.256	0.475
2	0.475	1.385	0.172	33.089	49.572	34.452	33.089	0.469
3	0.469	1.400	0.178	33.550	51.310	34.262	33.550	0.469
4	0.469	1.403	0.179	33.626	51.595	34.231	33.626	0.468

$t_d - CA$ = 0.468 in.

t_d = 0.531 in.

K.2.5.3 Hydrotest Condition

t_L = 0.767 in. (calculated hydrostatic thickness of lower shell course)

K.2.5.4 Trials

starting $rt_u = 2.6D(H - 1)/S_t = 0.558$ in.

	t_u in.	K	C	x_1 in.	x_2 in.	x_3 in.	x in.	t_t in.
1	0.558	1.375	0.168	34.186	48.461	37.358	34.1864	0.513
2	0.513	1.495	0.214	37.637	61.641	35.825	35.825	0.510
3	0.510	1.505	0.218	37.905	62.659	35.709	35.7092	0.510
4	0.510	1.504	0.217	37.886	62.586	35.717	35.7174	0.510

t_t = 0.510 in.

t_{min} = 0.531 in.

t_{use} = 0.531 in.

K.2.6 SHELL COURSE 4

09 K.2.6.1 Design Condition

D = 280 ft

Material A36

S_d = 23,200 psi

S_t = 24,900 psi

CA = 0 in.

G = 0.85

H = 16 ft

r = 1680 in.

$C = (K^{0.5}(K - 1))/(1 + K^{1.5})$

$K = t_L/t_u$

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

$x_2 = 12CH$

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

t_L = 0.468 in. (t_d of lower shell course less CA)

K.2.6.2 Trials

starting $t_u = 2.6D(H - 1)G/S_d = 0.400$ in.

	t_u in.	K	C	x_1 in.	x_2 in.	x_3 in.	x in.	$t_d - CA$ in.
1	0.400	1.171	0.082	20.827	15.665	31.629	15.665	0.392
2	0.392	1.195	0.093	21.339	17.769	31.306	17.769	0.387
3	0.387	1.210	0.099	21.640	19.001	31.118	19.001	0.385
4	0.385	1.218	0.103	21.818	19.732	31.008	19.732	0.383

$t_d - CA$ = 0.383 in.

t_d = 0.383 in.

K.2.6.3 Hydrotest Condition

t_L = 0.510 in. (calculated hydrostatic thickness of lower shell course)

K.2.6.4 Trials

starting $t_u = 2.6D(H - 1)/S_t = 0.439$ in.

	t_u in.	K	C	x_1 in.	x_2 in.	x_3 in.	x in.	t_t in.
1	0.439	1.1633	0.078	21.357	14.999	33.115	14.999	0.431
2	0.431	1.18301	0.087	21.767	16.713	32.838	16.713	0.427
3	0.427	1.19458	0.092	22.007	17.710	32.679	17.710	0.425
4	0.425	1.20142	0.095	22.147	18.295	32.586	18.295	0.423

09

t_t = 0.423 in.

t_{min} = 0.423 in.

t_{use} = 0.4375 in.

Note: $t_{use} > t_{use\ min}$, however, it is controlled by hydrotest, therefore, t_{1d} remains at 0.383 for subsequent calculations

K.2.7 SHELL COURSE 5

K.2.7.1 Design Condition

D = 280 ft

Material A36

S_d = 23,200 psi

S_t = 24,900 psi

CA = 0 in.

G = 0.85

H = 8 ft

r = 1680 in.

$C = (K^{0.5}(K - 1))/(1 + K^{1.5})$

$K = t_L/t_u$

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

$x_2 = 12CH$

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

$t_L = 0.383$ in. (t_d of lower shell course less CA)

K.2.7.2 Trials

starting $t_u = 2.6D(H - 1)G/S_d = 0.187$ in.

	t_u in.	K	C	x_1 in.	x_2 in.	x_3 in.	x in.	$t_d - CA$ in.
1	0.187	2.051	0.382	22.546	36.695	21.607	21.607	0.165
2	0.165	2.316	0.443	23.762	42.486	20.334	20.334	0.168
3	0.168	2.277	0.434	23.596	41.696	20.507	20.507	0.168
4	0.168	2.282	0.435	23.619	41.803	20.484	20.484	0.168

09

$t_d - CA = 0.168$ in.

$t_d = 0.168$ in.

K.2.7.3 Hydrotest Condition

$t_L = 0.423$ in. (calculated hydrostatic thickness of lower shell course)

K.2.7.4 Trials

starting $t_u = 2.6D(H - 1)/S_t = 0.205$ in.

	t_u in.	K	C	x_1 in.	x_2 in.	x_3 in.	x in.	t_t in.
1	0.205	2.06791	0.386	23.1831	37.10029	22.622	22.6219	0.179
2	0.179	2.36726	0.453	24.4925	43.50275	21.143	21.1433	0.182
3	0.182	2.3205	0.444	24.3042	42.58296	21.355	21.3553	0.182
4	0.182	2.32709	0.445	24.3311	42.71425	21.325	21.325	0.182

$t_t = 0.182$ in.

$t_{\text{use min}} = 0.182$ in.

$t_{\text{use}} = 0.375$ in.

Note: Minimum nominal thickness is $^3/_8$ in.

K.2.8 SHELL DESIGN SUMMARY

As required by W.1.5 to be listed on drawings.

Course	Material	S_d in.	S_t in.	t_d in.	t_t in.	t_{min} in.	t_{use} in.	
1	A573-70	28,000	30,000	1.000	0.914	1.000	1.000	09
2	A573-70	28,000	30,000	0.782	0.767	0.782	0.813	
3	A573-70	28,000	30,000	0.531	0.510	0.531	0.531	
4	A36	23,200	23,200	0.383	0.423	0.423	0.438	
5	A36	23,200	23,200	0.168	0.182	0.182	0.375	

(Sample calculated shell-plate thicknesses for various tank sizes and allowable stresses are given in Tables K-1a through K-3b.) 08

Table K-1a—(SI) Shell-Plate Thicknesses Based on the Variable-Design-Point Method (See 5.6.4) Using 2400-mm Courses and an Allowable Stress of 159 MPa for the Test Condition

08

Tank Des. Liq. Lvl. m	Tank Diameter m	Weight of Shell Mg	Shell Plate Thickness for Course, mm								Nominal Tank Volume m^3
			1	2	3	4	5	6	7	8	
12	60	233	21.40	16.18	11.96	8.00	8.00	—	—	—	33,900
	65	282	22.99	17.42	12.90	10.00	10.00	—	—	—	39,800
	75	363	26.09	20.95	14.58	10.00	10.00	—	—	—	53,000
	80	408	27.59	22.97	15.39	10.02	10.00	—	—	—	60,300
	85	457	29.06	24.95	16.21	10.59	10.00	—	—	—	68,100
	90	510	30.51	26.88	17.01	11.16	10.00	—	—	—	76,300
	100	621	33.31	30.59	18.57	12.28	10.00	—	—	—	94,200
	105	680	34.66	32.40	19.32	12.84	10.00	—	—	—	103,900
	110	741	35.99	34.21	20.06	13.39	10.00	—	—	—	114,000
	115	804	37.29	35.94	20.78	13.93	10.00	—	—	—	124,600
14.4	55	276	23.90	18.85	14.99	11.06	8.00	8.00	—	—	34,200
	60	322	25.90	20.43	16.29	11.96	8.00	8.00	—	—	40,700
	65	388	27.85	22.54	17.49	12.89	10.00	10.00	—	—	47,800
	75	505	31.65	27.47	19.76	14.78	10.00	10.00	—	—	63,600
	80	569	33.50	29.85	20.92	15.71	10.00	10.00	—	—	72,400
	85	638	35.32	32.17	22.05	16.63	10.53	10.00	—	—	81,700
	90	711	37.11	34.44	23.17	17.54	11.08	10.00	—	—	91,600
16.8	50	306	25.42	20.83	17.30	13.69	10.15	8.00	8.00	—	33,000
	55	364	27.97	22.77	18.98	14.96	11.06	8.00	8.00	—	39,900
	60	428	30.42	25.25	20.54	16.27	11.96	8.00	8.00	—	47,500
	65	514	32.73	28.17	22.02	17.59	12.89	10.00	10.00	—	55,700
	75	671	37.24	33.81	25.01	20.17	14.72	10.00	10.00	—	74,200
	77	705	38.12	34.91	25.60	20.69	15.09	10.00	10.00	—	78,200
19.2	50	390	29.12	24.42	20.95	17.28	13.69	10.15	8.00	8.00	37,700
	55	466	32.03	27.03	22.92	18.95	14.98	11.06	8.00	8.00	45,600
	60	551	34.95	30.39	24.75	20.63	16.27	11.96	8.00	8.00	54,300
	62.5	610	36.29	32.04	25.66	21.47	16.91	12.41	10.00	10.00	58,900

