WATER TANKS FOR FIRE PROTECTION

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1.0 SCOPE

There are four types of fire protection water tanks: gravity tanks, fire pump suction tanks, pressure tanks, and break tanks. This data sheet provides recommendations and general information relating to the selection and use of these fire protection tanks and their ancillary structures and equipment.

This document covers fire pump suction tanks constructed of steel, concrete or wood. For embankment supported fabric tanks, see Data Sheet 3-4, *Embankment-Supported Fabric Tanks,* and for lined-earth reservoirs, see Data Sheet 3-6, *Lined Earth Reservoirs for Fire Protection.* For fire pumps and their piping also see Data Sheet 3-7, *Fire Protection Pumps* and, where the location is exposed to earthquakes, Data Sheet 2-8, *Earthquake Protection for Water-Based Fire Protection Systems.*

1.1 Hazards

Fire protection water tanks that are not properly designed to resist hydrostatic forces, or forces from snow, wind, or earthquake, may fail. Tanks may also fail in locations subject to low temperatures if the contained water, or at least the top layer, freezes because heaters are inadequate. Additionally, without proper design and configuration of accessories (such as fill valves and suction tank anti-vortex plates) and ancillary equipment (such as heaters), tank function can be compromised. Finally, when tanks and their associated equipment are not properly maintained they can deteriorate; sediment and foreign objects can be introduced into the system, obstructing pipes and sprinklers; and water in the tank can freeze during cold weather. Proper design, configuration, and maintenance are required so the water supply is adequate and reliable under all conditions.

1.2 Changes

July 2022. Interim revision. The new FM Global Worldwide Freeze Map, available online at www.fmglobal.com, has been developed using recent worldwide temperature data. The map now uses 100-year return period daily minimum temperature (100-year DMT) zones to identify areas having a significant weather-related freeze hazard. This temperature measure differs from that previously used (the lowest one-day mean temperature [LODMT]). Data Sheet 9-18, *Prevention of Freeze-Ups*, has also been revised to align with the new FM Global Worldwide Freeze Map. Revisions are made such that guidance is appropriate for the new 100-year DMT zones and reflects Data Sheet 9-18, *Prevention of Freeze-Ups*, changes. Some editorial changes are made as well. Significant revisions include:

A. Added Section 1.1, Hazards

B. Revised Section 2.2.6, Protecting Tanks and Tank Piping Against Freezing

C. Revised Recommendation 2.3.9 to restore precautions, inadvertently deleted in the previous revision, to follow when tanks are drained

D. Added freeze-related Recommendation 2.3.10, and revised freeze guidance in Recommendations 2.3.11 and 2.3.12

E. Revised Section 3.7.2, Frost-proof Casings

F. Revised Section 3.8, Tank Heating Equipment

G. Revised Section 3.8.2, Circulating Heating Systems

H. Revised Section 3.8.3, Vertical Radiator Heaters

I. Revised Section 3.8.4, Steam Coil Inside Tanks

J. Revised heat loss guidance in Table 6 through Table 9, and water-circulating pipe guidance in Table 11

K. Replaced Figures 23 and 24 with an overview of the FM Global Worldwide Freeze Map

L. Added a reference to Data Sheet 9-18 in Section 4.1

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

Selection of a gravity tank is determined by the capacity and pressure required for both sprinklers and hose streams for the design duration of a fire. Pressure tanks used as the sole water supply must likewise provide adequate capacity, duration and pressure; however, pressure tanks may also be used in combination with other water sources to meet these demands. Fire pump suction tanks are usually sized to meet the total water demand for sprinklers and hose streams for the design duration of a fire.

Break tanks are used when a direct connection between a public water supply and a private fire protection system is prohibited. They act as a physical separation between public water distribution systems and private fire protection systems. Break tanks are not intended to have a capacity that meets the total sprinkler and hose stream demand for the design duration. A fire pump takes suction from one end of the tank as the public water supply automatically fills from the opposite end.

When purchasing a new fire protection tank, specify the type, capacity, and height; the roof live (or snow) load, wind speed and FM earthquake zone (see Section 2.2.3); and the need for FM Approval.

Use FM Approved equipment, materials, and services whenever they are applicable and available. For a list of products and services that are FM Approved, see the *Approval Guide,* an online resource of FM Approvals (www.approvalguide.com).

2.2 Construction and Location

2.2.1 General

2.2.1.1 Design ground-supported, flat-bottom, cylindrical steel (bolted or welded) suction tanks, steel gravity tanks, and their accessories per FM Approvals Standard 4020, *Approval Standard for Steel Tanks for Fire Protection* (access available via www.fmglobal.com) and other standards referenced by that document (also see Section 2.2.3 and Appendix E).

2.2.1.2 Design suction, break, and gravity tanks of other materials (e.g., concrete) using the general principles of FM Approvals Standard 4020 and consensus standards applicable to the material being used (e.g., American Concrete Institute standards ACI 350, ACI 350.3 and ACI 318). Ensure tanks have roofs and are designed to resist fluid loads, as well as snow, wind, earthquake and soil loads appropriate for the facility location as outlined in Section 2.2.3.

2.2.1.3 Design pressure tanks per the requirements in NFPA 22, *Standard for Water Tanks for Private Fire Protection and the ASME Boiler and Pressure Vessel Code,* “Rules for the Construction of Pressure Vessels,” Section VIII, Division 1. Locate the pressure tank, and associated valves and piping, in a heated area, or otherwise protect them from damage if subject to freezing temperatures.

2.2.1.4 Clients of FM should submit design documents (drawings, calculations, material cut sheets, etc.) to FM for review and approval.

2.2.1.5 If the tank is one of multiple water supplies, maximize system reliability and hydraulic characteristics by locating it at the end of the yard system opposite the other water source(s) if possible.

2.2.1.6 If possible, support gravity tanks on independent steel or concrete towers rather than on buildings, making them isolated structures unaffected by the failure of walls or columns. Design supporting tower and building structural members to carry all applicable loads from the tank (e.g., gravity loads from the tank and contained water weights, earthquake forces, wind forces). Do not use wood members to support gravity tanks.

2.2.1.7 Locate foundations for tanks as far as practicable from rivers likely to cause flooding, beaches likely to be scoured by strong waves, active earth faults, and the edges of hills subject to erosion.

2.2.1.8 Choose a location where the tank support structure will not be seriously exposed by combustible buildings or yard storage. If lack of yard room makes separation impracticable, protect exposed steel towers by open sprinklers or fireproof (fire resistance rating of not less than 4 hours) portions of the tower that are 20 ft (6.1 m) or closer to combustible yard storage and buildings, and windows and doors from which a fire may issue. If a tank structure is supported on a building of combustible occupancy, fireproof all steel columns and struts.

2.2.1.9 To limit the possibility of damage to empty tanks (e.g., from wind loads or from shrinkage of wood tank shells), complete the installation of all tank piping immediately after the tank is erected, and complete inspections and repairs expeditiously, so it can be placed in service promptly.

2.2.1.10 To limit the possibility of debris entering the water and obstructing the piping, leave no waste material inside tanks or in any space at the top of tanks during construction, inspection and repair.

2.2.1.11 To limit accumulation of sediment that could obstruct pipes and sprinklers, and to limit deterioration of steel or wood tank shells from continuous wetting and drying cycles, water tanks for fire protection should preferably not be used for other purposes. Where dual-service tanks cannot be avoided, do the following:

A. Equip suction tanks with a drain at floor level and equip gravity tanks with a blow-off connection discharging through the riser base and piped outside. Do not make pipe connections through the gravity tank riser shell near the bottom unless there is no possibility that the connection will freeze.

B. Provide plant service water pipe that is entirely separate from the fire protection piping and extends inside the tank to an elevation below which an adequate quantity of water will be constantly retained for fire protection. Plant service pipe inside the tank should preferably be brass (85% copper) or copper water tubing, but may be steel if the pipe is larger than 3 in. (75 mm) diameter. Rigidly attach the plant service piping to the tank at the pipe base, brace the pipe inside the tank near its top and at points not over 25 ft (7.6 m) apart, and provide any necessary expansion or flexible joints in the plant service water pipe outside the tank.

2.2.1.12 Do not use tank structures to support signs, flagpoles, steel stacks, micro-wave dishes, cell towers, or other structures unless specifically designed for this auxiliary purpose.

2.2.1.13 To avoid damage to the tank coating (paint) system, do not weld to the tank after its application.

2.2.1.14 Arrange pump suction piping for either horizontal shaft or vertical shaft turbine type pumps in accordance with Data Sheet 3-7, *Fire Protection Pumps.* In FM 50-year through 500-year earthquake zones, as shown in Data Sheet 1-2, *Earthquakes,* provide earthquake protection (e.g., pipe bracing and flexible couplings, controller anchorage) in accordance with Data Sheet 2-8, *Earthquake Protection for Water-Based Fire Protection Systems.* Provide an anti-vortex plate at the suction pipe inlet inside the tank configured as specified in Section 3.6.5.

2.2.1.15 Make adequate provision in pipe connections to accommodate the settling that may occur upon first filling the tank. Install flexible couplings or make final rigid connections after settling has taken place.

2.2.1.16 During construction of any tank, a licensed engineer representing the purchaser should inspect the work throughout all construction phases. They should be authorized to reject materials and workmanship not meeting specifications and the accepted project submittal. This engineer’s preliminary acceptance should not prevent subsequent rejection if the structure is found to be defective. A final acceptance letter by a licensed engineer representing the designer/manufacturer should be provided, confirming that the tank installed conforms to the plans accepted during the plan review process and verified throughout the construction of the tank.

2.2.1.17 Leak test the bottom of welded flat-bottom tanks after all joints in the lowest ring of the shell have been welded, but before the bottom plate is painted, by applying air pressure or vacuum to the joints and testing with a soap solution or other suitable material for the detection of leaks. Alternatively, joints may be inspected by the magnetic-particle method to determine discontinuities.

2.2.1.18 Make a visual joint inspection by the contractor and purchaser’s representative before and after the tank is filled. Where the quality of welded or bolted joints is suspect, perform non-destructive testing (e.g., magnetic-particle inspection) as necessary. After construction is complete, fill the tank to its maximum capacity and confirm that it is watertight to the satisfaction of the purchaser’s inspector. Make repairs as necessary to correct leaking joints.

2.2.2 Break Tanks

2.2.2.1 Do not use a break tank if the maximum flow rate of the fire pumps (150% of rated flow) exceeds the minimum rate (i.e., accounting for seasonal fluctuations, peak demand, etc.) that can be provided by the public water supply.

2.2.2.2 Provide a separate break tank for each fire pump for exclusive use as a fire protection water supply. Size the break tank so that the amount of water contained between the level 2 ft (0.6 m) above the pump suction pipe anti-vortex plate and the level where the automatic fill valves begin to operate is sufficient to supply pump operation at 150% of the pump rated capacity for 15 minutes.

2.2.2.3 Provide at least two redundant automatic and one easily accessible manual fill outlets for each break tank. Size each fill outlet to independently supply makeup water at a rate not less than 150% of the pump rated capacity. Configure automatic fill valves to open when the water level reaches 6 in. (150 mm) below the full water line.

2.2.2.4 Automatic fill valves may be of the float, altitude, or other suitable design arranged for direct or pilot operation. Float valves of modulating type are preferred. Size fill valves for break tanks such that suitable pressure differentials for proper valve operation are maintained.

2.2.2.5 Provide pipe wells for the float valves extending to within 6 in. (150 mm) of the tank bottom, sized at least 1 in. (25 mm) larger in diameter than the float, to ensure proper float valve operation and to facilitate valve testing. When pipe wells are used, provide valved pipe well drains for each pipe well at least 4 in. (100 mm) in diameter, located no more than 2 ft (0.6 m) above the tank bottom, arranged to discharge to a safe, frost-free location. For testing purposes and to make it impossible to close off the pipe wells, cut four 1.5 in. (38 mm) holes in each pipe well located no more than 1 ft (0.3 m) above the pipe well drains. Opening the drain valves will allow testing of float valves by draining water from the pipe wells faster than it can be replenished through the four 1.5 in. (38 mm) holes in the pipe wells.

2.2.2.6 Follow the design and location criteria given below for automatic fill outlets. When Item A or Item B cannot be met, demonstrate that pump operation is not affected by excessive turbulence or aeration. Where pump performance is affected, provide baffling in the tank or other measures that are demonstrated to correct the condition.

A. Locate fill outlets with a minimum centerline to centerline distance of 15 ft (4.6 m) horizontally from the pump suction pipe, and preferably at the side of the tank opposite the pump suction pipe. (see Figure 1)

B. Size the fill outlets so that water velocity at the maximum makeup water flow rate does not exceed 20 ft/sec (6.1 m/sec). Use Table 1 to determine the minimum fill pipe size.

C. Pipe the fill outlets so that makeup water enters the tank perpendicular to the tank water surface.

D. Terminate the fill outlets at a level at least equal to two fill pipe diameters above the water surface at the top capacity level (TCL) or one-half of the fill pipe diameter above the top of the overflow outlet, whichever is higher, unless a different a height is specified or required by the authority having jurisdiction.

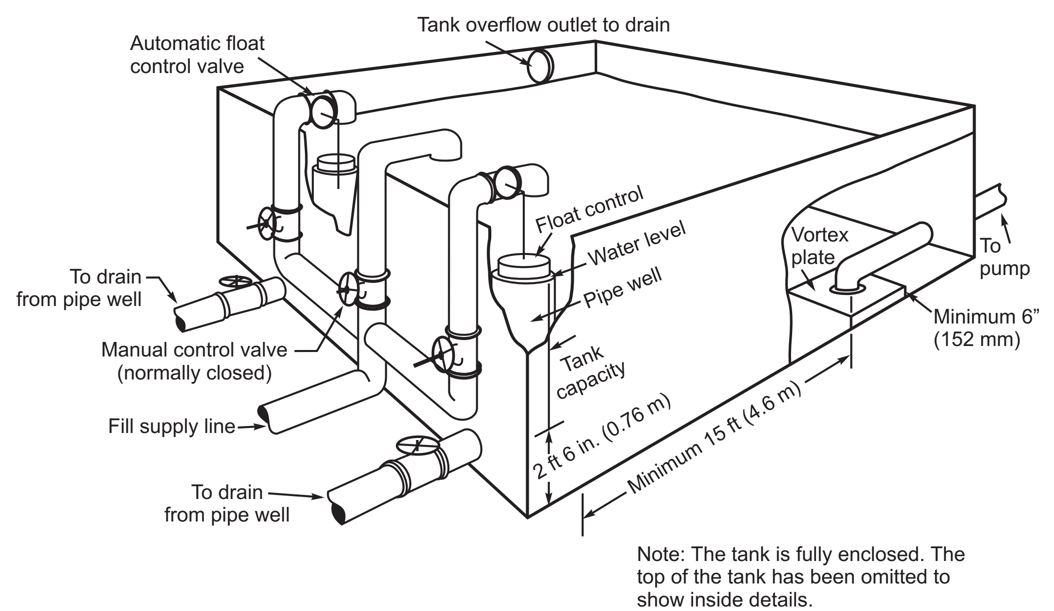


Fig. 1. Break tank

2.2.2.7 Arrange pump suction piping and provide an anti-vortex plate per Recommendation 2.2.1.14.

2.2.2.8 Provide a tank water level indicator visible to the fire pump operator.

2.2.2.9 Provide a low water level alarm in the tank, connected to a constantly attended location, to indicate when the tank water level drops to 9 in. (225 mm) below the full water line (signaling that more water is being pumped from the tank than is being replenished and allowing time to open the manual fill valve or to alert proper parties of this condition).

Table 1. Break Tank Fill Pipe Sizes

	Maximum Discharge at 20 ft/sec (6.1 m/sec)		*Largest Allowable Standard Size*	
Pipe Size	*Water Velocity*		*Fire Pump*	
in. (mm)	*gal/min*	*L/min*	*gal/min*	*L/min*
4 (102)	780	2965	500	1890
5 (127)	1225	4635	750	2840
6 (152)	1760	6670	1000	3785
8 (203)	3130	11,860	2000	7570
10 (254)	4895	18,535	3000	11,355
12 (305)	7050	26,690	4500	17,035

2.2.2.10 Provide a tank overflow outlet that is capable of discharging to a safe, frost-free location an amount of water no less than that which can be supplied by the fill mechanism. Size the overflow drainpipe at least one diameter larger than the fill pipe size.

2.2.2.11 Provide a fire department pumper connection downstream of the break tank/fire pump installation.

2.2.2.12 Locate the break tank, tank fill valves, fire pump and associated piping in a heated area, or otherwise protect them from damage if subject to freezing temperatures. Provide a tank heater if necessary. Adequately protect water in float valve pipe wells, which may not be subject to convective heating if a tank heater is used, and pilot lines on automatic fill valves from freezing.

2.2.3 Design Loads

Unless noted otherwise, design loads given in this section for atmospheric tanks are based on Allowable Stress Design (ASD) and stresses calculated from these design loads are intended to be compared to ASD stress limits.

2.2.3.1 Determine the basic load conditions for tank design based on the facility location and the location and configuration of the tank within the facility. Design tanks and their foundations to withstand controlling combinations of basic load conditions in accordance with the guidance in this section. Basic load conditions include:

- Dead load
- Fluid live load from contained water
- Roof live (or snow) load
- Wind load
- Earthquake load
- Loads due to the weight of soil and water in soil

2.2.3.2 Determine the dead load as the estimated weight of all permanent construction and fittings. Where appropriate (e.g., buried tanks and foundations), include the estimated weight of soil resting on structural elements as a dead load. Include dead load in all load combinations.

2.2.3.3 Determine the fluid live load from the weight of contained water assuming the tank is filled to the top capacity level (TCL). Include in load combinations that portion of the fluid live load that creates the most conservative condition for the item being designed.

2.2.3.4 Design for the larger of either the minimum roof live load or the roof snow load determined in this section.

2.2.3.4.1 Assume the roof live (or snow) load acts on the horizontal projection of the tank roof. Include in load combinations that portion of the roof live (or snow) load that creates the most conservative condition for the item being designed.

2.2.3.4.2 Use a minimum uniform roof live load of 15 psf (0.75 kPa). Do not reduce this minimum roof live load based on roof slope, tributary area, etc.

2.2.3.4.3 When the tank is a generic design that could be erected outdoors in any of several locations subject to snowfall, use a minimum uniform roof snow load of 25 psf (1.2 kPa). Do not reduce this minimum generic roof snow load based on roof slope, tributary area, etc. When the tank location is known the roof snow load determined from Recommendation 2.2.3.4.4 can instead be used.

2.2.3.4.4 When the specific location of the tank is determined, calculate the uniform roof snow load for tanks to be constructed outdoors from recommendations found in Data Sheet 1-54, *Roof Loads and Drainage,* except that no reduction of the flat roof snow load should be taken where the roof slope is less than 30°. Design the tank, or show that a generic tank design is adequate, for the location-specific roof snow load.

2.2.3.4.5 Where ladders, balconies, etc. are provided, design these and their attachments to the tank for dead and live loads specified by the appropriate design standard (e.g., FM Approvals Standard 4020 or local standards such as ASCE 7 and AWWA D100).

2.2.3.5 Design exterior above-grade tanks or parts of tanks for wind pressures as determined in this section.

2.2.3.5.1 Combine wind load with dead load, and with those portions of the roof live (or snow) load and the fluid live load that create the most conservative condition for the item being designed. Wind loads do not need to be combined with earthquake loads.

2.2.3.5.2 Determine design wind pressures based on FM Approvals Standard 4020, or, when not covered, based on ASCE 7-05, *Minimum Design Loads for Buildings and Other Structures.* Use an importance factor (I) of 1.15 and a minimum wind Surface Roughness Exposure Category C. Base the design wind pressure on the 3-second peak wind gust speed (V) for the facility location as given in Data Sheet 1-28, *Wind Design,* except use a minimum wind speed of 90 mph (40.2 m/sec). Use a higher wind speed and/or Surface Roughness Exposure Category D if appropriate for the site.

