Examination Standard
for
Steel Tanks for Fire Protection

Class Number 4020

September 2024

Foreword

This standard is intended to verify that the products and services described will meet stated conditions of performance, safety and quality useful to the ends of property conservation. The purpose of this standard is to present the criteria for examination of various types of products and services.

Examination in accordance with this standard shall demonstrate compliance and verify that quality control in manufacturing shall ensure a consistent and reliable product.

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1 INTRODUCTION

1.1 Purpose

1.1.1 This standard states testing and certification requirements for steel tanks used for fire protection.

1.1.2 Testing and certification criteria may include performance requirements, marking requirements, examination of manufacturing facility(ies), audit of quality assurance procedures, and a surveillance program.

1.2 Scope

1.2.1 This standard shall be used to measure and assess the ability of ground supported, flat bottom steel suction tanks to provide a highly reliable source of water for fire protection at anticipated rates and in emergency situations. Such tanks shall be permitted to utilize either bolted or welded shell plate designs as submitted by the manufacturer.

1.2.1.1 The standard shall also be used to measure and assess the ability of steel gravity tanks on steel towers (also referred to as elevated tanks in this document) to provide fire protection water as noted above. Such tanks shall utilize welded steel plate designs as submitted by the manufacturer.

1.2.2 The items addressed by this standard are limited to the tank proper, its foundation, penetrations and related appurtenances. Excluded from the scope of this standard are pumps, pump houses, internal and external piping and any item not specifically addressed.

1.2.3 This standard is not intended to determine the suitability for all end use conditions of a product as a conditions under which tanks are used vary widely. This standard, therefore, does not evaluate every condition or environment to which a suction tank might be exposed.

1.2.4 All tanks addressed in this standard shall be fabricated from carbon steel. All ground-supported suction tanks shall be cylindrical in shape. Elevated tanks shall be permitted to be elliptical, hemispherical, or conical in shape.

1.3 Basis for Requirements

1.3.1 The requirements of this standard are based on experience, research and testing and/or the standards of the certification agency and other organizations. The advice of manufacturers, users, trade associations and loss control specialists were also considered.

1.3.2 The requirements of this standard reflect tests and practices used to examine characteristics of ground supported, flat bottom bolted or welded steel suction tanks or elevated steel gravity tanks for the purpose of obtaining certification.

1.4 Basis for Certification

Certification is based upon a satisfactory evaluation of the product and the manufacturer in the following major areas:

- the structural integrity of the tanks to withstand anticipated design conditions;
- the ability of the manufacturer to properly design, fabricate and erect bolted or welded steel tanks in accordance with industry practices and the requirements of the certification agency;
- the ability to provide a highly reliable and durable structure for the storage of water for fire protection purposes and;

An examination of the manufacturing facilities and audit of quality control procedures may be conducted to evaluate the manufacturer's ability to consistently produce the product which is examined and tested, and the marking procedures used to identify the product. Subsequent surveillance may be required by the certification agency in accordance with the certification scheme to ensure ongoing compliance.

1.5 Basis for Continued Certification

Continued certification is based upon a satisfactory evaluation of the manufacturer in the following areas:

- the ability to design, fabricate and erect bolted or welded steel suction tanks in accordance with industry and certification requirements;
- the continued use of acceptable quality assurance procedures;
- compliance with the terms stipulated by the certification;
- satisfactory re-examination of production samples for continued conformity to requirements; and
- satisfactory surveillance audits conducted as part of the certification agency's product surveillance program.

1.6 Effective Date

The effective date of this certification standard mandates that all products tested for certification after the effective date shall satisfy the requirements of this standard.

The effective date of this standard is eighteen (18) months after the publication date of the standard for compliance with all requirements.

1.7 System of Units

Units of measurement used in this Standard are United States (U.S.) customary units. These are followed by their arithmetic equivalents in International System (SI) units, enclosed in parentheses. The first value stated shall be regarded as the requirement. The converted equivalent value may be approximate. Conversion of U.S. customary units is in accordance with ANSI/IEEE/ASTM SI 10.

1.8 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the cited edition applies.

American Concrete Institute (ACI)

318, *Building Code Requirements for Reinforced Concrete*

American Iron and Steel Institute

Steel Plate Engineering Data, Volumes 1 and 2

American Institute of Steel Construction, Inc.

Manual of Steel Construction

American Society of Mechanical Engineers (ASME)

Boiler and Pressure Vessel Code, Section IX

American Society for Testing and Materials (ASTM)

ASTM D1751, *Specification for Preformed Expansion Joint Filler for Concrete Paving and Structural Construction (Nonextruding and Resilient Bituminous Types*

American Society of Civil Engineers (ASCE)

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

American Water Works Association (AWWA)

AWWA D100, *Standard for Welded Carbon Steel Tanks for Water Storage*

AWWA D102, *Standard for Coating Steel Water Storage Tanks*

AWWA D103, *Standard for Factory Coated Bolted Steel Tanks for Water Storage*

National Fire Protection Association

NFPA 22, *Standard for Water Tanks for Private Fire Protection*

1.9 Terms and Definitions

For purposes of this standard, the following terms apply:

Anchor Bolt Chair – An assembly secured to both the tank and the foundation to prevent a tank from overturning when subjected to a seismic or wind load. The anchor bolt chair transfers the overturning or uplift forces from the tank shell to the anchor bolt and into the foundation.

Contractor – See manufacturer.

Dead Load – The estimated weight of all permanent construction and fittings.

Earthquake Load – The estimated forces applied to the tank as a result of an anticipated seismic event.

Earthquake Zone – Geographic areas based on the severity and frequency of an anticipated seismic event.

Certified Tank Design – The specific combination of design parameters, material specifications, geometries, components and notes as shown in the design documents that were reviewed as part of the certification process.

Freeboard – The distance from the inlet of the overflow or weir box to the top of the tank shell.

Gravity Tank – A water tank which is typically installed on a tower or elevated such that the stored water has an elevation considerably higher than that of the sprinkler system it supplies so as to provide the water at the needed pressure.

Interior Insulation – Insulation provided to prevent heat loss from the tank. It is installed between a tank liner and the interior surface of the tank shell plates.

Liner – A one-piece flexible membrane that serves to prevent water from leaking from a bolted tank. The use of flexible liners reduces or eliminates the need for placing a waterproof sealant where mating steel surfaces meet (such as at bolt holes and where adjacent shell plates overlap).

Live Load – The estimated weight of all temporary construction or attachments to the tank, including snow.

Manufacturer – The entity that obtains certification recognition and listing. The manufacturer may subcontract various aspects of their certification but shall be responsible for the design, fabrication and where applicable the installation or erection of the certified tank design(s). The manufacturer may also be referred to in this standard as the contractor or tank fabricator.

Net Capacity – The volume of water, in gallons (cubic meters) available for fire protection. For purposes of this standard, it shall be computed as the volume of water located between the inlet of the overflow and the bottom of the anti-vortex plate.

Nominal Capacity – The net capacity rounded off to the standard or published capacity.

Suction Tank – A water tank that is typically flat bottomed and has a water level at approximately the same elevation as the sprinkler system it supplies and slightly above that of the fire pump. Water is supplied to the sprinkler system at the necessary volume and pressure using a fire pump.

Tank Fabricator – See manufacturer.

Wind Load – The estimated forces applied to the tank resulting from a specified wind speed.

1.10 Nomenclature

The following nomenclature shall be used throughout this standard:

C	Value used in determining overturning due to wind
C_f	Force coefficient
D	Diameter of the cylindrical portion of the tank shell, ft (m)
F_u	Published minimum ultimate tensile stress of the steel under consideration, lbs/in^2 (MPa)
F_y	Published minimum yield stress of the steel under consideration, lbs/in^2 (MPa)
G	Wind gust factor
H	Height of the cylindrical portion of the tank shell, ft (m)
I	Importance factor
J	Value used to determine whether there is uplift during a seismic event
K_z	Wind pressure exposure coefficient evaluated at height z of the centroid of the projected area
L	Laterally unsupported column length, in (mm)
Lu	Maximum unbraced length of the compression flange, ft (m)
*MC*E	Maximum Considered Earthquake
M_{EQ}	Overturning moment applied to the bottom of the tank shell due to earthquake, ft-lbs (N-m)
M_W	Overturning moment applied to the bottom of the tank shell due to wind, ft-lbs (N-m)
N	Number of foundation bolts

Pw	Wind pressure, lbs/ft^2 (kPa)
S	Spacing between anchor bolts, ft (m)
T	Calculated - tensile load per bolt, lbs (N)
Ta	Allowable tensile load per bolt, lbs (N)
TCL	Top capacity level – the water level defined by the lip of the overflow
V	3 second peak gust wind speed, miles/hour (km/hr)
Va	Allowable shear load per bolt, lbs (N)
V_{EQ}	Calculated shear load per bolt, lbs (N)
W'	Total weight of the tank shell plus that portion of the roof supported by the shell, lbs (N)
d_a	Actual (provided) freeboard, ft (m)
d_{sl}	Calculated or required sloshing wave height, ft (m)
f_b	Calculated bending stress, lbs/in^2 (MPa)
q_z	Wind pressure evaluated at height z of the centroid of the projected area, lbs/ft^2 (kPa)
r	Least radius of gyration, in (mm)
w_t	Weight of the tank shell per foot of circumference, lbs/ft (N/m)
w_L	Weight of the tank contents per foot of circumference that may be used to resist the shell overturning moment, lbs/ft (N/m)
z	Height above finished grade, ft (m)

2 GENERAL INFORMATION

2.1 Product Information

2.1.1 Steel tanks for fire protection are used to provide a reliable source of water at desired rates and durations under anticipated design conditions.

2.1.2 Ground supported, flat bottom steel tanks consist of a floor, cylindrical shell and a roof fabricated from steel plates joined together, all of which rest upon a foundation. Tanks are filled with water from an outside source. Water is withdrawn in emergency situations through piping connected to a suction pump. Accessory items are provided to monitor the water level, gain access for inspection and repair and to prevent positive and negative pressures which could impair the structural integrity of the tank. Consideration shall be given to tank heating equipment and/or insulation in colder regions to keep the water from freezing.

2.1.3 Steel gravity tanks are similar to suction tanks except that they consist of a storage vessel supported by either multiple columns attached directly to the tank shell or by a support cone and tubular tower. A multiple column tank consists of a roof, shell, and suspended bottom. A single pedestal tank consists of a roof, shell and support cone.

2.2 Certification Application Requirements

The manufacturer shall provide the following preliminary information with any request for certification consideration:

- A complete list of all models, types, sizes, and options for the products or services being submitted for certification consideration;
- general assembly drawings, complete set of manufacturing drawings, materials list, anticipated marking format, piping and electrical schematics, nameplate format, brochures, sales literature, spec. sheets, installation, operation, and maintenance procedures;
- the number and location of manufacturing facilities; and
- all documents shall identify the manufacturer's name, document number or other form of reference, title, date of last revision, and revision level. All documents shall be provided with English translation.

2.3 Requirements for Samples for Examination

2.3.1 Following authorization of a certification examination, the manufacturer shall submit calculations and drawings.

2.3.2 Requirements for calculations and drawings may vary depending on design features or the results of prior or similar examinations.

2.4 Design Loads

2.4.1 Tanks are designed to withstand the dead load of all permanent construction, a water load filled to just overflowing, a roof live (snow) load and a wind load. In addition, tanks that are located in areas in which a seismic event is likely to occur are also designed to withstand the anticipated earthquake loads.

2.4.2 The **dead load** shall be the estimated weight of all permanent construction and fittings. The unit weights used shall be 490 lbs/ft^3 (7850 kg/m^3) for steel and 150 lbs/ft^3 (2400 kg/m^3) for concrete except for special materials where the weight is known to be greater.

2.4.3 The **water load** shall be the weight of all the water when the tank is filled to the high water level (inlet of the overflow or top of the weir box) and shall be considered as 62.4 lbs/ft^3 (1000 kg/m^3).

2.4.4 The **live load** is an allowance for the weight resulting from a snow loading. The live load shall be considered over the horizontal projection of the tank when the roof slope is less than 30 degrees (7 in 12). On roofs with a greater slope, the live load may be reduced.

2.4.5 It is recommended that tanks submitted for certification be designed based on a roof live load of 25 lbs/ft^2 (1.2 kPa). Consideration of lower roof live loads shall be given for specific locations in warm weather areas where the lowest one day mean temperature is 5°F (-15°C) or warmer and local experience indicates that a smaller load may be used. The minimum roof live load shall be 15 lbs/ft^2 (0.75 kPa). Conversely, when tanks are designed for specific locations in cold weather areas, greater roof live loads may be required.

2.4.5.1 In cases where a tank is to be erected in a locale that requires a snow load greater than that originally certified, revised drawings and calculations shall be submitted to the certification agency for review and certification.

2.4.5.2 In cases where a tank is to be erected in a locale that requires a snow load less than that originally certified, the certified roof design shall be utilized unless revised drawings and calculations are submitted to the certification agency for review and certification.

2.4.6 A wind load shall be considered for all designs submitted for certification. The resulting pressure shall be based upon a minimum wind speed of 90 miles per hour (145 km/hr) and a wind Exposure C. The wind speed referenced in this document shall be considered as a (three) 3 second peak gust wind speed. Many codes, Authorities Having Jurisdiction or other documents (including ASCE 7) require that wind loadings be based on the three (3) second peak gust wind speed which is greater than the fastest mile wind speed. See Table 2.4.6 for a correlation between 3 second peak wind gusts and fastest mile wind speeds. certification shall be permitted to be granted for Exposure D.

Table 2.4.6

Saffir-Simpson	*3 Second Peak Gusts*	*Fastest Mile Speeds*
Category 1	88-115 mph (39-51 m/s)	74-99 mph (33-44 m/s)
Category 2	115-133 mph (51-60 m/s)	100-117 mph (45-52 m/s)
Category 3	133-158 mph (60-70 m/s)	118-139 mph (53-62 m/s)
Category 4	158-187 mph (70-84 m/s)	140-169 mph (63-76 m/s)
Category 5	>187 mph (>84 m/s)	>170 mph (>76 m/s)

2.4.6.1 The wind pressure shall be calculated using the following formula:

$P_w = q_z G\, C_f \geq 30\, C_f$ where $q_z = 0.00256\, K_z I V^2$ and $G = 1.0$ and $I = 1.15$

2.4.6.2 The following force coefficients, C_f shall be used:

Type of Surface	C_f
a) Vertical plane surfaces	1.0
b) Projected areas of cylindrical surfaces	0.6
c) Projected areas of conical and double curved plate surfaces	0.5

2.4.6.3 The wind pressure exposure coefficient, K_z, shall be permitted to be calculated in accordance with ASCE 7 or the following coefficients shall be used.