Table K-1b—(USC) Shell-Plate Thicknesses Based on the Variable-Design-Point Method (See 5.6.4) Using 96-in. Courses and an Allowable Stress of 23,000 lbf/in.^{2} for the Test Condition

08

Tank Des. Liq. Lvl. ft)	Tank Diameter ft	Weight of Shell tons	Shell Plate Thickness for Course, in.								Nominal Tank Volume bbl
			1	2	3	4	5	6	7	8	
40	200	272	0.871	0.659	0.487	0.317	0.313	—	—	—	224,000
	220	333	0.949	0.720	0.533	0.375	0.375	—	—	—	271,000
	240	389	1.025	0.807	0.574	0.375	0.375	—	—	—	322,500
	260	453	1.099	0.907	0.613	0.398	0.375	—	—	—	378,500
	280	522	1.171	1.004	0.653	0.427	0.375	—	—	—	439,000
	300	594	1.241	1.098	0.692	0.454	0.375	—	—	—	504,000
	320	671	1.310	1.189	0.730	0.482	0.375	—	—	—	573,400
	340	751	1.377	1.277	0.768	0.509	0.375	—	—	—	647,300
	360	835	1.433	1.362	0.804	0.536	0.375	—	—	—	725,700
	380	923	1.506	1.448	0.840	0.562	0.375	—	—	—	808,600
48	180	312	0.956	0.755	0.600	0.443	0.313	0.313	—	—	217,700
	200	376	1.055	0.832	0.664	0.487	0.317	0.313	—	—	268,800
	220	463	1.150	0.943	0.721	0.533	0.375	0.375	—	—	325,200
	240	543	1.243	1.063	0.776	0.579	0.375	0.375	—	—	387,000
	260	633	1.334	1.181	0.833	0.625	0.397	0.375	—	—	454,200
	280	729	1.423	1.295	0.889	0.669	0.424	0.375	—	—	526,800
	298	821	1.502	1.394	0.938	0.710	0.448	0.375	—	—	596,700
56	160	333	0.995	0.817	0.678	0.537	0.398	0.313	0.313	—	200,700
	180	412	1.119	0.912	0.760	0.599	0.443	0.313	0.313	—	254,000
	200	502	1.239	1.033	0.836	0.663	0.487	0.317	0.313	—	313,600
	220	615	1.351	1.175	0.908	0.727	0.532	0.375	0.375	—	379,400
	240	723	1.462	1.313	0.982	0.790	0.577	0.375	0.375	—	451,500
	247	764	1.500	1.361	1.007	0.812	0.592	0.379	0.375	—	478,300
64	160	423	1.139	0.957	0.820	0.677	0.537	0.398	0.313	0.313	229,300
	180	527	1.282	1.078	0.918	0.758	0.599	0.443	0.313	0.313	290,300
	200	646	1.423	1.242	1.007	0.841	0.662	0.487	0.317	0.313	358,400
	212	735	1.502	1.338	1.061	0.890	0.700	0.514	0.375	0.375	402,600

Table K-2a—(SI) Shell-Plate Thicknesses Based on the Variable-Design-Point Method (See 5.6.4) Using 2400-mm Courses and an Allowable Stress of 208 MPa for the Test Condition

08

Tank Des. Liq.Lvl. m	Tank Diameter m	Weight of Shell Mg	Shell Plate Thickness for Course, mm								Nominal Tank Volume m^3
			1	2	3	4	5	6	7	8	
12	75	298	20.26	15.36	11.38	10.00	10.00	—	—	—	53,000
	80	332	21.45	16.48	12.06	10.00	10.00	—	—	—	60,300
	85	369	22.63	18.07	12.65	10.00	10.00	—	—	—	68,100
	90	409	23.78	19.63	13.27	10.00	10.00	—	—	—	76,300
	100	493	26.03	22.64	14.51	10.00	10.00	—	—	—	94,200
	105	537	27.12	24.10	15.12	10.00	10.00	—	—	—	103,900
	110	585	28.20	25.52	15.72	10.37	10.00	—	—	—	114,000
	115	636	29.25	26.92	16.31	10.79	10.00	—	—	—	124,600
	120	688	30.29	28.30	16.88	11.22	10.00	—	—	—	135,700
14.4	65	316	21.55	16.99	13.52	10.00	10.00	10.00	—	—	47,800
	75	406	24.54	19.96	15.41	11.37	10.00	10.00	—	—	63,600
	80	456	26.01	21.86	16.27	12.09	10.00	10.00	—	—	72,400
	85	509	27.45	23.73	17.14	12.81	10.00	10.00	—	—	81,700
	90	565	28.87	25.55	18.02	13.52	10.00	10.00	—	—	91,600
	100	684	31.64	29.10	19.76	14.92	10.00	10.00	—	—	113,100
	105	747	33.00	30.81	20.61	15.62	10.00	10.00	—	—	124,700
	110	814	34.33	32.49	21.44	16.31	10.28	10.00	—	—	136,800
	115	885	35.65	34.18	22.26	17.01	10.68	10.00	—	—	149,600
	120	958	36.94	35.83	23.08	17.73	11.08	10.00	—	—	162,900
16.8	60	341	23.32	19.05	15.85	12.51	9.27	8.00	8.00	—	47,500
	65	410	25.27	20.53	17.13	13.50	10.00	10.00	10.00	—	55,700
	75	533	28.84	24.92	19.40	15.51	11.36	10.00	10.00	—	74,200
	80	601	30.58	27.09	20.53	16.50	12.07	10.00	10.00	—	84,400
	85	672	32.29	29.23	21.68	17.48	12.76	10.00	10.00	—	95,300
	90	747	33.98	31.33	22.82	18.46	13.46	10.00	10.00	—	106,900
	100	907	37.29	35.41	25.05	20.42	14.82	10.00	10.00	—	131,900
	105	992	38.91	37.39	26.14	21.46	15.48	10.00	10.00	—	145,500
	110	1083	40.51	39.36	27.23	22.64	16.11	10.30	10.00	—	159,700
	115	1179	42.08	41.28	28.33	23.79	16.74	10.72	10.00	—	174,500
	120	1278	43.63	43.14	29.44	24.94	17.36	11.14	10.00	—	190,000
19.2	60	433	26.71	22.34	19.19	15.83	12.52	9.27	8.00	8.00	54,300
	65	520	28.94	24.70	20.63	17.11	13.51	10.00	10.00	10.00	63,700
	75	679	33.16	29.77	23.42	19.67	15.47	11.36	10.00	10.00	84,800
	80	766	35.17	32.22	24.85	20.93	16.45	12.06	10.00	10.00	96,500
	85	858	37.15	34.64	26.25	22.18	17.41	12.77	10.00	10.00	109,000
	90	955	39.12	37.01	27.65	23.44	18.36	13.46	10.00	10.00	122,100
	100	1163	42.96	41.63	30.38	26.27	20.19	14.85	10.00	10.00	150,800
	101	1185	43.34	42.08	30.65	26.56	20.37	14.98	10.00	10.00	153,800

Table K-2b—(USC) Shell-Plate Thicknesses Based on the Variable-Design-Point Method (See 5.6.4) Using 96-in. Courses and an Allowable Stress of 30,000 lbf/in.^{2} for the Test Condition