2.2.3.5.3 For the specific case of suction tanks that are 100 ft (30.5 m) or less in height and are supported at grade, the uniform lateral (horizontal) wind pressure (P_w) may be determined per this section in lieu of a more detailed analysis using Recommendation 2.2.3.5.2.

For Surface Roughness Exposure Category C sites having 3-second peak wind gust speed (V) of 97 mph (43.4 m/sec) or less, and for Surface Roughness Exposure Category D sites having V of 90 mph (40.2 m/sec) or less, use a minimum P_w, acting toward the tank on the vertical projected area, of 18 psf (0.862 kPa) when the tank shell is cylindrical and 30 psf (1.44 kPa) when the tank walls are flat vertical plane surfaces (e.g., for a cube-shaped tank). Increase these minimum P_w values when the 3-second peak wind gust speeds appropriate for the site are higher as follows:

A. Where the site is classified as Surface Roughness Exposure Category C and V is greater than 97 mph (43.4 m/sec), multiply the minimum P_w values by a factor of $(V)^2/(97)^2$ where V is in mph (SI units: $[V]^2/[43.4]^2$ where V is in m/sec).

B. Where the site is classified as Surface Roughness Exposure Category D and V is greater than 90 mph (40.2 m/sec), multiply the minimum P_w values by a factor of $(V)^2/(90)^2$ where V is in mph (SI units: $[V]^2/[40.2]^2$ where V is in m/sec).

2.2.3.6 Design tanks located in FM 50-year through 500-year earthquake zones, as shown in Data Sheet 1-2, *Earthquakes,* for earthquake forces as determined in this section. Tanks located in FM >500-year zones do not require earthquake design.

2.2.3.6.1 Include in earthquake load combinations the effects of gravity, lateral (horizontal) earthquake accelerations and vertical earthquake accelerations acting on the following weights:

A. The total dead weight of the tank.

B. The weight of contained water, assuming the water is at the TCL. Where the tank bottom is supported at or below grade, determine horizontal earthquake design forces considering the contained water to be composed of an impulsive fluid mass near the base that moves as a rigid body with the tank and a convective (sloshing) fluid mass near the free surface. For other tank configurations (e.g., gravity [elevated] tanks on a dedicated structure), horizontal earthquake design forces may be determined assuming the entire fluid mass acts as a rigid mass (i.e., in an impulsive mode) unless otherwise allowed by a consensus standard.

C. Include roof live (or snow) load by either: (1) assuming 25% of the roof live (or snow) load is present when determining the earthquake base shear, and overturning moment but using none of this live (or snow) load to resist these, or (2) performing an analysis using 100% of the roof live (or snow) load to both determine and resist base shear and overturning moment, and a second analysis using no roof live (or snow) load.

D. Where the tank is buried, include earthquake effects of soils as required by the geotechnical engineer's recommendations.

Earthquake loads do not need to be combined with wind loads.

2.2.3.7 For buried tanks, establish design forces resulting from the weight of soil and water in soil as required by the geotechnical engineer's recommendations. Such forces may be vertical downward (e.g., from soil on top of the tank), lateral (e.g., soil/water pressure against tank walls) or vertical upward (e.g., buoyancy in water-saturated soil).

2.2.4 Coating New Steel Water Tanks and Steel Accessories for Corrosion Protection

2.2.4.1 Protect interior and exterior steel surfaces of water tanks in accordance with AWWA D102 (for welded tanks) and AWWA D103 (for bolted tanks), with modifications as permitted in FM Approvals Standard 4020. The editions of AWWA D102 and AWWA D103 listed in Section 4.3 have been used in part for the recommendations that follow.

2.2.4.2 Use interior and exterior lead-free coating systems having at least an eighteen month documented history of satisfactory service in conditions similar to those anticipated at the facility. For interior wet surfaces (i.e., exposed to the stored water or its vapor) choose coating systems that are suitable for submerged service, resistant to high humidity and alternating wetting and drying, and chemically resistant to the stored water. Apply all coating systems as directed by the manufacturer.

2.2.4.3 Protect plates of bolted steel tanks in accordance with the following requirements.

2.2.4.3.1 Provide a factory-applied hot-dip galvanized, glass fused-to-steel, thermoset liquid (epoxy) or thermoset powder (epoxy) coating system on interior and exterior steel surfaces. Apply the coating system to the underside of steel bottom plates of ground-supported tanks unless this is not possible, in which case instead provide a treated sand base per Recommendation 2.2.4.5 for corrosion protection.

2.2.4.3.2 In preparation for coating, grit-blast all steel surfaces in accordance with Society for Protective Coatings (SSPC)/NACE International (NACE) SSPC-SP10/NACE No. 2, *Near White Metal Blast Cleaning.* Where allowed by AWWA D103, surfaces may instead be prepared by pickling according to SSPC-SP8.

2.2.4.3.3 Inspect steel panels before and after field erection. Replace panel sections where damaged or scratched coatings cannot be adequately repaired according to the manufacturer's specifications.

2.2.4.4 Protect plates of welded steel tanks in accordance with the following requirements.

2.2.4.4.1 For interior wet and dry surfaces, use a coating system consistent with those shown in Table 2.

2.2.4.4.2 For exterior weather-exposed surfaces, use a coating system consistent those shown in Table 3. Where a tank is to be insulated, attaching the insulation directly over the primed tank is acceptable provided the primer is either an organic or inorganic zinc-rich primer and the insulation is protected such that it is not exposed to water and does not retain moisture.

2.2.4.4.3 Leave the underside of the bottom plate bare and provide a treated sand base per Recommendation 2.2.4.5 for corrosion protection. For small tanks an acceptable alternative would be to apply an appropriate coating system (2 coats minimum) that is compatible with the base material supporting the tank (e.g., sand/lime mixture) after the bottom plate has been completely welded. Where a coating system is applied to the underside of the bottom plate, the plate must be completely covered with no voids.

2.2.4.4.4 The primer must be compatible with the finish coating. The tank may be field primed or shop primed. In the latter case, eliminate or reduce shop-applied primer within 4 in. (100 mm) of areas to be welded where weld quality may be affected.

2.2.4.4.5 In preparation for the prime coat, grit-blast interior wet surfaces in accordance with SSPC-SP10/NACE No. 2, *Near White Metal Blast Cleaning,* and grit-blast interior dry surfaces and exterior surfaces in accordance with SSPC-SP6/NACE No. 3, *Commercial Blast Cleaning* providing a final surface profile appropriate for the coating system as recommended by the coating manufacturer.

2.2.4.4.6 After welding shop-primed tanks, clean areas where the primer was not applied or has been damaged in accordance with Recommendation 2.2.4.4.5 and apply the coating system primer. Alternatively, the areas can be cleaned per SSPC-SP11 (*Power Tool Cleaning to Bare Metal*) for interior wet surfaces and per SSPC-SP15 (*Commercial Grade Power Tool Cleaning*) for interior dry surfaces and exterior surfaces.

2.2.4.4.7 Before applying the finish coat(s) on shop-primed tanks, clean surfaces of dirt, oil and other foreign materials. If required by the manufacturer's instructions, scarify the shop-primed surfaces by a method acceptable to the manufacturer (e.g., SSPC-SP7/NACE No. 4, *Brush-Off Blast Cleaning*).

2.2.4.5 For ground-supported steel tanks, where the underside of the steel bottom is not coated for corrosion protection, provide an oiled sand or a lime/sand layer under the bottom plate. Provide a minimum 4 in. (100 mm) thick treated sand layer above compacted grade or a minimum 1 in. (25 mm) thick treated sand layer above a reinforced concrete slab. See Section 3.1.6 for more information.

2.2.4.6 Other coating systems having adequately documented test data, service history and toxicological information may be considered where they are generally equivalent to the generic systems given in Sections 2.2.4.3 and 2.2.4.4. However, in no case should wax coatings or thick (>20 mils [>0.51 mm] dry film thickness [DFT]) coatings of coal tar or other bituminous/asphaltic material be used on interior wet surfaces.

2.2.4.7 Do not coat tanks outdoors during wet weather or when surfaces are damp. Do not apply coatings when the temperature is below 50°F (10°C), unless otherwise allowed by the coating manufacturer.

2.2.4.8 As soon as the paint dries thoroughly, rinse and partially fill the tank, and flush the water through a drain to prevent debris from entering the main riser or suction line.

Table 2. Inside Coating Systems (ICS) for Interior Welded Tank Surfaces

Coating System	*Primer Coat*	*Intermediate and/or Finish Coat(s)*	*Total DFT mils[Note 1] (mm)*
ICS-1 (2 coats)	1 coat of two-component epoxy primer	1 coat of two-component epoxy	8.0 (0.20)
ICS-2 (3 coats)	1 coat of two-component epoxy primer	2 coats of two-component epoxy	12.0 (0.30)
ICS-3 (1 or 2 coats)	1 coat of two-component epoxy primer or zinc-rich primer (optional may be omitted)	1 coat of high solids (96%) two-component epoxy	20-21 (0.51-0.53)
ICS-4 (1 or 2 coats)	1 coat of primer compatible with finish coat (optional may be omitted)	1 coat of two-component, 100% solids fast-setting polyurethane or polyurea	25-26 (0.64-0.66)
ICS-5 (3 coats)	1 coat of zinc-rich primer	2 coats of two-component epoxy	10.0 (0.25)

Note 1. DFT = dry film thickness; 1 mil. = 0.001 in. (0.0254 mm).

Table 3. Outside Coating Systems (OCS) for Exterior, Weather-Exposed Welded Tank Surfaces

CoatingSystem	*Primer Coat*	*Intermediate and/or Finish Coat(s)*	*Total DFT mils[Note 1] (mm)*
OCS-1 (3 or 4 coats)	1 or 2 coats of red iron oxide, zinc oxide, oil and alkyd primer, without lead or chromate pigments	2 coats of aluminum alkyd or 2 coats of gloss alkyd enamel or 1 intermediate coat of alkyd and 1 finish coat of high-gloss silicone-alkyd	4.0-6.5 (0.10-0.17)
OCS-2 (3 coats)	1 coat of single-component moisture-cure polyurethane zinc-rich primer	2 coats of single-component moisture-cure polyurethane	6.5 (0.17)
OCS-3 (3 coats)	1 coat of zinc-rich primer	2 coats of single-component water-based industrial acrylic or modified acrylic emulsion	6.0 (0.15)
OCS-4 (3 coats)	1 coat of zinc-rich primer	1 intermediate coat of two-component aliphatic polyurethane and 1 finish coat of two-component aliphatic fluorourethane	6.5 (0.17)
OCS-5 (3 coats)	1 coat of two-component epoxy primer	1 intermediate coat of two-component epoxy and 1 finish coat of two-component aliphatic polyurethane	6.0 (0.15)
OCS-6 (3 coats)	1 coat of zinc-rich primer	1 intermediate coat of two-component epoxy and 1 finish coat of two-component aliphatic polyurethane	6.0 (0.15)
OCS-7 (3 coats)	1 coat of two-component water-based epoxy primer	1 intermediate coat of two-component water-based epoxy and 1 finish coat of two-component water-based aliphatic polyurethane	6.0 (0.15)

Note 1. DFT = Dry film thickness; 1 mil. = 0.001 in. (0.0254 mm).text

2.2.5 Tank Foundations and Foundation Anchors

2.2.5.1 Determine soil conditions, such as bearing values or pile requirements, at foundation locations based upon subsurface investigation. Where soil conditions appear unfavorable, and at all elevated tank locations, at least one deep test boring should be made by the foundation contractor.

2.2.5.2 Design and detail foundations and foundation anchors to resist the maximum shear, compression, and tension forces determined using Section 2.2.3 loads, FM Approvals Standard 4020 and the following recommendations.

2.2.5.2.1 Locate tops of foundations 6 in. (150 mm) above adjacent grade and slope the surrounding grade away from the tank for positive drainage.

2.2.5.2.2 Locate bottoms of foundations below the extreme frost depth but not less than 12 in. (300 mm) below adjacent grade (e.g., for a mat foundation). Unless otherwise allowed by a geotechnical engineer, use a minimum ring wall size of 10 in. (250 mm) wide by 3 ft. (910 mm) high with its bottom at least 2.5 ft. (0.8 m) below grade, and locate the bottom of piers for tower columns at least 4 ft (1.2 m) below grade.

2.2.5.2.3 Provide foundation concrete with a minimum compressive strength of 3000 psi (21 MPa).

2.2.5.2.4 Reinforce foundations as required to resist gravity, wind, earthquake and earth pressure forces, but not less than the minimum required to resist temperature and shrinkage per ACI 318, *Building Code Requirements for Structural Concrete and Commentary.* For ring walls, provide minimum vertical reinforcement of 0.0015 times the cross sectional area on a horizontal plane, and horizontal reinforcement of 0.0025 times the cross sectional area on a vertical plane.

2.2.5.2.5 Project foundations at least 3 in. (75 mm) beyond column bearing plates or the tank shell. Where foundation anchors are required, extend the foundation at least 9 in. (230 mm) beyond the tank shell.

2.2.5.2.6 When foundation anchors are required to resist wind or earthquake uplift forces, analyze the foundation to verify that there is adequate weight or other means (e.g., pile friction capacity) to resist the upward tensile load in the anchors.

2.2.5.2.7 Ensure foundation anchors that resist earthquake uplift of ground-supported cylindrical steel suction tanks meet the following minimum requirements:

A. Maximum spacing of 10 ft (3.0 m) between anchors measured along the tank circumference.

B. Anchors are bolts (not straps) with a diameter of at least ¾ in. (19 mm).

C. Bolts have heads, nuts, or welded plates (not hooks) at their embedded end.

D. Bolts extend not closer than 3 in. (75 mm) from the bottom of the foundation

E. Bolts are protected from corrosion (a design accounting for corrosion may be acceptable).

F. Bolts extend a sufficient distance above the foundation to allow them to be connected to steel chairs on the tank.

G. Bolts have a threaded portion that projects above the top of the steel chair with sufficient free length of thread to fully engage the nut and allow peening of the threads (or, alternatively, to fully engage a nut and lock nut).

Use of post-installed concrete anchors for earthquake uplift anchors is strongly discouraged but may be considered if they meet the requirements in Data Sheet 1-2 and are allowed by FM Approvals.

2.2.5.2.8 Shear anchorage may consist of post-installed concrete anchors. In FM 50-year through 500-year earthquake zones, these anchors must meet the requirements in Data Sheet 1-2.

2.2.5.2.9 Wind uplift anchorage may consist of embedded bolts (similar to Recommendation 2.2.5.2.7), embedded steel anchor straps (minimum 0.25 in. [6.4 mm] thick) or post-installed concrete anchors. The anchorage should be protected against corrosion and have a maximum spacing of 10 ft (3.0 m) between anchors (measured along the tank circumference for cylindrical tanks).

2.2.6 Protecting Tanks and Tank Piping Against Freezing

2.2.6.1 Base the need for protection of tanks and their associated piping from freezing on regional data for the 100-year return period daily minimum temperature (100-year DMT) as shown in the FM Worldwide Freeze Map, available online at www.fmglobal.com and the 100-year DMT thresholds in the following recommendations. An overview of the worldwide map is shown in Figures 23 and 24. Use local data where known conditions exist that are more severe than the regional data indicate (e.g., in mountainous areas). See also Data Sheet 9-18, *Prevention of Freeze-Ups*, for additional guidance.

2.2.6.2 Ensure heating and insulation, when required by the following recommendations, are adequate to maintain the water in the tank or piping at a minimum temperature of 42°F (5.6°C) on the coldest design day. Protect insulation from weather and deterioration.

2.2.6.3 At locations within a 100-year DMT 20°F (-6.7°C) zone or colder (i.e., the 100-year DMT is 20°F [-6.7°C] or less), provide a frost proof casing or insulation for pipe risers less than 3 ft (0.91 m) in diameter that are exposed or within pedestal-supported tanks, and for exposed suction tank piping. The insulating value (“R” value) should be adequate to satisfy Recommendation 2.2.6.2, but not less than the following:

- 100-year DMT zone is 20°F (-6.7°C) to -5°F (-20.6°C), inclusive: R ≥ 3.5 hr-ft^2-°F/Btu (0.62 m^2-°C/W)
- 100-year DMT zone is -10°F (-23.3°C) to -20°F (-28.9°C), inclusive: R ≥ 5.5 hr-ft^2-°F/Btu (0.97 m^2-°C/W)
- 100-year DMT zone is -25°F (-31.7°C) or colder: R ≥ 7 hr-ft^2-°F/Btu (1.23 m^2-°C/W)

2.2.6.4 At locations within a 100-year DMT 5°F (-15°C) zone or colder (i.e., the 100-year DMT is 5°F [-15°C] or less), heat gravity tank pipe risers less than 3 ft (0.91 m) in diameter that are exposed or within pedestal-supported tanks, and exposed piping for pump suction tanks.

2.2.6.5 At locations within a 100-year DMT -5°F (-20.6°C) zone or colder (i.e., the 100-year DMT is -5°F [-20.6°C] or less), heat pump suction tanks, and steel gravity tanks and their risers. Insulation may be installed to conserve heat.

2.2.6.6 Protect piping inside unheated buildings where freezing may occur using frost proof casings, insulation having an “R” value of 3.5 hr-ft^2-°F/Btu (0.62 m^2-°C/W) or more, and/or heating.

2.2.6.7 Provide a low-water-temperature alarm set at 40°F (4.4°C) and connected to a central station supervisory service or a continuously manned local control room.

2.3 Operation and Maintenance

2.3.1 Keep the tank full, or in the case of pressure tanks at their design capacity level, at all times.

2.3.2 Inspect, test and maintain the automatic fire pump installation in accordance with Data Sheet 2-81, *Fire Protection System Inspection, Testing and Maintenance.*

2.3.3 Maintain break tank automatic fill valves in accordance with the manufacturer's recommendations. Test break tank automatic fill valves monthly by opening the pipe well drain valve and flowing enough water until the automatic fill valve opens fully. Annually verify that the rate of inflow from break tank automatic and manual valves at least equals that specified in Recommendation 2.2.2.1.

2.3.4 For pressure tanks, inspect the water level and air pressure/air pressure source weekly if not equipped with supervised water level alarms and air pressure alarms, and monthly if these alarms are provided.

2.3.5 Inspect, test and maintain all other tank-related fire protection system control valves and equipment in accordance with current guidelines in Data Sheet 2-81.

2.3.6 Make a thorough visual inspection annually of all systems and equipment that can be accessed without draining the tank, conducting an underwater evaluation or disassembly: tank; tower; piping; control and check valves; heating systems; water level indicator; pressure, temperature and water level alarms; expansion joint; frost proof casing; liner; insulation; overflow and all other accessories. Correct any deficiencies. Inspect and clean screened or open vents in the roofs of tanks annually.

2.3.7 On dual-service tanks taking water from a filtered source, and all tanks taking water from an unfiltered source, open the drain at least annually to flush out sediment. If the water is from an unfiltered source, more frequent flushing may be needed, depending upon the amount of sediment.

2.3.8 Examine all exterior coatings at least every two years. Where the exterior of the tank is insulated, partially expose the tank to adequately assess corrosion and insulation, replacing insulation afterwards. Clean, prepare the surface and repaint/recoat steel and iron work, and steel tank exteriors, as necessary to prevent corrosion.