Height above finished grade, ft (m)	Exposure C	Exposure D
0 to 50 ft (15.2)	1.09	1.27
50 to 100 ft (15.2) to 30.5)	1.27	1.43
Over 100 ft (30.5)	See ASCE 7	

2.4.6.4 Certain locations, particularly along coastal areas subjected to high wind events, may require a tank to be designed for wind loadings for wind speeds greater than 90 miles per hour (145 km/hr). In such cases, the wind speed shall be increased in multiples of 5 miles per hour (8 km/hr).

2.4.6.5 The wind pressures defined by the above shall be applied to the vertical projected areas of the tank. The wind speed, Exposure type and notation that the wind pressures are based on a 3 second peak gust shall be shown on the design drawings.

2.4.6.6 In cases where a tank is to be erected in a location that requires a wind speed greater than that originally certified, revised drawings shall be submitted to the certification agency for review and certification.

2.4.7 An **earthquake load** shall be considered for all tanks located in Earthquake Zones 50-year through 500-year. The method to be used takes into account impulsive and convective (sloshing) actions of the liquid in flexible steel tanks fixed to rigid or flexible foundations. For details, see paragraph 2.19 of this standard.

2.4.7.1 the certification agency recognizes five (5) earthquake zones: 50-year; 100-year; 250-year; 500-year; and >500-year. With this methodology, Earthquake Zone 50-year is the most severe. These earthquake zones are unique and do not necessarily correlate with the zoning of other code bodies such as the AWWA. An approximate correlation is shown in Table 2.4.7-1.

Table 2.4.7-1

New FM Earthquake Zone Designation	Return Period of Damaging Ground Motion
50-year	Up to 50 years
100-year	51 to 100 years
250-year	101 to 250 years
500-year	251 to 500 years
>500-year	>500 years

2.4.7.2 Tanks erected in Earthquake Zone >500-year do not require a seismic analysis to comply with this standard but may be required by other codes or regulations. Tanks that are analyzed for erection in a particular zone may be erected in other, less severe earthquake zones. For example, a tank certified for Earthquake Zone 50-year shall be permitted to be erected in any of the zones. A tank certified for Earthquake Zone 250-year shall be permitted to be erected only in Earthquake Zones 250-year, 500-year or >500-year.

2.4.7.3 When tanks have been seismically designed, the certification listing shall show the Earthquake Zone Designation(s) where the tank is permitted to be erected (see Table 2.4.7-1).

2.5 Individual Tank Designs

2.5.1 A complete set of design drawings and qualifying calculations shall be submitted for review for each certified tank design.

2.5.2 Changes to a certified tank design, including but not limited to, material specifications, capacities, allowable stresses, shell plates, roof supports, tank bottoms, accessories, corrosion protection, foundations, welding, general notes and drawings, earthquake zones, foundation bolts, alternative design parameters, tank heating and insulation shall not be permitted unless otherwise stated in this examination standard or the individual certification reports.

2.5.3 Subsequent fabrication and erection of certified tank designs shall be permitted if in accordance with the certified design documents and certification report(s). The certification agency shall be notified, and agree to in writing, of any changes in the design parameters, the tank proper, penetrations and accessories unless specifically allowed otherwise in this standard or individual certification report(s).

2.6 Materials

2.6.1 All materials incorporated into any certified steel tank shall be new, previously unused, in first class condition, and shall comply with all the requirements of this standard.

2.6.2 All steel incorporated into any certified steel tank shall have their properties verified for compliance to the material specifications. Verification shall be in the form of a mill test report that lists the physical, dimensional and chemical properties of the material. Steel materials of an unidentified specification shall be tested by a qualified testing laboratory and found to be in compliance with all physical, dimensional and chemical requirements of this Standard prior to use.

2.6.3 Allowable design stresses shall be based on the published yield stress of the material. Increasing allowable design stresses based on the results of mill test reports shall not be allowed.

2.6.4 Use of materials other than those contained in AWWA D103 (for bolted tanks) or AWWA D100 (welded and elevated tanks) shall be handled on a case-by-case basis. Materials specifications shall be submitted to the certification agency.

2.6.5 All material specifications, minimum and maximum thicknesses and size requirements for bolts, anchor bolts, rods, reinforcing steel, plates, sheets, structural shapes, forgings, pins, filler metals, electrodes and components not specifically addressed in this Standard shall be as specified in the applicable AWWA standard.

2.7 Standard Capacities

2.7.1 The standard capacities for tanks submitted for certification shall be in increments of 10,000 US gallons (37.8 m^3). Certification of other capacities shall be considered on a case-by-case basis.

2.7.2 The net capacity shall be the volume of water between the bottom of the anti-vortex plate and the TCL. All tanks shall have a minimum freeboard of 2 in. (50 mm).

2.7.3 The net capacity shall be at least 99% of the nominal published capacity except as allowed in paragraph 2.7.4.

2.7.4 Tanks designed for Earthquake Zones 50-year, 100-year, 250-year and 500-year shall have a net capacity of at least 97% of the nominal published capacity. This is allowed due to the extra freeboard required at the top of the tank to accommodate the height of the sloshing wave in an effort to minimize damage to the roof support system during a seismic event (see paragraph 2.19.3).

2.8 Unit Stresses

2.8.1 Except for roof supports and other exceptions specifically provided for elsewhere in this standard, all steel members shall be designed such that the resulting maximum stresses produced by any design load or combination of design loads shall not exceed their allowable values as specified in AWWA D100 for welded and elevated tanks and AWWA D103 for bolted tanks. Allowable unit stress values, wherever stated in this standard, shall be reduced by any applicable joint efficiencies as detailed in AWWA D100.

2.8.2 Consideration shall be given for stresses produced by the combination of wind with dead and live loads or by wind alone or produced by the combination of earthquake with dead and live loads, or by earthquake alone. In such cases, the allowable unit stresses shall be permitted to be increased 33 1/3% provided that the resulting section is not less than that required for dead and live loads alone. Wind and earthquake loads do not need to be considered simultaneously.

2.8.2.1 For the design of concrete foundations, consideration shall be given for the increase in design stresses when including either wind or earthquake with dead and live loads. An increase of 33 1/3% for both allowable concrete and reinforcing steel stresses as permitted by ACI 318 shall be used, provided that the foundation design is not less than that required for the combination of dead and live loads alone.

2.8.3 In the design of welded tanks, consideration shall be given for increased allowable stresses of certain items if the alternative design basis contained in AWWA D100, is followed (see paragraph 2.20).

2.9 Shell Plates

2.9.1 The minimum thickness for all welded steel tank cylindrical shell plates shall be 1⁄4 in. (6.4 mm). The minimum thickness for all bolted steel tank cylindrical shell plates shall be 0.094 in. (2.4 mm).

2.9.2 All tank shell plates shall be cold rolled to the proper curvature to suit the configuration of the tank.

2.9.3 The thickness of cylindrical shell plates stressed by the pressure of the tank contents shall be calculated by the formulas shown in AWWA D100 and AWWA D103. For welded tanks, built to AWWA D100 the joint efficiency shall be 0.85 for tanks that are not designed using the alternative design method.

2.9.4 All openings in the tank shell greater than 4 in. (100 mm) in diameter and subject to hydrostatic pressure shall be reinforced in accordance with AWWA D100 or AWWA D103.

2.9.5 Intermediate shell girders (wind stiffeners) shall be permitted to be installed as a means of stiffening the tank shell for wind loading. The maximum unstiffened height and the method of determining the minimum section modules shall be determined in accordance with AWWA D103 (bolted tanks) or AWWA D100 (welded and elevated tanks) as applicable.

2.10 Roof Supports

2.10.1 All tanks shall have roofs. When the roof is supported by rafters arranged in a radial pattern, they shall be located such that when measured along the tank circumference, the spacing between rafters shall not exceed 6 ft 3 in. (1.9 m). They shall be placed above the overflow water level, such that no part of the rafters or support clips are in contact with the water.

2.10.2 Designs shall be in accordance with the steel construction specifications of the American Institute of Steel Construction, except as noted in this Standard. Consideration shall be given to roof rafter depth less than f_b/600,000 provided the roof slope is 3⁄4 in 12 or greater.

2.10.2.1 The roof rafters shall utilize an allowable bending stress which shall be the greater of 15,000 lbs/in^2 (103 MPa) or 0.4F_y, unless the rafter compression flange is laterally supported. Friction between the roof plate and the top flange of the rafter shall not be considered as a means of providing lateral support of the rafter compression flange for purposes of this standard. When the compression flange is provided with lateral support, the allowable rafter bending stress may be increased to 0.6F_y. In such cases, the unbraced length of the rafter compression flange shall not exceed the maximum allowable unbraced length of the compression flange, L_U, as shown in the AISC Manual of Steel Construction.

2.10.2.2 Columns supporting roofs shall be designed as secondary members. The maximum slenderness ratio, L/r, for columns supporting rafters shall be 175. The maximum permissible compressive stress shall be determined as shown in AWWA D-100 and D103.

2.10.2.3 Consideration shall be given to column cap plates and column base plates designed to utilize an allowable bending stress of 20,000 lbs/in^2 (140 MPa).

2.10.2.4 The minimum thickness of all roof support members shall be 3⁄16 in. (5 mm).

2.10.2.5 When the roof slope is less than 1 in 2.75(20°), the minimum thickness of flat roof sheets shall be 0.094 in (2.4 mm). Roof sheets shall be permitted to be thinner than 0.094 in (2.4 mm) if the roof sheet is corrugated and placed perpendicular to the roof support beams. Such roofs shall be fastened to the roof supports in each trough using minimum 0.25 in (6 mm) diameter self-tapping screws. The minimum thickness of the corrugated sheets shall be based on the material, section properties, span and applied live load.

2.10.3 Consideration shall be given to roofs made from other types of materials if in accordance with AWWA D100 and AWWA D103.

2.10.4 For rafter design guidelines, see Appendix C of this standard.

2.11 Tank Bottoms

2.11.1 Flat bottom, ground supported welded tanks – the minimum thickness for all welded steel tank bottom plates shall be 1⁄4 in. (6.4 mm). Lap welded tank bottoms need only be welded on the top side with a continuous, full height fillet weld on all seams. Plates under the bottom ring of cylindrical shells shall have the outer ends of lap joints depressed to form a smooth bearing for all shell plates. The minimum lap shall be 1in. (25 mm). Butt joints shall be welded from the top side using a suitable backing strip or equivalent means to ensure at least 90% joint fusion.

2.11.1.1 Tank bottoms shall utilize either lap joint construction or butt joint construction. All three-plate laps or three-plate joints in the tank bottom shall be at least 12 in. (300 mm) from each other and from the tank shell.

2.11.1.2 The bottom edge of the lowest course of shell plates and the bottom plates shall be joined by a continuous fillet weld, 1⁄4 in. (6 mm) minimum, on both sides of the plate. After trimming, the bottom plate shall extend a minimum of 1 in. (25 mm) beyond the toe of the weld.

2.11.1.3 All openings in the tank bottom greater than 4 in. (100 mm) in diameter shall be reinforced in accordance with AWWA D100.

2.11.2 Flat bottom, ground supported bolted tanks – the minimum thickness for all bolted steel tank bottom plates shall be 0.094 in. (2.4 mm). When a concrete mat has been provided for the foundation, the steel bottom plates may be omitted provided that the bottom course of shell has been anchored or cast into the concrete. When this occurs, a flexible, continuous waterproof sealant shall be installed at the mating surface between the steel plate and concrete foundation. Openings in the tank floor plates, if provided, shall be fabricated in accordance with AWWA D103.

2.11.2.1 When tanks are provided with a rubber or flexible liner, the tank bottom shall be permitted to be a bed of sand placed within a concrete ringwall.

2.11.2.2 When a tank is provided with a rubber or flexible liner and is to be erected within Earthquake Zones 50-year, 100-year, 250-year or 500-year, either a concrete mat or steel bottom plate shall be required. When a steel bottom plate has not been provided, see Paragraph 2.18 for guidelines on the use of foundation bolts.

2.11.3 Elevated tanks provided with a suspended bottom shall be elliptical, hemispherical or conical in shape. The bottoms on single pedestal tanks shall utilize a support cone.

2.12 Accessories for Tanks

2.12.1 Accessories for flat-bottom suction tanks shall be provided in accordance with the following. The criteria is consistent with NFPA 22. All accessories shall be fabricated from galvanized steel or as otherwise certified or acceptable to the certification agency. All accessory items shall be provided by the tank manufacturer.

2.12.1.1 A **shell manhole** shall be provided in the 1st ring of the tank. The minimum size shall be 24 in. (600 mm) in diameter for circular manholes and 18 in. × 22 in. (450 mm × 550 mm) for elliptical shaped manholes. All portions including the neck, bolting and cover shall be designed to withstand the weight and pressure of the tank contents. Fillet welds between the manway neck and cover flange shall be equal or greater than the minimum material thickness of the neck or flange.

2.12.1.2 A **roof vent** located above the maximum water level and near the center of the roof. The screened area of the vent shall have an area at least 1 1⁄2 times the cross-sectional area of the suction line or fill line, whichever is larger. The screening shall have either 3⁄8 in. (10 mm) or 1⁄2 in. (13 mm) openings and be fabricated from a corrosion resistant metal. The overflow pipe shall not be considered as part of the roof vent.

2.12.1.3 A **roof manway** located near the center of the roof. It shall have a removable cover, have a minimum dimension of 20 in. (500 mm) or be at least 20 in. (500 mm) in diameter, and have a 4 in. (100 mm) minimum curb height. The roof manway is optional when a flanged roof vent is provided.

2.12.1.4 A **roof hatch** located near the outside tank ladder. It shall have a clear opening dimension of at least 24 in. (600 mm) in one direction and 15 in. (380 mm) in the other direction, or have a minimum diameter of 24 in. (600 mm). It shall be provided with a hinged cover and hasp suitable for a lock. It shall have a 4 in. (100 mm) minimum curb and the cover shall have a downward overlap of at least 2 in. (50 mm). As an alternative, a gasketed watertight cover may be provided in lieu of the 4 in. (100 mm) curb and 2 in. (50 mm) overlap.

2.12.1.5 A **fill line** capable of filling the tank in less than eight (8) hours. It shall have a minimum diameter of 2 in. (50 mm). If an over the top fill line is utilized, the water shall be directed downward as it discharges from the pipe. If an automatic fill line is used, it shall be located so as to discharge into a different quadrant (more than 90° away) from the suction line. Fill lines that penetrate the tank roof shall be provided with a watertight seal. As an alternative, the automatic fill line shall be oriented such that the water discharges a minimum of 15 ft (4.6 m), measured horizontally, from any part of the anti-vortex plate.