08

Tank Des. Liq. Lvl. ft	Tank Diameter ft	Weight of Shell tons	Shell Plate Thickness for Course, in.								Nominal Tank Volume bbl
			1	2	3	4	5	6	7	8	
40	240	320	0.798	0.603	0.447	0.375	0.375	—	—	—	322,500
	260	365	0.856	0.651	0.482	0.375	0.375	—	—	—	378,500
	280	417	0.914	0.729	0.511	0.375	0.375	—	—	—	439,000
	300	472	0.971	0.806	0.541	0.375	0.375	—	—	—	504,000
	320	530	1.026	0.880	0.572	0.375	0.375	—	—	—	573,400
	340	594	1.08	0.952	0.602	0.395	0.375	—	—	—	647,300
	360	661	1.133	1.022	0.632	0.416	0.375	—	—	—	725,700
	380	731	1.185	1.090	0.660	0.437	0.375	—	—	—	800,600
	400	803	1.235	1.156	0.689	0.458	0.375	—	—	—	896,000
48	220	374	0.892	0.704	0.561	0.412	0.375	0.375	—	—	325,200
	240	436	0.966	0.773	0.608	0.446	0.375	0.375	—	—	387,000
	260	505	1.038	0.866	0.650	0.482	0.375	0.375	—	—	454,200
	280	579	1.109	0.958	0.692	0.517	0.375	0.375	—	—	526,800
	300	656	1.178	1.047	0.736	0.552	0.375	0.375	—	—	604,800
	320	739	1.247	1.135	0.778	0.587	0.375	0.375	—	—	688,100
	340	827	1.314	1.220	0.820	0.621	0.392	0.375	—	—	776,800
	360	921	1.379	1.302	0.862	0.655	0.412	0.375	—	—	870,900
	380	1019	1.444	1.383	0.902	0.688	0.433	0.375	—	—	970,300
	400	1121	1.507	1.462	0.942	0.721	0.452	0.375	—	—	1,075,200
56	200	400	0.953	0.778	0.648	0.511	0.378	0.313	0.313	—	313,600
	220	490	1.048	0.858	0.709	0.560	0.412	0.375	0.375	—	379,400
	240	575	1.135	0.968	0.764	0.609	0.446	0.375	0.375	—	451,500
	260	668	1.220	1.075	0.819	0.658	0.481	0.375	0.375	—	529,900
	280	766	1.305	1.180	0.876	0.706	0.515	0.375	0.375	—	614,600
	300	871	1.387	1.283	0.932	0.754	0.549	0.375	0.375	—	705,600
	320	981	1.469	1.383	0.987	0.801	0.583	0.375	0.375	—	802,800
	340	1100	1.549	1.481	1.041	0.849	0.616	0.393	0.375	—	906,300
	360	1225	1.627	1.577	1.094	0.895	0.649	0.413	0.375	—	1,016,000
	380	1358	1.705	1.671	1.148	0.951	0.679	0.434	0.375	—	1,132,000
	392	1441	1.750	1.726	1.180	0.986	0.698	0.446	0.375	—	1,204,700
64	200	508	1.092	0.913	10.784	0.647	120.511	0.378	0.313	0.313	358,400
	220	623	1.201	1.034	0.853	0.710	0.560	0.412	0.375	0.375	433,600
	240	734	1.304	1.159	0.922	0.772	0.608	0.447	0.375	0.375	516,000
	260	853	1.403	1.280	0.992	0.834	0.655	0.481	0.375	0.375	605,600
	280	981	1.501	1.399	1.061	0.896	0.703	0.516	0.375	0.375	702,400
	300	1116	1.597	1.515	1.129	0.957	0.749	0.550	0.375	0.375	806,400
	320	1259	1.692	1.629	1.196	1.017	0.796	0.584	0.375	0.375	917,500
	332	1350	1.748	1.696	1.236	1.059	0.822	0.604	0.384	0.375	987,600

Table K-3a—(SI) Shell-Plate Thicknesses Based on the Variable-Design-Point Method (See 5.6.4) Using 2400-mm Courses and an Allowable Stress of 236 MPa for the Test Condition

08

Tank Des. Liq. Lvl. m	Tank Diameter m	Weight of Shell Mg	Shell Plate Thickness for Course, mm								Nominal Tank Volume m³
			1	2	3	4	5	6	7	8	
14.4	65	293	19.03	15.04	11.95	10.00	10.00	10.00	—	—	47,800
	75	368	21.76	17.19	13.70	10.05	10.00	10.00	—	—	63,600
	80	413	23.07	18.78	14.48	10.69	10.00	10.00	—	—	72,400
	85	460	24.36	20.45	15.24	11.33	10.00	10.00	—	—	81,700
	90	510	25.63	22.10	16.00	11.96	10.00	10.00	—	—	91,600
	100	617	28.12	25.30	17.56	13.21	10.00	10.00	—	—	113,100
	105	674	29.34	26.85	18.32	13.82	10.00	10.00	—	—	124,700
	110	733	30.54	28.37	19.07	14.44	10.00	10.00	—	—	136,800
	115	794	31.73	29.87	19.81	15.05	10.00	10.00	—	—	149,600
	120	856	32.89	31.34	20.54	15.66	10.00	10.00	—	—	162,900
16.8	60	308	20.56	16.86	14.00	11.08	8.21	8.00	8.00	—	47,500
	65	376	22.27	18.17	15.13	11.93	10.00	10.00	10.00	—	55,700
	75	480	25.56	21.48	17.24	13.70	10.05	10.00	10.00	—	74,200
	80	541	27.11	23.43	18.23	14.58	10.67	10.00	10.00	—	84,400
	85	604	28.64	25.35	19.23	15.45	11.29	10.00	10.00	—	95,300
	90	671	30.15	27.24	20.25	16.32	11.91	10.00	10.00	—	106,900
	100	815	33.12	30.92	22.24	18.04	13.12	10.00	10.00	—	131,900
	105	891	34.57	32.70	23.22	18.90	13.72	10.00	10.00	—	145,500
	110	970	36.01	34.46	24.19	19.77	14.31	10.00	10.00	—	159,700
	115	1053	37.42	36.19	25.15	20.80	14.87	10.00	10.00	—	174,500
	120	1139	38.82	37.92	26.11	21.83	15.43	10.00	10.00	—	190,000
19.2	60	389	23.54	19.76	16.94	13.98	11.08	8.21	8.00	8.00	54,300
	65	471	25.51	21.32	18.31	15.10	11.94	10.00	10.00	10.00	63,700
	75	609	29.37	25.79	20.78	17.37	13.67	10.05	10.00	10.00	84,800
	80	687	31.17	27.99	22.02	18.49	14.53	10.68	10.00	10.00	96,500
	85	769	32.94	30.16	23.27	19.60	15.39	11.30	10.00	10.00	109,000
	90	855	34.69	32.29	24.51	20.70	16.24	11.92	10.00	10.00	122,100
	100	1041	38.13	36.45	26.96	22.99	17.90	13.15	10.00	10.00	150,800
	105	1140	39.82	38.47	28.16	24.27	18.70	13.76	10.00	10.00	166,300
	110	1243	41.49	40.47	29.34	25.57	19.49	14.36	10.00	10.00	182,5000
	115	1351	43.14	42.45	30.55	26.85	20.27	14.97	10.00	10.00	199,400
	117	1395	43.80[a]	43.22	31.03	27.36	20.59	15.21	10.00	10.00	206,400

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[a] Exceeds maximum allowed material thickness.

Table K-3b—(USC) Shell-Plate Thicknesses Based on the Variable-Design-Point Method (See 5.6.4) Using 96-in. Courses and an Allowable Stress of 34,300 lbf/in.^{2} for the Test Condition

Tank Des. Liq. Lvl. ft	Tank Diameter ft	Weight of Shell tons	Shell Plate Thickness for Course, in.								Nominal Tank Volume bbl
			1	2	3	4	5	6	7	8	
48	220	341	0.784	0.619	0.492	0.375	0.375	0.375	—	—	325,200
	240	394	0.850	0.670	0.534	0.393	0.375	0.375	—	—	387,000
	260	453	0.914	0.736	0.574	0.423	0.375	0.375	—	—	454,200
	280	519	0.977	0.818	0.611	0.454	0.375	0.375	—	—	526,800
	300	588	1.039	0.898	0.649	0.485	0.375	0.375	—	—	604,800
	320	662	1.100	0.977	0.687	0.515	0.375	0.375	—	—	688,100
	340	738	1.160	1.053	0.724	0.545	0.375	0.375	—	—	776,800
	360	819	1.218	1.127	0.761	0.575	0.375	0.375	—	—	870,900
	380	904	1.276	1.200	0.797	0.605	0.381	0.375	—	—	970,300
	400	994	1.333	1.271	0.832	0.634	0.399	0.375	—	—	1,075,200
56	200	358	0.834	0.684	0.568	0.449	0.333	0.313	0.313	—	313,600
	220	441	0.917	0.747	0.623	0.491	0.375	0.375	0.375	—	379,400
	240	514	0.998	0.825	0.674	0.534	0.393	0.375	0.375	—	451,500
	260	596	1.074	0.921	0.723	0.577	0.422	0.375	0.375	—	529,900
	280	684	1.149	1.015	0.771	0.620	0.453	0.375	0.375	—	614,600
	300	777	1.222	1.107	0.821	0.662	0.483	0.375	0.375	—	705,600
	320	875	1.295	1.197	0.869	0.703	0.512	0.375	0.375	—	802,800
	340	978	1.366	1.284	0.918	0.745	0.542	0.375	0.375	—	906,300
	360	1086	1.436	1.370	0.965	0.786	0.571	0.375	0.375	—	1,016,000
	380	1200	1.505	1.454	1.012	0.827	0.600	0.382	0.375	—	1,132,000
	400	1322	1.573	1.536	1.058	0.873	0.627	0.400	0.375	—	1,254,400
64	200	453	0.955	0.801	0.687	0.567	0.449	0.333	0.313	0.313	358,400
	220	556	1.051	0.884	0.752	0.622	0.491	0.375	0.375	0.375	433,600
	240	653	1.146	0.994	0.812	0.677	0.533	0.393	0.375	0.375	516,000
	260	759	1.235	1.102	0.872	0.731	0.575	0.423	0.375	0.375	605,600
	280	872	1.321	1.208	0.933	0.786	0.617	0.453	0.375	0.375	702,400
	300	992	1.406	1.311	0.994	0.839	0.658	0.483	0.375	0.375	806,400
	320	1119	1.490	1.413	1.053	0.893	0.699	0.513	0.375	0.375	917,500
	340	1252	1.573	1.512	1.112	0.946	0.740	0.543	0.375	0.375	1,035,700
	360	1394	1.655	1.610	1.170	1.007	0.779	0.572	0.375	0.375	1,161,200
	380	1543	1.735	1.705	1.228	1.071	0.817	0.601	0.382	0.375	1,293,800
	384	1574	1.751[a]	1.724	1.240	1.083	0.824	0.607	0.385	0.375	1,321,200

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[a] Exceeds maximum allowed material thickness.