2.3.9 Thoroughly inspect the interior of tanks for signs of pitting, corrosion, spalling, rot, coating failure, debris, aquatic growth, liner failure, insulation failure or water saturation, etc. at an interval not exceeding five years. Inspect interior piping and anti-vortex plates. Inspect tank floors for evidence of voids beneath. Clean the tank interior and repair any deterioration as necessary and repaint/recoat the tank interior if needed to prevent corrosion. Replace interior liners and insulation if required. Where paint is exposed to unusually corrosive water or atmospheric conditions, or where the 5-year inspection indicates deterioration of the tank interior is occurring, more frequent inspection may be necessary. An underwater evaluation after removing the silt from the tank floor is acceptable if the tank can be adequately assessed using this method; in this case the tank need only be drained as necessary to make repairs. Whenever the tank is to be drained, take the applicable precautions when fire protection is out of service (impaired) as discussed in Data Sheet 2-81. In addition, if wind anchorage is not present, restrain the empty tank as necessary to resist wind forces.

2.3.10 In areas having a significant weather-related freeze hazard (i.e., where the 100-year return period daily minimum temperature [100-year DMT] zone is 20°F [-6.7°C] or colder as shown in the FM Worldwide Freeze Map) follow guidance in Data Sheet 9-18, *Prevention of Freeze-Ups* as well as Recommendations 2.3.11 through 2.3.13.5.

2.3.11 During freezing weather, keep a gravity tank, its supporting structure, and building roofs under it free of ice, and make daily (or more frequent if conditions warrant) checks of the temperature inside pressure tank enclosures, and other enclosures where freezing of break tanks, pipes, etc. may occur, to confirm they are no less than 40°F (4.4°C).

2.3.12 If the water in a water tank is partially or fully frozen, provide an adequate emergency water supply for the fire protection system and follow guidelines in Section 3.8.8.

2.3.13 Inspect and maintain tank heating systems per the following requirements.

2.3.13.1 During freezing weather, make daily (or more frequent if conditions warrant) checks to confirm that the cold water temperature is being maintained at a minimum of 42°F (5.6°C), indicating that the heating system is operating properly.

2.3.13.2 Flush out the water circulating pipe and heater in the fall before the heating season starts, and about monthly during the heating season. After the first monthly flushing during the heating season, increase (to not more than two months) or decrease the flushing time interval depending upon the rate of sedimentation. After flushing, make sure that all valves are wide open, the drain valve closed, and the tank filled. If the tank level is checked by overflowing, do not let ice form on the tank or tower.

2.3.13.3 In the fall before the heating season starts, test the tank heating system; check the accuracy of thermometers, pressure gauges, and low water temperature alarms; as well as the adjustment of relief valves, steam regulators, pressure-reducing valves, thermostats, and safety pilots.

2.3.13.4 At the end of the heating season, clean and overhaul heaters, traps, strainers, and other accessories as necessary. Take apart and renew gaskets of steam, electric, and hot water heaters. Wire brush the steel or iron heating surfaces of coal, fuel oil, or gas-fired heaters, and coat with oil. Follow manufacturer's instructions regarding lubrication. Have gas- or oil-fired heaters serviced and inspected by a service organization during the summer.

2.3.13.5 Every five years, or at the interval recommended by the manufacturer, perform major inspection and maintenance on heaters, steam coils, etc. (e.g., clean pipes, replace badly corroded pipe) per the manufacturer's specifications.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Suction and Gravity Tanks

3.1.1 General

Fire pump suction tank capacities vary widely from less than 10,000 gal (37.9 m^3) to 1,000,000 gal (3,790 m^3) of water or more. Suction tanks are usually of welded or bolted steel construction. They are most commonly ground-supported, essentially flat-bottomed and cylindrical with a roof of steel or aluminum. The roof may be supported solely on the perimeter shell of the tank (also known as a "self-supported roof"), or may have one or more interior columns (also known as a "supported roof").

Ideally, cylindrical ground-supported steel suction tanks, see Figure 25 in Appendix E, have a bottom plate to which the shell plates are attached; connections between adjacent steel plates are welded or bolted. Foundations are discussed below, but a common configuration is a reinforced concrete ring beam that supports the tank shell and also retains compacted gravel and sand on which the tank bottom rests. The tank can also be supported by other types of foundations such as a reinforced concrete mat.

Suction tanks are less commonly constructed of aluminum, wood, reinforced concrete, prestressed concrete or embankment-supported fabric. Rectangular, bolted pressed steel tanks (see Figure 2), typically designed with little consideration of wind forces/anchorage and without consideration of seismic forces/anchorage, are used in some parts of the world.

Some cylindrical steel or wood suction tanks have no bottom plate but instead retain the water using an interior rubber (e.g., butyl or EDPM) or PVC liner (see Section 3.1.7). The liner typically rests on one or more layers of material (e.g., polyester or industrial felt) that is lapped a short way up the shell. Some of these tanks have interior insulation (see Section 3.8.1) between the liner and the tank shell (which can be acceptable if installed in accordance with FM Approvals Standard 4020).

Tanks lacking bottom plates are undesirable in earthquake zones (see Section 3.1.3.6). Where a bottom plate does not exist, the tank must be anchored to resist both shear (sliding) and overturning. If this anchorage is not provided, sliding of the tank can break pipe connections and damage the liner. The liner can also be damaged as the tank shell lifts from overturning. Figure 3 shows a wood suction tank after an earthquake in Christchurch, New Zealand that lacked both a bottom plate and anchorage. The tank has displaced, piping is broken and the liner failed.

Gravity, or elevated, tanks are most commonly made of welded steel plate supported on steel or, occasionally, reinforced concrete towers. They are available in many capacities and shapes that vary by manufacturer. Small tanks have capacities of 200,000 gallons (757 m^3) or less while large capacity tanks are available to contain more than 500,000 gallons (1,890 m^3) of water. Figures 4 and 5 show examples of gravity tanks.

3.1.2 FM Approval

Fire protection tanks are FM Approved as either gravity tanks or pump suction tanks. Information on FM Approved tanks is contained in the *Approval Guide,* an online resource of FM Approvals, in the Fire Protection Section. Few gravity tanks are FM Approved, but many suction tanks are FM Approved in a variety of sizes and are broken down into four categories:

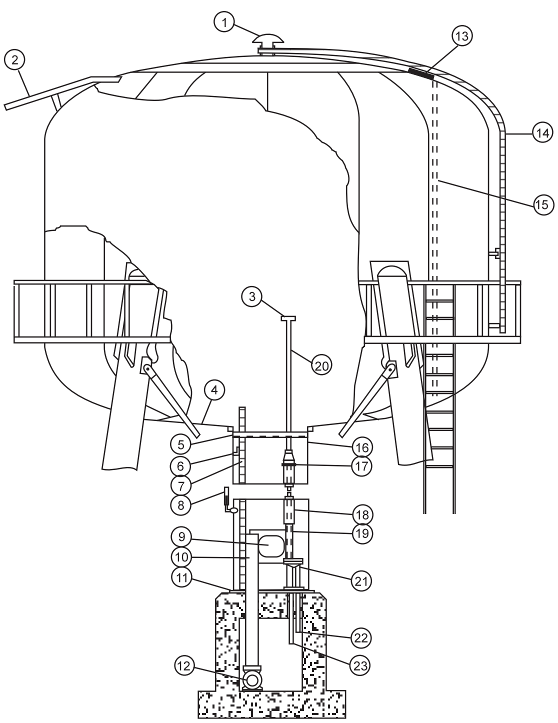
- Welded Steel
- Bolted Steel
- Bolted Aluminum
- Embankment-supported Fabric (see Data Sheets 3-4 and 3-6)

FM Approvals Standard 4020, *Approval Standard for Steel Tanks for Fire Protection,* covers bolted and welded steel tanks (see also Appendix E in this data sheet). The design provisions in this standard are largely similar to those in several American Water Works Association (AWWA) standards, including: AWWA D100, *Welded Carbon Steel Tanks for Water Storage;* AWWA D103, *Factory-Coated Bolted Carbon Steel Tanks for Water Storage;* and AWWA D102, *Coating Steel Water-Storage Tanks.* However, the provisions of FM Approvals Standard 4020 vary to some degree from the AWWA standards, so a tank designed to the AWWA standards may not completely conform to FM Approvals requirements.

The *Approval Guide* provides information regarding the roof live (or snow) load, the wind speed and exposure, and the FM earthquake zone per Data Sheet 1-2, *Earthquakes,* for which each tank is FM Approved. With respect to earthquake, the tanks are listed for the most hazardous FM earthquake zone in which the tank can be used. FM earthquake zones from the most to the least hazardous are 50-year, 100-year, 250-year, 500-year, and >500-year. Therefore, tanks listed as Approved for FM 50-year earthquake zones can be used in any FM earthquake zone; a tank Approved for FM 100-year zones can be used in any FM earthquake zone except 50-year, etc. If the listing does not specify an earthquake zone, the tank can only be used in FM >500-year earthquake zones.

Fig. 2. Pressed steel suction tank

Fig. 3. Earthquake damage to a wood suction tank lacking anchorage and bottom plate



1. Perforated plate or screened finial vent
2. Stub overflow pipe
3. Hot water tee outlet at one third depth
4. Tank bottom
5. Heater pipe brace
6. Ladder bracket
7. Ladder in riser
8. Thermometer
9. Manhole
10. Inlet and discharge pipe
11. Grout under riser base plate
12. C.I. base elbow
13. Roof hatch with hinged cover and catch to keep closed
14. Fixed-type outside ladder
15. Inside ladder
16. Steel riser
17. Pipe support
18. Hot water circulating pipe
19. W.I. condensing pipe
20. Hot water pipe
21. Heater connection
22. Condensate outlet
23. Steam inlet

Fig. 4. All-welded steel tank, steel column supported, with large steel-plate riser and radiator heater

3.1.3 Design Loads

3.1.3.1 General

The information in this section is based on FM Approvals Standard 4020 (see also Appendix E). Although that standard primarily covers welded and bolted steel suction tanks, design loads for other types of tanks will be similar.

Tanks must be designed for several basic load conditions either individually or, more commonly, in a limited number of appropriate load combinations. At a minimum, tanks must resist dead, fluid live and roof live loads. Where snow loads are greater, they are used in lieu of the roof live load. Most tanks must also be designed for wind load, tanks in FM 50-year through 500-year earthquake zones must be designed for earthquake forces, and buried tanks or foundations may need to be designed for earth and/or groundwater pressures. The specific loads depend on the facility location (e.g., to determine the controlling wind speed and FM earthquake zone) as well as the tank's configuration (e.g., if it is an elevated tank, a ground-supported suction tank or a buried tank) and location within that facility (e.g., whether it is located inside or outside of a building).

The load combinations that control the design of various tank elements can vary. Cylindrical ground-supported steel suction tank shell plate thicknesses, for example, may be controlled at some heights by the tension forces resulting from hydrostatic pressure, at others by the wind forces on the shell of an empty tank and at still others by the vertical loads resulting from gravity loads combined with earthquake overturning of a full tank.

3.1.3.2 Dead Load

Roof dead loads, combined with the greater of the roof live or snow load, are used to design the roof gravity system (e.g., radial beams). Dead loads are also included in load combinations for design of vertical tank elements (e.g., columns, shell plates). The tank dead load (roof, shell, bottom plate, etc.) can resist some or all of the sliding (via friction of a ground-supported suction tank bottom plate against the soil or concrete mat) and overturning caused by wind or earthquake forces, and is included in the mass subject to earthquake accelerations.

Dead loads typically include the weight of tank elements, but may in some cases include the weight of soil (e.g., soil on top of foundations that helps to resist uplift from overturning). The unit weight of steel is 490 pcf (7850 kg/m^3), and typical unit weights of 150 pcf (2400 kg/m^3) for concrete and 30 pcf (480 kg/m^3) for wood can be assumed unless better information is available. Soil dead weights vary.

3.1.3.3 Fluid Live Load from Contained Water

The tank should be considered to be either empty or full, depending on which creates a more conservative condition for the item being designed. For example, assuming the tank is empty is usually more conservative when designing above-ground tank anchorage resisting wind forces or anchorage against buoyancy forces for buried tanks. Assuming the tank is full is more conservative when designing shell plates for hydrostatic or earthquake forces. The unit weight of water is taken as 62.4 pcf (1000 kg/m^3).

3.1.3.4 Roof Live and Snow Loads

Minimum tank roof live loads in other standards are commonly 15 psf (0.75 kPa) where there is no possibility of snow and 25 psf (1.2 kPa) where snow may occur. Since roof snow loads can vary widely and be much higher or lower than these minimums, this data sheet references Data Sheet 1-54, *Roof Loads and Drainage,* for determination of appropriate roof snow loads.

From Data Sheet 1-54, flat roof (slopes less than 5° or a rise:run ratio of about 1:12) snow loads (P_f) are 80% to 100% of the 50-year mean recurrence interval (MRI) ground snow load (P_g). The P_f value will apply for most tanks because this data sheet allows a reduction only where the roof slope is 30 degrees (rise:run ratio of approximately 7:12) or more. When the roof slope is 30 degrees or more, the Data Sheet 1-54 reduction factors assuming a cold roof may be used (reductions allowed by Data Sheet 1-54 for lesser slopes should not be used for tanks). “Slippery surfaces” can only be assumed where the roof surface is metal configured such that the snow can slide off unobstructed (e.g., metal deck spanning between radial beams with flutes essentially parallel to the tank shell would not qualify).

A generically-designed tank will be adequate when the actual 50-year MRI ground snow load (P_g) does not exceed the assumed minimum roof live (or snow) load. Where P_g is greater than the assumed minimum roof live (or snow) load an analysis is needed to determine whether the actual roof snow load exceeds the assumed roof live (or snow) load, and, if so, what modifications are needed.

Roof live (or snow) load is typically not included in wind load combinations since it would provide additional resistance to sliding (via friction between the bottom plate of a ground-supported tank against the soil or concrete mat) or overturning. Part of the roof live (or snow) load is included in earthquake load combinations as specified in Recommendation 2.2.3.6.1.

3.1.3.5 Wind Loads

3.1.3.5.1 General

Lateral (horizontal) wind forces cause sliding and overturning of the tank. Anchorage may be needed where these exceed the sliding friction and moment that can be resisted by the tank dead load. Also, stiffeners may be needed on thin shell plates to resist wind design pressures, and compression stresses in shell plates from wind overturning forces must be added to those resulting from gravity loads.

The controlling load combinations for wind forces generally will not include roof live (or snow) loads nor fluid live loads (i.e., the tank is empty) since these tend to increase the stability of the tank.

3.1.3.5.2 Determining Lateral Wind Pressures

Lateral wind pressures are based on 3-second peak wind gust speeds given in Data Sheet 1-28, *Wind Design.* If other wind data are used and are reported using a different unit of wind speed (e.g., fastest-mile or 10-minute), these must be converted to equivalent 3-second gust speeds using guidance in Data Sheet 1-28.

A minimum wind speed of 90 mph (145 km/hr or 40 m/sec) and minimum Surface Roughness Exposure Category C (open terrain) are specified for Approved tanks because they are not overly conservative (minimum wind design pressures will control most designs - see below) and will allow the tank to be used or re-used within a very large geographical area without redesign. However, higher wind design pressures may be needed for sites having faster wind speeds and/or where Surface Roughness Exposure Category D (5000 ft [1524 m] of open water, smooth mud flats, ice or similar) is appropriate. Using Surface Roughness Exposure Category B (2600 ft [792 m] of terrain with numerous large closely-spaced obstructions such as urban or wooded areas) is not allowed. See Data Sheet 1-28 for more information on surface roughness exposure categories.

The uniform wind design pressure (P_w), which is applied toward the tank on the projected area (A_f) on a vertical plane (e.g., for a cylindrical flat bottom ground-supported tank, A_f is equal to the tank height times the tank diameter), is determined in FM Approvals Standard 4020 from the equations:

U.S. Customary Units	*SI Units*
$P_w = q_z G C_f \geq 30 C_f$	$P_w = q_z G C_f \geq 1.436 C_f$
$q_z = 0.00256 K_z I V^2$	$q_z = 0.000613 K_z I V^2$

Where:

P_w = uniform design wind pressure, psf (kN/m^2 [kPa])
G = gust-effect factor (taken as 1.0)
C_f = force coefficient.
q_z = wind velocity pressure evaluated at height “z” of the centroid of the area A_f, psf (kN/m^2 [kPa])
K_z = wind velocity pressure exposure coefficient evaluated at height “z”
I = Importance factor (taken as 1.15)
V = Design 3-second peak gust wind speed, miles/hr (m/sec)

AWWA D100 and D103 and ASCE 7 are very similar to, but not exactly the same as, FM Approvals Standard 4020; ASCE 7 is more complex. A detailed analysis in accordance with ASCE 7-05 (do not use ASCE 7-10) to determine wind pressures should be used for situations that fall outside of those given in FM Approvals Standard 4020.

3.1.3.5.3 Wind Forces on Typical Ground-Supported Suction Tanks

This section applies only to the common case of a flat-bottom, ground-supported tank with a height of 100 ft [30.5 m] or less (i.e., the distance “z” from grade to the centroid of the vertical projected area [A_f] is 50 ft [15.2 m] or less). For these tanks the values noted below from FM Approvals Standard 4020 are applicable.

- Gust-effect factor: G = 1.0
- Importance factor: I = 1.15
- Force coefficient
  C_f = 0.6 (cylindrical tank shells)
  C_f = 1.0 (tank walls are vertical plane surfaces, e.g. a cube-shaped tank)
- Wind velocity pressure exposure coefficient evaluated at height ″z″
  K_z = 1.09 (Surface Roughness Exposure Category C)
  K_z = 1.27 (Surface Roughness Exposure Category D

Using the above values, the minimum uniform design wind pressure (P_w) can be calculated as:

- P_w minimum = 30C_f (psf) (SI units: 1.436C_f kPa):
  Cylindrical tank shell, P_w minimum = 18 psf (0.862 kPa)
  Vertical plane tank wall surfaces, P_w minimum = 30 psf (1.44 kPa)

A minimum design 3-second peak gust wind speed (V_{min}) can be determined that corresponds to the P_w minimum values above. When the actual wind speed (V) at the facility is more than V_{min}, the actual P_w can be determined by multiplying P_w minimum by a factor of $V^2/(V_{min})^2$. The values of V_{min} vary with the value of the wind velocity pressure exposure coefficient (K_z):

- Surface Roughness Exposure Category C
  U.S. Customary units: V_{min} = 96.7 mph
  SI units: V_{min} = 43.23 m/sec
- Surface Roughness Exposure Category D
  U.S. Customary units: V_{min} = 89.6 mph
  SI units: V_{min} = 40.05 m/sec

The wind speeds in miles per hour above, and the corresponding SI values, are rounded in Recommendation 2.2.3.5.3.

3.1.3.6 Earthquake Loads

3.1.3.6.1 General

Where earthquakes are likely, tank structures require greater resistance to lateral forces than needed for wind forces. In such areas, the tank, tower, and foundation should meet all local requirements and FM recommendations. Earthquake resistance of gravity tanks can require unusually large diagonal bracing, particularly in the top panel of the tower, and a special foundation.

Lateral (horizontal) and vertical forces result from ground accelerations during an earthquake. Lateral accelerations cause sliding (shear) and overturning of the tank, and cause the water at the top of tanks to slosh. Anchorage may be needed where the earthquake-caused sliding and overturning forces exceed the sliding friction and moment that can be resisted by the tank dead and fluid loads. Roof members may need to be designed to resist the impact of sloshing liquid where the freeboard provided is inadequate. Vertical accelerations increase the effective weight of the contained water and, thus, the hydrostatic tension stresses on the tank shell.