2.12.1.6 A **suction line** that is sized according to the anticipated rating of the suction pump. Normally, the suction line penetrates the tank shell and is terminated with a 90° elbow pointing downward. An anti-vortex plate is attached to the inlet and shall be located 6 in. (150 mm) or one-half the suction line diameter, whichever is greater, above the tank floor. The anti-vortex plate shall be fabricated from 1⁄4 in. (6 mm) minimum thickness steel with each side of the plate, or it's diameter, at least twice the diameter of the suction line. Alternatively, the suction line may penetrate the tank bottom. In such cases, it shall extend at least 4 in. (100 mm) above the tank bottom. The anti-vortex plate, sized as described above, shall be located 6 in. (150 mm) or one-half the diameter of the suction line, whichever is greater, above the rim of the inlet. All anti-vortex assemblies shall be securely attached to either the suction line or the tank bottom.

2.12.1.7 An **overflow pipe** at least one pipe size larger than the fill line, terminating at the top with a weir box or other appropriate intake. When a stub overflow is utilized, it shall project at least 12 in. (300 mm) beyond the tank shell. When an overflow to ground is utilized, it shall be placed down the outside of the tank, be supported at proper intervals, terminate with an elbow and discharge over a drainage inlet or splash block. The discharge end of the overflow shall be covered with corrosion resistant metal screening having either 3⁄8 in. (10 mm) or 1⁄2 in. (13 mm) openings. The overflow shall be sized to provide a capacity at least equal to the pumping rate with a water level not more than 6 in. (150 mm) above the weir.

2.12.1.8 A **domestic suction line** for plant use is optional. Design drawings shall clearly state the elevation of this line and the resulting capacity available for fire protection purposes. The capacity available for fire protection shall be determined as the volume of water between the domestic suction inlet to the antivortex plate. When a domestic suction line has been provided, a bottom drain line flush with the tank bottom shall also be provided.

2.12.1.9 **Relief** and **test lines** are optional. If they are capable of discharging while the suction pump is operating, they shall be located such that they discharge into a different quadrant (more than 90° away) from the suction line.

2.12.1.10 A **water level gauge** shall be provided as a means of monitoring the water level in the tank. An exterior gauge board with a target is preferred. Alternatively, a high water/low water level electric alarm shall be permitted to be used. When used, the high level alarm shall be located within 2 in. (50 mm) of the overflow inlet. The low level alarm shall be located within 12 in. (300 mm) of the overflow inlet. They shall be connected to a central supervising station.

2.12.1.11 An **exterior ladder** shall be provided, beginning at 8 ft (2.4 m) above the level of the tank bottom, and located to provide access to the roof hatch. The side rails shall not be less than 2 × 3⁄8 in (50 x 10 mm) with a spacing between the side rails not less than 16 in. (400 mm). The rungs shall not be less than 3⁄4 in. (19 mm) round or square bars, spaced 12 in. (300 mm) apart on centers. The maximum spacing of supports attaching the ladder to the tank shall not exceed 10 ft (3 m).

2.12.1.12 An **internal ladder** shall be permitted only when the location where the tank is to be erected is located on the warm side of either the 5°F (-15°C) lowest one day mean or the 30°F (-1°C) normal daily minimum for January. If provided, its construction shall be in accordance with the requirements for the external ladder shown above.

2.12.1.13 Consideration shall be given to additional accessories, such as drains, safety cages, platforms, or roof ladder handrails. These items shall be permitted to be provided if detailed drawings are submitted for review and certification.

2.12.2 Accessories for Elevated Tanks – shall be as described in AWWA D100. When provided, the items shall contain the physical characteristic of the similar item described in Paragraph 2.12.1.

2.13 Corrosion Protection

2.13.1 Welded Tanks – after satisfactory tests have been completed (see paragraph 2.16.1.7), the tank shall be painted in accordance with AWWAD 102, "Coating Steel Water Storage Tanks." All interior surfaces exposed to water immersion or the vapor phase zone above the high-water level shall be cleaned by Near White Blasting, SSPC-SP10. All exterior surfaces shall be cleaned by Commercial Blasting, SSPC-SP6. All interior and exterior surfaces shall be primed and painted in accordance with AWWA D 102 except that Inside Coating System No. 5 (coal-tar enamel coating) shall not be used.

2.13.1.1 Consideration shall be given for a zinc-rich primer when insulation is provided on the tank exterior in lieu of the finish coat (see paragraph 2.21).

2.13.1.2 In cases where a certified tank is subsequently erected, the coating system shall be permitted to be different from that which was originally certified provided that the new coating system continues to meet the requirements of AWWA D 102 and paragraph 2.13 of this standard.

2.13.2 Bolted Tanks – all bolted tanks shall be coated in accordance with AWWA D103. Manufacturers shall make touch up kits available for instances where the coating is damaged during shipping or erection.

2.13.2.1 In cases where galvanizing has been provided as a corrosion protection system for the tank shell plates, the shell plates shall meet one of the following criteria:

a) Be coated at a minimum coating thickness of 1 oz/ft^2 (305 g/m^2) per exposed surface and contain a butyl rubber liner or other flexible material as allowed by the certification agency supported from the top of the tank;
b) Be coated at a minimum coating thickness of 2 oz/ft^2 (610 g/m^2) per exposed surface; or
c) Be coated at a minimum coating thickness of 1 oz/ft^2 (305 g/m^2) per exposed surface and the inside surface shall be coated with two (2) layers of a bituminous coating that has a total thickness between 0.008 in. to 0.020 in. (0.2 mm to 0.51 mm) [190 to 500 microns]. When used, the manufacturer shall provide specific installation procedures to ensure good adhesion between the coating and the galvanizing.

2.13.3 Tanks shall be permitted to be provided with a rubber liner supported at the top edge of the tank.

2.13.4 Liners shall be permitted to be used to provide corrosion resistance and water tightness in bolted tanks. Liners shall be of sufficient strength and flexibility to withstand the anticipated loads. A protective geotextile material shall be placed around the inside circumference of the tank where the bottom shell plates and foundation form a joint. The geotextile material shall also extend up the side of the bottom shell plate for a distance of not less than 12 inches (300 mm). Care shall also be taken at all openings and transitions to ensure that the liner does not tear or become punctured. Interior insulation may be installed as permitted by Paragraph 2.21.

2.14 Foundations

2.14.1 All tanks shall be supported on a concrete ringwall, concrete slab or compacted berm with steel retainer ring. When a steel retainer ring has been provided, it shall contain a protective coating or galvanizing. Tanks that require anchor bolts or are located in Earthquake Zones 50-yr, 100-yr, 250-yr or 500-yr shall be supported on a concrete ringwall with steel bottom plates or a concrete slab.

2.14.2 Concrete foundations shall be built of concrete with a specified compressive strength of not less than 3000 lbs/in^2 (21 MPa). Design, materials and construction shall conform to ACI 318 with water considered as the live load.

2.14.3 The tops of foundations shall project at least 3 in. (75 mm) beyond the tank shell. The top corners shall be neatly rounded or finished with a suitable bevel. When foundation bolts are required, the foundations shall extend at least 9 in. (230 mm) beyond the tank shell.

2.14.4 If a reinforced concrete ringwall is used, it shall extend below the frost line, be at least 2.5 ft (0.8 m) deep and 10 in. (250 mm) thick and shall be placed directly beneath the tank shell for tanks supported on crushed stone or granular bases. It shall project at least 6 in. (150 mm) above the finished grade with the surrounding grade sloped for positive drainage away from the tank. It shall be reinforced against temperature and shrinkage with additional reinforcement as required for resisting lateral earth pressure. The minimum vertical temperature reinforcing shall be .0015 of the cross-sectional area and the minimum horizontal temperature reinforcing shall be .0025 of the cross-sectional area unless a greater amount of reinforcing steel is required by ACI 318. Ringwalls and slabs, after grouting or before placing the cane fiber joint filler, shall be level within ±1⁄8 in. (3 mm) in any 30 ft (9.1 m) circumference under the shell. The levelness on the circumference shall not vary by more than ±1⁄4 in. (6 mm) from an established plane. The tolerance on poured concrete before grouting shall be ±1 in. (25 mm).

2.14.4.1 Tank bottoms shall be placed on at least 4 in. (100 mm) of crushed stone, or clean sand, laid on the compacted grade. It shall slope uniformly upward towards the center of the tank at a minimum slope of 1 in. (25 mm) vertical to 10 ft (3.0 m) horizontal.

2.14.4.2 A mixture of 1:1.5 cement-sand grout shall be placed beneath the tank bottom and top of the ringwall. The cement-sand grout shall be a minimum of 1 in. (25 mm) thick and shall fill the entire space beneath the tank bottom to the sand cushion. The minimum width of the cements and grout shall be 6 in. (150 mm). In lieu of the 1 in. (25 mm) of grout, cane joint filler, 1⁄2 in. (13 mm) thick, conforming to the requirements of ASTM D1751 may be used as a sealant. When the tanks have been designed for Earthquake Zones 50-year, 100-year, 250-year or 500-year, see paragraph 2.14.11.

2.14.4.3 All topsoil, organic material and undesirable material within the ringwall shall be removed and replaced with a controlled, load bearing compacted backfill. The natural soils and load bearing backfills within the ringwall shall be capable of supporting the tank bottom without general settling or localized settling, causing breakdown of the tank bottom adjacent to the ringwall.

2.14.5 Tanks that are supported on concrete slabs shall project at least 6 in. (150 mm) above the finished grade with the surrounding grade sloped for positive drainage away from the tank and have a sand cushion at least 1 in. (25 mm) thick placed between the tank bottom and the concrete slab. In place of a sand cushion, a 1⁄2 in. (13 mm) thick layer of cane fiber joint filler meeting the requirements of ASTM D1751 shall be provided. The space between the tank bottom and the concrete slab, from the outside edge of the tank bottom inward for a distance of not less than 6 in. (150 mm) shall be filled with a 1:1.5 cement-sand grout. As an alternative, this space may also be filled with a cane fiber joint meeting the requirements of ASTM D1751. An exception to this rule is when a tank bottom plate has not been provided as shown in paragraph 2.11.2. When tanks have been designed for Earthquake Zones 50-year, 100-year, 250-year or 500-year, see paragraph 2.14.11 and 2.18.

2.14.6 Tanks that are supported on well-graded stone or gravel berms with steel retainer rings shall have the retainer rings located at least 12 in. (300 mm) from the shell to ensure berm stability. They shall project at least 6 in. (150 mm) above the finished grade with the surrounding grade sloped for positive drainage away from the tank.

2.14.6.1 Steel retainer rings shall be either welded or bolted together. If bolted, the threaded ends of the bolts shall be peened to prevent loosening of the nuts. As an alternative, lock washers may be used.

2.14.6.2 All surfaces of the steel retainer ring (and bolts, if provided) shall be provided with a suitable coating for corrosion protection.

2.14.6.3 Steel retainer rings shall be provided with weep holes to allow rainwater to exit. A suitable non-biodegradable fabric shall be placed over the weep holes to prevent sand within the retainer ring from escaping.

2.14.7 The minimum depth of foundations below the ground line shall extend below the extreme frost penetration depth as shown in AWWA D100 or D103. The minimum depth shall be 12 in. (300 mm).

2.14.8 In cases where a certified tank design is subsequently erected, alternate foundation designs shall be permitted due to variability in site conditions.

2.14.9 Foundations supplied by the tank fabricator shall show the following:

- Foundation height, width and depth below grade
- Amount and spacing of circumferential and vertical reinforcing steel as well as the grade of reinforcing steel
- Compressive strength of the concrete
- Indication that the foundation must extend below the frost line
- Either 1⁄2 in. (13 mm) of cane fiber or 1 in. (25 mm) of grout between the tank bottom and the top of the ringwall (except when paragraph 2.12.11 applies)
- A minimum 4 in. (100 mm) thick cushion of crushed stone or clean sand
- The tank bottom sloped up to the center 1 in in 10 ft (25 mm in 3 m)
- The top of the foundation at least 6 in. (150 mm) above the grade level with the surrounding grade sloping away from the tank

2.14.10 When the foundation is not supplied by the tank fabricator, a note shall be added to the drawings stating that "The foundation shall be supplied and designed by others." In such cases, guidance shall be provided so that a suitable foundation can be designed. It is preferred that a ringwall be shown in phantom on the drawings along with the last five bulleted items shown in paragraph 2.14.9.

2.14.11 When the tank has been designed for erection in Earthquake Zones 50-year, 100-year, 250-year or 500-year, the space between the tank bottom and the top of the ringwall shall be shimmed with steel plates prior to the placement of the cement-sand grout mixture. The use of cane fiber shall not be permitted.

2.15 Welding

2.15.1 Welded tanks – All welding shall be in accordance with AWWA D 100 as summarized below.

2.15.1.1 Tanks may be welded by any process that does not include the application of pressure. The welding shall be performed manually, semi-automatically, automatically or by machine welding.

2.15.1.2 Specifications for each welding procedure shall be qualified in accordance with the rules in ASME Boiler and Pressure Vessel Code, Section IX, except as stated below for horizontal joints and fillet welds. The contractor shall conduct tests of the procedures to demonstrate their suitability in making welds that conform to specified requirements.

2.15.1.3 All welders and welding operators shall be qualified in accordance with ASME Boiler and Pressure Vessel Code, Section IX. The contractor shall conduct tests for all welders assigned to manual or semiautomatic welding, and all welding operators assigned to automatic or machine welding, in order to demonstrate their ability to make welds.

2.15.1.4 The tests shall be as described in ASME Boiler and Pressure Vessel Code, Section IX.

2.15.1.5 Tests conducted by one contractor shall not qualify a welder or welding operator to do the work for another contractor.

2.15.1.6 The contractor shall maintain a record of all welders showing the date and results of tests and the identifying mark assigned to each.

2.15.1.7 For tanks fabricated and erected outside of North America, the certification of welding and welders shall be permitted to be done in according to an equivalent national welding code acceptable to the certification agency.

2.15.2 Bolted tanks – all welding shall be limited to the shop installation of nozzles, vents, manways, connections and subassemblies.

2.15.2.1 Welders shall be certified to a nationally recognized welding code acceptable to the certification agency.

2.16 General Notes and Design Drawings

2.16.1 Design drawings for certified steel suction tanks shall include the following notes and information. Additional notes and information may be required as deemed necessary by the certification agency.

2.16.1.1 Fabricator name, address, project number, drawing scale and descriptive tank data (nominal capacity, height, diameter). In addition, each drawing shall be assigned a unique drawing title and number clearly showing the revision level and date of issue. A brief description of all changes made for a particular revision shall be noted in the drawing revision block on the drawings. Note: In cases where a certified tank is subsequently erected, the above information, other than the descriptive tank data, shall be permitted to be revised without the need to notify the certification agency.