APPENDIX L—API STD 650 STORAGE TANK DATA SHEET 07

Note: The Data Sheets contained in this appendix can be purchased by contacting Publications@api.org. 08

● L.1 Introduction

L.1.1 PURPOSE

This appendix provides guidance to Purchasers (owners, engineering contractors, and other designated agents) and Manufacturers (fabricators and erectors) for the preparation and completion of the *Atmospheric Storage Tank Data Sheet* (hereafter referred to as the **Data Sheet**). The Data Sheet shall be prepared in conjunction with this Standard such that comprehensive proposals (bids) may be made and subsequent contracts may be placed for the fabrication and erection of tanks.

L.1.2 SCOPE

This appendix explains information to be placed on the Data Sheet primarily by Purchasers for use by Manufacturers. However, some of the instructions apply to either the Purchaser or the Manufacturer, depending on which party assumes certain responsibilities.

● L.2 Use of This Appendix

● L.2.1 DATA SHEET PURPOSE

The Data Sheet (attached to this appendix) shall be part of a complete tank specification. The Data Sheet provides space for defining specific technical information such as geometry, design loads, materials, and appurtenances, as well as an outline sketch of the tank. The Data Sheet may be used as part of the Owner's permanent record describing the tank. Because some information on the Data Sheet may be determined by the Manufacturer, the Data Sheet may also be used to facilitate gathering of the complete design requirements. The floating roof section of the Data Sheet may be omitted if no floating roof is required for the tank.

● L.2.2 PURCHASER'S RESPONSIBILITY 07

The preparer(s) of the Data Sheet shall have tank design experience and shall ensure that the requirements are both accurate and complete. The Purchaser is primarily responsible for initiating and completing the Data Sheet.

L.2.3 MANUFACTURER'S RESPONSIBILITY

The Manufacturer shall complete the Data Sheet as required to describe the proposal and shall provide the relevant information required on all lines marked with an asterisk (*) that have not been provided by the Purchaser. The Data Sheet shall be submitted at various times during the project as described in W.1.2(2).

● L.2.4 TEXT LEGIBILITY

All text placed on the Data Sheet shall be of size and quality to be readable and reproducible. Use additional sheets or extend the form electronically for more space or necessary additions.

● L.3 Specific Instructions

L.3.1 LINE-BY-LINE INSTRUCTIONS

Each place for data entry (numbered lines, boxes, table cells, etc.) on the Data Sheet shall be completed. In no case should a line be left blank. Marking "NA" (not applicable), "Later," "TBD" (to be determined), or other such terminology can be used. The "Later" and "TBD" notations shall be edited to reflect subsequent decisions and as-built configurations (see W.1.2).

Use consistent units for all dimensions and other data on the Data Sheet. *Show appropriate units for every appropriate numerical entry.*

The following numbered items correspond to the numbered lines and numbered tables on the Data Sheet:

- **Heading:**

  Data Sheet Status: Typical entries include: For Quotation, Bid, For Design Review, For Design Revision, and As-Built. Revise to suit the status when submitted by the Purchaser or by the Manufacturer.

- **General:**
  - Special Documentation Package Requirements: List any exceptions to the default requirements listed in Appendix W.
  - Measurement Units to be used in API Std 650: Identify the set of units to be used when applying the rules in API Std 650.

● 1. Tank Manufacturer

- Manufacturer's name.*
- Contract number*: Enter proposed or assigned number.
- Address*: Enter physical address, not a post office box.
- Manufacturer's serial number for tank.*
- Year built.*
- Edition and Addendum of API Std 650 used for design and fabrication.*

● 2. Purchaser

- Purchaser's name.
- Contract number or designation.
- Address: Enter physical address, not a post office box.
- Tank designation: For example, item number, equipment tag number, or other description.

● 3. Owner/Operator

- Owner/operator name.
- Location of facility where tank will be operated. 07

● 4. Tank Dimensions

- Size Limitations*: Specify size limitations only when exact dimensions are to be determined by the Manufacturer (e.g., maximum and minimum diameters, shell heights, overall heights, etc.).
- Tank Diameter*: Specify diameter and indicate ID, OD, or CL/BSC (centerline diameter of bottom shell course).
- Shell Height*: Specify the distance from the top surface of the bottom plate or annular ring to the upper edge of the cylindrical shell including top angle, if any.
- Maximum Capacity* and Net Working Capacity*:
- Criteria*: Method used to determine capacity of tank: An example would be *API RP 2350.*

● 5. Products Stored

- Liquid: Specify liquid(s) to be stored in the tank.
- Maximum Specific Gravity: Enter specific gravity of the stored liquid(s) at designated temperatures. Use greatest value of all products when tanks are to be designed for multiple products.
- Blanketing Gas: Specify blanketing gas in the space above the liquid.
- Vapor Pressure: Specify absolute vapor pressure at the maximum operating temperature. Use the largest value for tanks designed for multiple products.
- % Aromatic: Specify percentage by weight of aromatic hydrocarbons in tank. Refer to any supplemental specification for protecting the materials of construction, as applicable.
- Hydrogen Sulfide Service? (Yes/No): If "Yes," a supplemental specification for material selection and hardness shall be required. See 5.3.4.
- Other Special Service Conditions: Include any conditions that may require further consideration. Consider thermal expansion or shock, cyclic vibratory fatigue, and issues or regulations concerning the product stored, e.g., chloride, caustic, amine, or ethanol corrosion, hydrogen blistering or embrittlement, oleum, sulfuric acid, or ammonia service, RCRA (Resource Conservation and Recovery Act), HON (Hazardous Organic National Emission Standard for Hazardous Air Pollutants), RMP (Clean Air Act Risk Management Plan), etc. Provide supplemental specifications as needed. See 5.3.3.

- **Design and Testing**

  Purchaser to Review Design Prior to Ordering Materials: Indicate if the Manufacturer is free to order materials prior to Purchaser reviewing the design documents. Schedule may be affected. See W.1.3.

6. Applicable Appendices*: See 1.1.6. Appendix E may be selected on Line 8 of the Data Sheet. If no appendices are chosen, the basic design of this Standard is intended. 07

7. Design Parameters
   - Maximum Design Temperature: See 3.13 for definition. This differs from the operating temperature. For temperature limits, see 1.1.1, and Appendices M and S. If the roof design temperature is different than the shell temperature, as in the case of an uninsulated roof on an insulated shell, then use Line 23 to specify the roof maximum design temperature. 08
   - Design Metal Temperature*: Enter either lowest 1-day mean temperature plus 8°C (15°F) or a lower temperature as specified by the Purchaser if operating conditions and/or local atmospheric conditions control fracture toughness issues.
   - Design Liquid Level*: See 5.6.3.2, C.3.1.1, and E.2.2.
   - Design Pressure: Specify pressure and units in the vapor space.
   - External Pressure: See 5.2.5.
   - Pressure Combination Factor: This factor is a modifier for the design internal pressure when used in load combinations with other variable loads. Value equals normal operating pressure/design internal pressure or a minimum of 0.4. Manufacturer to use 0.4 when not specified. 11
   - Maximum Fill Rate: Specify rate and units (e.g., 100 gallons per minute).
   - Maximum Emptying Rate: Specify rate and units (e.g., 75 gallons per minute).
   - Flotation Considerations (Yes/No): Include design consideration that advise the Manufacturer about tank flotation anchorage, bottom uplift, and partial submersion pressures arising out of flood or dike impoundment.
   - Flotation Supplemental Specifications*: Refer to any that may describe external liquid depth, external fluid specific gravity, minimum internal liquid level, and any other information necessary for design.
   - Section 5.2.4 makes the design criteria here a matter of agreement between the Purchaser and the Manufacturer.
   - Applied Supplemental Load Specification: Refer to supplemental specifications that provide concentrated loads applied to the shell, such as openings or appurtenances from attached equipment, valves, or piping, or reactions from stairs and platforms for determination of strength and stiffness issues by the Manufacturer. If this information is not provided, the requirements of W.2(5) still apply. 07