Some ground-supported suction tanks do not have a bottom plate, but instead have an interior flexible (e.g., rubber) liner that hangs from the upper shell to contain the water. The water weight is resisted by the hydrostatic shell forces, and by the soil or mat interior to the tank shell upon which the rubber liner rests. However, as a consequence of having no bottom plate there is only a minimal contact surface between the thin tank shell plates and the foundation, thus friction at the base of the tank (which, for most tanks having bottom plates resists all or a majority of the substantial shear force) cannot be used to resist sliding. Further, without a bottom plate the contained water adjacent to the shell cannot be lifted to partially resist overturning. Also, the rigidity of the tank shell, and its ability to evenly distribute loads, may be compromised in tanks lacking bottom plates. Therefore, only half of the anchors are effective in shear or tension, essentially doubling the number of anchors required. A final consideration is that uplift anchors do not usually function as shear anchors and shear anchors do not usually function as uplift anchors unless detailed to do so.

Since significantly more earthquake shear and overturning anchorage is needed when a tank lacks a bottom plate, and since earthquake damage to internal liners is possible even if tanks lacking a bottom plate are anchored, it is very undesirable to construct tanks subject to earthquake forces without a bottom plate in FM 50-year through 500-year zones. Omission of the bottom plate for tanks subject to earthquake forces is strongly discouraged.

Where it occurs in earthquake zones, a mat foundation (not a ring wall) must be used and adequate anchorage provided.

The controlling load combinations for earthquake forces generally include the total fluid live load (i.e., the tank is full), since the contained water contributes the bulk of the mass subject to acceleration, in addition to the total tank dead weight. The roof live or snow load is included through one of the two methods given in Recommendation 2.2.3.6.1.

3.1.3.6.2 Earthquake Response of Water in a Tank

FM uses the effective mass method to determine the earthquake response of contained water, as outlined in AWWA D100 and AWWA D103 and described below.

The contained water in a tank constitutes a very large part (e.g., perhaps 95% for cylindrical steel suction tanks, 70% to 90% for concrete suction tanks) of the mass subject to earthquake acceleration. In order to understand the horizontal seismic response of water within a storage tank, visualize that it is divided into two parts: (a) an impulsive mass, and (b) a convective mass. Horizontal earthquake accelerations cause the impulsive liquid near the tank base to move essentially as a rigid mass in unison with the tank walls and the convective liquid near the free surface at the top of the tank to slosh.

The relative proportions of the convective and impulsive liquid depend on the ability of the tank to confine the liquid. The greater the confinement, the greater is the impulsive liquid (and, consequently, the earthquake lateral forces) and the smaller is the convective liquid. For example, in a ground-supported cylindrical suction tank with sufficient freeboard and constant water height (H), as the tank diameter (D) decreases, the confinement of the liquid (and, thus, the impulsive liquid weight) increases. The impulsive liquid is about 20% of the total liquid weight when the tank diameter is six times its height, but increases to about 75% of the total liquid weight when the tank diameter and height are equal.

The natural period of vibration of the impulsive liquid is low (for ground-supported tanks, it is typically less than the period defined as $T_s = S_{D1}/S_{DS}$) and so it experiences high accelerations (see Figure 28 in Appendix E). Conversely, the natural period of vibration of the convective liquid is high (often in the range of 2 seconds to 4 seconds and potentially much higher) and so it experiences much lower accelerations and contributes negligibly to the seismic loads in the tank. Therefore even when the convective liquid weighs much more than the impulsive liquid, the impulsive liquid still controls the seismic loads (base shear and overturning moment) in the tank. For ground-supported cylindrical steel tanks, horizontal acceleration of the impulsive water mass typically causes 90% or more of the sliding (base shear) force and 85% or more of the overturning moment.

It is desirable to provide sufficient freeboard so that the sloshing waves do not impact the roof during earthquakes. Insufficient freeboard causes: 1) upward load on the roof due to impacts from the sloshing wave, and 2) increase in impulsive mass due to constraining action of the roof. When provided freeboard is insufficient, some of the liquid that would have responded in a convective mode instead responds in an impulsive mode. Since the convective accelerations of common suction tanks range from about 10% to 30% of impulsive accelerations, the increase in impulsive liquid weight resulting from confinement of the water by the roof can significantly increase earthquake forces on the tank. Where up-and-down movement of the free-surface is restricted by other means (e.g., by adding baffles in the tank), these also confine the liquid, increasing the impulsive mass and, hence, the seismic forces.

Determining the weight of the tank itself (i.e., roof, shell, bottom plate) and the weight of the roof live (snow) load subject to earthquake accelerations is straightforward. However, determining the impulsive and convective liquid weights, and the allowable stress design (ASD) force factors, depends on the configuration and properties of the tank (and, in the case of elevated tanks, the structure supporting the tank).

The effective mass method for rectangular concrete tanks outlined in ACI 350.3, *Seismic Design of Liquid-Containing Concrete Structures and Commentary* results in values for the impulsive and convective water masses and their heights, the required freeboard and the tank base shear and overturning moment similar to those found using the AWWA method. When determining these values for a rectangular tank, the inside dimension of the rectangular tank parallel to the direction of ground motion (L) is substituted for the tank diameter (D) in the AWWA equations. Note, however, that most other equations used for cylindrical tanks in Appendix E of this data sheet (e.g., those to determine the earthquake uplift parameter [J] and to determine required bolt tension force [T_r]) cannot be used for rectangular tanks.

3.1.3.7 Soil Loads

Buried tanks should be designed for lateral earth and groundwater pressure as determined by a geotechnical engineer.

3.1.4 Fireproofing Steel Towers

Where fireproofing is necessary, details of application and materials should be determined by a structural engineer. Fireproofing is not usually performed by the tank contractor. Concrete is ordinarily used where the steel is exposed to the weather, and lightweight aggregate plasters held in place by wire or metal lath where the steel is inside a building.

Steel columns, horizontal struts, and compression portal braces should be fireproofed to give 4-hr fire resistance. Fireproofing is not required on diagonal wind rods or large steel-plate risers.

Ordinarily, columns are so nearly vertical that the weight of the fireproofing material does not cause significant bending stresses. If columns are considerably inclined, place reinforcing bars in the fireproofing material to make it self-supporting. With horizontal struts and compression portal braces, locate reinforcing rods near the bottom of the section. Care should be taken in designing the supports. Compression members are not usually strong enough to resist bending; struts should be carefully checked. Flash all intersections of fire-proofing materials and steel. Instead of fireproofing the members, open sprinklers or spray nozzles may be used to protect tank towers if water supplies are sufficient and other conditions satisfactory.

3.1.5 Lightning Protection for Wood Tanks

It is advisable to equip exposed, wooden gravity tanks (on independent towers or above building roofs) and wooden pump suction tanks with a lightning rod system.

Provide a lightning rod of 1/2 in. (13 mm) diameter solid copper, pointed at the top and extending at least 12 in. (0.3 m) above the peak of the roof. Connect the base of the rod to a copper down conductor weighing not less than 187 lb/1000 ft (278 kg/1000 m) for structures 75 ft (23 m) or less in height and 375 lb/1000 ft (558 kg/1000 m) for taller structures. More detailed information on lightning protection can be found in NFPA 780, *Standard for the Installation of Lightning Protection Systems.* The down conductor should be securely fastened to the outside of the tank and soldered to a lug which is bolted to a ground clamp around the tank riser or discharge pipe. Before attaching the ground clamp, thoroughly scrape and clean the riser to obtain a good electrical connection.

3.1.6 Coating Systems for Corrosion Protection of Steel Surfaces

Interior and exterior steel surfaces are typically protected from environmental deterioration by applying appropriate coating systems (e.g., paint). Cathodic protection can reduce the corrosion of submerged steel surfaces, preventing metal loss at any void in the coating system below the water level. Since it is relatively uncommon and somewhat complex, cathodic protection will not be covered here.

The thickness of paint systems and coatings is often given as the Dry Film Thickness (DFT) in mils (1/1000 inch). Where a one-piece interior flexible rubber liner supported from the top edge of a ground-supported suction tank is provided (usually in bolted tanks) the steel surface protected by it can typically be considered an interior dry surface. In addition to aesthetics, considerations in selecting the coating systems used include cost, environmental factors (e.g., potential for condensation or “sweating” on the tank, windblown debris, extreme temperatures, etc.), coating system life and abrasion resistance, ease of application and expected temperature/humidity at application, and ease of repairing/recoating the in-service tank.

Coating systems have changed substantially over the years due to advances in coatings technologies, regulations limiting the level of volatile organic compounds (VOCs), and restrictions on certain coating ingredients such as red lead. The detailed coating system guidelines in the AWWA D102 (welded tanks) and D103 (bolted tanks) editions listed in Section 4.3, as modified by FM Approvals Standard 4020, should be followed. Coating systems allowed by other standards can be considered where they are generally equivalent to those given in the AWWA and FM Approvals documents. Wax, coal tar, coal-tar enamel and asphalt coating systems are no longer allowed in AWWA D102. Wax coatings can soften and run during extreme temperatures. Additionally, when bituminous coatings are thick (> 20 mils [> 0.51 mm] DFT), peeling or cracking of the coating may dislodge a piece large enough to block a sprinkler head and, thus, should not be used on tank interior wet surfaces.

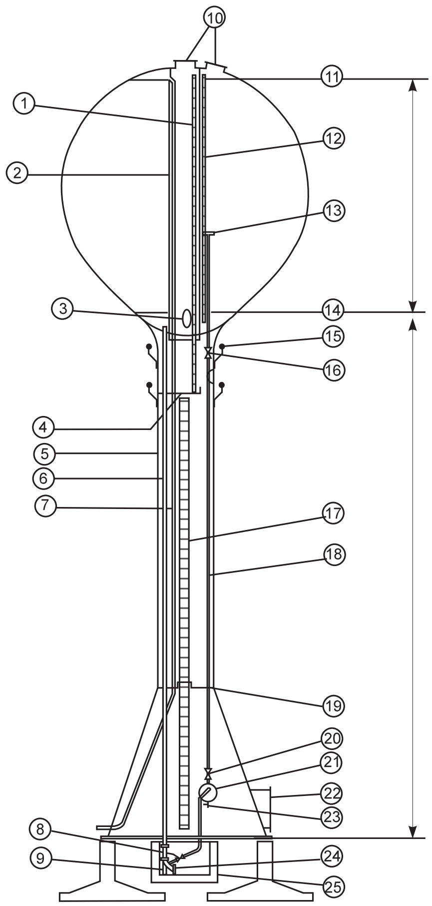


Fig. 5. Section through typical pedestal supported tank with circulating heater

The underside of flat-bottomed steel suction tank plates set on soil or a concrete slab should be protected against corrosion. Using a coating system for corrosion protection of the underside of ground-supported steel bottom plates is reasonable for factory-coated bolted tanks, but is not recommended for welded tanks since the coating will not be continuous and a greater level of corrosion can be expected at voids in the coating. If coating the underside of a welded bottom plate is desired, a system suitable for the specific service should be applied after it has been completely welded together.

Where a coating system on the underside of the steel bottom plate is not provided, the tank bottom plates should be supported on load-bearing compacted fill below a minimum 4 in. (100 mm) thick sand cushion treated with lime or oil, or on a concrete slab with a minimum 1 in. (25 mm) treated sand cushion to prevent corrosion. The sand can be treated by one of the following methods:

A. Where allowed by environmental authorities, the preferred method is to provide oiled sand as the base material. The oiled sand mixture should consist of 6 to 18 gallons of Number 2 fuel oil or a heavy-base petroleum oil per cubic yard of clean sand (30 to 89 L/m^3). Sand should be coated (using a concrete mixer), but not running with excess oil, such that it can be formed into a ball without dripping oil.

B. Use a lime/sand mixture as the base material. The mixture should consist of hydrated lime added to clean sand such that the pH of the mixture is between 7.0 and 10.5. The chloride content of the mixture should be less than 100 ppm and the sulfate content should be less than 200 ppm. When the underside of the tank bottom is to be coated, the coating system should be compatible with the lime/sand mixture.

In addition, corrosion of the ground-supported bottom plates is mitigated by:

- sloping the bottom plate upward toward the tank center (minimum 1 in. [25 mm] vertical to 10 ft [3.0 m] horizontal).
- preventing water infiltration under the tank (e.g., by locating tops of foundations 6 in. [150 mm] above adjacent grade and sloping the ground for positive drainage away from the tank, and by providing granular fill and water diversion ditches where needed).

Surface preparation is the single most important factor in preventing coating system failure. Surface preparation cleans the steel of contaminants and roughens or "profiles" smooth surfaces such that the first (primer) coat mechanically adheres to the surface. Additionally, grinding of welds, smoothing of corners and edges, and filling of voids may be necessary to prepare the surface.

Surface preparation usually includes solvent cleaning to remove visible grease and oil followed by blast cleaning (blasting the surface with an abrasive) to remove contaminants such as old paint, rust, and scale and to provide a suitable anchor pattern for the coating application. Blast cleaning creates a roughened profile about 1.0 to 3.0 mil (25-76 micrometer) high. In some cases blast cleaning may be replaced by power tool cleaning (for small areas) or cleaning in an acid solution. The coating system primer (or the coating system itself if no primer is called for) must then be applied before any surface rusting or accumulation of dust, etc. can occur.

Specifications for surface preparation of steel and other materials issued jointly or separately by the Society for Protective Coatings (SSPC) and NACE International (NACE) are commonly used. Other common surface preparation standards are the International Standard ISO 8501-1 (equivalent or essentially equivalent to Swedish Standard SIS055900 and British Standard BS 7079), and the outdated British Standard BS4232.

Information on commonly used SSPC/NACE surface preparation methods for new tanks follows. For approximately equivalent international surface preparation standards related to blast and power tool cleaning, refer to Table 4. Surface preparation by high and ultrahigh pressure water jetting has limited applicability and is not covered.

Solvent Cleaning (SSPC-SP1): Used prior to surface preparation methods specified for the removal of rust, mill scale, or paint contaminants (i.e., blast, power tool or chemical cleaning) to remove visible grease and oil contaminants and prevent them from spreading during subsequent cleaning.

White Metal Blast Cleaning (SSPC-SP5/NACE No. 1): Leaves the metal white, with no shadows or visible contaminants (e.g., oil, grease, dirt, dust, mill scale, rust, paint, coatings, oxides, corrosion products and other foreign matter) left on the surface. It is the most expensive and stringent of all the surface preparation methods. It is not normally specified unless severe service exposure or immersion is required.

Near-White Metal Blast Cleaning (SSPC-SP10/NACE No.2): This method is between SSPC-SP5/NACE No. 1 and SSPC-SP6/NACE No. 3. All visible contaminants are removed, but 5% staining (from rust, mill scale, or previously applied coating) in each unit area (any square measuring 3 in. x 3 in. [76 mm x 76 mm]) is allowed. It is used where a higher degree of performance is required than is provided by SSPC-SP6/NACE No. 3 (e.g., interior wet surfaces) and where SSPC-SP5/NACE No. 1 is not economically justified. Near White Blast Cleaning is adequate for moderate to moderately severe exposure conditions.

Commercial Blast Cleaning (SSPC-SP6/NACE No. 3): The most economical of the abrasive cleaning methods, and provides an acceptable degree of cleaning before primer application. All visible contaminants are removed, but 33% staining (from rust, mill scale, or previously applied coating) in each unit area is allowed. This method is appropriate for mild to moderate corrosion environments.

Brush-Off Blast Cleaning (SSPC-SP7/NACE No. 4): This method involves the removal of all visible oil, grease, dirt, dust, loose mill scale, loose rust, and loose coating. Tightly adherent mill scale, rust, and coating may remain on the surface. It is useful in touch-up work, or repainting old coatings that are in relatively good condition.

Power Tool Cleaning to Bare Metal(SSPC-SP11): Power tool cleaning to remove all visible contaminants (e.g., oil, grease, dirt, dust, mill scale, rust, paint, coatings, oxides, corrosion products and other foreign matter) to produce a bare metal surface and to retain or produce a minimum 1.0 mil (25 micrometer) surface profile. This standard differs from SSPC-SP 15, in that no surface staining is permitted (slight residues of rust and paint may be left in the lower portion of pits). It differs from SSPC-SP3 in that it requires more thorough cleaning and a surface profile. Although not equivalent, this method is used for areas where abrasive blasting is prohibited or not feasible.

Commercial Grade Power Tool Cleaning (SSPC-SP15): Power tool cleaning to remove all visible contaminants and to retain or produce a minimum 1.0 mil (25 micrometer) surface profile. This standard permits random staining to remain on 33% of each unit area of the cleaned surface, where SSPC-SP 11 requires removal of surface staining. This standard differs from SSPC-SP3 in that it requires more thorough cleaning and a surface profile.

Power Tool Cleaning (SSPC-SP3): This method involves rotary wire brushes and grinders. It is usually used for small areas and results in a highly polished surface. Power tool cleaning does not provide a good surface profile for most primers.

Pickling (SSPC-SP8): This method is used where the object can be immersed in the cleaning solution (e.g., in metal shops) but it is not widely used. The process involves complete removal of all rust, mill scale and foreign matter by chemical reaction or electrolysis in acid solutions.

Table 4. Surface Preparation Standards

SSPC/NACE Standards		*Nearest Equivalent Standard*	
SSPC	NACE	International Standard ISO 8501-1 Swedish Standard SIS055900 British Standard BS 7079	British Standard BS4232
SSPC-SP5 White Metal Blast Cleaning	1	Sa3	First Quality
SSPC-SP10 Near-White Metal Blast Cleaning	2	Sa2-1/2	Second Quality
SSPC-SP6 Commercial Blast Cleaning	3	Sa2	Third Quality
SSPC-SP7 Brush-Off Blast Cleaning	4	Sa1	--
SSPC-SP11 Power Tool Cleaning to Bare Metal	--	--	--
SSPC-SP15 Commercial Grade Power Tool Cleaning	--	--	--
SSPC-SP3 Power Tool Cleaning	--	St3	--

3.1.7 Flexible Liners for Suction Tanks

Although it is not necessarily desirable, particularly in earthquake zones (see Section 3.1.1 and Section 3.1.3.6), in some tanks water is contained using a flexible internally-supported membrane, or liner. Common liner materials include synthetic rubber (e.g., EDPM, CSPE [CSM or Hypalon]), polypropylene and PVC.

If used, the liner material should be packaged and protected against damage in transportation and be sufficiently durable to be handled and installed with minimal damage. Liners should be supplied with repair kits.

Some, but not necessarily all, considerations when selecting a liner include the following:

A. Compatibility with the stored water (e.g., pH, chlorine, water hardness, etc.).

B. Durability for typical water temperatures, serviceability for expected maximum and minimum water temperatures, and resistance to failure at extreme temperatures. Use of a liner should be reconsidered when freezing of water in the tank is of concern.

C. Tank height and diameter.

D. Conditions that may require fabricating the liner in more than one piece or splicing the liner (e.g., large tanks, tanks with internal roof support columns) and the consequences of this.

E. The needed support to minimize effects of elongation, and the stability of the liner against shrinkage (suggestion is less than 3% over the design life of the liner).

F. The effects on the liner resulting from fluctuating water levels (for dual-service tanks) and multiple cycles of tank draining and refilling over its design life.

G. The permeability of the liner (some permeability of liners used in wood tanks may be desirable so that the wood does not dry out; liners covering internal insulation should be essentially impermeable).

H. The expected life (should not be less than 10 years).

I. Environmental conditions for any exposed portion of the liner (especially exposure to ultraviolet light).

Tank liners vary widely in thickness. It is suggested that an unreinforced liner be not less than 30 mils (0.75 mm) thick and a scrim-reinforced (e.g., with woven polyester) liner be not less than 24 mils (0.6 mm) thick. When the tank is 20 ft (6 m) tall or more, liners should be scrim reinforced (with a suggested tensile strength of about 110 lb/in. of liner [19.3 kN/m of liner]).