2.16.1.2 Complete material specifications.

2.16.1.3 Design parameters including live (snow) load, wind speed based on 3 second peak gusts, wind exposure class and Earthquake Zone.

2.16.1.4 A loading diagram showing the following:

a) The minimum allowable soil bearing pressure required (lbs/ft^2 [kPa]).
b) The center column load, if applicable (lbs [N]).
c) The weight of the tank contents (lbs/ft^2 [kPa]).
d) The weight of the tank shell plus the weight of the portion of the roof supported by the tank shell per linear foot (meter) of circumference (lbs/ft [N/m]).
e) Tensile load per foundation bolt, if applicable (lbs [N]).

2.16.1.5 Notes shall be provided (welded tanks only)

a) That all welders and welding procedures have been certified in accordance with AWWA D 100. In addition, all weld sizes and symbols shall be shown.
b) All interior surfaces shall be blast-cleaned to a near white finish as specified in AWWA D 102, SSPC SP10. All exterior surfaces shall be blast-cleaned to an SP6 (commercial) finish. All interior and exterior paint systems shall conform to AWWA D 102 except that Inside Coating System No. 5 (heavy coal tar enamel) shall not be used.
c) Tank heating and insulation (if required) shall be approved by the certification agency..
d) All nozzles, fittings and accessories may be oriented by the customer, however, any nozzle that can possibly be discharging while the pump is operating (automatic fill, recirculation lines) shall be located such that it discharges into a different quadrant (more than 90° away) from the suction inlet. [This note shall be permitted to be modified in accordance with Paragraph 2.12.1.5].
e) All shell plates shall be cold rolled to the proper radius.
f) The overflow pipe shall be at least one pipe size larger than the fill line.

2.16.1.6 Statements that the following tests shall be conducted:

a) Shell plate welds shall be tested by radiographic examination or other method allowed by AWWA D100 (welded tanks only)
b) A vacuum leak test shall be conducted on the floor lap plates.
c) The tank shall be filled with water to the lip of the overflow and checked for leaks prior to being placed into service.

2.16.1.7 When a center column is provided, the following note shall be shown:

CONSIDERATION SHALL BE GIVEN TO A REINFORCED CONCRETE FOOTING REQUIRED UNDER THE CENTER COLUMN BASE FOR SUPPORT DEPENDING UPON THE EXISTING SOIL CONDITIONS AND ALLOWABLE SOIL BEARING PRESSURE. COLUMN BASE PRESSURE (INCLUDING TANK CONTENTS) IS lbs/ft^2 (kPa). THE DESIGN AND INSTALLATION OF THE FOOTING BY OTHERS (only if applicable). .

2.17 Tank Stability Against Overturning

2.17.1 All tanks submitted for certification shall be qualified for stability against wind and the need for intermediate wind stiffeners in accordance with AWWA D100 and D103 as appropriate. If intermediate stiffeners are required, the minimum size section modulus shall be determined as shown in the applicable AWWA standard.

2.17.2 All tanks submitted for certification shall be qualified for resistance to overturning due to wind and seismic forces (if applicable). There are two cases that govern. The first case is when the tank is empty with the wind at the maximum anticipated velocity. The second case is when the tank is full during a seismic event. The seismic analysis shall not be required for tanks located within Earthquake Zone >500-year.

2.17.3 When the tank is empty, it is susceptible to overturning due to wind. The overturning moment from the wind pressure shall be calculated as shown below. When the value of C in the formula shown below exceeds 0.66, anchor bolts shall be provided.

$C = 2M_W/(DW')$ where $M_W = 0.5\ DH^2\ P_W$ and $P_{W =}$ is determined in accordance with paragraph 2.4.6.1

2.17.4 The design tensile load per bolt can be determined using the following formula:

$$T = (4M_W/ND) - (W'/N)$$

2.17.5 When the tank is full, it is susceptible to overturning during a seismic event (if applicable). It is possible, however, for a flat-bottomed tank to survive a seismic event without anchorage by considering a portion of the liquid contents near the shell as resisting the overturning forces. To determine whether anchorage is needed, the value for J in the following formula must be found:

$$J = \frac{M}{D^2(w_t + w_L)}$$

a) Resistance to seismic overturning needs to be addressed only when the tank is located within Earthquake Zone 50-year, 100-year, 250-year or 500-year.

b) If $J \leq 0.785$, there is no uplift

If $J > 0.785$ but < 1.54, uplift exists

If $J \geq 1.54$ but < 2, the tank must be anchored, or the bottom annular ring thickened

If $J \geq 2$, the tank must be anchored.

c) The design tensile load per bolt can be determined by the following formula:

$$T = \left[\left(\frac{1.273M_{EQ}}{D^2}\right) - (w_t + w_L) \cdot S\right]$$

2.17.6 When foundation bolts are required, an analysis shall be provided verifying that the foundation design provides a sufficient weight acting downward to overcome the upward tensile load in the bolt thereby preventing the tank from overturning. In determining the total weight acting downward, credit shall be given for the weight of the concrete in the foundation as well as the weight of the soil and/or water directly above the foundation. When determining the weight of the water acting downward, and resisting overturning, only the amount in excess of w_L shall considered (since w_L has already been subtracted from the pullout force). See Appendix E for guidance on determining w_L and w_t).

2.17.7 For foundation anchor bolt design requirements, see paragraph 2.18.

2.17.8 When tanks are seismically designed for Earthquake Zones 50-yr, 100-yr; 250-yr or 500-yr and the tank incorporates a flexible liner, see Par. 2.11.2 and 2.18 for special conditions regarding the determination of loads on foundation bolts.

2.18 Foundation Bolts

2.18.1 In cases where calculations indicate that the tank is unstable and subject to sliding, overturning or uplift due to anticipated wind or seismic forces, the tank shall be anchored. Anchorage shall consist of foundation bolts embedded in a reinforced concrete ringwall or concrete mat, and connected to the lower part of the tank shell by anchor bolt chairs.

2.18.2 When tanks have been provided with a steel bottom plate or when the bottom shell sheet has been embedded in the concrete ringwall or mat, the bolts shall be designed to resist the maximum anticipated uplift force as determined in paragraph 2.17.4 and 2.17.5.

2.18.3 Foundation bolts shall be fabricated from either plain or deformed bars, either upset or not upset, shall have a minimum diameter of 3⁄4 in. (19 mm) (see 2.18.3.1 for an exception) and be galvanized or provided with an alternate means of corrosion protection. The threaded ends of foundation bolts shall project a minimum of 2 in. (50 mm) above the nominal level of the tops of the foundation bolt nuts. The threads shall be upset or peened in all cases. Single nuts shall be used in conjunction with a lock washer. As an alternative, double nuts may be provided. The maximum spacing of foundation bolts, measured circumferentially, shall be 10 ft (3.0 m).

2.18.3.1 In some cases, manufacturers provide foundation bolts where they are not required structurally to resist uplift. In these cases, they are used solely as a construction aid when erecting the tank. In these cases, the minimum diameter bolt shall be permitted to be less than 0.75 in (19 mm) in diameter bolt as specified in Paragraph 2.18.3.

2.18.4 Foundation bolts shall be designed to resist the maximum anticipated uplift force. The allowable stress on the bolts shall be 15,000 lbs/in^2 (103 MPa) when the tensile stress area is used. This allowable may be increased by 33% due to wind or seismic loadings. The allowable stress on bolts hall be permitted to be 0.33 Fu when the nominal bolt diameter is used. This allowable stress shall not be increased by 33% due to wind or seismic loadings when the nominal bolt diameter is used.

2.18.5 Foundation bolt embedment length shall be determined based on a shear cone analysis method (see Appendix D).

2.18.6 Foundation bolt design shall be based on the assumption that they only need to be able to resist that portion of the calculated base shear that exceeds the calculated frictional resistance created by the tank bottom plate and soil/concrete mat. For guidelines on determining the frictional shear resistance of the tank, see Appendix E, Paragraph E-9.

2.18.7 Foundation bolts shall not extend closer than 3 in. (75 mm) to the bottom of the foundation. They shall be headed bolts. The use of washers or plates welded to the bottom of the anchor bolts is an acceptable method to reduce the required embedment length. In such cases, supporting calculations shall be submitted verifying the additional resistance provided by the washers or plates. Hooked bolts shall not be allowed.

2.18.8 Post installed anchor design shall conform to the requirements of ACI 318, Appendix D of this standard and the anchor manufacturer's requirements. In the case of conflicting requirements, the more stringent shall govern. Anchor manufacturer's capacity data shall indicate the failure mode and shall provide a minimum factor of safety of 4 to 1 against failure based on the allowable stress (service load) design.

2.18.9 When anchor bolts are required on tanks certified for Earthquake Zones 50-yr, 100-yr, 250-yr and 500-yr, they shall be attached to the tank shell plates using anchor bolt chairs. The design and analysis of the anchor bolt chairs shall be in accordance with AISI Steel Plate Engineering Data, Volumes 1 and 2, December 1992.

2.18.9.1 When tanks are designed to be installed only in Earthquake Zone >500-yr and need to be anchored solely to resist overturning due to wind, the use of straps or bolts embedded in concrete or anchor bolts fastened through a plate or circumferential bottom ring angle shall be permitted.

2.18.10 When tanks are certified for use in Earthquake Zones 50-yr, 100-yr, 250-yr and 500-yr require anchor bolts, have been provided with a flexible liner and do not incorporate a steel bottom plate, only one-half (½) of the anchor bolts provided shall be considered in determining the tensile and shear loads and stresses on the bolts. This is to account for the fact that without a steel bottom plate, the rigidity of the tank shell under seismic conditions and its ability to evenly distribute the loads may be compromised.

2.18.11 Anchor bolts shall be qualified as shown below. When the calculated frictional resistance of the tank exceeds the applied shear load, the equation essentially reduces to a ratio of the actual tensile load to the applied tensile load.

$$T/Ta + V_{EQ}/Va \leq 1$$

2.19 Earthquake Design

2.19.1 All tanks erected at locations contained within Earthquake Zone 50-year, 100-year, 250-year or 500-yearshall be seismically analyzed in accordance with the method shown in Appendix E, "Seismic Analysis of Certified Suction Tanks".

2.19.2 the certification agency recognizes five (5) earthquake zones: 50-year, 100-year, 250-year, 500-year and >500-year. With this methodology, Earthquake Zone 50-year is the most severe. Earthquake Zone 500-year is the least severe and does not require a seismic analysis. Tanks qualified for a particular zone also qualify for less severe zones. For example, if a tank is designed for Earthquake Zone 100-year, it can also be erected in Earthquake Zones 250-year, 500-year and >500-year. These zones are unique to the certification agency and do not necessarily correlate with the zoning of other code bodies such as the AWWA. The methods used to analyze the forces that are developed also differ from methods currently shown in any of the AWWA documents. See Appendix E for details on the methodology.

2.19.2.1 This method considers the two response modes of the tank and its contents. The first is the impulsive mass near the base of the tank that moves in unison with the tank wall. The second is the convective mass near the free surface that is subjected to a sloshing motion.

2.19.2.2 The response of the impulsive mass determines the seismic base shear and overturning moment in the tank. The response of the convective mass determines the height of the sloshing wave near the free surface of the tank. Tanks with an inadequate freeboard, the impacts from the sloshing liquid generate upward forces on the tank roof which are transmitted to the tank wall.

2.19.3 All seismically designed tanks shall be provided with a sufficient amount of freeboard in an attempt to minimize damage to the roof and loss of contents from the sloshing wave during a seismic event. The sloshing wave height, dsl, shall be determined as shown in Appendix E. When the provided freeboard, da is less than dsl, a portion of the tank roof will be wetted by the sloshing wave. This causes uplift forces on the tank roof. In addition, the constraining action of the roof on the sloshing motion causes a portion of the convective liquid to act as an impulsive force. When this condition occurs, the roof shall be designed to withstand these uplift forces. See Appendix F, "Roof Loads in Suction Tanks With Insufficient Freeboard", for guidance on determining these uplift forces.

2.19.4 Tanks may be designed using the spectral acceleration zone factors shown in Appendix E. When designed using these zone factors, the tank shall be permitted to be erected anywhere within the zone under consideration as well as any less severe seismic zone.

2.19.4.1 Tanks shall be permitted to be designed using site specific spectral acceleration factors. When site specific seismic response factors are used, they shall be selected in accordance with ASCE 7. The MCE values of 5% damping bedrock outcrop spectral acceleration at 0.2 seconds and 1.0 seconds (S_S and S_I respectively) shall be read from the maps. These values shall be multiplied by the soil amplification factors F_a and F_v, to obtain the free surface spectral accelerations S_{MS} and S_{MI} where $S_{MS} = S_S \times F_a$ and $S_{MI} = S_I \times F_v$.

2.19.4.2 The design values used in the calculations shall be 2/3 of S_{MS} and S_{MI} as follows:

$$S_{DS} = {}^{2}/_{3} \times S_{MS} \quad and \quad S_{DI} = {}^{2}/_{3} \times S_{MI}$$

2.19.4.3 For locations outside the USA, the design response spectra shall be 2⁄3 of the 2475-year response spectrum or the 475-year response spectrum, depending on the design practice in the respective country.

2.19.4.4 When tanks are designed using site specific seismic response spectra, it shall be so noted in the listing and on the nameplate indicating certification.

2.19.5 The analysis shall consider 25% of the roof live load acting simultaneously with the seismic event in determining the overturning moment. The roof live load shall not be considered when determining the weight of the tank resisting overturning. In lieu of this approach, two separate analyses shall be performed. The first shall consider 100% of the roof live load acting simultaneously with the seismic event in determining the overturning moment. In this case, 100% of the roof live load shall be considered in determining the weight of the tank resisting overturning. The second analysis shall consider none of the roof live load when determining overturning moment or resisting tank weight.

2.19.6 Tanks shall be designed using an importance factor of $I = 1.25$.

2.19.7 Seismically designed tanks shall be analyzed assuming the water level is at the TCL.

2.19.8 When tanks are located in seismic zones and utilize insulation installed on the interior of the tank, see Paragraph 2.21.6 and 2.21.7 for limitations and restrictions.

2.20 Alternative Design (Welded Tanks Only)

2.20.1 Consideration shall be given to certified welded steel pump suction tanks that utilize the alternative design basis contained in AWWA D100.

2.20.2 The rules, design stresses and inspection requirements used to ensure suitable designs and workmanship, and the proper temperature ranges for economical use of higher grade steels shall be as specified in AWWA D100.

2.20.3 Tanks designed on this basis shall incorporate all provisions contained in AWWA D100.

2.20.4 Tanks designed on this basis shall state such in the design drawing notes and on the label indicating certification.