● 8. Seismic Design Data
   - Seismic Design? (Yes/No): Indicate whether design for earthquakes is required. The Purchaser may specify Appendix E, or an alternate criterion.
   - Appendix E: Mark the box provided if this appendix shall be used for seismic design.
   - Alternate Seismic Criteria: Refer to any supplemental criteria different from this Standard that shall be followed. All required design factors shall be included in this supplemental specification.
   - Seismic Use Group: See E.3.1.
   - Site Class: See Table E.4-B.
   - Vertical Seismic Design: Indicate if this design is required.
   - Vertical Ground Motion Accelerator: Provide per E.6.1.3.
   - Basis of Lateral Acceleration: Select one of the three methods listed, and specify the appropriate parameters. See E.4.
   - Freeboard: For SUG I designs, indicate if freeboard is required. See E.7.2.
   - Roof Tie Rods @ Outer Ring?* (Yes/No): See E.7.5

● 9. Design Wind Issues
   - Top Wind Girder Style*: See 5.9, and Figure 5-24, for open-top and external floating roofs.
   - Dimensions of Top Wind Girder*: For example, if style were "Curb Angle," the dimension might be $3 \times 3 \times {}^{3}/_{8}$ (in.).
   - Use Top Wind Girder as Walkway? (Yes/No): See 5.9, and Figure 5-25, and note 3 ft-6 in. dimension preference of 5.9.4 if choice is "Yes."
   - Intermediate Wind Girders* (Yes/No): Specify "Yes" whenever wind girders shall be added to the shell to satisfy shell stability stiffening predicated by wind loads. Specify "No" if shell stiffening is to be accomplished by increasing the shell thickness. If not specified by the Purchaser, the Manufacturer must select between the two alternatives and indicate the choice here.
   - Intermediate Wind Girder Style*: See 5.9 and Figure 5-24, for all kinds of tanks whenever wind girders are specified.

- Dimensions of Intermediate Wind Girders*: For example, if style were "formed plate," dimension might be $b = 30$ in. per Figure 5-24.
- Check Buckling in Corroded Condition? (Yes/No): If "Yes," the wind load shall be applied to the corroded shell (an option covered in 5.9.7.1) to establish the adequacy of the thicknesses and/or stiffening rings to resist the applied forces.

● 10. Shell Design

- 1-Foot Method?* (Yes/No): The Purchaser may select this shell thickness design method. The method is subject to the applicable limitations noted in 5.6.3, A.4, J.3.3, and S.3.2. If not selected by the Purchaser, the Manufacturer may select either this design method or one of the other two methods that this Standard lists, subject to the restrictions of this Standard and the Purchaser's approval.
- Variable-Design-Point Method?* (Yes/No/Alternate): The Purchaser may select this shell thickness design method. This method is subject to the restrictions detailed in 5.6.4. If the 1-Foot Method or Elastic Analysis Method is selected by the Purchaser and the Variable-Design-Point Method is also selected as an "Alternate" by the Purchaser, the Variable-Point Design Method may be used in addition to the Purchaser-selected method, but the resulting proposal must be clearly marked as an "Alternate." If the method is not selected by the Purchaser, the Manufacturer may select either this design method or one of the other two methods that this Standard lists, subject to the restrictions of this Standard and the Purchaser's approval.
- Elastic Analysis Method?* (Yes/No/Alternate): The Purchaser may select this shell thickness design method. This method is subject to the restrictions detailed in 5.6.5. Cases when this method is mandatory are named in 5.6.5 as well as requirements on the analysis boundary conditions. When it is not mandatory, the Purchaser may select this shell design method. If the 1-Foot or Variable-Design-Point Method is selected by the Purchaser and the Elastic Analysis Method is also selected as an "Alternate" by the Purchaser, the Elastic Analysis Method may be used in addition to the Purchaser-selected method, but the resulting proposal must be clearly marked as an "Alternate." If the method is not selected by the Purchaser, the Manufacturer may select either this design method or one of the other two methods that this Standard lists, subject to the restrictions of this Standard and the Purchaser's approval.
- 07 Plate-Stacking Criteria* Centerline-Stacked? (Yes/No) or Flush-Stacked on the Inside or Outside? (Yes/No)?:
- Plate Widths (Shell Course Heights) and Thicknesses*: Specify nominal shell course heights and thicknesses. The first course is attached to the bottom.
- Joint Efficiency*: Specify in percentage. Applicable only to Appendices A, J, and S designs. Mark "NA" for all other designs.
- Shell-to-Bottom Weld Type*: See Figure 5-3A (inside and outside corner fillets), Figure 5-3C (inside and outside partial penetration corner welds with fillet weld reinforcement), and J.3.2.4 (full penetration butt weld to flanged flat bottom).
- Shell-to-Bottom Weld Inspection Method*: Choose among the options listed in accordance with 7.2.4.

● 11. Open-Top and Fixed-Roof Data (see page 6 of the Data Sheet for Floating Roofs)

- Open Top?* (Yes/No) Specify "Yes" if tank has no fixed roof or has an external floating roof. Specify "No" for all other tanks.

Note: The remaining entries in this line apply to fixed roofs ONLY:

- Fixed Roof Type*: Enter description, such as supported cone with internal structure, supported cone with external structure, structurally-supported aluminum geodesic dome, self-supporting cone, self-supporting dome, self-supporting umbrella, flanged only flat top, or other. See 5.10.1 or Appendix G
- Roof Support Columns*: Specify pipe or structural shape. If structural shape is specified, indicate the kind (e.g., wide flange, back-to-back channel, etc.).

Commentary: Pipe-type roof columns are preferred for internal floating roof tanks. In many cases the openings are $^3/_4$ NPT threaded couplings that allow the user to plug the openings when the tank is in service, to minimize corrosion of the supports and reduce emission from the tank. The openings are needed to allow the free drainage and cleaning of the columns when the tank is out of service.

- Cone Slope*: Specify rise to run as a dimensionless ratio, e.g., "$^3/_4$:12".
- Dome or Umbrella Radius*: See 5.10.6 for self-supporting approximate spherical radius of roof.

- Weld Joints*: Describe the type of roof plate weld joint, which may be lap joint, butt joint, or some combination thereof.

Note: Appendix F, Section F.7 roofs shall conform to API Std 620.

- Seal Weld Underside of Lap Joints? (Yes/No): May be required for roof plates with internal lining or to prevent crevice corrosion. 11
- Seal Weld Underside of Wind Girder Joints? (Yes/No): See 5.1.5.8.
- Gas-tight? (Yes/No): See 7.3.7.
- Joint Efficiency*: Use only for Appendix F, Section F.7 roofs. See API Std 620, Table 3-2.
- Thickness*: Provide nominal thickness of roof plates.
- Snow-Load*: Purchaser to provide the snow load for non-U.S. Sites. For non-US sites, the Manufacturer should indicate the 50-year ground snow load selected. See 5.2.1e. For instructions on combining loads, see 5.10.2.1.
- Applied Supplemental Loads Specification*: Indicate supplementary specifications for both dead and live roof loads that are concentrated or have local distributions (e.g., the personnel loads of 5.8.6.2 and H.4.2.2). Specify any reactions from platforms or walking surfaces as well as loads applied by equipment, valves, and piping.
- Column Lateral Load: Purchaser may optionally specify lateral loads imposed upon roof-supporting columns in accordance with 5.10.2.9.
- Venting Devices*? Enter type and quantity of devices for normal venting per API Std 2000, and pressure settings. Also, enter type(s) and quantity of emergency venting devices that meet either API Std 2000, circulation venting per Appendix H, or a frangible roof design per 5.10.2.6 as applicable. The frangibility of tanks less than 50 ft in diameter may require additional design considerations beyond those required by this Standard.
- For Non-Frangible Roofs:
  - Seal Weld Roof Plates to Top Angle on the Inside? (Yes/No): When "Yes" is selected, the shell-to-roof-joint shall be seal-welded on the inside. For certain designs, this may adversely affect frangibility.
  - Weld Rafters to Roof Plates? (Yes/No):
- Roof-to-Shell Detail*: See Figures 5-3A and F-3, J.3.5, and API Std 620, Figure 3-6. 07
- Radial Projection of Horizontal Component to Top Angle*: Specify inward or outward projection.

● 12. Required Bottom Data

- Thickness*: Enter nominal thickness, including corrosion allowance.
- Style*: Enter one of the following: flat, cone up to center, cone down to center, side to side (tilted plane), cone down to off-center. Enter all sump requirements (number, size, location, etc.) in Data Sheet (Table 3, Line 23, or on the Tank Plan).
- Slope*: Enter rise versus run. For the off-center style above, the slope specified is the maximum slope.
- Weld Joint Type*: Enter one of the following: single-welded full-fillet lap joint, single-welded butt with backing strip that remains in place, double-welded butt without backing strip, double-welded full-fillet lap joints, or other, to be detailed on Data Sheet Line 23 if necessary.
- Provide Drip Ring (Yes/No): If required, a drip ring shall be provided per 3.4.5. Unless the following Alternate Specification is provided, the default drip ring shall be provided.
- Alternate Specification: Refer to an acceptable drip ring design specification if the Purchaser requires a drip ring but declines the default design of 5.4.5.
- Annular Ring* (Yes/No): The Purchaser may stipulate this type of detail even if not required by this Standard. A Purchaser's choice of "No" does not relieve the Manufacturer from complying with the requirements of this Standard in this regard.
- Annular Ring Minimum Radial Width* and Thickness*: Specify width and thickness.