Liners need to be positively attached to support their self weight. At the top circumference the liner should be bolted or screwed (suggested maximum spacing of 12 in. [300 mm]) to minimize sagging. The suggested failure strength of each connection is 125 lb (550 N) with minimum #12 to #14 (0.216 in. to 0.242 in. [6 mm] diameter) screws or minimum 3/8 in. (10 mm) diameter bolts. The rim of the tank may need additional hoop reinforcement (e.g., using a rectangular hollow section) to prevent the rim from rolling in and to increase the thickness through which the screws or bolts can be placed. Intermediate liner supports will likely be needed when the tank exceeds about 13 ft (4 m) in height.

When the tank is supported by a ring beam, the liner should rest on a minimum 2 in. (50 mm) depth of clean, washed bedding sand. In FM 50-year through 500-year earthquake zones, the liner must be supported by a steel bottom or a concrete mat foundation. A geo-textile material should be used to protect the base of the liner from foundation materials, preferably over the whole base but at least where the bottom shell plates and foundation form a joint, and be lapped up the side of the bottom shell plate for a distance of not less than 12 in. (300 mm). The liner should be protected against sharp edges of tank elements, including, for example, the anti-vortex plate. Interior insulation (where used) attachments to the tank must be configured or covered so they do not damage the liner under normal or earthquake (in FM 50-year through 500-year earthquake zones) conditions.

The fill line should be located to prevent discharge behind the liner (at least two pipe diameters from the tank wall and directed towards the center of the tank). Other piping connections and the top of the liner (including any geo-textile material that extends to the top of the tank) should be detailed or sealed to prevent water infiltration behind the liner, particularly if interior insulation is used. The vortex inhibiter should be detailed or another method employed to prevent sucking up the liner.

The visible parts of the liner should be inspected yearly (Recommendation 2.3.6), and the tank should be drained (leaving a minimum of 2 in. [50 mm] of water to prevent liner movement) and the liner inspected thoroughly at intervals not exceeding five years (Recommendation 2.3.9). An indication of the life remaining in a tank liner should be estimated at each drain and clean interval. Subsequent tank drain and inspection frequency intervals may need to be adjusted based on the estimated remaining life of the liner or the expiration of the manufacturer's warranty.

Above the water line, liners should be checked for: eyelet corrosion, failure of eyelets or punched-hole connectors, discoloration, shrinkage (e.g., notable increased membrane tension), brittleness, surface deterioration, cuts and tears. Below the water line check for discoloration, elongation, bulging, loss of flexibility and for signs of leaks, cuts and tears. Remove all sludge and debris without using sharp tools to prevent tearing and puncturing of the liner. Patching of a liner is an acceptable method of repair if the patch repair work matches the performance of the factory-built liner. Ensure the liner is in the correct position prior to refilling; this includes the positioning of the neoprene mat (where fitted) under the vortex plate bottom support.

3.1.8 Other Suction Tank Types

Reinforced concrete suction tanks are not FM Approved, but if designed in accordance with American Concrete Institute standards ACI 350, ACI 350.3 and ACI 318 for the Section 2.2.3 design loads in this data sheet they would be expected to perform well under normal and natural hazard (e.g., earthquake) loadings.

Seismic design forces in ACI 350.3 are based on the effective mass method (i.e., impulsive and convective motion of contained water) for rectangular tanks that yields results similar to FM Approval Standard 4020.

3.2 Break Tanks

A break tank is an automatically filled tank that provides a suction water supply for a fire pump. The tank capacity is not adequate to supply the total sprinkler and hose stream demand for the required duration.

Careful consideration should be given to providing a full-size suction tank or reservoir. Larger underground mains to fill the break tank, and additional equipment and appurtenances can result in a break tank installation cost approaching or exceeding that of a full-size suction tank. This, coupled with the decreased reliability of the fire protection system, may make the full-sized suction tank a more attractive alternative.

Reliability of a break tank is less than that of an adequately sized suction tank because the automatic fill mechanisms are subject to mechanical failure. Also, the makeup water flowing into the break tank from the public supply can reduce pump performance due to excessive aeration and turbulence.

Break tanks provide a means of cross-connection control where jurisdictional authorities prohibit any direct connections between the public water supply and a private fire protection system, either for health or hydraulic reasons. This is accomplished by creating a physical break, or gap, between the public water supply and the private fire protection system. Water from the public water supply enters the break tank at a height above the tank overflow outlet and falls into the tank. Since the water in the tank is considered potable, the top of the tank should be enclosed.

The water from the public supply is no longer under pressure once it enters the break tank, so a fire pump taking suction from the break tank is needed to supply the fire protection water at adequate pressure. A booster fire pump, which previously took suction from the public water supply and was considered an adequate fire protection water supply, may not provide adequate water flow and pressure for fire protection if it is re-configured to take suction from a break tank. The flow and pressure characteristics of the public water supply will no longer affect the actual flow and pressure characteristics of the fire protection water supply downstream from the fire pump.

Guidelines for the fire pump installation are contained in Data Sheet 3-7, *Fire Protection Pumps.*

There are two types of float valves, modulating and non-modulating. Modulating float valves operate using a pilot controlled system to balance influent and effluent rates. The float valve responds to changing water levels by draining small amounts of water from the pilot control system, which creates a pressure differential across the fill valve. The pressure differential determines valve position, and thus the flow rate into the tank. Maximum recommended valve capacities can be obtained from valve manufacturers.

Non-modulating float valves open wide when the water level reaches the low float set point, and close fully when the water level reaches the high float set point. Because of this positive valve action, problems with water hammer may be introduced into the piping system feeding the fill valves. For this reason, modulating type float valves are preferred over non-modulating type float valves.

To confirm that the rate of inflow from automatic and manual fill valves has not been adversely affected by changes to the public water supply or valve deterioration over time, verify the inflow rate at least annually. Providing an annubar or other flow-measuring device on automatic fill lines as required by some codes, such as Australian Standard AS 2304, *Water Storage Tanks for Fire Protection Systems,* may be appropriate to allow more frequent verification when the public system is particularly vulnerable to seasonal variations.

3.3 Pressure Tanks

Pressure tanks are horizontal cylindrical steel tanks with a water capacity on the order of 200 to 20,000 gal (0.75 to 76 m^3). The tank water capacity is typically two-thirds of the total listed tank capacity (i.e., a 30,000 gal [114 m^3] tank usually contains 20,000 gals [76 m^3] of water). The remaining volume of the tank is filled with pressurized air. The 2/3 capacity line (or the line corresponding to a different design water level if applicable) must be marked and labeled on the tank plate behind the gauge glass.

A pressure tank may be used as a primary or secondary water supply to feed a sprinkler system and hoses, and multiple pressure tanks can be used in combination if needed to meet capacity demands. Pressure tanks may also be used where there is enough water from another supply source but the water pressure is too low, where extra water pressure is needed to supply the highest line of sprinklers or hoses, or to provide adequate pressure until automatic fire pumps have sufficiently increased the water supply pressure. When combined with gravity tanks, connections must be arranged to prevent air lock (residual pressure tank pressure holding the gravity check valve closed) by, for example, locating the connections of the discharge pipes and the gravity tank check valve at least 45 ft. (13.7 m) below the gravity tank bottom.

Pressure tanks should be painted as for other welded steel tanks (see Section 2.2.4). They should ideally be located above all the system piping so that the pressure required is reduced, but can be located at or below grade. Pressure tanks are usually housed in an enclosed structure (and must be if subjected to freezing); the tank room must be maintained at no less than 40°F (4.4°C).

If buried, backfill at least 12 in. (0.3 m) of sand around the tank, design the tank to resist the soil loads and provide a cathodic system to protect against corrosion. Project the end, and 18 in. (0.46 m) of the shell, of buried pressure tanks into a heated basement or pit. Buried tanks must also be located below the frost line to protect against freezing and above the maximum ground water level to protect against buoyancy (or be anchored against buoyancy).

Horizontal pressure tanks must have steel or concrete supports at each end so that the tank doesn't sag or vibrate and so that stresses are below allowable limits. In FM 50-year through 500-year zones, adequate anchorage is needed if support configuration does not prevent sliding and supports must be designed to transfer the lateral forces.

Pressure tanks should have the following:

A. A manhole below the water line

B. A water-level gauge with normally closed isolating brass valves at each end and a brass petcock for drainage

C. A tank discharge pipe (not less than 4 in. [100 mm] diameter) with a check valve, an indicating valve, and swing or expansion joints; and connected at the bottom of the tank to a fitting that projects 2 in. (50 mm) above the tank bottom (to form a settling basin)

D. A fill line (not less than 1.5 in. [38 mm] diameter), with a check valve, an indicating control valve, and a brass pressure-relief valve; and capable of filling the tank with the air pressure restored in 4 hours

E. An air supply pipe (not less than 1 in. [25 mm] diameter) connected to the tank above the water level with a check valve, a globe valve, and a brass pressure relief valve; and supplied by an air compressor with automatic controls (capable of delivering 20 ft^3/min [0.57 m^3/min] for tanks greater than 7500 gal [28.39 m^3] total capacity, and 16 ft^3/min [0.45 m^3/min] for smaller tanks)

F. A 4.5 in. (114 mm) dial, double spring air pressure gauge connected into the air chamber with a range twice the normal working pressure, and an adjacent brass plugged outlet for an inspector's gauge

G. An emergency drain (not less than 1.5 in. [38 mm] diameter) and valve at the bottom of the tank, and independent of all other tanks and the sprinkler system

H. Where the tank is the sole water supply, two alarms, one for low air pressure and one for low water, supplied from an electrical circuit independent of the air compressor. It is preferable to have two high and low alarm systems; one system to monitor the high and low air pressure and the other system to monitor the high and low water levels on all tanks.

The volume of water in the tank must be adequate to meet the required demand and the quantity of air in the tank and its pressure must be sufficient to push all of the water out of the tank while maintaining the necessary residual pressure at the top of the system. As the volume of air increases, the required pressure to accomplish this decreases. If the pressure is too high (e.g., exceeds the rated pressure of sprinkler system components) the amount of air carried in the tank will have to be increased, possibly requiring a larger tank. The air in the tank is typically maintained under a minimum pressure of 75 psi (5.2 bar) with the last water leaving the tank at a pressure of 15 psi (1.03 bar).

See NFPA 22 for methods to calculate the required pressure in the tank and for other provisions related to pressure tanks.

3.4 Operation and Maintenance

Keep the tank filled. Keep the filling bypass closed when not in use, even if the tank is filled by a fire pump. An open bypass would result in loss of needed firefighting water.

Keep the roof hatch cover and the door at the top of the frost-proof casing fastened to prevent wind damage, keep out birds, and conserve heat in winter.

A review of the tank exterior and equipment should be conducted at least annually, and more often for some items (e.g., see Section 3.8.6 for tank heating equipment) to expose problem areas. Any questionable conditions should be reported immediately to the management and necessary repairs recommended.

Keep the base of tower columns and suction tanks free from dirt, rubbish, or combustible material of any kind that might cause failure of the steel by fire, heat or corrosion. Keep the whole site clear of weeds, brush, and grass. Keep the tops of foundations at least 6 in. (150 mm) above ground level, and the bases of columns in which water accumulates filled with concrete sloped and flashed to shed water. Any intersection of masonry or concrete and steel should be kept flashed.

During repainting or repairs, the contractor or engineer should carefully inspect the entire structure, including foundations in the ground building directly beneath the tank, frost-proof casing, and accessories.

When repainting, give special attention to areas that are difficult to clean, such as around clevis pins, inside channel columns near foundations if pockets are formed by batten plates, and inside surfaces of angular members that are separated by thin lattice bars, washers, or short pipes.

Structural members passing through roofs or walls sometimes are not adequately waterproofed at the intersection. They should be exposed to determine their condition, repaired if necessary, and carefully cleaned, painted, and waterproofed. Pockets at the bases of columns or elsewhere that do not drain should be filled with concrete and the tops sloped to shed water. Flash the contact surfaces between concrete and steel with asphalt.

Parts affecting the strength of the structure should be renewed or repaired by a competent tank contractor. Do not remove diagonal wind rods or other members unless the tank is empty and struts or guys are arranged to prevent collapse.

The plates at the water surface of a steel tank that has not been painted frequently enough may be seriously corroded and require replacement. Conditions in individual cases will determine whether it will be less expensive to replace the whole tank or only the seriously corroded plates.

Repair leaking joints in welded tanks by removing all defective metal and rewelding to full strength. Welded joints should be repaired only after completely draining the tank or lowering the water at least 2 ft (0.6 m) below the joint to be repaired. Do not attempt to make repairs by welding or hammering while a tank is full. Prepare the surface and repaint the tank at the new weld.

Leaks in existing riveted tanks may be repaired by one or a combination of methods. With caution, welding may be used on a limited basis without causing leakage at adjacent seams and rivets. To keep the heat of the metal as low as possible and still be consistent with good welding practice, one should employ small weld beads for each pass. The tank surface will need to be prepared and repainted at welded locations. Partial welding combined with caulking adjacent to the weld, rather than welding all seams and rivets, can be effective. This method is more successful near the high water line than lower in the tank where joints are subject to greater stress fluctuations between full and empty conditions. Where minor seepage is encountered, epoxy cement can be used effectively.

Welded repairs should be completed using welders and welding procedures that are qualified and certified in accordance with AWWA D100. Filler and patch materials must be weldable and compatible with the original materials of construction. Joint design should be in accordance with the original code of construction and/or recognized industry repair standards (such as the National Board Inspection Code [NBIC]).

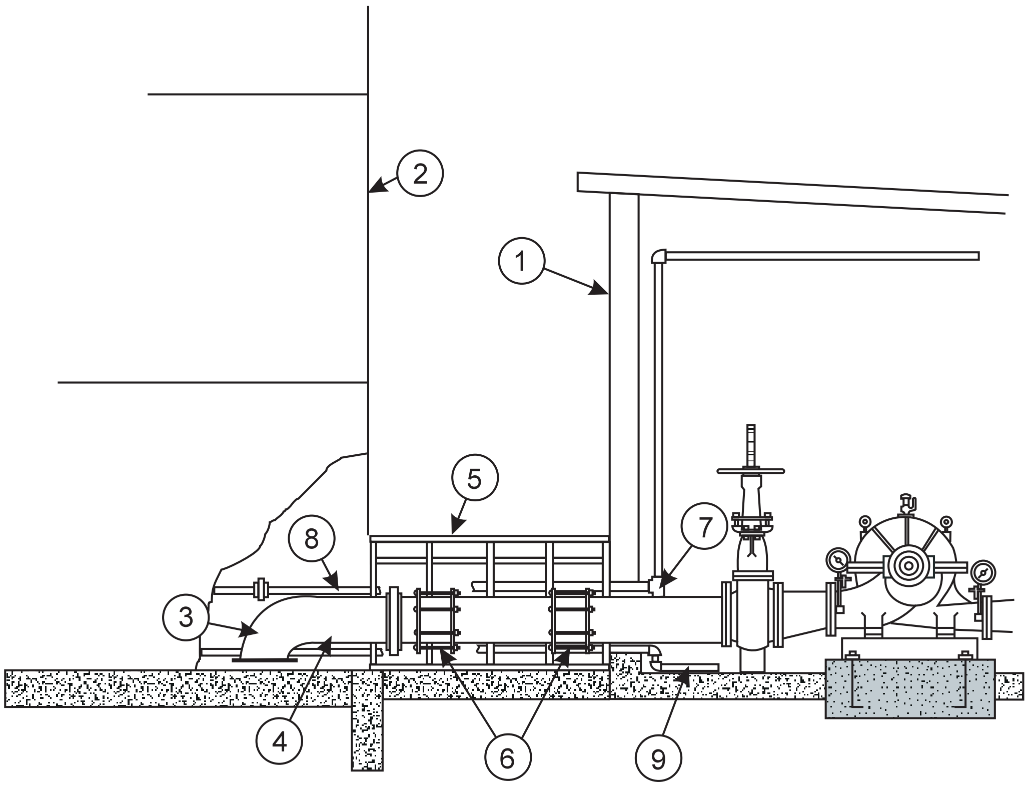
Old wooden tanks develop small leaks even though the lumber may be generally sound. Leakage may result in dangerous icing on tank structures, and should be promptly remedied. Waterproofing preparations have stopped slight leakage for three to five years and even longer. However, waterproofing or plastic bag liners are suggested only when the tank is otherwise in good condition, and should always be regarded as a temporary remedy. If the lumber is generally rotted, replace the tank.

Repair and securely anchor roofs of wooden tanks that have been in service for ten years, as well as those in which nails are badly rusted or roof boards and their supports rotted. The following procedure is recommended:

1. Have the roof carefully inspected by a qualified contractor.

2. Replace all rotted lumber, including that in the hatches.

3. Re-nail boards and supports with corrosion-resistant nails such as those of galvanized, chromium nickel steel alloy, or Monel metal.



1. Pump room
2. Approved above ground suction tank
3. Entrance elbow with anti-vortex plate or flange above bottom of tank (see section 3.6.5)
4. Suction pipe
5. Frostproof casing, about 4 ft (1.2 m) high and 4 ft (1.2 m) wide
6. Flexible couplings
7. Steam trap on steam supply
8. Heating coil inside tank
9. Condensate return line to steam trap

Fig. 6. Discharge pipe connected to side of suction tank

3.5 Foundations

Tanks and tank towers may be supported on foundations in the ground, by building walls, or by framework.

3.5.1 Foundations in the Ground

The overall foundation design, including necessary soil exploration, is the responsibility of the purchaser or his engineering representative. This design must be coordinated with the tank contractor, who usually takes no direct responsibility in this area but will furnish a suggested foundation design as part of his contract if requested.

Cylindrical tanks at grade are most commonly founded on a reinforced concrete ring beam that transfers the concentrated dead weight of the tank shell and the roof supported by the tank shell to the soil, and also retains compacted gravel and sand on which the tank bottom rests. The concrete ring beam center line should be the same diameter as the tank. Although it is not preferred, in FM >500-year zones, and where wind anchorage is not needed, a compacted berm with a corrosion-resistant steel retaining ring may be adequate for a small tank.

Where cylindrical ground-supported tanks require anchorage to resist earthquake overturning, ring beams may need to be extremely deep and/or wide to provide enough dead load to resist uplift forces. The uplift can be resisted by the weight of the concrete in the foundation, and the weight of the soil and water directly above the foundation (but only the weight of the water in excess of the water weight already assumed to be picked up by the tank bottom plate to resist overturning). Alternatives to a large ring beam could include providing piles under the ring beam, or providing a mat foundation.

Piers supporting large steel-plate risers may be hollow (Figures 14 and 15) or of solid reinforced concrete. Provide a solid reinforced concrete pier to support the base elbow of a pipe riser.

Use of expansion bolts to anchor columns of elevated tanks or for suction tank uplift anchorage should be avoided. The stressed portions of anchor bolts should not be exposed. If they must be, protect them from corrosion by, for example, encasement in cement mortar. This is unnecessary if they are accessible for complete cleaning and painting.

3.5.2 Supporting Buildings

Buildings supporting tanks should be of fire-resistive construction. If a gravity tank or supporting tower is to be placed on the walls of a new building, construct the building to carry the maximum loads. Old buildings should be carefully checked by an engineer to determine whether the tank can be safely installed. Existing buildings in active seismic areas require special review before a tank is constructed on them.

3.6 Pipe Connections and Fittings

Make watertight intersections between all tank pipes and building roofs, and waterproof floors so that water from above cannot flow down the outside of pipes to lower floors or basement. For existing gravity tank installations and all pressure tank installations where earthquake protection is needed, provide clearance holes around tank piping at roofs, floors, partitions and walls of buildings unless the buildings are designed to resist earthquakes as a rigid unit. The holes should provide at least 1 in. (25 mm) of clearance around pipes. Mineral wool or other noncombustible but compressible material should be retained in the space by pipe collars for a substantially watertight intersection.