2.21 Tank Heating and Insulation

2.21.1 Tank heating and insulation shall be in accordance with Paragraph 2.21.5 or 2.21.6.

2.21.2 Heating equipment is required for uninsulated pump suction tanks located on the cold side of either the 5°F (-15°C) lowest one-day mean or the 30°F (-1°C) normal daily minimum, whichever is colder, as shown on the Data Sheet 3-2 isothermal maps.

2.21.3 The heating system shall be of such capacity that the temperature of the coldest water in the tank shall be maintained at or above 42°F (5.6°C) during the coldest weather. A low water temperature alarm, set at 40°F (4.4°C) shall be provided.

2.21.4 When tank heating or insulation is required, certified systems shall be specified.

2.21.5 Heat loss from steel tanks can be greatly reduced by the application of insulation over the exterior of the tank. Polyurethane foam can be sprayed on the tank to the desired thickness with an elastomeric type coating applied to protect the foam from the weather. Board stock or fiber type insulations can also be used. When these types are used, a metal jacket is placed over the insulation to protect it from the weather.

2.21.6 As an alternative to Paragraph 2.21.5, tanks that utilize flexible internal liners shall be permitted to place insulation between the liner and inside surface of the tank shell plates. The tank manufacturer shall submit complete details for certification on the insulation being used and how it is to be installed. When interior insulation is utilized, the insulation shall have the following properties or characteristics:

- Have a minimum nominal density of 1.8 lbs/ft^3 (30 kg/m^3).
- Be made of flame retardant material that has a minimum Euroclass E fire classification or a flame spread rating of 25 or less and a smoke developed rating of 450 or less when tested in accordance with ASTM E-84.
- Have a minimum compressive strength of 1% nominal compression at 14.5 lbs/in^2 (100 kPa).
- Be formed to suit the curvature of the tank such that the insulation does not crack or break under the pressure caused by the water load. To accomplish this, rigid insulation boards shall be permitted to have their reverse surfaces scored or cut to allow the board to be formed to match the tank curvature. In such cases, the seams shall be covered with tape to prevent damage to the liner.
- Utilize at least two (2) galvanized fixing brackets per insulation board at all horizontal seams. In such cases, a protective pad shall be placed over the fixing bracket to protect the liner.
- When spray applied, any insulation surfaces shall be prepared and primed in accordance with the spray foam manufacturer’s written installation instructions. The foam shall be applied to a smooth finish and uniform density without any voids.

2.21.7 When internal insulation is used in tanks that are designed to be installed at locations contained within Earthquake Zones 50-yr, 100-yr, 250-yr or 500-yr, the method of securing the insulation to the tank wall shall be evaluated. When a mechanical fastening system is used to hold the insulation in place, they shall be evaluated to make sure that they will not protrude beyond the face of the insulation after consideration is given to additional deformation or compression of the insulation that could occur during a seismic event as the water is sloshing around in the tank. Fasteners that could project beyond the face of the insulation in such a manner that they could damage or puncture the flexible liner shall be prohibited.

3 GENERAL REQUIREMENTS

3.1 Review of Documentation

3.1.1 During the initial investigation and prior to physical testing, the manufacturer's specifications and details shall be reviewed to assess the ease and practicality of installation and use. The certification investigation shall define the limits of the certification.

3.2 Markings

3.2.1 All tanks fabricated and erected in accordance with a certified design shall be identified by a corrosion resistant metal nameplate denoting certification. The nameplate shall be permanently attached to the exterior of the tank adjacent to the shell manway. A sample or facsimile shall be kept on file at the certification agency.

3.2.2 All nameplates shall contain the following information:

- the certification mark of the certification agency;
- the manufacturer’s name and address;
- the nominal tank capacity, diameter and height;
- roof type, “FMS” (supported roofs) or “FMSS” (self-supported);
- date of fabrication/erection;
- manufacturer’s contract/job name.

3.2.3 Certified tank designs that have been seismically analyzed shall show each Earthquake Zone where it can be erected. If the tank has been designed using site specific seismic response spectra, the words “(site specific response spectra)” shall be shown after the earthquake zone designation.

3.2.4 Certified welded steel tanks which have been designed utilizing increased design allowables in accordance with AWWA D100 shall so indicate on the nameplate denoting certification.

3.2.5 Tanks that are designed for the dual purpose of fire protection and plant usage shall also show the amount of water available for fire protection purposes assuming that all water dedicated to plant usage is unavailable for fire protection purposes.

3.3 Manufacturer’s Installation and Operation Instructions

The manufacturer shall

- prepare instructions for the installation, maintenance, and operation of the product;
- provide facilities for repair of the product and supply replacement parts, if applicable; and
- provide services to ensure proper installation, inspection, or maintenance for products of such nature that it would not be reasonable to expect the average user to be able to provide such installation, inspection, or maintenance.

3.4 Calibration

3.4.1 Each piece of equipment used to verify the test parameters shall be calibrated within an interval determined on the basis of stability, purpose, and usage. A copy of the calibration certificate for each piece of test equipment is required. The certificate shall indicate that the calibration was performed against working standards whose calibration is certified and traceable to an acceptable reference standard and certified by an ISO/IEC 17025 accredited calibration laboratory. The test equipment shall be clearly identified by label or sticker showing the last date of the calibration and the next due date. A copy of the service provider's accreditation certificate as an ISO/IEC 17025 accredited calibration laboratory should be available.

3.4.2 When the inspection equipment and/or environment is not suitable for labels or stickers, other methods such as etching of control numbers on the measuring device are allowed, provided documentation is maintained on the calibration status of thus equipment.

4 PERFORMANCE REQUIREMENTS AND VERIFICATION

4.1 Design Attributes

4.1.1 Requirement - All proposed tank designs submitted for certification recognition shall be subjected to a drawing and calculation review.

4.1.2 Test/Verification

4.1.2.1 Drawings of the proposed tank design shall be reviewed for completeness and accuracy of all details essential to the complete fabrication and erection of the tank. Items to be reviewed shall include, but not be limited to, material specifications; shell, bottom and roof plate thicknesses; roof supports; accessories; foundations; welding details; corrosion protection; and general notes.

4.1.2.2 Calculations of the proposed tank design shall be reviewed for completeness and accuracy in regards to the qualification of items for structural adequacy and conformance of anticipated stresses against stresses allowed by applicable codes or this document using sound engineering practices. Items to be reviewed shall include, but not be limited to, shell plates; roof supports including columns, cap plates and base plates; foundations; soil bearing pressures; wind stability; and seismic analyses, if applicable.

4.2 Inspection and Testing

4.2.1 Requirement – All tanks designed, fabricated, erected and bearing a nameplate indicating certification shall be inspected and tested in accordance with AWWA D100, Section 11 or AWWA D103, Section 9 prior to being placed into service.

4.2.2 Test/Verification – welded tanks

4.2.2.1 Tanks shell welded joints shall be inspected by radiographic examination or by other methods as described in AWWA D100. The number and location of radiographs shall be as described per AWWA D100.

4.2.2.2 Tank bottom joints shall be tested using either the magnetic particle method or a vacuum leak test that utilizes soapsuds, linseed oil or other material suitable for detection of leaks in accordance with AWWA D100.

4.2.2.3 Upon completion, the tank shall be tested hydrostatically by filling it with water to the maximum working water level and checking for leaks. This shall be performed under the constant supervision of the tank manufacturer or his representative.

4.2.2.4 All leaks or defective welds disclosed by any of the above required tests shall be repaired. Defective welds shall be removed by chipping with a round nosed tool or by arc or oxygen gouging, from one or both sides of the joint, and then re-welded in compliance with qualified procedures. Removal of the defective welds is required only to the extent necessary to remove the defects present. Repairs shall be re-inspected by the original test procedure. No repair work shall be done on any joint unless the water in the tank is at least 2 ft (0.6 m) below the point being repaired.

4.2.3 Test/Verification – bolted tanks

4.2.3.1 Tank bottom joints shall be tested using a vacuum leak test that utilizes soapsuds, linseed oil or other material suitable for detection of leaks in accordance with AWWA D103.

4.2.3.2 Upon completion, the tank shall be tested hydrostatically by filling it with water to the maximum working water level and checking for leaks. This shall be performed under the constant supervision of the tank manufacturer or his representative.

5 MANUFACTURER'S REQUIREMENTS

5.1 Demonstrated Quality Control Program

5.1.1 A quality assurance program is required to assure that subsequent products produced by the manufacturer shall present the same quality and reliability as the specific products examined. Design quality, conformance to design, and performance are the areas of primary concern.

- Design quality is determined during the examination and tests and may be documented in the certification report.
- Continued conformance to this standard is verified by the certifier's surveillance program.
- Quality of performance is determined by field performance and by periodic reexamination and testing.

5.1.2 The manufacturer shall demonstrate a quality assurance program which specifies controls for at least the following areas:

- existence of corporate quality assurance guidelines;
- incoming quality assurance, including testing;
- in-process quality assurance, including testing;
- final inspection and tests;
- equipment calibration;
- drawing and change control;
- packaging and shipping; and
- handling and disposition of non-conforming materials.

5.1.3 Documentation/Manual

There should be an authoritative collection of procedures/policies. It should provide an accurate description of the quality management system while serving as a permanent reference for implementation and maintenance of that system. The system should require that sufficient records are maintained to demonstrate achievement of the required quality and verify operation of the quality system.

5.1.4 Records

To assure adequate traceability of materials and products, the manufacturer shall maintain a record of all quality assurance tests performed, for a minimum period of two years from the date of manufacture.

5.1.5 Drawing and Change Control

- The manufacturer shall establish a system of product configuration control that shall allow no unauthorized changes to the product. Changes to critical documents, identified in the certification report, must be reported to, and authorized by, the certification agency prior to implementation for production.
- Records of all revisions to all certified products shall be maintained.

5.2 Surveillance Audit

5.2.1 An audit of the manufacturing facility is part of the certification investigation to verify implementation of the quality assurance program. Its purpose is to determine that the manufacturer's equipment, procedures, and quality program are maintained to ensure a uniform product consistent with that which was tested and certified.

5.2.2 Certified products or services shall be produced or provided at, or provided from, location(s) disclosed as part of the certification examination. Manufacture of products bearing a certification mark is not permitted at any other location prior to disclosure to the certification agency.

5.3 Installation Inspections

Field inspections may be conducted to review an installation. The inspections are conducted to assess ease of application, and conformance to written specifications. When more than one application technique is used, one or all may be inspected at the discretion of the certification agency.

5.4 Product Modifications

The manufacturer shall notify the certification agency of changes in product construction, components, raw materials, physical characteristics, coatings, component formulation or quality assurance procedures prior to implementation.

6 BIBLIOGRAPHY

ISO/IEC 17025, *General Requirements for the Competence of Testing and Calibration Laboratories*.

FM Global Property Loss Prevention Data Sheets

Data Sheet 1-2, Earthquakes

Data Sheet 1-28, Wind Design

Data Sheet 1-54, Roof Loads for New Construction

Data Sheet 3-2, Water Tanks for Fire Protection

APPENDIX A:

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APPENDIX B:

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APPENDIX C: Rafter Design Guidelines

C-1 Introduction

This appendix has been included to provide assistance in designing certain features of the tank not covered in the main body of the Standard. Use of these formulas and methods are given as guidance and their use is not mandatory. Other methods are acceptable provided that they are based on sound engineering principles and practices. The method contained in this appendix is intended to analyze traditional straight rafters installed in a radial fashion. It shall not be used to design umbrella or dome type roofs.

C-2 Nomenclature

The following nomenclature shall be used throughout this appendix.

D_i	Diameter to the inner support for rafters, ft (m)
D_o	Diameter to the outer support for rafters, ft (m)
F_b	Allowable bending stress, lbs/in^2 (MPa)
F_y	Yield stress, lbs/in^2 (MPa)
L	Rafter length, ft (m)
M	Applied bending moment, ft-lbs (N-m)
Rc	Shear at the end of the rafter supported by the center column, lbs (N)
Rsh	Shear at the end of the rafter supported by the tank shell, lbs (N)
S_i	Rafter spacing at the inner support, ft (m)
S_o	Rafter spacing at the outer support, ft (m)
W	Load on the rafter due to the uniformly increasing load, lbs (N)
W_i	Uniform load at the bearing point of the rafters on the column top plate, lbs/ft (N/m)
W_o	Uniform load at the outer end of the rafter, lbs/ft (N/m)
Z	Section modulus, in^3 (mm^3)
f_b	Actual bending stress, lbs/in^2 (MPa)
n	Number of rafters
t	Thickness of the roof plate, in (mm)
w	Total uniform load on the rafter, lbs/ft (N/m)
we	Applied live (snow) load on the rafter, lbs/ft (N/m)
wr	Weight of the rafter, lbs/ft (N/m)

C-3 Rafter Design

C-3.1 When rafters are configured radially, they shall be designed as simply supported beams subjected to a trapezoidal loading. Upon selecting the number of rafters and their length, the analysis may proceed as follows:

C-3.1.1 Determine the spacing and uniform loads at the inner and outer ends of the rafter where

$S_O = \pi D_O/n$ and $S_i = \pi D_i/n$

$W_O = S_O(we + 40.83t)$ and $W_i = S_i(we + 40.83t)$

C-3.1.2 Determine the total uniform load on the rafters:

$w = wr + W_i$

C-3.1.3 Determine the load on the rafter due to the uniformly increasing load (dead load and live load), W:

$W = (W_o - W_i)(L/2)$

C-3.1.4 From this, the applied bending moment can be determined:

$M = [0.1283WL + (wL^2/8)]\ (12)$

C-3.1.5 The actual bending stress can be determined as follows:

$f_b = M/Z$ where $f_b \geq F_b$

When lateral bracing consists only of the frictional resistance between the roof plate and the rafter compression flange, F_b = 15,000 lbs/in^2 (105 MPa) or 0.4 F_y. Stresses up to 0.6 F_y can be accepted if adequate lateral bracing (angles, etc.) are provided, or if the roof plate is welded or bolted to the rafter top flange.

C-3.1.6 Shear forces at each end of the rafter are determined as follows:

$Rc = (W/3) + (wL/2)$ and $Rsh = (2W/3) + (wL/2)$

APPENDIX D: Design of Foundation Bolts Using a Shear Cone Analysis

D-1 Introduction

This appendix has been included to provide assistance in designing certain features of the tank not covered in the main body of the Standard. Use of these formulas and methods are given as guidance and their use is not mandatory. Other methods are acceptable provided that they are based on sound engineering principles and practices.

D-2 Nomenclature

The following nomenclature shall be used throughout this appendix.