● 13. Foundation Information

- Furnished by*: Indicate Purchaser, Manufacturer, or others.
- Type*: Indicate materials and form. See Appendices B and I (e.g., concrete ring-wall or steel wide flange grillage on concrete pile cap).
- Soil Allowable Bearing Pressure*: Estimate pressure from geotechnical report, experience with similar tanks in the same area, etc.
- Per Specification*: Refer to any specification that describes soil allowable bearing pressure.
- Anchor Size*: See 5.3.1.1 and 5.12. Provide materials of construction, geometric forms, and corrosion allowance for anchors in Table 2 of the Data Sheet.

- Anchor Quantity*: Indicate the total number of anchors or anchor bolts to be provided.
- Foundation Design Loads: See W.3(15). These loads are unfactored after the manner of the Allowable Stress Design methodology. (Sign convention is as follows: positive acting downward, negative acting upward.)
  - Base Shear*: Indicate the values for the wind and seismic conditions in units of force.
  - Overturning Moment*: Indicate in units of force-distance. See 5.11 for wind, and Appendix E, or alternate seismic criteria as specified on Line 8 of the Data Sheet, for seismic criteria.
  - Ring Forces*: Indicate loads delivered by the shell in units of force per circumference of shell.

  Note: The uniformly distributed loads are shell plus roof weight (both new and corroded), roof live load, internal pressure, and partial vacuum.

  Note: The non-uniform loads are the peak magnitudes of the longitudinal compressive distributed force derived from the wind and seismic-overturning moments without regard to any other compressive or tensile loads in the shell.

  - Bottom Forces*: Indicate support loads that are the uniformly applied forces to the bottom away from the shell ring in units of force per unit area. These include weight of bottom plates, product and test liquid weights, and pressure/vacuum loads. Mark all inapplicable entities as "NA."
  - Other Foundation Loads*: Provide an attachment to describe these loads such as lateral soil pressure, overburden, roof column reactions, pore pressure, uplift anchor forces, etc.
  - Minimum Projection of Foundation Above Grade: Specify the minimum required projection of the foundation above grade, if any.

● 14. Pressure Test (See 7.3.5)

- Responsibility for Heating Test Water, if Required: Select one.
- Hydro-Test Fill Height*: See 7.3.5, F.4.4, and F.7.6.
- Settlement Measurements (Yes/No): Purchaser may waive the measurement of foundation settlement during the hydrotest in accordance with 7.3.6.5. 07
- Extended Duration of Hydro-Test: Provide the number of hours or days if the tank is to be kept full of water for an extended period.
- Predicted Settlement Profile is Attached: Check if the Purchaser elects to inform the Manufacturer of relevant settlement predictions.
- Responsibility for Setting Water Quality: Specify party responsible for setting water quality standards. Refer to supplemental specifications as required. For guidance, see 7.3.6.3.
- Test Water Source and Disposal Tie-In Locations: Provide the location of the supply and disposal points for hydro-test water that the Manufacturer shall use.
- Test Requirements for Appendix J Tanks: Hydrostatic Testing (Yes/No): If "No" is selected, the Purchaser must specify the required Alternative Test from J.4.2.2.
- Penetrant Testing Allowed in lieu of Hydro-Testing: Check if there is no means of providing test water at the tank site, e.g., very remote tank sites. See 7.3.5.
- Post-Pressure-Test Activities Required of the Manufacturer: Select the activities desired according to 7.3.6.2(4).

● 15. Optional Fabrication, Erection, Inspection, and Testing Requirements

- Inspection by: Designate Purchaser's inspectors. See 7.3.1.1.
- Supplemental NDE (Non Destructive Examination) Responsibility and Supplemental NDE Specifications: Specify NDE options (e.g., see 8.3.5) or indicate additional NDE options, such as weld hardness testing or additional radiographs. For possible additional responsibilities, see 7.3.2.3.
- Positive Material Identification (Yes/No): Include criteria to be followed.
- Maximum Permissible Plate Thickness for Shearing: Specify the thickest plate to be butt-welded that may be sheared in accordance with 6.1.2.
- Must Welds not exceeding 6 mm ($^{1}/_{4}$ in.) or welds greater than 6 mm ($^{1}/_{4}$ in.) be Multi-Pass? (Yes/No): See 5.1.3.6
- Leak Test Method*: Describe leak tests for each component. For example, see 7.3.3, 7.3.4, 7.3.5, 7.3.7, C.3.6, and H.6.2.
- Modify or Waive API Dimensional Tolerances (see 7.5)? (No/Yes/Specify): If the API tolerances are not adequate, specify the required tolerances here.
- Specify Additional Tolerances, if any, and Circumferential and Vertical Measurement Locations: Indicate any supplemental tolerances for plumbness and roundness, giving the tolerance limit and the locations for the tolerance readings.

Note: If Additional Radial Tolerance measurements are specified, radial tolerances measured higher than 0.3 m (1 ft) above the shell-to-bottom weld shall be three times the tolerances given in 7.5.3, unless specified otherwise by the Purchaser. 07

• 16. Coating Data

- Internal Linings by: Describe responsible party or indicate "Not Req'd."
- Per Specification*: Refer to supplemental specifications to address the detailed coating/galvanizing requirements for items such as internal structural supports, inside surface of roof, bottom, piping flanges, stairs, platforms, ladders, underside of bottoms, and top surface of foundation. Ensure that all requirements address issues such as joint contour preparation (e.g., shell-to-bottom, sharp edges of laps, crevices, etc.) and reduced weld build-up or undercut. For guidance on internal bottom linings, see API RP 652. 11
- External Coating by: Describe responsible party or indicate "Not Req'd."
- Per Specification*: Refer to any supplemental specification fully describing the process.
- Under-Bottom Coating by: Describe responsible party or indicate "Not Req'd."
- Per Specification*: Refer to a supplemental specification fully describing the process.

• 17. Cathodic Protection

- Cathodic Protection System? (Yes/No): See API RP 651 for guidance.
- Per Specification*: Describe requirements and responsible parties.

• 18. Leak Detection System

- Leak Detection System? (Yes/No): Provide a passive leak detection system as described in Appendix I. Active elements may be specified; however, the system must also provide leak detection by passive means. If active leak detection schemes (e.g., volumetric inventory records, mass change, acoustic emissions sensing, and tracer element detection) are required, describe the requirements by means of a specification herein. 07
- Per Specification*: Describe requirements and responsible parties.

• 19. Release Prevention Barrier (See Appendix I, I.1.1, Note, for definition.)

- Release Prevention Barrier? (Yes/No): Examples of barriers are vault floors, double bottoms, and impermeable membranes.
- Per Specification*: Describe requirements and responsible parties.

• 20. Tank Measurement System

- Required? (Yes/No): Examples are float gauge, differential pressure level indicator, level alarm, radar, and level gauge.
- Remote Capability Required? (Yes/No): Indicate whether level measurements are required to be relayed to remote control stations.
- By*: Designate the provider of the measurement system.
- Per Specification*: Refer to supplemental specification.

• 21. Tank Weights and Lifting Requirements

- Full of Water*: Indicate weight filled with water to design liquid level.
- Empty*: Indicate weight when empty. For specification of lift lugs, see Data Sheet, Line 28. For tanks that are to be lifted, rigging and handling instructions and temporary bracing may be required. Provide reference to a supplemental specification as required.
- Shipping*: Specify weight for Appendix J tanks only.
- Brace/Lift Specification*: Refer to any supplemental bracing/lifting specifications.

• 22. References: Include relevant documents.

• 23. Remarks: Use this for issues not adequately covered elsewhere. Include any alternate shell opening designs specified by the Purchaser in accordance with 5.7, with reference to the alternate criteria (e.g., API Std 620).

● Table 1 Materials of Construction

List material specifications (e.g., CSA G40.21M-260W, ASTM A573-65, ISO 630 Gr E355-C, etc.), and supplied thickness of items in the left column only.

State corrosion allowance for each component. See 5.3.2. For internals, indicate if the corrosion allowance is to be applied to each exposed surface. Unless indicated otherwise, it applies to the total thickness specified. Show units of measure.

Any materials that either have received any heat treatment, such as normalizing, beyond the minimum heat-treating requirements of the material specification or have been qualified by impact tests shall be identified by reference to notes located under the "remarks" lines. The notes shall define the heat treatment received and/or the energy acceptance levels, test temperature, and specimen orientation for impact tests.