3.6.1 Riser and Connections

Risers for gravity tanks may be of either pipe or fabricated steel plate. When pipe is used, conditions at individual plants determine the size of the riser. The diameter, however, should not be less than 6 in. (150 mm) for tanks up to 25,000 gal (94.6 m^3) capacity, not less than 8 in. (200 mm) for 30,000 to 100,000 gal (114 to 378 m^3), or less than 10 in. (250 mm) for greater capacities. Larger pipe may be necessary because of the location and arrangement of piping, height of buildings, or other conditions. Pipe risers for FM Approved tanks are flanged cast iron, steel, or welded steel pipe. Copper, lead, or high quality rubber gaskets are placed between the flanges.

Risers fabricated from steel plate should be at least 3 ft (0.91 m) in diameter. When supported on a hollow pier (Figures 14 and 15), the short length of vertical discharge pipe should be either wrought steel with a welded connection or cast iron with a lead joint through the bottom plate of the riser.

Where earthquake-resistant construction is necessary, weldable steel or other ductile metal for the riser pipe, base elbow, and other pipes and fittings is used rather than cast iron, unless FM Approved flexible couplings are installed. A small pipe riser is preferred to a large steel plate riser because it weighs less and, consequently, transmits smaller earthquake forces to the tower and foundation.

The top of a pipe riser extends above the inside of the tank bottom to form a settling basin. With large steel-plate risers, the vertical discharge pipe extends above the bottom or the connection is through the side of the riser. The minimum depth of settling basins is 4 in. (100 mm) for a flat-bottom tank; 18 in. (457 mm) for a suspended-bottom, steel gravity tank with a pipe riser; 18 in. for an elevated, spherical tank; and 3 ft (0.91 m) at the base of a large steel-plate riser.

The inlet to the vertical discharge pipe in elevated tanks with large steel-plate risers, 3 ft (0.91 m) or larger in diameter, should be protected against the entry of foreign materials. Provide a flat, protective cover plate (Figure 16) extending at least 4 in. (100 mm) beyond the outside diameter of the pipe and a minimum of one pipe diameter above the inlet.

3.6.2 Bracing and Support of Riser

Brace tank risers laterally to resist wind damage, using rods not less than 5/8 in. (16 mm) in diameter connected to the tower columns near each panel point. Such braces should be installed at each strut level for large steel plate risers. End connections of braces should consist of eyes, shackles, or nuts; open hooks should not be used.

Where earthquake-resistant construction is necessary, brace risers and other tank pipes to the panel points of the columns so that they will follow the tower vibration without being over stressed. With pipe risers, FM Approved flexible couplings may be installed. Brace base elbows and bottoms of large steel-plate risers to resist lateral movement. Secure existing tank pipes inside buildings to prevent them from vibrating independently.

Support a pipe riser with no offsets at its base by a double-flanged base elbow resting on a concrete foundation (Figure 9). If an offset is unavoidable and the distance from it to the tank is more than 35 ft (10.7 m) for a flat-bottom tank or 75 ft (22.8 m) for a steel tank with suspended bottom, support the pipe at the offsetting elbow directly beneath the expansion joint (Figure 8) and at points not over 12 ft (3.7 m) apart horizontally. Inside a building, provide rigid, lateral bracing for offsets at the base of the riser, and support the elbow at the base of the vertical pipe by a hanger from the floor. Use a reinforced concrete pier to support a large steel-plate riser for a tank or an independent tower.

3.6.3 Provision for Expansion in Riser

When a base elbow of a pipe riser without offset is more than 35 ft (10.7 m) from the bottom of a tank, provide an expansion joint at the tank bottom (Figures 8 and 9). With the more modern, pedestal-supported tanks, use the expansion joint at the ground end of the pipe riser. It is easier to service at the lower end, and in case of leakage, the riser pipe insulation will not be wet. If an offset in a pipe riser is more than 35 ft (10.7 m) from the bottom of a tank, provide an expansion joint, or make the offset a four-elbow swing joint unless it needs to be supported (Figures 9 and 10). When a four-elbow swing joint is used, rigidly connect the pipe riser to the bottom of the tank. Provide a four-elbow swing joint at any offset in a pipe riser where the vertical length of the pipe riser below the offset is more than 35 ft (10.7 m).

Where earthquake-resistant construction is necessary, provide expansion joints of steel or other ductile metal. Cast iron may be used if FM Approved flexible couplings are installed in the pipe in addition to the expansion joints.

Rigidly connect the top of a large steel plate riser to the suspended bottom of the tank. For a tank over a building, rigidly connect the discharge pipe to the base of the riser.

3.6.4 Valves in Riser

Install an FM Approved check valve horizontally in the discharge pipe from a gravity tank. Locate it in a pit under the tank if the tank is on an independent tower (Figure 10), and in an outside pit if the tank is located over a building (Figure 7). If yard room is not available, the check valve may be located on the ground floor or in the basement of a building, provided it is adequately protected against breakage. The check valve should ordinarily be bossed, drilled, and tapped for a filling bypass.

Provide an FM Approved, indicating-type valve in the discharge pipe on the yard side of the check valve. Install it between the check valve and any connection of the tank discharge to other piping (Figures 7 and 10). If yard room for an indicator post is not available, a valve similarly arranged but inside the valve pit or house may be used.

Provide another indicating-type valve in the discharge pipe on the tank side of the check valve. If the tank is on an independent tower, place this valve in the pit with the check valve, preferably on the yard side of the base elbow. If the tank is located over a building, place the valve under the roof near the point where the riser enters the building (Figure 7). Existing earthquake-resistant tank structures over buildings, however, should have control valves in the tank pipes just above the building roof.

3.6.5 Suction and Break Tank Pipe Connection

The suction pipe may be connected to the side or bottom of a steel tank. An anti-vortex plate or flange is needed to reduce eddies and the tendency for air to be drawn into the suction pipe during a large flow as the water level approaches the top of the pipe. The anti-vortex plate should be fabricated from steel and be configured as follows:

A. When the suction line passes through the side of the tank (Figure 6), provide a 90 degree long radius elbow down with an anti-vortex plate (minimum ¼ in. [6 mm] thick having a diameter or each plan dimension at least twice the diameter of the suction line) at its end. Locate the anti-vortex plate 6 in. (150 mm) or half the suction line diameter (whichever is greater) above the tank bottom.

B. When the suction line enters from the bottom of the tank (Figure 11), extend the suction line least 4 in. (100 mm) above the bottom to act as a silt stop. Locate the anti-vortex plate a minimum of 6 in. (150 mm) or half the diameter of the suction line (whichever is greater) above the end of the suction line. The anti-vortex plate should be a minimum of ¼ in. (6 mm) (but preferably at least 3/8 in. [9.5 mm]) thick, have each plan dimension at least twice the diameter of the suction line, and be reinforced at the edges with a 2 x 2 x 1/4 in. (50 x 50 x 6 mm) steel angle on the upper side and provided with vertical support for the edges of the plate on legs of similar-sized angles welded or bolted to the tank bottom and the reinforcing angles.

The rated capacity of the tank is the amount of water contained between the overflow inlet and the anti-vortex plate.

For a concrete tank, the suction pipe may be connected in the same way as to a steel tank, or enter the sidewall of the tank and extend to a bottom sump. This sump should be at least 5 ft (1.5 m) square and 2 ft (0.6 m) deep. The suction pipe should terminate in a commercial flange-and-flare fitting whose open end is at least 15 in. (0.38 m) below the tank bottom and in the center of the sump. Pipe passing through concrete should have a special fitting, such as a wall casting or sleeve with a circular lug, buried in the concrete. The rated capacity for a tank with such a sump will be the amount of water contained between the overflow inlet and the bottom of the tank at the sump.

3.6.6 Tank Filling Connections

When a gravity tank is filled from the fire protection system under public water or fire pump pressure, the filling pipe should be a bypass around the check valve (Figures 7 and 10). Connect the bypass into tapped bosses on the valve body or into the discharge pipe between the check and main controlling valves. The bypass should be a 2 in. (50 mm) pipe, but 3 in. (75 mm) pipe may be accepted. Provide an OS&Y gate valve in the bypass.

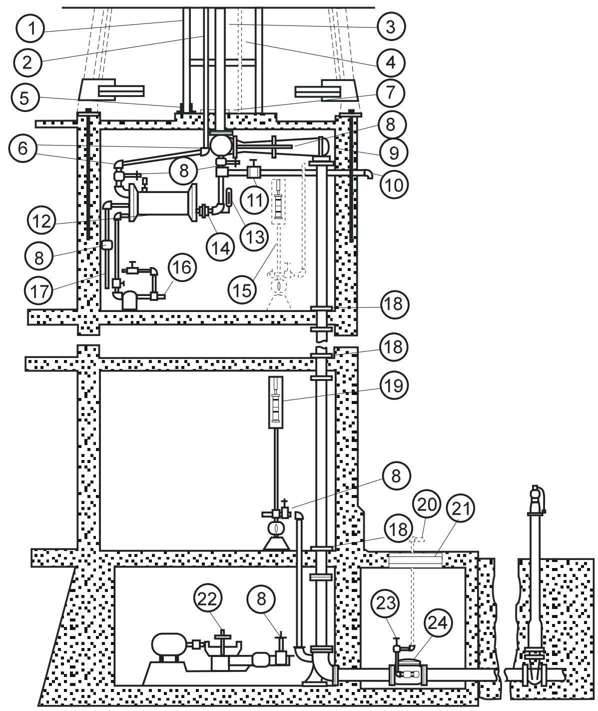
When a special pump is used, it should be large enough to fill the gravity tank in 8 hours. The filling pipe should be steel and at least 2 in. (50 mm) in diameter. It may be connected directly to the tank discharge pipe (Figure 7). The water supply should be potable if the water in the fire protection mains is. Conversely, if the fire protection water is non-potable, the filling water should also be from a non-potable source. Provide OS&Y gate and check valves in the filling pipe near the connections to the tank discharge pipe, with the check valve on the pump side of the gate valve. Do not connect the filling pipe to a fire service main supplied from the tank.

Pump suction tanks may be filled through a separate pipe by a special pump or, in some cases, a bypass around the check valve on the discharge side of the fire pump. Select pipe sizes and arrange the filling pipes similarly to those for gravity tanks.

3.6.7 Overflow Pipe

Inside overflow drains should be discouraged whenever possible. If the pipe leaks, the tank will drain unnoticed.

When dripping water or small accumulations of ice are not objectionable, the overflow pipe may pass through the side of the tank near the top (Figure 4). The pipe should project not more than 4 ft (1.2 m), have a slight downward pitch, discharge beyond the tank or balcony and away from any ladder, and be adequately supported. Vertical extensions of pipe to any balcony or below are not recommended because they may plug with ice.



1. Frostproof casing
2. Hot water circulating pipe
3. Pipe riser
4. Inside brass overflow pipe when used
5. Flashing
6. Four-elbow swing joint
7. Watertight intersections
8. Approved OS&Y gate valve
9. Four-elbow wing joint
10. Heater cleanout pipe
11. Globe valve
12. Steam-heated water heater with water pressure relief valve
13. Thermometer
14. Cold water circulating pipe
15. Alternative position of mercury gauge
16. Condensate return
17. Steam supply pipe
18. Watertight thimbles
19. Mercury Gauge
20. Drain discharge with 21/2 in. (64 mm) hose connection (Dashed portion to be removed when not in use)
21. Round manhole with cover
22. Filling pump, if necessary, capable of filling tank in 8 hrs. Locate in basement or pit as shown
23. Drain valve, at least 2 in. (50 mm) in diameter
24. Approved check valve with bypass and OS&Y gate valve

Fig. 7. Gravity tank tower located over a buildling

If dripping water or ice accumulations are objectionable, a gravity tank overflow pipe may be located inside the tank and extend through the bottom and inside the frost-proof casing or large steel-plate riser. The pipe will discharge through the casing or riser near ground or roof level. The section of pipe inside the tank and riser should be of a type shown in Table 5. The inside overflow pipe should be braced to the tank and riser plates by substantial clamps at points not over 25 ft (7.6 m) apart. The discharge should be visible and the pipe pitched to drain. If the discharge is exposed, its length should not exceed 4 ft (1.2 m) and should avoid the entrance to the valve pit or house.

Table 5. Pipe Material for Water Storage Tanks

The following materials may be used for pipes provided they meet the standard shown.	
Material	Standard
Copper	Accepted
Brass	Accepted
Seamless carbon steel	ASTM A-106
Seamless steel Grades A & B	ASTM A-53
Cold-drawn, low-carbon steel	ASTM A-192
Seamless medium carbon steel	ASTM A-210
Proprietary low-allow steel	Submit to FM for review

Note: Pipe should be Schedule 40. Tube should have a wall thickness approximately equal to the thickness of Schedule 40 pipe of the same nominal diameter.

3.6.8 Cleanout Opening and Drain Pipes

An FM Approved, steel gravity tank with a large steel-plate riser has a manhole near the base of the riser (Figures 14 and 15) through which the settling basin can be cleaned. If the tank has a pipe riser and suspended bottom, a hand-hold is provided in the saucer plate outside the frost-proof casing (Figure 8). FM Approved flat bottom, steel or wooden tanks have at least a 2 in. (50 mm) diameter clean-out opening outside the frost-proof casing.

An FM Approved steel suction tank whose top is above the ground has a manhole in the side.

Connect a drain pipe at least 2 in. (50 mm) in diameter near the base of a pipe riser, discharge pipe from a large steel-plate riser, or vertical suction pipe from a suction tank. If possible, make this connection on the tank side of all valves. Provide a control valve and 1/2 in. (13 mm) cock for the drain pipe. If the drain pipe is to be used for a hose stream, the control valve should be an FM Approved unit. Fit the open end of the drain pipe with a 2-1/2 in. (65 mm) hose connection unless it discharges into a funnel or cistern pipes to a sewer. If the drain is piped directly to a sewer, provide a sight glass or 3/4 in. (19 mm) test valve on the underside of the pipe.

If a circulating tank heater is located near the base of the tank riser, connect the drain pipe to the cold-water return pipe between the cold water valve and the heater. This permits water to be flushed from the tank through the hot water pipe, heater, and drain (Figure 10).

3.6.9 Water Level Indicator

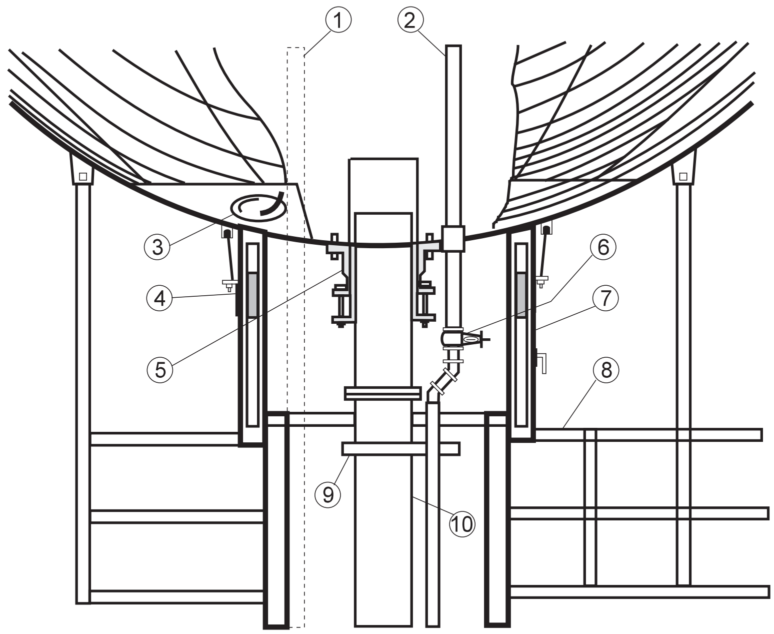
Gravity and suction tanks should have a means of observing the water level. FM Approved mercury gauges with mercury catchers or altitude gauges are most commonly used. Mercury gauges must be located in heated areas where sufficient building height is available for the column. Altitude gauges should have corrosion resistant cases and be suitable for measuring small head differentials.

Gauges are not important for a tank equipped with a supervised water-level signaling system.

3.7 Valve Enclosures and Frost Protection

3.7.1 Valve Pit or House

When the gravity tank is on an independent tower, provide a valve pit (Figure 10) or a house at the base of the riser to enclose the valves, tank heater, and other fittings. A valve pit is preferable. When a suction tank has the suction pipe connected to its bottom, provide a valve pit as shown in Figure 11. The pit or house should have sufficient headroom and provide at least 12 in. (0.3 m) clearance around all equipment. If



1. Inside brass overflow pipe, if used
2. Hot water circulating pipe
3. Handhold for removing sludge
4. Frostproof casing when required
5. Expansion joint
6. Approved OS&Y gate valve
7. Door in frostproof casing
8. Walkway
9. Brace for hot water circulating pipe
10. Pipe riser

Fig. 8. Details of pipe connections to bottom of steel gravity tank with pipe riser

possible, provide 18 in. (0.46 m) of clearance. If the equipment includes a heater with a bolted end, provide sufficient space to remove the tube assembly for annual cleaning without disturbing the heater shell.

Construct the pit of concrete with the top at least 6 in. (150 mm) above grade. The bottom should be far enough below grade to place the base elbow below the frost line and at an elevation where connections to the yard-pipe system can be made conveniently. If a large steel-plate riser is supported on a hollow pier, provide a slip joint between the pier and valve pit (Figures 14 and 22). Provide a sump and drain if a sewer or other suitable drainage connection is available. If the pit is below drainage level, waterproof its outside surfaces and provide a water ejector or sump pump (Figure 20). One method is to paint the pit with asphalt and cover it with at least two alternating layers of felt and asphalt, over lapping the felt 18 in. (0.46 m).

If subsurface drainage or rock formations make an above grade valve house more practical, construct it of concrete, masonry, or cement plaster on metal lath. Provide a solid concrete pier for the base elbow of a pipe

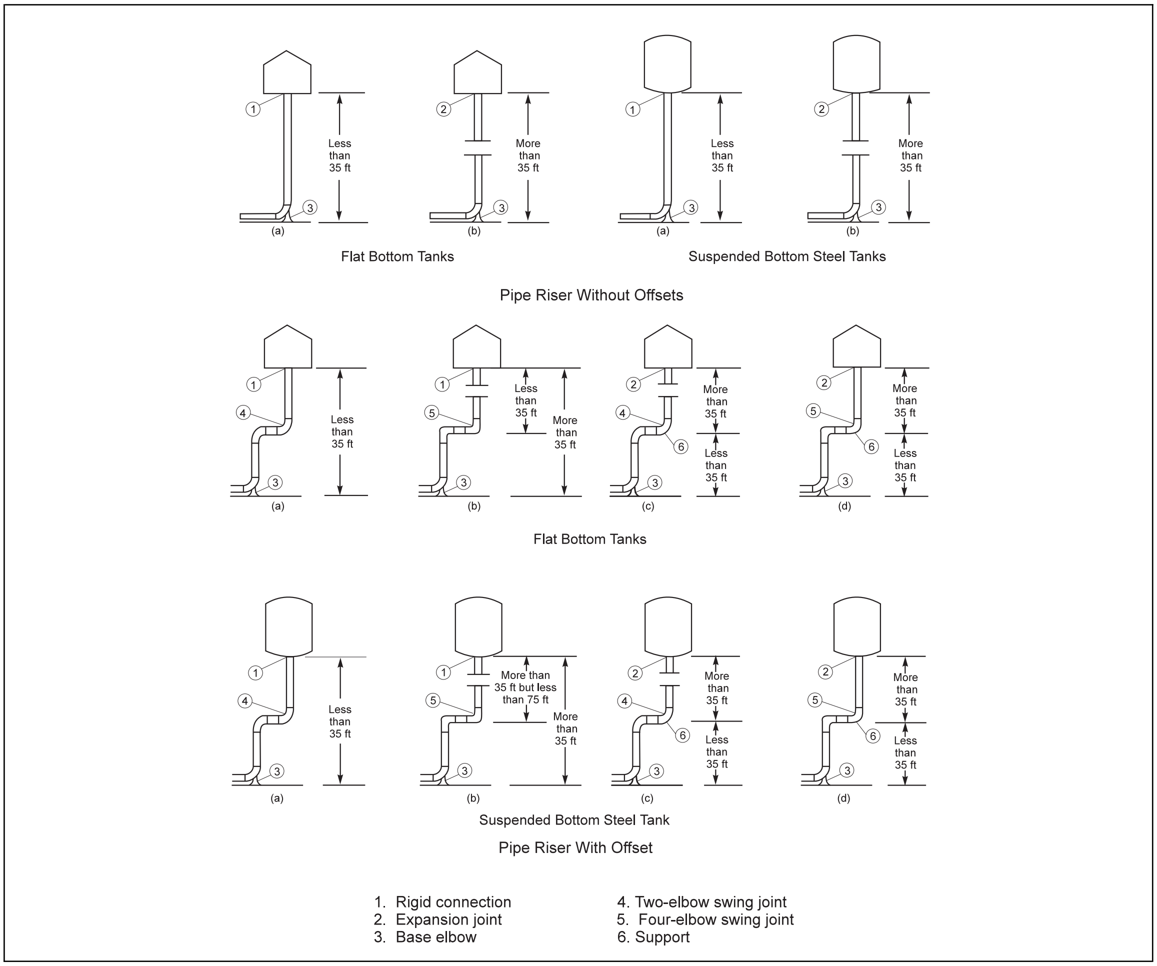


Fig. 9. Support and provision for expansion of pipe risers (35 ft = 10.7 m; 75 ft = 22.8 m)

riser or the base of a large steel-plate riser. If the tank has a pipe riser, the main control valve may be placed in the vertical part of the riser. If it has a large steel-plate riser, connect the discharge pipe to the side of the riser, and place the main control valve in the horizontal pipe. In any case, locate the check valve in a pit below grade.