Φ	Concrete reduction factor, 0.65
d	Foundation bolt diameter, in (mm)
f'_c	Concrete compressive strength, lbs/in^2 (MPa)
m	Minimum foundation bolt edge distance, in (mm)
Acp	Area of shear cone, in^2 (mm^2)
AS	Tensile stress area of the foundation bolt, in^2 (mm^2)
Fu	Published ultimate tensile strength of the foundation bolt, lbs/in^2 (MPa)
Fut	Ultimate tensile strength of the foundation bolt, lbs/in^2 (MPa)
LB	Anchor bolt embedment length, in (mm)
PC	Concrete pull-out strength, lbs/in^2 (MPa)
R	Radius of the shear cone, in (mm)

D-3 Background

D-3.1 The capacity of foundation bolts is based on the pullout strength of the concrete failing in a shear cone type failure (a cone of concrete with an apex below the bottom of the foundation bolt). See Figure D-1.

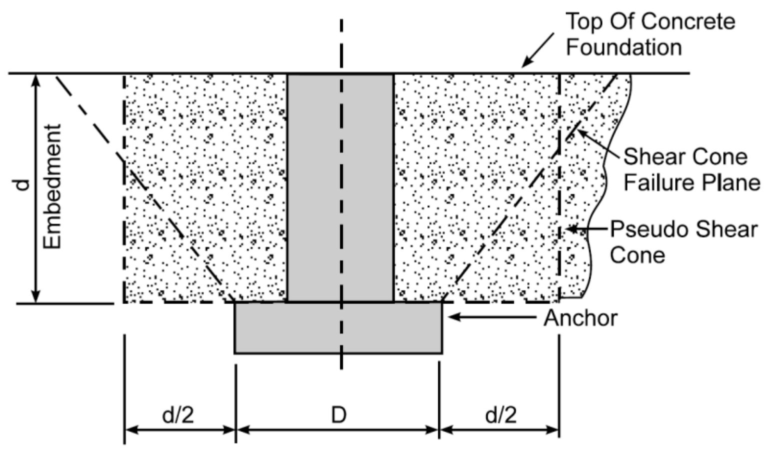


Figure D-1

D-3.2 Foundation bolt manufacturers publish values that include minimum center to center and free edge distance requirements that are needed in order for the bolt to develop its full strength. When these values are not maintained, the capacity of the bolt must be reduced because of the reduction of amount of concrete available to develop a shear cone. When bolts are spaced too close together, the capacity must be reduced to account for the fact that a certain portion of the shear cone is needed by both bolts in order to develop their full strength. In the case of bolts being placed too close to the edge of the concrete, the necessary area required for the development of the full strength in unavailable. See Figure D-2.

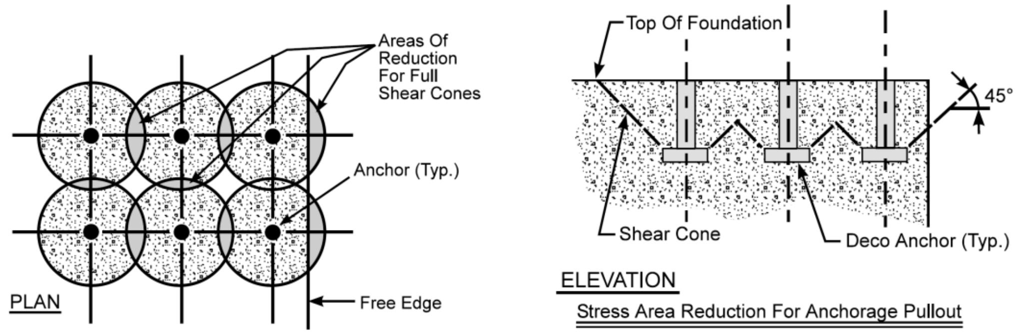


Figure D-2

D-3.3 The goal in using this method is to develop the concrete pull-out strength, PC, such that it is greater than the ultimate tensile strength of the foundation bolt, Fut, therefore,

$P_C \geq Fut$ where $Fut = A_S Fu$.

D-3.4 The minimum *Acp* is determined from the formula $\boldsymbol{Acp_{min}} = \boldsymbol{Fut}/[\mathbf{4}\ \boldsymbol{\Phi}\ (\boldsymbol{f'_c}^{1/2})\ ]$.

D-3.5 Based on Figure D-1, the area of the concrete cone radiating at a 45° from the bolt head (size of bolt head assumed to be 1.5*d*) is:

$Acp = \Pi\ [R^2 - (1.5d/2)^2]$ where $R = L_B + 1.5d/2$

therefore the minimum foundation bolt embedment length, $L_B = R - 1.5d/2$.

D-3.6 The minimum center to center bolt spacing $\geq 2R$.

D-3.7 The minimum foundation bolt edge distance is:

$$m = \left[0.25\ Fut/\left(4\ \Phi\ \Pi\ (\boldsymbol{f'_c}^{1/2})\right)\right]^{1/2}$$

D-3.8 When the center to center spacing or minimum edge distance is less than required, the capacity of the bolt shall be reduced in proportion to the reduction in the area of the conical surface.

APPENDIX E: Seismic Analysis of Certified Suction Tanks

E-1 Introduction

This appendix has been included to provide assistance in conducting a seismic analysis of flat bottom, ground supported pump suction tanks located in Earthquake Zones 50-year, 100-year, 250-year and 500-year.

E-2 Nomenclature

The following nomenclature shall be used throughout this appendix.

A	Area used to determine the centroid of the shell, ft^2 (m^2)
C_c	Coefficient for the convective period
C_i	Coefficient for the impulsive period
D	Tank diameter, ft (m)
E	Young's modulus of elasticity, lbs/in^2 (N/m^2)
G	Specific gravity
H	Height of the liquid in the tank, ft (m)
H_{sh}	Total height of the tank shell, ft (m)
I	Importance factor
J	Value used to determine whether there is uplift during a seismic event
MCE	Maximum Considered Earthquake
M_{EQ}	Overturning moment applied at the base of the tank shell due to earthquake, ft-lbs (N-m)
$M_{EQ}(z)$	Overturning moment at a height z above the tank base, ft-lbs (N-m)
M'_{EQ}	Overturning moment below the base of the tank due to earthquake, ft-lbs (N-m)
R	Tank radius, ft (m)
R_C	Force reduction factor for convective action (Allowable Stress Design)
R_i	Force reduction factor for impulsive action (Allowable Stress Design)
SA_c	Convective spectral acceleration (g)
SA_i	Impulsive spectral acceleration (g)
SA_v	Spectral acceleration of the vertical mode of vibration (g)
S_{Dl}	Design spectral acceleration at 1s period
S_{DS}	Design spectral acceleration at 0.2s period
T_c	Period of the convective mode, sec
T_i	Period of the impulsive mode, sec
TS	Control period of the design response spectra, s

V_{EQ}	Design shear at the base of the tank shell due to earthquake, lbs (N)
V_{RES}	Actual shear resistance at the base of the tank shell due to earthquake, lbs (N)
d_{sl}	Required freeboard, ft (m)
d_a	Actual (provided) freeboard, ft (m)
g	Acceleration due to gravity, ft/sec2 (m/sec2)
h_c	Height of the convective mass, ft (m)
h'_c	Height of the convective mass for obtaining the convective moment below the base plate, ft (m)
h_i	Height of the impulsive mass, ft (m)
h'_i	Height of the impulsive mass for obtaining the impulsive moment below the base plate, ft (m)
h_r	Distance to the center of gravity of the roof measured from the tank base, ft (m)
h_{sh}	Distance to the center of gravity of the tank shell measured from the tank base, ft (m)
m_b	Weight of the tank bottom plate, lbs (N)
m_c	Weight of the convective liquid, lbs (N)
$m_{C\text{-}IF}$	Weight of the convective liquid in the tank with insufficient freeboard, lbs (N)
m_i	Weight of the impulsive liquid, lbs (N)
$m_{i\text{-}IF}$	Weight of the impulsive liquid in the tank with insufficient freeboard, lbs (N)
m_l	Total liquid weight, lbs (N)
m_r	Weight of the roof (dead load and live load), lbs (N)
m_{sh}	Weight of the tank shell, lbs (N)
t_b	The thickness of the tank bottom plate, in (mm)
t_s	Thickness of the shell at the base, in (mm)
t_z	Thickness of the tank shell at height z, in. (mm)
t_{eq}	Equivalent uniform thickness of the tank shell, in (mm)
w_L	The maximum weight of the tank contents per foot of circumference that may be used to resist the shell overturning moment, lbs/ft (kg/m)
w_t	The weight of the tank shell per foot of circumference, lbs/ft (kg/m)
$\bar{y}$	Distance to the centroid of a section as measured from a datum, ft (m)
z	Height from the tank base, ft (m)
μ_c	Factor for reducing the convective moment with height z from the base
μ_i	Factor for reducing the impulsive moment with height z from the base

ρ	Weight density of the liquid, lbs/ft^3 (N/m^3)
ρ_v	Hydrodynamic base pressure due to vertical motion, lbs/ft^2 (N/m^2)
σ_c	The longitudinal shell compression stress, lbs/in^2 (MPa)
σ_h	The hoop tensile stress at any point z from the tank base, lbs/in^2 (MPa)
σ_y	The allowable shell plate yield stress, lbs/in^2 (MPa)

E-3 Background (Ref. 1, 2, 3 and 4)

E-3.1 The liquid mass in a tank subjected to seismic shaking is divided into two parts. The first is the impulsive mass near the base of the tank that moves in unison with the tank wall. The second is the convective mass near the free surface that is subjected to a sloshing motion.

E-3.2 The response of the impulsive mass determines the seismic base shear and overturning moment in the tank. The response of the convective mass determines the height of the sloshing wave near the free surface of the tank.

E.3.2.1 For tanks with an inadequate freeboard, the impacts from the sloshing liquid generate upward forces on the tank roof which are transmitted to the tank wall. These forces must be considered when designing the tank. For guidelines on analyzing suction tanks that have insufficient freeboard, see Appendix F.

E-3.3 The analysis assumes that the damping value for the impulsive action is 5% of the critical damping value and the damping value for the convective action is 0.5% of the critical damping value.

E-4 Determining the Sloshing Wave Height

E-4.1 The maximum vertical displacement of the sloshing wave, d_{sl} (which also happens to be the required freeboard) at the perimeter of the liquid surface shall be determined as follows:

$$d_{sl} = \frac{D \times SA_c}{2} \qquad \text{(Eq. 1)}$$

where SA_c is the convective acceleration determined from paragraph E-6.1.

E-4.2 When the actual (provided) freeboard, $d_a \geq d_{sl}$, there are no resulting uplift forces on the tank roof. The impulsive and convective masses are determined from Table E-1.

E-4.3 When the actual (provided) freeboard, $d_a < d_{sl}$, then consideration must be given to the resulting uplift forces on the tank roof (see Appendix F) as the constraining motion causes a portion of the convective liquid to act as an impulsive load. When this occurs, the impulsive and convective weights shall be revised as follows:

$$m_{i-IF} = m_i + \left[m_c \times \left(1 - \frac{d_a}{d_{sl}}\right)\right] \qquad \text{(Eq. 2)}$$

$$m_{C-IF} = m_l - m_{i-IF} \qquad \text{(Eq. 3)}$$

$$m_l = \frac{\pi D^2 H}{4} \times \rho \qquad \text{(Eq. 4)}$$

Where m_i and m_c are determined from Table E-1.

References:

1. 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.
2. Malhotra, P., Wenk, T., and Wieland, M., "Simplified Procedure for Seismic Analysis of Liquid-Storage Tanks," *Structural Engineering International,* Vol. 10, No. 3, 2000.
3. ASCE 7-02, "Minimum Design Loads for Buildings and Other Structures," *American Society of Civil Engineers,* Reston, VA, 2003.
4. Malhotra, P., "Sloshing loads in liquid-storage tanks with insufficient freeboard," *Earthquake Spectra,* Vol. 21, No. 4, 2005.

E-5 Determination of Overturning Moments and Base Shear

E-5.1 The base shear and overturning moments due to seismic forces shall be determined in accordance with the following formulas:

E-5.2 The overturning moment above the base plate shall be determined as follows: [used for determining the shell stress at the base and overturning moment in a ringwall foundation].

$$\boldsymbol{M_{EQ}\,(z)} = \sqrt{\left\{\frac{[(\boldsymbol{m_i \times h_i}) + (\boldsymbol{m_{sh} \times h_{sh}}) + (\boldsymbol{m_r \times h_r})] \times \boldsymbol{SA_i}}{\boldsymbol{R_i / I}}\right\}^2 + \left\{\frac{(\boldsymbol{m_c \times h_c \times \mu_c \times SA_c})}{\boldsymbol{R_c}}\right\}^2} \qquad \text{(Eq. 5)}$$

where m_i , h_i , mc and h_c are determined from Table E-1

R_i and R_c are determined from Table E-2

I = 1.25

SA_i and SA_c are determined from paragraph E-6

E-5.3 The overturning moment at a height *z* from the base shall be determined as follows:

$$M_{EQ}\,(z) = \sqrt{\left\{\frac{[(m_i \times h_i \times \mu_i) + (m_{sh} \times (h_{sh} \times \mu_i)) + (m_r \times (h_r - z))] \times SA_i}{R_i / I}\right\}^2 + \left\{\frac{(m_c \times h_c \times \mu_c \times SA_c)}{R_c}\right\}^2} \qquad \text{(Eq. 6)}$$

where z = the height at any point above the tank base

μ_i and μ_c are values that are determined from Figure E-3

E-5.4 The overturning moment below the base plate shall be determined as follows: [used in the design of mat and pile foundations]

$$M'_{EQ} = \sqrt{\left\{\frac{[(m_i \times h'_i) + (m_{sh} \times h_{sh}) + (m_r \times h_r)] \times SA_i}{R_i / I}\right\}^2 + \left\{\frac{m_c \times h'_c \times SA_c}{R_c}\right\}^2} \qquad \text{(Eq. 7)}$$

where h'_i and h'_c are determined from Table E-1

E-5.5 The natural periods of the impulsive (Ti) and the convective (Tc) modes of vibration, in seconds, shall be determined as follows*:

$$T_i = \frac{C_i \times \sqrt{\rho} \times H}{\sqrt{\frac{t_{eq}}{6D}} \times \sqrt{144\,Eg}} \qquad \text{(Eq. 8)}$$

*This equation is valid only for US units.

where
$$T_c = C_c \times \sqrt{0.5D} \qquad \text{(Eq. 9)}$$

where C_i and C_c are determined from Table E-1

t_{eq} is the equivalent uniform tank shell thickness using only the normally wetted portions of the tank shell

[t_{eq} is a weighted average based on the thickness of each shell plate and the distance from the centroid of that shell plate to the top of the overflow − see paragraph E-12.3]

E-5.6 The shear force at the base of the tank shall be determined as follows:

$$V_{EQ} = \sqrt{\left\{\frac{(m_i + m_{sh} + m_r + m_b) \times SA_i}{R_i/I}\right\}^2 + \left\{\frac{(m_c \times SA_c)}{R_c}\right\}^2} \quad (1.1^*) \qquad \text{(Eq. 10)}$$

*1.1 is a safety factor applied to V_{EQ}

Table E-1

Recommended design values for the impulsive and convective modes of vibration as a function of the liquid height to radius ratio (*H/R*) for the tank.