When thermal stress relief is applied to a part in accordance with the requirements of 5.7.4, the part shall be identified by a note under the "remarks" lines.

● Table 2 Bolts and Anchors

Complete all bolting and anchorage information (see 4.7, 5.11.3, 5.12, E.6.2, E.7, F.7.4, and J.3.9), including head and nut shape and material specifications. Show units of measure for the corrosion allowance and see 5.3.2. Corrosion allowance may be marked "NA" for galvanized, special corrosion-resistant coated, or stainless steel anchor bolts.

● Table 3 Nozzle and Manhole Schedule* (for Fixed Roof, Shell, and Bottom)

Include nozzles (e.g., both blanked and piped-to connections), equipment and instrument attachment and access openings, sumps, inspection ports, and manholes in the fixed roof, shell and bottom.

The description of, and examples for, the information that may be specified in Table 3 is as follows:

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Entry Field	Comments	Representative Example
Mark	Purchaser's mark or designation	Nozzle "A-1" in shell
Service	Stated service or purpose	Product Out
Size, NPS, or Diameter (In.)	Conventional size description of pipe and tube	NPS 24
Neck Schedule or Wall Thickness	Pipe schedule or wall thickness	Sch 40S
Reinf. Plate Dimensions	Circular, Diamond, etc.	49.5" OD × 0.188"
Full Pen. On Open. (Y/N)	See 5.7.2.2	Yes
Flange Type	Fabricated, S.O., WN, LJ, etc.	ASME B16.5 Lap Joint
Flange Class or Thickness	ASME, ANSI, API Std 650 Table	Cl 150
Gasket Bearing Surface Dimension and Finish	Dimension and finish of bearing surface in contact with gasket	27.25" OD, 125-250 R_a μ-in.
Gasket Thickness and Dimension		0.125" × 24" ID × 28.25" OD
Gasket Material and Description	Generic, Brand, ANSI Std, etc.	Non-asbestos sheet, per Manufacturer
Proj. to FF or CL or from Datum Lines	See paragraph below	18" FF

ASME B16.47 flanges are not available in all sizes, materials, and flange types (see 5.7.6.1).

COMMENT: Lap joint nozzle flanges should be avoided in connections where the combined stresses (such as bending, cyclic,
11 and seismic) in the nozzle where attached to the lap joint stub-end exceed the API 650 basic allowable stress at the maximum
design temperature. Lap joint nozzle flanges should also be avoided in connections with vibration or when susceptible to environmental stress corrosion cracking.

Nozzle projections shall be measured from the outside of the shell to the face of the shell flange (FF) and from datum line to the face of the flange for roof and floor openings, unless otherwise specified. Shell opening elevations shall be from the datum line to the centerline of the opening, unless otherwise specified. Roof opening locations shall be measured radially from the centerline of
07 the tank. Specify datum line and elevations with orientations on the "Tank Plans and Sketch" of the Data Sheet.

For fabricated flanges requiring ASME *Boiler and Pressure Vessel Code,* Section VIII, Division 1, UG-34 and Appendix 2 calculations, place the "m" and "y" values for the gasket in the "Remarks" section of the Data Sheet, Line 23. Clearly indicate to which gaskets these values apply.

Consider listing in Table 3, items such as:

- Water draw-offs.
- Thermowells (make, model, stem length).
- Suction trough (size, reference drawing).
- Couplings (number, size).
- Sump.
- Inspection hatches for observation of floating roofs (as specified on Line 34).

Some items require that supplemental information be supplied, such as reference drawings, model numbers, and other specifications. Provide any supplemental information on Line 23.

Other Tank Appurtenances:

● 24. Platform, Stairway and Railing: See 5.8.10 and C.3.14.6.

- Galvanizing Required? (Yes/No)*: Examples are stairways, platforms, and handrails to be galvanized. Identify components in Remarks, Line 23. See S.2.1.3.
- Stairway Style*: Specify whether straight along a radius or helical.
- Walking Surface Type*: Describe type of walking surface on platform and stairs (e.g., diamond-checkered pattern plate, bar and rod grating, expanded metal grating, etc.).
- Stairway and Walkway Clear Width*: See 5.9.4, Table 5-17, and Table 5-18.
- National Safety Standards*: Indicate all standards that shall be observed for ladders, stairs, walkways, platforms, and other architectural/structural items (e.g., OSHA 1910).
- Architectural/Structural Specification*: Provide details for alloys, shapes, fasteners, coating, etc.
- Gauger's Platform Required? (Yes/No).
- Quantity of Gauger's Platforms Required*.
- Per Specification*: Refer to any supplemental specification, if gauger's platform specification differs from the architectural/structural reference specification above.

● 25. Jackets and Other Heaters or Coolers

- Is a Jacket Required? (Yes/No)*: If Yes, a supplemental specification may be required to address some or all of the following items: 07
  - Should the jacket be integral (utilize the shell as one boundary wall) or stand-alone (able to hold pressure when detached from shell).
  - How should the jacket be attached to the shell.? Specify whether welded, bolted, or otherwise attached.
  - What type of jacket is required? Consider annular cylinder, pipe coil, half-pipe helix, panel coil, or other types to be described.
- Are Other Heaters or Coolers Required? (Yes/No)*: If Yes, a supplemental specification may be required to address some or all of the following items:
  - Specify the type of heater or cooler. For example, internal coils, bayonet heat exchangers, or below bottom piping
  - Provide specifications for any other heaters or coolers.
  - Specify design pressures for jacket or heaters or coolers, both internal pressure and partial vacuum.
  - Specify design temperatures for jackets and heaters/coolers.

● 26. Mixer/Agitator

- Quantity: Indicate number required.
- Size*:
- Per Specification*: Provide reference to supplemental specification.

● 27. Insulation Data

- Required? (Yes/No):
- Thickness*: Indicate thickness of insulation in inches.

Note: If not uniform for entire tank shell and roof, defer to Purchaser-supplied supplemental insulation specification.

- Material*: Designate material and density of insulation.

  - Per Specifications*: Provide references to insulation and insulation support specifications.
  - Responsibility for Insulation and Installation: Indicate Purchaser, Manufacturer, or others.

28. Structural Attachments
    - Lift Lugs for Maintenance or Installation?* (Yes/No): Specify projection if insulation is required.
    - Description*: Describe the type of lifting lugs required.
    - Shell Anchorage?* (Yes/No): Wind or seismic loading may require anchorage. See 5.11, 5.12, and Appendices E and F.
    - Type*: Specify type of shell anchorage (e.g., chairs, lugs, sleeves, rings, straps, etc.).
    - Scaffold Cable Supports? (Yes/No): Indicate if required. See Figure 5-22.

29. Various Other Items
    - Flush-Type Shell Connection and Flush-Type Cleanout Fitting: Mark the blocks indicating which type(s) is required. See Figures 5-12 and 5-14.
    - Waive Application of Appendix P: Indicate if the Manufacturer is required to analyze nozzle loads in accordance with Appendix P. It is not intended that this appendix necessarily be applied to piping connections similar in size and configuration to those on tanks of similar size and thickness for which satisfactory service experience is available. See Appendix P for limitations.
    - Enter miscellaneous items not found elsewhere on the Data Sheet.

Table 4 Other Tank Appurtenances Schedule*:

07 Include all appurtenances not described elsewhere on the Data Sheet.
Consider listing in Table 4 such items as the following:

- Ladders
- Overflow openings (number and size). See H.5.3.
- Circulation vents (number and size). See H.5.2.2.
- Pressure-vacuum relief valves (nominal size, model number, etc.).
- Free vent/flame arrestor.
- Grounding clips (quantity and style).

Some items require supplemental information, such as reference drawings, model numbers, and other specifications. Provide any supplemental information on Line 23.

Floating Roof Data:

30. Floating Roof Selection
    - Design Basis: Check which API Appendix is to be applied?
    - Type of Roof*: Specify the option listed in Appendix C or H. Only the Purchaser may specify "Other" and describe another option.

31. Seals
    - Primary Seal: Select from types listed, or specify "Other" and supply necessary details or reference specification. Foam seal material may absorb some products over time, becoming a potential safety issue. See C.3.13 and H.4.4.
    - Shoe Mechanism: Indicate mechanism required for mechanical primary seal. Select the Manufacturer's standard, or specify a particular type (e.g., pantograph, leaf spring, safety-pin spring, coil spring scissors, etc.).

- Electrically Isolate Mechanism from Shoes? (Yes/No): Indicate if required to insulate to prevent possible arcing.
- Wax Scrapers Required? (Yes/No): Such devices remove wax-like substances from the tank shell as the roof descends to provide a cleaner sealing surface. 07
- Nominal Shoe Thickness*: Include units. See C.3.13 and H.4.4.4. 11
- Carbon Steel Shoes to be Galvanized? (Yes/No): This option cannot be selected for stainless steel shoes.
- Secondary Seal: Indicate the need for a secondary seal.
- Supplementary Specification: Refer to supplementary specification for secondary rim seal.