For earthquake-resistant construction, provide a clearance of at least 2 in. (50 mm) around pipes where they extend through the roof, walls, or floors of the valve pit or house. Install watertight packing or flashing where necessary to exclude groundwater from the pit.

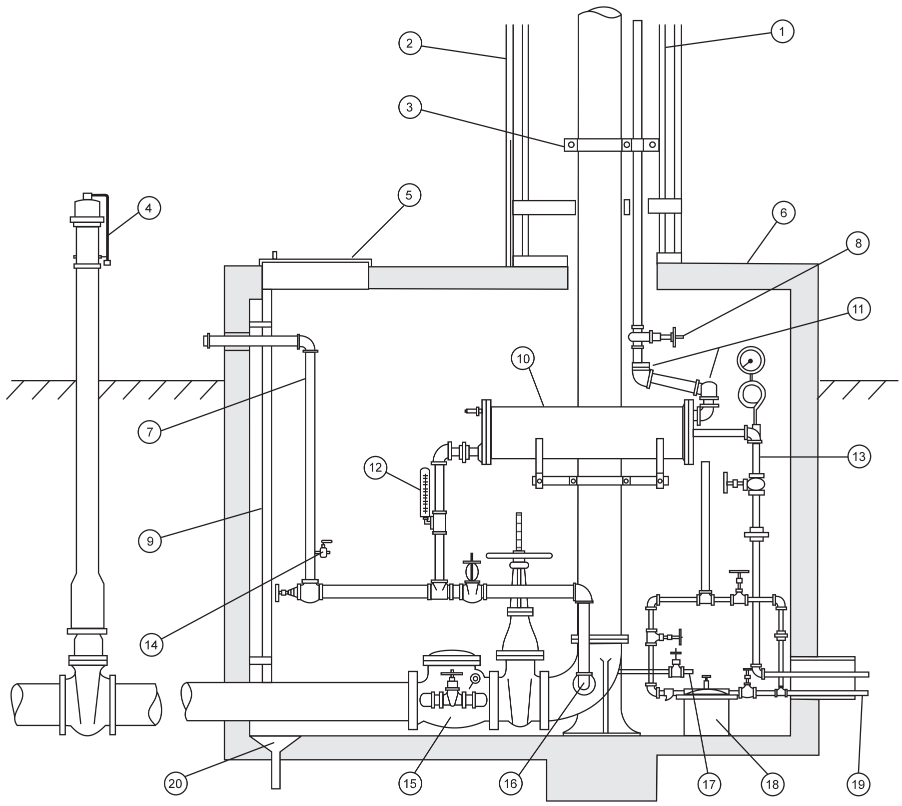
Provide a standard round manhole in the roof of the valve pit with a cover at least 24 in. (0.6 m) in diameter. A square, metal manhole with sturdily hinged cover at least 20 in. (0.51 m) on a side, or a raised hatch of equivalent size with a hinged cover may also be used. Where there is no heater in the pit, the manhole should have a fitted, inside cover of 2 in. (50 mm) plank or its equivalent located at least 4 in. (100 mm) below the outer cover. Provide a rigidly secured steel ladder from the manhole to the floor.

If a heater house is built above the valve pit, it should be of noncombustible construction. It also should have a strong roof to support any planned frost-proof casing and other loads without excessive deflection. Provide a tight-fitting double door large enough to admit people and equipment.

If the house contains a heater that burns oil or heavier-than-air gas, and is located over a below-grade valve pit, locate the entrance to the pit outside the heater house.

The portion of the floor over the pit should be of continuous concrete, tightly caulked around all pipes.

Maintain a temperature of at least 40°F (4.4°C) at all times in a valve pit or house.



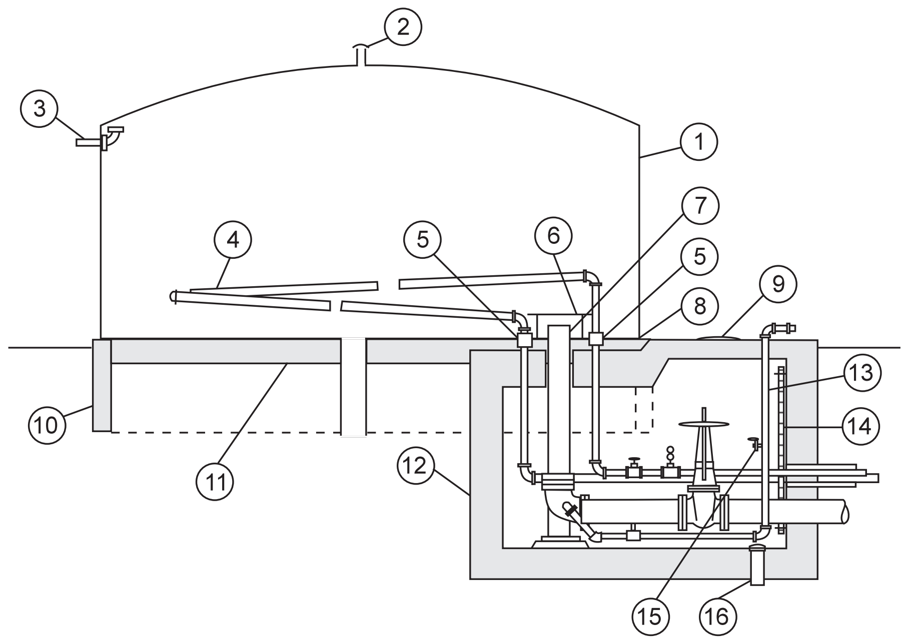
1. Hot water circulating pipe
2. Frostproof casing
3. Pipe clamps. Locate at about 25 ft (7.6 m) intervals. Loose fit around hot water circulating pipe
4. Indicator-post valve. May be replaced with indicating-type valve in pit on yard side of check valve if space is not available for indicator post
5. Hatch cover
6. Valve pit
7. Drain pipe
8. OS&Y gate valve
9. Ladder
10. Tank heater with relief valve set at 120 psi (825 kPa)
11. Four-elbow swing joint
12. Thermometer
13. Steam supply pipe
14. Drain cock, 1/2 in. (13 mm)
15. Approved check valve with bypass
16. Cold water circulating pipe
17. Pipe to mercury gauge
18. Steam trap
19. Condensate return
20. Valve-pit drain

Fig. 10. Valve pit and pipe connections at base of tank on independent tower (tank has a pipe riser and steam-heated gravity circulating heating system)

3.7.2 Frost-proof Casings

Noncombustible materials are preferred for frost-proof casings or insulation for exposed pipe risers, risers within pedestal-supported tanks, and exposed discharge pipes from suction tanks (see Figure 12). Protect insulation exposed to the elements with a weather tight jacket.

In order to meet the minimum insulating “R” values specified in Recommendation 2.2.6.3, wooden, frost-proof casings (Figure 13) should not be less than four-ply with two air spaces in localities where the 100-year return



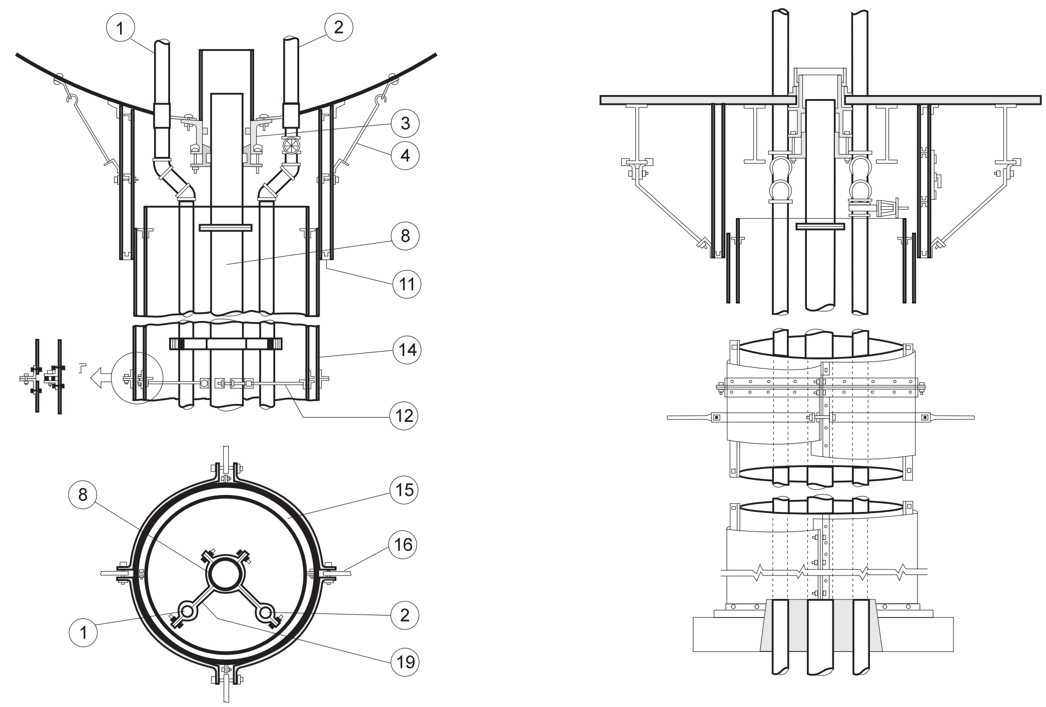
1. Approved pump suction tank
2. Screened vent
3. Stub overflow pipe
4. Steam coil for heating
5. Extra-heavy couplings welded to tank bottom
6. Anti-vortex plate (see section 3.6.5)
7. Watertight lead slip joint
8. Flashing around tank
9. Round manhole with cover
10. Concrete ring wall
11. Sand or concrete pad (depending upon soil conditions)
12. Valve pit
13. Drain pipe
14. Ladder
15. Drain cock, 1/2 in. (13 mm)
16. Valve-pit drain

Fig. 11. Discharge pipe connected to bottom of suction tank

period daily minimum temperature (100-year DMT) zone is -25°F (-31.7°C) or colder. For a 100-year DMT zone of -10°F (-23.3°C) to -20°F (-28.9°C), inclusive, the casings should be three-ply with two air spaces. For a 100-year DMT zone of -5°F (-20.6°C) to 20°F (-6.7°C), inclusive, casings should be at least two-ply with one air space. In some areas, insulation equipment with a weather tight jacket may be used for frost-proofing. To prevent settling, insulating material should be of the preformed type or adequately secured to the pipes and tank bottom.

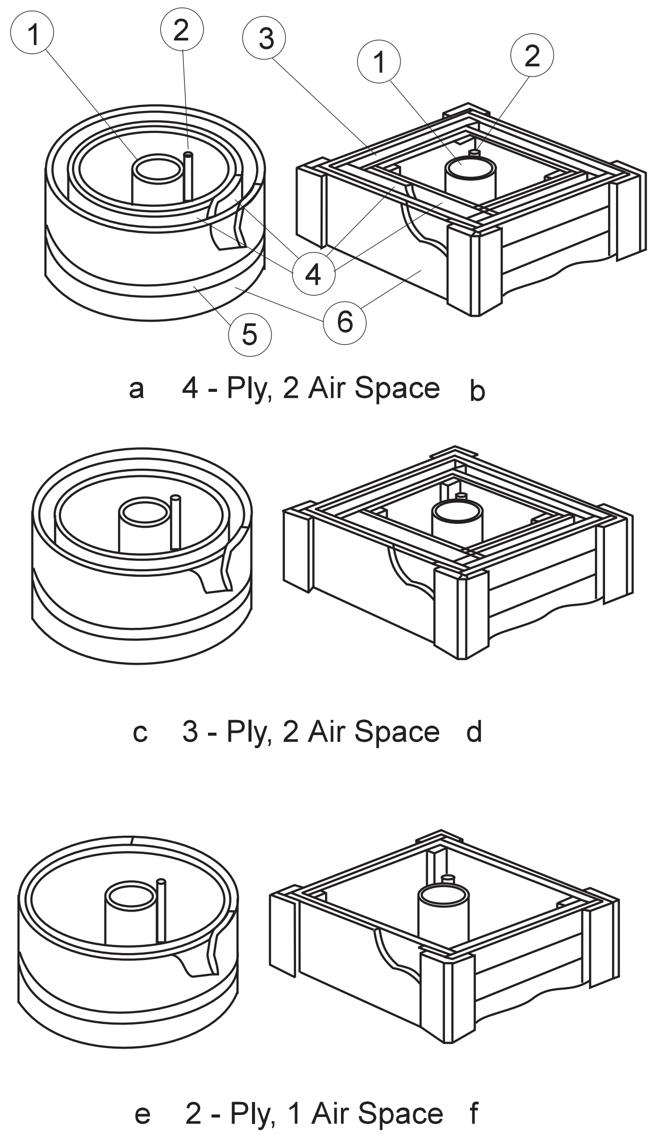
Where access openings are needed, the covers should have insulating properties equivalent to those of the casing. Absorbent insulation materials should not be in contact with iron or steel pipes.

A wooden casing of two-ply construction with one air space or the equivalent will usually suffice to protect piping inside unheated buildings where freezing may occur.



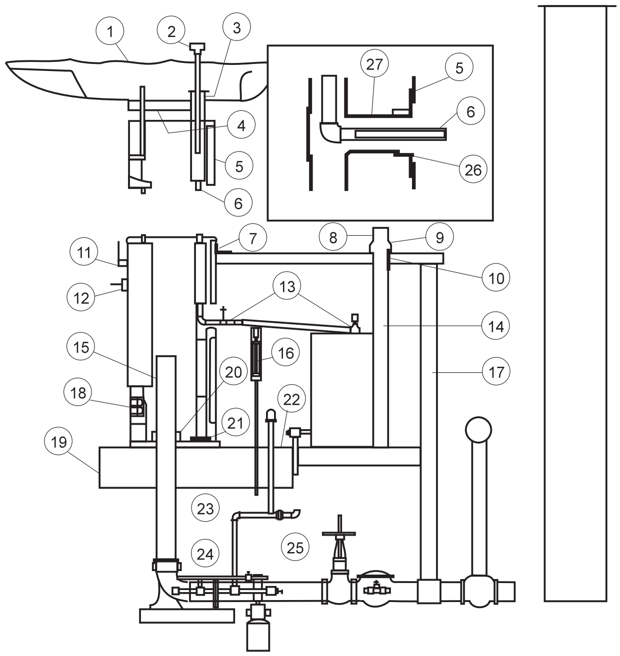
1. Inside overflow pipe
2. Hot water circulating pipe
3. Expansion joint
4. Hook bolts (provide four)
5. Eyebolts (provide four)
6. Door near valve; also needed with steel tanks
7. Dunnage (or grillage) beams
8. Pipe riser
9. Continuous angle, 3 by 3 by 1/4 in. (75 x 75 x 6 mm)
10. Angle, 3 by 2 by 1/4 by 6 in., spaced 2 ft on centers (75 x 50 x 6 x 150 mm, spaced at 0.6 m)
11. Continuous channel
12. Adjustable bolts and pipe collar, four at 20 to 25 ft (6.1 to 7.6 m) intervals
13. Vertical flanged edge and angle stopped off to permit dropping of enlarged upper section
14. 20-gauge galvanized steel or painted Toncan metal or aluminum
15. 3-in. (75 mm) space filled with noncombustible insulation
16. Frostproof casing brace, 5/8 in. (16 mm) rod at each panel point of lowest columns.
    Do not connect to horizontal struts
17. Drain hole
18. Watertight intersections
19. Pipe braces

Fig. 12. Insulated metal frost-proof casing for tanks having pipe risers



1. Pipe riser
2. Hot water circulating pipe
3. Air Space, 1 to 2 in. (25 to 50mm)
4. Building paper, one thickness of two-ply building paper round inner casing and between piles of wood
5. Galvanized iron flats (11/2 by 1/16 in.) (38 x1.6 mm) or round hoops, 1/8 in. (9.5,,) in diameter, at each horizontal nailing strip (not shown); nailing strips located about 4 fr (1.2m) apart
6. Wood sheathing, dressed from 1 in. (25mm) stock

Fig. 13. Wooden frost-proof casings



1. Steel gravity tank
2. Hot water outlet
3. Outer pipe
4. Brace rods, at least 1/2 in. (13mm) in diameter and not more
5. Large steel-plate riser
6. Hot water circulating pipe
7. Well flashed joint
8. Vent or stack, size and height as given in heater manufacturer's tables. Guy adequately and do not locate near tower steelwork
9. Apron
10. Thimble
11. Thermometer
12. Temperature sensing element for automatic control of heater when desired. Locate at least 1 ft (300mm) away from outer pipe 3
13. Four- elbow joint
14. Damper if needed when heater is coal-fired
15. Discharge pipe
16. Mercury gauge
17. Noncombustible heater house
18. Manhole cover
19. Hollow-center pier and valve pit
20. Welded connection
21. Watertight joint
22. Iron grating
23. Caulking where pipes pass through sleeves in concrete floor
24. Drain pipe
25. Drain cock, 1/2 in. (13mm)
26. Extra-heavy coupling welded to plates
27. Pipe nipple, of sufficient diameter to provide 2 in. (50mm) clearance around hot water circulating pipe 6

Fig. 14. Gravity circulation system with aboveground, fuel-fired water heater for tank with large steel-plate riser

3.8 Tank Heating Equipment

Ice in or on tank structures has been the direct cause of collapse in several cases. Factors contributing to freeze-ups have been the incorrect arrangement of heating equipment, failure to maintain heating equipment, forgetting or delaying the start of heating, and failure to maintain sufficient heat over a weekend or other non-operating period.

Water in gravity or suction tanks loses temperature slowly, a few degrees per day. To prevent freezing in any part of the tank equipment, the heating system must replace the heat loss from the tank and piping when the temperature of the coldest water is just above the freezing point and the atmospheric temperature is at its lowest for the locality.