H/R (1)	m_i/m_l (2)	m_c/m_l (3)	C_i (4)	C_c* (5)	C_v (6)	h_i/H (7)	h_c/H (8)	h_i'/H (9)	h_c'/H (10)
0.3	0.176	0.824	9.28	1.153	9.83	0.400	0.521	2.640	3.414
0.5	0.300	0.700	7.74	0.959	7.91	0.400	0.543	1.460	1.517
0.7	0.414	0.586	6.97	0.881	7.04	0.401	0.571	1.009	1.011
1.0	0.548	0.452	6.36	0.838	6.43	0.419	0.616	0.721	0.785
1.5	0.686	0.314	6.06	0.820	6.03	0.439	0.690	0.555	0.734
2.0	0.763	0.237	6.21	0.817	5.87	0.448	0.751	0.500	0.764
2.5	0.810	0.190	6.56	0.817	5.80	0.452	0.794	0.480	0.796
3.0	0.842	0.158	7.03	0.817	5.75	0.453	0.825	0.472	0.825

*C_c expressed in s / √ft

Note – values are to be interpolated where appropriate.

Table E-2

Tank type	*Ri*	*Rc*
Anchored (welded or bolted)	4	2
Unanchored (welded or bolted)	3.5	2

Values are for Allowable Stress Design (ASD)

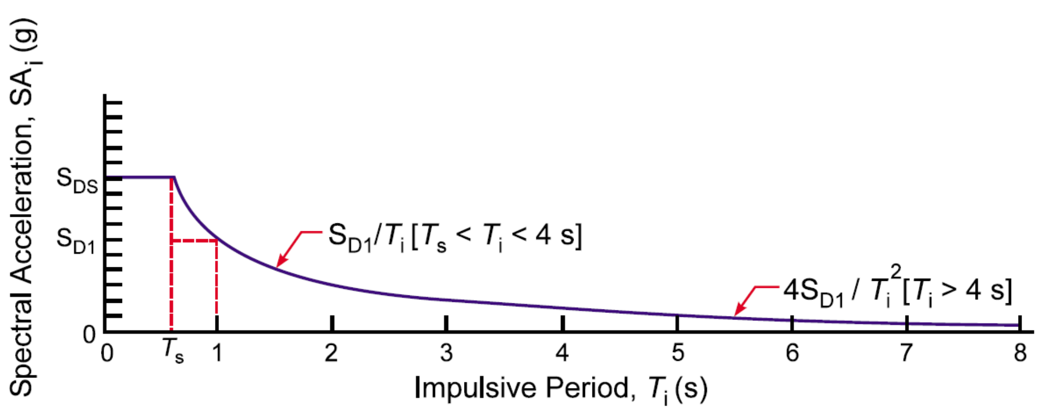
E-6 Seismic Response Spectra

E-6.1 The seismic response spectra of the horizontal base motion are needed to calculate the impulsive and convective spectral accelerations SA_i and SA_c. These are then used in calculating the sloshing wave height, the overturning moments and the base shear. Generic seismic spectral accelerations are shown in Table E-3. If the tank is to be designed using site specific spectral acceleration factors, see paragraph 2.17.4 of this standard for guidance.

E-6.2 The soil-structure interaction (SSI) shall be permitted to be considered to increase the impulsive period and damping. The net reduction in impulsive spectral acceleration, SA_i, due to SSI shall not be more than 30%.

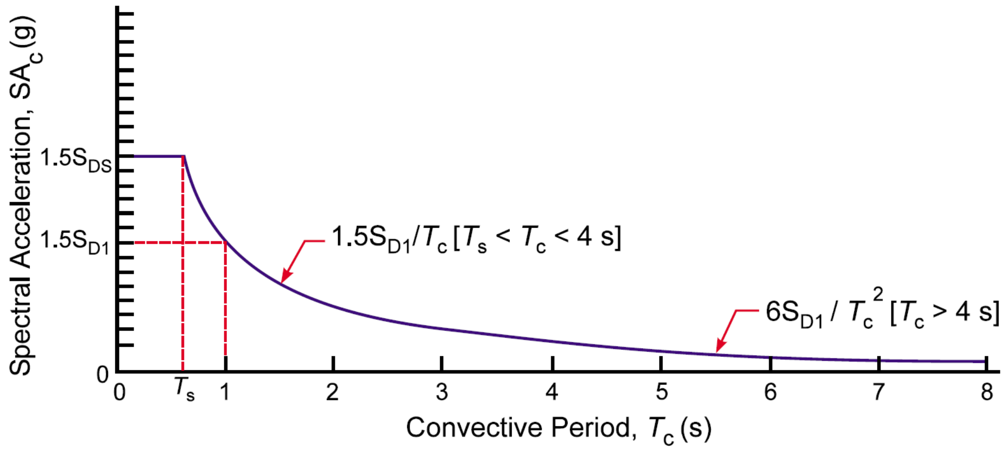
Table E-3

FM Zone	S_{DS}	S_{D1}
50-year	1.3 g	0.8 g
100-year	0.9 g	0.45 g
250- / 500-year	0.55 g	0.25 g



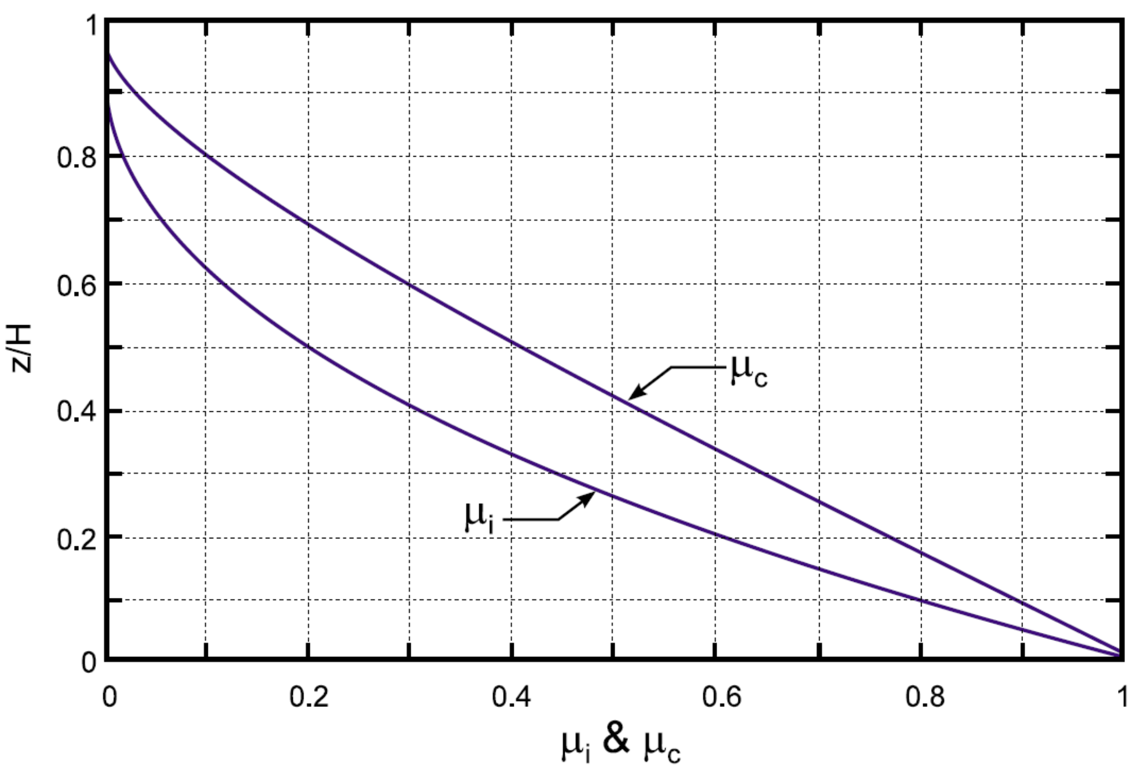
5% of Critical Damping Response Spectrum for Impulsive Action

Figure E-1



0.5% of Critical Damping Response Spectrum for Convective Action

Figure E-2



Factors for Reducing Impulsive and Convective Overturning Moments with Height (z) from the Base

Figure E-3

E-6.3 The impulsive spectral acceleration, SAi is determined from Figure E-1 for the various period ranges defined as follows:

$$SA_i\,(T_i) = \begin{cases} S_{DS} & T_i \; < \; T_s \\ S_{D1}/T_i & T_S \; \leq \; T_i \leq 4\text{ sec} \\ 4S_{D1}/T_i^2 & T_i \; > \; 4\text{ sec} \end{cases} \qquad \text{(Eq. 11)}$$

where

$$T_S = \frac{S_{D1}}{S_{DS}} \qquad \text{(Eq. 12)}$$

E-6.4 The convective spectral acceleration, SAc, is determined from Figure E-2 for the various period ranges defined as follows:

$$SA_c\,(T_c) = \begin{cases} 1.5\,S_{DS} & T_c \; < \; T_s \\ 1.5\,S_{D1}/T_c & T_S \; \leq \; T_c \leq 4\text{ sec} \\ 6\,S_{D1}/T_i^2 & T_c \; > \; 4\text{ sec} \end{cases} \qquad \text{(Eq. 13)}$$

E-7 Spectral Acceleration of Vertical Motion

E-7.1 E-7.1 The vertical motion of the tank base includes hydrodynamic wall pressures which are uniform in the circumferential direction and increase approximately linearly from the water surface to the base of the tank. The hydrodynamic wall pressures induce hoop stresses in the tank wall which need to be combined with the hoop stresses due to hydrostatic pressure.

E-7.2 E-7.2 The natural period of the vertical mode of vibration is determined from the equation below*. The coefficient Cv is taken from Table E-1.

$$T_v = \frac{C_v \times \sqrt{\rho}\; \times\; H}{\sqrt{\frac{t_{eq}}{6D}} \times \sqrt{144Eg}} \qquad \text{(Eq. 14)}$$

*This equation is valid only for US units.

E-7.3 The spectral acceleration of the vertical motion, SA_V, is taken as ⅔ the spectral acceleration read from the 5% damping response spectrum (Fig. E-1) for the period $T = T_V$.

E-8 Resistance to Overturning

E-8.1 The resistance to the overturning moment at the bottom of the shell may be provided by the weight of the tank shell, the weight of the roof deadload supported by the tank shell and by the weight of a portion of the tank contents adjacent to the shell for unanchored tanks or by anchorage of the tank shell.

E-8.2 For unanchored tanks, the portion of the contents that may be used to resist overturning is dependant on the width of the bottom annulus. The annulus may be a separate ring or an extension of the bottom plate if the required thickness does not exceed the bottom thickness. The weight of the annulus that lifts off the foundation shall be determined as follows:

$w_L = 7.9\; t_b\, [\sigma_y\;\; H\, G]^{½} \leq 1.28\;\; H\, D\, G$ (lbs/ft)

where t_b = the thickness of the bottom annulus (in)

σ_y = the minimum specified yield strength of the bottom annulus (lbs/in^2)
H = the maximum depth of the water (ft)
D = the tank diameter (ft)
G = specific gravity (1.0 for water)

E-8.3 The weight of the tank shell and the deadload of the roof supported by the shell, wt, in pounds per foot of circumference, shall be determined as follows:

$$w_t = \frac{m_{sh} + m_r}{\pi \times D}$$

where msh = the weight of the tank shell (lbs)
D = the tank diameter (ft)
mr = the weight due to the deadload of the roof acting on the shell (lbs)

E-9 Resistance to Sliding

E-9.1 For unanchored tanks, the resistance to sliding shall be determined as follows:

$V_{RES} = \tan 20^\circ \quad (m_{sh} + m_r + m_i + m_c + m_b)\,(1.0 - [\,0.4 \times SA_v]\,)$

$V_{RES} \geq V_{EQ}$

where SA_v is the spectral acceleration of vertical motion. It is taken as ⅔ the spectral acceleration read from the 5% damping response spectrum (Fig. E-1) for the period T = Tv.

E-10 Shell Compression

E-10.1 The determination of the maximum longitudinal shell compression depends on whether the amount of uplift as well as whether the tank is anchored or unanchored. To determine if uplift exists, the value for the equation shown below must be determined:

$$J = \frac{M_{EQ}}{D^2\,(w_t + w_L)}$$

E.10.1.1 When $J \leq 0.785$, there is no uplift

E.10.1.2 When $0.785 < J \leq 1.54$, there is uplift

E.10.1.3 When $J \geq 1.54$, the bottom annulus must be thickened or the tank must be anchored.

E-10.2 The maximum longitudinal shell compression stress at the bottom of the shell when there is no uplift or when the tank has been anchored shall be determined as follows:

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

E-10.3 When there is uplift but the tank has not been anchored, the maximum longitudinal shell compression stress at the bottom of the shell shall be determined as follows:

$$\sigma_c = \left(\frac{w_t + w_L}{0.607 - 0.18667\left[\frac{M_{EQ}}{D^2(w_t + w_L)}\right]^{2.3}} - w_L\right)\frac{1}{12\,t_s} \qquad \text{(Eq. 15)}$$

E-10.4 E-10.4 The allowable seismic stress, σe, shall be determined in accordance with AWWA D100-96 (welded tanks) or D103-97 (bolted tanks).

E-11 Hydrodynamic Base and Hoop Tensile Stresses

E-11.1 The hydrodynamic base pressure due to vertical motion is determined as follows:

$$p_v = \frac{\rho \cdot SA_v \cdot H}{(R_i/I)} \quad \text{(Eq. 16)}$$

E-11.2 The hoop tensile stress due to vertical motion at any height z from the tank base is determined as follows:

$$\sigma_h = \frac{p_v \times D}{24t_z} \times \frac{H-z}{H} \quad \text{(Eq. 17)}$$

E-11.3 The net hoop stress at any height z is determined as follows:

$$\sigma_t = \sigma_h + \left[\rho \times (H+z) \times \frac{D}{24t_z}\right] \quad \text{(Eq. 18)}$$

E-12 Seismic Analysis Example

E-12.1 The following is provided as an example on how this method is used. For this example, the following information is provided:

- Earthquake Zone 100-year
- All steel, F_y = 36,000 lbs/in2
- The tank is anchored
- Tank bottom plate thickness = 0.313 in
- Tank height = 24 ft
- Tank diameter = 47.83 ft
- Freeboard provided = 14 in
- Live load = 25 lbs/ft^2
- Total dead load of the roof carried by the shell = 21,000 lbs

Note: This example will be done using English units. Units, if not shown, have been omitted for clarity.