● 32. Data for All Floating Roofs:

- Overflow Openings in Shell Acceptable? (Yes/No): See C.3.1.1.
- Shell Extension? (Yes/No): Select a windskirt per C.3.1.1. If Yes is selected, this may affect capacity, design liquid level, and the need for an overflow indicator (alarm), requiring a Purchaser-supplied supplemental specification under Line 20. See API RP 2350. 07
- Roof-Drain Check Valves Required? (Yes/No): See C.3.8.1.
- Roof-Drain Isolation Valves Required? (Yes/No): See C.3.8.1.
- Freeze Protection for Roof Drains Required? (Yes/No): See C.3.8.1. Freeze protection is not required in all climates.
- Roof-Drain Piping to External Nozzles: Select the type of piping from the blocks provided. If "Other" is selected, provide description or reference supplemental specification. The number of roof drains required and sump details shall be shown on the construction drawings.
- Foam Dam? (Yes/No): See C.3.15.2.
- Supplementary Specification: Provide supplementary foam dam specification reference.
- Nominal Deck Thickness*: Specify a nominal deck thickness greater than that stated in C.3.3.2. If not specified, the Manufacturer shall insert the thickness stated in the above reference. 11
- Bulkhead Top Edges to be Liquid-Tight? (Yes/No): See H.4.1.8. This is mandatory for external floating roofs but is a Purchaser's option for internal floating roofs.
- Seal-Weld Underside of Roof?: Select "Yes" to provide increased corrosion protection or additional stiffness. This applies to seal welds in addition to the seal welding required in C.3.3.3 and H.4.3.5.
- Electrical Bonding: Indicate if either shunts or cables will be used to bond the roof electrically to the shell, and provide a supplemental specification to designate any technical requirements.
- Quantity of Non-Guide Pole Gauge Wells Required: See C.3.14.1(2), for manual gauging apparatus in wells not associated with a guide pole.
- Quantity of Sample Hatches Required: See C.3.15.3 for sample hatches without gauging apparatus. 07
- Guide Pole for Gauging? (Yes/No): Indicate whether the guide pole (anti-rotation device) shall be used for gauging.
- Slots in Guide Pole? (Yes/No): Indicate whether guide pole, if used for gauging, shall be slotted.
- Datum Plates? (Yes/No): Indicate if required. See C.3.14.4.
- Striking Plates? (Yes/No): Indicate if required. See C.3.14.5.
- Guide Pole Emissions-Limiting Devices: Indicate any required by regulation or any additional devices requested by the Purchaser for guide poles from the list provided. See C.3.14.1(1).
- Quantity of Roof Manholes*: See C.3.5, C.3.11, and H.5.5.

07 – Minimum Roof Clearances Above Bottom: Indicate elevations above the bottom to the landed floating roof for both the minimum operating level and the minimum maintenance level. These choices affect access and capacity. See C.3.10.3, H.4.6.2, and API RP 2350.

09 – Removable Leg Storage Racks? (Yes/No): Indicate if required.

– Leg Sleeves or Fixed Low Legs: Mark the block that specifies whether the leg-supported floating roof shall be provided with a sleeve through the roof plate or with fixed low legs.

● 33. Additional Data for External Floating Roofs (See Appendix C):

– Weather Shield? (Yes/No): Indicate the need for a weather shield on external floating roofs. If secondary rim seals serve as weather shields, they shall not be additionally requested here.

– Supplementary Specification: Provide references for weather shield specifications.

– Rolling Ladder Required?* (Yes/No): Unless the Purchaser specifically declines here, a rolling ladder is to be provided in accordance with C.3.7.

– Must Each Leg be Field-Adjustable? (Yes/No): Indicate if required. If potential bottom settlement is an issue, the Purchaser has the option to require a two-position removable leg that can accommodate local adjustments that may differ for each leg. This option is for all floating roofs and is specifically discussed in C.3.10.3.

– Design Rainfall Intensity: Specify a rainfall rate, a minimum period of duration, and an association with a statistically occurring storm such as that found in Technical Report No. 40 (e.g., 0.5 in. per hour for 5 minutes for the 2-year storm).

– Design Accumulated 24-hour Rainfall: Specify height of water accumulated in 24 hours associated with a statistically occurring storm (e.g., 12 in. in 24 hours for the 100-year storm). See C.3.4 for minimum requirements.

07 – Distortion and Stability Determinations Required? (Yes/No): List option per C.3.4.2.

– Supplemental Specification: Document any established methodology chosen by agreement between the Purchaser and the Manufacturer.

– Landed Live Load*: See C.3.10.2. This space gives the Purchaser the option of specifying a larger live load for external floating roofs and for specifying the stated live load for internal floating roofs even if drains are provided that may normally negate the need for such live load design.

● 34. Additional Data for Internal Floating Roofs

– Two-Position Legs Required? (Yes/No): See H.4.6.2. If the two positions shall be field-adaptable to account for bottom settlement, indicate this in Line 23 of the Data Sheet.

– Cable-Supported Floating Roof? (Yes/No): Indicate if required. This is an internal floating roof option as found in H.4.6.5.

– Fixed-Roof Inspection Hatches Required? (Yes/No): Indicate number required for evaluation of condition of floating roof without having to enter the vapor space. See H.5.5.3.

– Internal Roof Drain Required? (Yes/No): See H.4.1.10

– Omit Distribution Pads Supporting Uniform Live Loads? (Yes/No): See H.4.6.6

– Corrosion Gauge Required? (Yes/No): See H.5.8.

– Fixed Ladder Required? (Yes/No): This applies to vertical ladders attached to the shell, which will also require a manhole in the fixed roof to be specified in Table 3.

– Modified Minimum Point Load? (Yes/No): Point or concentrated loads are stated in H.4.2.2 for internal floating roofs, but may be waived for tanks 9 m (30 ft) or smaller in diameter.

- Mfr. to Leak Test Compartments: Indicate the % of compartments to be tested by the Manufacturer and the location of the tests. If unknown prior to the Purchaser doing a field inspection, special contract terms may be required to cover the additional costs.
- Roof Erector's Flotation Test: Indicate when this test is to be performed: See H.6.5, H.6.6 for restrictions on these options.
- Flotation Test Media: Indicate the media to be used and the water quality. See H.6.6. Provide a separate specification, if required, to stipulate requirements.
- Flotation Test Duration, Fill Height,: See H.6.6.
- Flotation Test Items provided by Purchaser: List any items being supplied including those (gaskets, fasteners, test blanks, etc.) after the test is completed. See H.6.6.
- Responsible Party for Conducting Flotation Test and Inspecting Roof during Test: Purchaser can delegate these. See H.6.6.

• Table 5 Floating Roof Materials

According to C.3.1.2, the application of corrosion allowances (C.A.) shall be a matter of agreement between the Purchaser and the Manufacturer. Document this agreement on the Data Sheet "Remarks" Line 23 (e.g., "Manufacturer affirms that the nominal thicknesses chosen for floating roof components include the corrosion allowances shown in the Table for Floating Roof Materials on page 7 of the Data Sheet").

• L.3.2 TANK PLAN AND SKETCHES (PAGE 8 AND SUPPLEMENTS)

L.3.2.1 General

Page 8 of the Data Sheet shall be used to show the shell and roof appurtenance orientations. A single sheet is normally adequate for this purpose; however additional sheets may be necessary to show special details or configurations. All sheets shall be identified and sequenced as part of the Data Sheet. Sketches may be made with CAD or manual drafting. All sheets shall be identified by revision date or other means of record change. 07

Note: Consider the prevailing wind direction when locating equipment requiring personnel access.

L.3.2.2 Sketch Views

The sketch view shall include an orthographic "Plan View" that may be used for the orientation of shell, roof, and bottom openings. Other views may be added.

L.3.2.3 Drafting Practices for Data Sheet Sketches

Drafting practices shall be consistent with the following items:

- Where practicable, sketches shall be to scale, but the scale need not be shown on the sketches.
- Bottom views are not allowed.
- Plant north or geographic north arrow shall point upward on the sketch.
- Plant north or geographic north shall be at the "0 degrees" orientation, as applicable.
- Component thicknesses need not be shown on the sketch.
- Internal details shall be identified and located. Provide only enough information to describe the item, or provide reference to standard details. These items shall also be itemized in the appropriate tables in the Data Sheet.
- External appurtenances may be omitted from the sketch; however they must be itemized in the appropriate tables in the Data Sheet.
- Foundation or anchorage details not clearly defined elsewhere shall be shown in the Data Sheet. This may require that an "Elevation View" be provided.