E-12.2 Determine the following constants:

$\frac{H}{R}$ where

$$H = 24 - \left(\frac{14}{12}\right) = 22.8 \text{ ft}$$

$$R = \frac{47.83}{2} = 23.92 \text{ ft}$$

$$\frac{H}{R} = \frac{22.8\text{ ft}}{23.92\text{ ft}} = .95$$

Live load on the roof $= \frac{\pi(47.83)^2\,(25)}{4} = 44{,}920\text{ lbs}$

E.12.2.1 Interpolating from Table E-1:

$\frac{m_i}{m_l} = .526$ $C_i = 6.46$ $C_v = 6.53$

$\frac{m_c}{m_l} = .474$ $C_c = .845$

$\frac{h_i'}{H} = .769$ ∴ $h_i' = 17.53$

$\frac{h_c'}{H} = .823$ ∴ $h_c' = 18.76$

$\frac{h_c}{H} = .609$ ∴ $h_c = 13.89$

$\frac{h_i}{H} = .416$ ∴ $h_i = 9.48$

E-12.3 Determine the equivalent uniform shell plate thickness. Each shell ring is 8 ft in height:

Ring	*t*
3 (Top)	0.25 in.
2	0.25 in.
1	0.313 in.

$$t_{eq} = \frac{\left[\left(\frac{0.313}{12}\right)(8)(22.8-4)\right] + \left[\left(\frac{0.25}{12}\right)(8)(22.8-12)\right] + \left[\left(\frac{0.25}{12}\right)(8)(22.8-4*)\right]}{(8 \times 18.8) + (8 \times 10.8) + (6.8 \times 3.4)}$$

$$= \frac{6.289}{259.92} = 0.024\text{ ft} = 0.29\text{ in}$$

* Note: The value 19.4 $= \frac{(22.8-16)}{2} + 8 + 8$

E.12.3.1 The weight of the shell is determined as follows:

$$m_{sh} = \left(\frac{0.313 + 0.25 + 0.25}{12}\right)(490)(8)(\pi)(47.83) = 39{,}906 \text{ lbs}$$

E-12.4 Determine the centroid of the shell:

Ring	A		$\bar{y}$	$\bar{y}A$
3	$\left(\frac{.25}{12}\right)(8) =$	.167	20	3.33
2	$\left(\frac{.25}{12}\right)(8) =$	.167	12	2.00
1	$\left(\frac{.313}{12}\right)(8) =$	.209	4	.84
	$\sum =$	.543	$\sum =$	6.17

$$\bar{y} = \frac{\Sigma \bar{y}A}{\Sigma A} = \frac{6.17}{.543} = 11.36 \text{ ft} = h_{sh}$$

E-12.5 Determine T_i, T_c and T_v

$$T_i = \frac{6.46(62.4)^{½}(22.8)}{\left(\frac{.29}{(6)(47.83)}\right)^{½}\left[(144)(29 \times 10^6)(32.2)\right]^{½}} = .101 \text{ sec} \quad \text{(Eq. 8)}$$

$$T_c = .845\,[0.5 \times 47.83]^{½} = 4.13 \text{ sec} \quad \text{(Eq. 9)}$$

$$T_v = .101\left(\frac{6.53}{6.46}\right) = .100 \text{ sec} \quad \text{(Eq. 14)}$$

E-12.6 Determine the seismic response spectra SA_i and SA_c

From Table E-3, the 100-year values are:

$S_{DS} = .9\,g$ $\qquad$ $S_{D1} = .45\,g$

$$T_s = \frac{S_{D1}}{S_{DS}} = \frac{.45\,g}{.9\,g} = .5 \text{ sec} \quad \text{(Eq. 12)}$$

E.12.6.1 Determine *SAi*

$T_i = .101$ sec $\qquad$ $T_s = .5$ sec

since $T_i < T_s$; $SA_i = S_{DS} = .9\,g$ (Eq. 11)

E.12.6.2 Determine SA_c

$T_c = 4.13 \quad > 4\,\text{sec}$

$$SA_c = \frac{(6)(0.45)}{4.13^2} = .158\,g \qquad \text{(Eq. 13)}$$

E-12.7 Determine the sloshing wave height

$$d_{sl} = \frac{(47.83)(0.158)}{2} = 3.78\text{ ft} \qquad \text{(Eq. 1)}$$

The freeboard provided, d_a = 1.17 ft < d_{sl}

Since d_a < d_{sl} , the effect of the roof must be considered and m_i and m_c must be adjusted. The values m_i and m_c will be replaced in the equations by $m_{i\text{-}If}$ and $m_{C\text{-}IF}$ respectively.

E-12.8 Adjustments to the masses due to insufficient freeboard

$$m_l = \frac{\pi\,(47.83)^2\,(22.8)\,(62.4)}{4} = 2{,}556{,}290\text{ lbs} \qquad \text{(Eq. 4)}$$

$$m_i = (2{,}556{,}290)(.526) = 1{,}344{,}609\text{ lbs} \qquad \text{(see E-12.2)}$$

$$m_c = (2{,}556{,}290)(.474) = 1{,}211{,}681\text{ lbs} \qquad \text{(see E-12.2)}$$

$$m_{i-IF} = 1{,}344{,}609 + \left[\left(1{,}211{,}681\right)\left(1 - \frac{1.17}{3.78}\right)\right] = 2{,}181{,}246\text{ lbs} \qquad \text{(Eq. 2)}$$

$$m_{C-IF} = 2{,}556{,}290 - 2{,}181{,}246 = 375{,}044\text{ lbs} \qquad \text{(Eq. 3)}$$

**Note: $m_{i\text{-}IF}$ and $M_{C\text{-}IF}$ are substituted for m_i and m_c only when the freeboard is insufficient.

E-12.9 Determine the overturning moments (using 100% of the roof live load) [A second analysis would also be required using 0 lbs as the roof live load per paragraph 2.17.5]

E.12.9.1 M_{EQ} – the moment above the base plate (used for shell plate stresses)

$$M_{EQ} = \left[\left[\frac{(2{,}181{,}246)(9.48) + (39{,}906)(11.4) + (21{,}000 + 44{,}920)(24)(.9)}{4/1.25}\right]^2 + \left[\frac{(375{,}044)(13.89)(.158)}{2}\right]^2\right]^{1/2}$$

$$= 6{,}403{,}017\text{ ft-lbs} \qquad \text{(Eq. 5)}$$

E.12.9.2 M_{EQ} *(z)*– The moment at any height above the base plate. Use z = 8 ft

E.12.9.2.1 Determine $\boldsymbol{\mu_i + \mu_c}$ @ $\boldsymbol{z = 8}$

$$\frac{z}{H} = \frac{8}{22.8} = .35$$

$\mu_i = .38$ $\qquad$ $\mu_c = .58$ $\qquad$ Fig E-3

E.12.9.2.2 M_{EQ} (8) =

$$\left[\left[\frac{(2{,}181{,}246)(9.48)(.38) + (39{,}906)(11.4)(.38) + (21{,}000\ + 44{,}920)(24-8)(.9)}{4/1.25}\right]^2 + \left[\frac{(375{,}044)(13.89)(.58)(.158)}{2}\right]^2\right]^{1/2}$$

= 2,604,032 ft-lbs (Eq. 6)

E-1.1.1.1 M'_{EQ}– the moment below the base plate (used for designing the foundation)

$$M'_{EQ} = \left[\left[\frac{[(2{,}181{,}246)(17.53) + (39{,}906)(11.4)(.38) + (21{,}000\ + 44{,}920)(24)(.9)]}{4/1.25}\right]^2 + \left[\frac{(375{,}044)(18.76)(.158)}{2}\right]^2\right]^{1/2}$$

= 11,341,883 ft-lbs (Eq. 7)

E-12.10

$$V_{EQ} = \left[\left[\frac{[(2{,}181{,}246 + 39{,}906 + (21{,}000\ + 44{,}920) + 22{,}927)(.9)\ )]}{4/1.25}\right]^2 + \left[\frac{[(375{,}044)\ (.158)]}{2}\right]^2\right]^{1/2} \quad (1.1)$$

= 715,398 lbs (Eq.10)

E-12.11 Determine the resistance to overturning

w_L = (7.9)(.313)[(36,000)(22.8)(1)]½ = 2240 lbs/ft (see E-8.2)

but is limted to

(1.28)(22.8)(47.83)(1) = 1396 lbs/ft (controls)

$$w_t = \frac{(42{,}115 + 21{,}000)}{\pi(47.83)} = 420 \text{ lbs/ft}$$ (see E-8.3)

E-12.12 Determine the resistance to sliding

E.12.12.1 Determine SA_v (see E-7.3)

A_t T_v = .100 sec and T_s = .5 sec (see E-12.5 and E-12.6)

SA_i = S_{DS} = .9 *g*

SA_v = 2/3 (.9 *g*) = .6 *g*

E.12.12.2

$$V_{RES} = \tan 20° \,(39{,}906 + 21{,}000 + 44{,}920 + 2{,}181{,}246 + 375{,}044 + 22{,}927)\ [1 - (0.4)(0.6)]$$

= 742,730 lbs (see E-9.1)

Since $V_{RES} > V_{EQ}$ ∴ OK

E-12.13 Determine if there is uplift

$$J = \frac{6{,}403{,}017}{(47.83)2\ [420 + 1396]} = 1.55 > 1.54$$

Therefore the tank must be anchored. (see E-10)

E-12.14 Because there is uplift, the shell compressive stresses would be determined per E-10.2. The allowable stresses would be determined by E-10.4.

E-12.15 Anchor bolts would need to be designed per Appendix D.

E-12.16 The roof design must be analyzed for consideration of the effects of constraint due to insufficient freeboard per E-11 and Appendix F.

APPENDIX F: Roof Loads in Suction Tanks with Insufficient Freeboard

F-2 Introduction

F-2.1 This appendix has been included to provide assistance in determining the seismic forces imparted onto he roofs of flat bottom, ground supported pump suction tanks when the provided freeboard is less than the calculated freeboard.

F-2.2 When the actual freeboard, da is smaller than the required freeboard, d_{sl}, a portion of the tank roof will be wetted by the sloshing wave (see Figure F-1). This causes uplift forces on the tank roof.

F-2.3 In addition, the constraining action of the roof on the sloshing motion causes a portion of the convective liquid to act as an impulsive liquid. For the effect of this on the convective and impulsive masses, see Appendix E.

F-2.4 When the provided freeboard is equal to/or greater than the calculated freeboard, the effect of the sloshing wave on the roof is not required.

F-2.5 For the purpose of calculating roof loads in tanks with cone or dome shaped roofs, the actual freeboard shall be permitted to be increased by an amount h_r /3.

F.3 Nomenclature

F_{max} Maximum uplift force per circumferential width of the roof to shell connection, lbs (N)

P_{max} Maximum uplift pressure on the perimeter of the roof due to the sloshing wave, lbs/ft^2 (N/m^2)

D Tank diameter, ft (m)

SA_c The convective spectral acceleration (see Appendix E)

d_{sl} Required freeboard, ft (m)

d_a Actual (provided) freeboard, ft (m)

h_r The maximum height of the cone/dome roof measured from the top of the tank shell, ft (m)

x_f Wetted width of the tank roof due to sloshing action, ft (m)

ρ Weight density of water, lbs/ft^3 (kg/m^3)

F-3 Roof Loads

F-3.1 The normalized wetted width, x_f / D is read from Figure F-2 as a function of the ratio between the actual and the required freeboard, d_a /d_{sl}

F-3.2 The maximum uplift pressure on the perimeter of the roof due to the sloshing wave is determined as follows:

$$P_{max} = \rho \ x_f \ SAc$$

F-3.3 F-3.3 The maximum uplift force per circumferential with of the roof to shell connection is estimated from the following equation, or it may be calculated more accurately:

$$F_{max} \approx 0.5 \rho \ x_f{}^2 \ SA_c$$

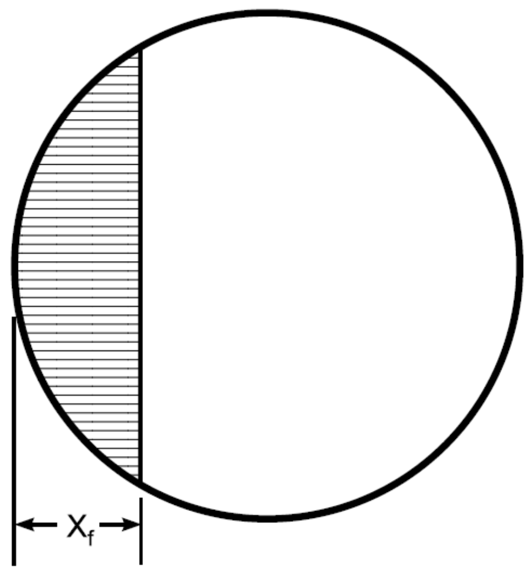


Figure F-1. Top view of a tank showing the wetted portion of the roof.

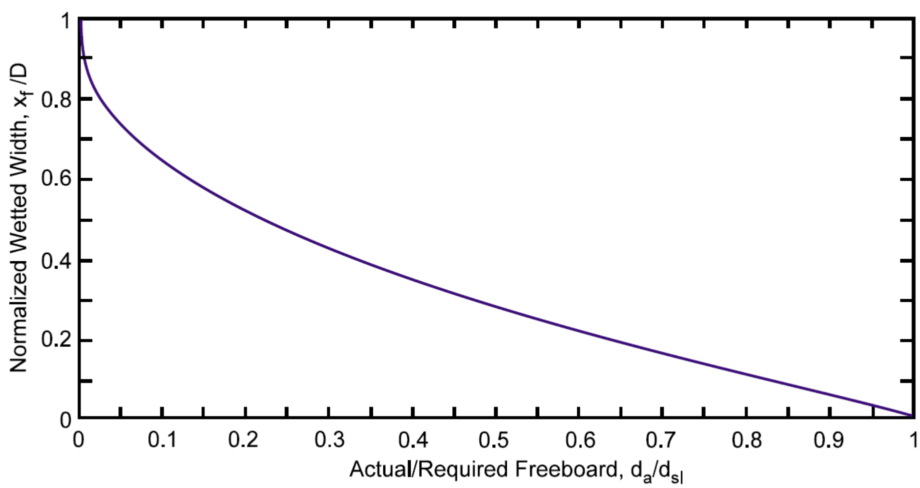


Figure F-2. Normalized wetted width of the tank roof, xf /D as a function of the actual/required freeboard.