Weather-related freezing risk depends on the configuration of an item (e.g., size, liquid contained, insulation) as well as the exposure temperatures and times. Based on empirical studies, freeze losses for inadequately protected items are well-correlated to areas having a 100-year return period daily minimum temperature (100-year DMT) of 20°F (-6.7°C) or colder. The FM Worldwide Freeze Map (see Figures 23 and 24 for an overview and in detail online at www.fmglobal.com) shows 100-year DMT zones. The temperature zone name indicates the 100-year DMT at the warm side of the zone. For example, the -5°F (-20.6°C) zone ranges from -5°F (-20.6°C) at its warm (usually southernmost for locations in the northern hemisphere) side to -10°F (-23.3°C) at its cold (usually northernmost) side (where the zone does not adjoin a colder zone, the temperature indicated is the 100-year DMT within the entire zone).

100-year DMT are most often 10°F (5.6°C) to 15°F (8.3°C) colder than the lowest one-day mean temperature (LODMT) previously used in this data sheet and still used in some external references. Guidance, such as temperature thresholds for insulating pipes and heating tanks, in this data sheet have therefore been adjusted to be applicable for use with the 100-year DMT values. Additionally, although the temperature varies within each 100-year DMT zone, the temperature range is small (5°F [2.8°C]), so guidance is now based on the zone in which the location falls rather than the “exact” temperature within the zone (i.e., no interpolation of the temperature is needed).

If record-breaking cold spells occur in borderline areas, a flow of water through the tank will prevent freezing. Care should be taken that ice buildup due to overflow does not create dangerous conditions. If necessary, ice on the surface of the tank should be broken manually.

Heating in sprinkler tanks rates next in importance to their structural design. Heating systems should be reliable, convenient, and economical. To determine the proper amount of heat for a sprinkler tank, the 100-year DMT zone should be used in conjunction with Tables 6-9.

Table 6-US. Heat Loss from Uninsulated Steel Gravity Tanks (U.S. Customary Units).
(Thousands of British thermal units lost per hour when the temperature of the coldest water is 42°F. Mean water temperature is 54°F.)

100-year DMT Zone, °F	*Heat Loss, Btu/hr/ft² Tank Radiating Surface*	*Tank Capacity, U.S. gal 1000*							*Add Btu/hr/lin ft Uninsulated Steel Riser*	
		50 (1,800)*	75 (2,370)	100 (2,845)	150 (3,705)	200 (4,470)	250 (5,240)	300 (5,905)	*3 ft dia*	*4 ft dia*
		Btu Lost per Hour (thousands)								
10	93.6	169	222	267	347	419	491	553	519	692
5	110.9	200	263	316	411	496	582	655	670	893
0	128.9	233	306	367	478	577	676	762	820	1,092
-5	148.5	268	352	423	551	664	779	877	982	1,309
-10	168.7	304	400	480	626	755	884	997	1,152	1,536
-15	190.7	344	452	543	707	853	1,000	1,127	1,329	1,771
-20	213.2	384	506	607	790	954	1,118	1,259	1,515	2,020
-25	236.8	427	562	674	878	1,059	1,241	1,399	1,718	2,291
-30	262.3	473	622	747	972	1,173	1,375	1,549	1,926	2,568
-35	288.1	519	683	820	1,068	1,288	1,510	1,702	2,145	2,860
-40	316.0	569	749	900	1,171	1,413	1,656	1,866	2,381	3,174
-45	344.0	620	816	979	1,275	1,538	1,803	2,032	2,620	3,494
-55	405.6	731	962	1,154	1,503	1,814	2,126	2,396	3,139	4,186

*Numbers in parentheses are square feet of tank surface used for each capacity to compute the tabulated heat-loss values, and are typical for tanks with D/4 ellipsoidal roofs and bottoms (see text for tanks having different capacities or surface areas)

Table 6-SI. Heat Loss from Uninsulated Steel Gravity Tanks (SI Units).
(Kilowatts lost when the temperature of the coldest water is 5.6°C. Mean water temperature is 12.2°C).

100-year DMT Zone, °C	*Heat Loss, W/m² Tank Surface*	*Tank Capacity, m³*							*Add W/lin m Uninsulated Steel Riser*	
		189 (167)*	284 (220)	379 (264)	568 (344)	757 (415)	946 (478)	1136 (549)	0.91 m dia	1.2 m dia
		Kilowatts Lost								
-12.2	305.0	51	67	81	105	127	146	167	872	1150
-15	347.6	58	76	92	120	144	166	191	994	1310
-17.8	406.6	68	89	107	140	169	194	223	1162	1533
-20.6	478.2	80	105	126	165	198	229	263	1367	1803
-23.3	548.3	92	121	145	189	228	262	301	1568	2067
-26.1	600.0	100	132	158	206	249	287	329	1715	2262
-28.9	677.9	113	149	179	233	281	324	372	1938	2556
-31.7	759.3	127	167	200	261	315	363	417	2171	2862
-34.4	872.2	146	192	230	300	362	417	479	2493	3288
-37.2	903.8	151	199	239	311	375	432	496	2584	3407
-40	996.2	166	219	263	343	413	476	547	2848	3756
-42.8	1085.2	181	239	286	373	450	519	596	3102	4091
-48.3	1259.3	210	277	332	433	523	602	691	3600	4747

*Numbers in parentheses are square meters of tank surface used for each capacity to compute the tabulated heat loss values, and are typical for tanks with D/4 ellipsoidal roofs and bottoms (see text for tanks having different capacities or surface areas).

Table 7-US. Heat Loss from Uninsulated Steel Suction Tanks (U.S. Customary Units)
(Thousands of British thermal units lost per hour when the temperature of the coldest water is 42°F). (Mean water temperature is 54°F.)

100-year DMT Zone, °F	*Heat Loss, Btu/hr/ft² Tank Radiating Surface*	*Tank Capacity, U.S. gal × 1000*								
		100 (2,610)*	150 (3,505)	200 (4,175)	250 (4,795)	300 (5,360)	400 (6,375)	500 (7,355)	750 (9,650)	1,000 (11,740)
		Btu Lost per Hour (thousands)								
10	93.6	244	328	391	449	502	597	688	903	1099
5	110.9	289	389	463	532	594	707	816	1070	1302
0	128.9	336	452	538	618	691	822	948	1244	1513
-5	148.5	388	520	620	712	796	947	1092	1433	1743
-10	168.7	440	591	704	809	904	1075	1241	1628	1981
-15	190.7	498	668	796	914	1022	1216	1403	1840	2239
-20	213.2	556	747	890	1022	1143	1359	1568	2057	2503
-25	236.8	618	830	989	1135	1269	1510	1742	2285	2780
-30	262.3	685	919	1095	1258	1406	1672	1929	2531	3079
-35	288.1	752	1010	1203	1381	1544	1837	2119	2780	3382
-40	316.0	825	1108	1319	1515	1694	2014	2324	3049	3710
-45	344.0	898	1206	1436	1649	1844	2193	2530	3320	4039
-55	405.6	1059	1422	1693	1945	2174	2586	2983	3914	4762

*Numbers in parentheses are square feet of surface used for each capacity to compute the tabulated heat-loss values, and they are typical for cone-roof reservoirs on grade (see text for tanks having different capacities or surface areas).

Table 7-SI. Heat Loss from Uninsulated Steel Suction Tanks (SI Units)
(Kilowatts lost per hour when the temperature of the coldest water is 5.6°C.) (Mean water temperature is 12.2°C)

100-year DMT Zone, °C	*Heat Loss, W/m² Tank Radiating Surface*	*Tank Capacity, m³*								
		379 (243)*	568 (326)	757 (388)	946 (445)	1136 (498)	1514 (592)	1893 (683)	2839 (897)	3785 (1091)
		Kilowatts Lost								
-12.2	305.0	74	99	118	136	152	181	208	274	333
-15	347.6	84	113	135	155	173	206	237	312	379
-17.8	406.6	99	133	158	181	202	241	278	365	444
-20.6	478.2	108	145	172	197	221	263	303	398	484
-23.3	548.3	133	179	213	244	273	325	374	492	598
-26.1	600.0	146	196	233	267	299	355	410	538	655
-28.9	677.9	165	221	263	302	338	401	463	608	740
-31.7	759.3	185	248	295	338	378	450	519	681	828
-34.4	872.2	212	284	338	388	434	516	596	782	952
-37.2	903.8	220	295	351	402	450	535	617	811	986
-40	996.2	242	325	387	443	496	590	680	894	1087
-42.8	1085.2	264	354	421	483	540	642	741	973	1184
-48.3	1259.3	306	411	489	560	627	746	860	1130	1374

*Numbers in parentheses are square meters of surface used for each capacity to compute the tabulated heat loss values, and they are typical for cone-roof reservoirs on grade (see text for tanks having different capacities or surface areas).

Tables 6 and 7 show the heat loss from uninsulated steel gravity tanks and steel suction tanks within 10 to -55°F (-12.2 to -48.3°C) 100-year DMT zones. They also indicate the capacity in thousands of Btu (kilowatts) per hour that the heating system should supply.

Tables 8 and 9 show heat losses for insulated steel gravity and suction tanks.

Heat loss for a size tank not shown in the tables may be obtained by multiplying the surface area by the tabulated heat loss per ft² (m²) for the 100-year DMT zone in which the tank is located. The surface area is the wetted surface area exposed to atmosphere plus the water surface area. For tanks with large steel-plate risers, the heat loss from the riser must be added to that from the tank. No heat loss need be figured for tank bottoms resting on grade.

Table 8-US. Heat Loss from Insulated Steel Gravity Tanks (U.S. Customary Units). (Thousands of British thermal units lost per hour when the temperature of the coldest water is 42°F. Mean water temperature is 54°F.)*

100-year DMT Zone, °F	Heat Loss, Btu/hr/ft² Tank Surface	Tank Capacity, U.S. gal × 1000							Add Btu/hr/lin ft Insulated Steel Riser	
		50 (1,800)**	75 (2,370)	100 (2,845)	150 (3,705)	200 (4,470)	250 (5,240)	300 (5,905)	3 ft dia	4 ft dia
		Btu Lost per Hour (thousands)								
10	3.90	7.02	9.24	11.10	14.45	17.43	20.4	23.0	36.8	49.0
5	4.40	7.92	10.43	12.52	16.30	19.67	23.1	26.0	41.5	55.3
0	4.90	8.82	11.61	13.94	18.15	21.9	25.7	28.9	46.2	61.6
-5	5.40	9.72	12.79	15.36	20.0	24.1	28.3	31.9	50.9	67.9
-10	5.90	10.62	13.98	16.79	21.9	26.4	30.9	34.8	55.6	74.1
-15	6.40	11.52	15.17	18.21	23.1	28.6	33.5	37.8	60.3	80.4
-20	6.90	12.42	16.35	19.36	25.6	30.8	36.2	40.1	65.0	86.7
-25	7.40	13.32	17.54	21.1	27.4	33.1	38.8	43.1	69.7	93.0
-30	7.90	14.22	18.72	22.5	29.3	35.3	41.4	46.6	74.5	99.3
-35	8.40	15.12	19.91	23.9	31.1	37.5	44.0	49.6	79.2	105.6
-40	8.90	16.02	21.1	25.3	33.0	39.8	46.6	52.6	83.9	111.8
-45	9.40	16.92	22.3	26.7	34.8	42.0	49.3	55.5	88.6	118.1
-55	10.40	18.72	24.6	28.6	38.5	46.5	54.5	61.4	98.0	130.7

*Based on an "R" factor of 10 hr-ft²-F°/Btu (for other R values, use Heat Loss = Tabulated x [10/R]).

**Numbers in parentheses are square feet of tank surface used for each capacity to compute the tabulated heat loss values, and are typical for tanks with D/4 ellipsoidal roofs and bottoms (see text for tanks having different capacities or surface areas).

Table 8-SI. Heat Loss from Insulated Steel Gravity Tanks (SI Units). (Kilowatts lost when the temperature of the coldest water is 5.6°C. Mean water temperature is 12.2°C)*

100-year DMT Zone, °C	Heat Loss, W/m² of Tank Surface	Tank Capacity, m³							Add W/lin m Insulated Steel Riser	
		189 (167)**	284 (220)	379 (264)	568 (344)	757 (415)	946 (437)	1136 (549)	0.9 m dia	1.2 m dia
		Kilowatts Lost								
-12.2	12.61	2.11	2.77	3.33	4.34	5.23	6.14	6.92	36.1	47.6
-15	13.75	2.30	3.03	3.63	4.73	5.71	6.70	7.55	39.3	51.8
-17.8	15.45	2.58	3.40	4.08	5.32	6.41	7.53	8.48	44.2	58.3
-20.6	17.16	2.87	3.77	4.53	5.90	7.12	8.36	9.42	49.1	64.7
-23.3	18.86	3.15	4.15	4.98	6.49	7.83	9.19	10.36	53.9	71.1
-26.1	20.00	3.34	4.40	5.28	6.88	8.30	9.74	10.98	57.2	75.4
-28.9	21.70	3.62	4.77	5.73	7.47	9.01	10.57	11.92	62.1	81.8
-31.7	23.41	3.91	5.15	6.18	8.05	9.71	11.40	12.85	66.9	88.3
-34.4	25.11	4.19	5.52	6.63	8.64	10.42	12.23	13.79	71.8	94.7
-37.2	26.25	4.38	5.78	6.93	9.03	10.89	12.78	14.41	75.0	99.0
-40	27.95	4.67	6.15	7.38	9.62	11.60	13.61	15.35	79.9	105.4
-42.8	29.66	4.95	6.52	7.83	10.20	12.31	14.44	16.26	84.8	111.8
-48.3	32.50	5.43	7.15	8.58	11.18	13.49	15.83	17.84	92.9	122.5

*Based on an "R" factor of 1.76m²-C°/W (for other R values, use Heat Loss = Tabulated x [1.76/R]).

**Numbers in parentheses are square meters of tank surface used for each capacity to compute the tabulated heat loss values, and are typical for tanks with D/4 ellipsoidal roofs and bottoms (see text for tanks having different capacities or surface areas).

Table 9-US. Heat Loss from Steel Suction Tanks. Walls and Roof Insulated (U.S. Customary Units).*
(Thousands of British thermal units lost per hour when the temperature of the coldest water is 42°F. Mean is 54°F.)

100-year DMT Zone, °F	*Heat Loss, Btu/hr/ft^2 Tank Surface*	*Tank Capacity, U.S. gal × 1000*								
		100 (2,610)**	150 (3,505)	200 (4,175)	250 (4,795)	300 (5,360)	400 (6,375)	500 (7,355)	750 (9.650)	1,000 (11,740)
		Btu Lost per Hour (thousands)								
10	3.90	10.2	13.7	16.3	18.7	20.9	24.9	28.7	37.6	45.8
5	4.40	11.5	15.4	18.4	21.1	23.6	28.1	32.4	42.5	51.7
0	4.90	12.8	17.2	20.5	23.5	26.3	31.2	36.0	47.3	57.5
-5	5.40	14.1	18.9	22.5	25.9	28.9	34.4	39.7	52.1	63.4
-10	5.90	15.4	20.7	24.6	28.3	31.6	37.6	43.4	56.9	69.3
-15	6.40	16.7	22.4	26.7	30.7	34.3	40.8	47.1	61.8	75.1
-20	6.90	18.0	24.2	28.8	33.1	37.0	44.0	50.7	66.6	81.0
-25	7.40	19.3	25.9	30.9	35.5	39.7	47.2	54.4	71.4	86.9
-30	7.90	20.6	27.7	33.0	37.9	42.3	50.4	58.1	76.2	92.7
-35	8.40	21.9	29.4	35.1	40.3	45.0	53.6	61.8	81.1	98.6
-40	8.90	23.2	31.2	37.2	42.7	47.7	56.7	65.5	85.9	104.5
-45	9.40	24.5	32.9	39.2	45.1	50.4	59.9	69.1	90.7	110.4
-55	10.40	27.1	36.5	43.4	49.9	55.7	66.3	76.5	100.4	122.1

*Based on an "R" factor of 10 hr-ft^2-F°/Btu (for other R values, use Heat Loss = Tabulated x [10/R]).

**Heat admitted to tank water from the ground not included. Numbers in parentheses are square feet of surface used for each capacity to compute the tabulated heat loss values (see text for tanks having different capacities or surface areas).

Table 9-SI. Heat Loss from Steel Suction Tanks. Walls and Roof Insulated (SI Units).*
(Kilowatts lost when the temperature of the coldest water is 5.6°C. Mean water temperature is 12.2°C)

100-year DMT Zone, °C	*Heat Loss, W/m^2 of Tank Surface*	*Tank Capacity, m^3*								
		379 (243)**	568 (326)	757 (388)	946 (445)	1136 (498)	1514 (592)	1893 (683)	2839 (897)	3785 (1091)
		Kilowatts Lost								
-12.2	12.61	3.06	4.11	4.89	5.61	6.28	7.47	8.61	11.31	13.76
-15	13.75	3.34	4.48	5.34	6.12	6.85	8.14	9.39	12.33	15.00
-17.8	15.45	3.75	5.04	5.99	6.88	7.69	9.15	10.55	13.86	16.86
-20.6	17.16	4.17	5.59	6.66	7.64	8.55	10.16	11.72	15.39	18.72
-23.3	18.86	4.58	6.15	7.32	8.39	9.39	11.17	12.88	16.92	20.6
-26.1	20.00	4.86	6.52	7.76	8.90	9.96	11.84	13.66	17.94	21.8
-28.9	21.70	5.27	7.07	8.42	9.66	10.81	12.85	14.82	19.46	23.7
-31.7	23.41	5.69	7.63	9.08	10.42	11.66	13.86	15.99	21.0	25.5
-34.4	25.11	6.10	8.19	9.74	11.17	12.50	14.87	17.15	22.5	27.4
-37.2	26.25	6.38	8.56	10.18	11.68	13.07	15.54	17.93	23.5	28.6
-40	27.95	6.79	9.11	10.84	12.44	13.92	16.55	19.09	25.1	30.5
-42.8	29.66	7.21	9.67	11.51	13.20	14.77	17.56	20.3	26.6	32.4
-48.3	32.50	7.90	10.60	12.61	14.46	16.18	19.24	22.2	29.2	35.5

*Based on an "R" factor of 1.76m^2-C°/W (for other R values, use Heat Loss = Tabulated x [1.76/R]).

**Heat admitted to tank water from the ground not included. Numbers in parentheses are square meters of surface used for each capacity to compute the tabulated heat loss values (see text for tanks having different capacities or surface areas).

3.8.1 Insulating of Tanks

Heat loss from steel tanks can be greatly reduced by the application of insulation. Exterior insulation is preferred and must be protected from weather and deterioration. Interior insulation is an allowable, but not preferred, option and can only be used if it is installed behind a flexible liner (see Section 3.1.7) and attached to the interior surface of the tank shell plates. Additionally, the tank net capacity must be reduced for the volume of the interior insulation.

Since the insulating value ("R" factor) of materials can vary, it should be based on the specific material chosen. Approximate values are provided in Table 10. The heat conductivity or heat transmission of a material is the reciprocal of the "R" factor (i.e., 1/R).

See FM Approvals Standard 4020 for specific requirements regarding interior insulation. When allowed by FM Approvals, interior insulation must have a minimum nominal density of 1.8 lb/ft^3 (30 kg/m^3), and a compressive strength corresponding to 1% nominal compression at 14.5 psi (100 kPa). The insulation must also be made of flame-retardant material. At least two galvanized fixing bracket attachments per insulating board at all horizontal seams are to be used. These attachments must be configured or covered so they do not damage the liner under normal or earthquake (in FM 50-year through 500-year earthquake zones) conditions. Interior insulation should ideally have limited potential for moisture retention and/or insulating properties that are not severely affected if the insulation becomes wet. The liner material should be impermeable. Anchorage of the liner at the top of the tank shell and details of the overflow inlet and freeboard should prevent tank overfilling (or sloshing water during an earthquake) from spilling behind the liner and into the space between the insulation and the tank shell.

Polyurethane foam can be sprayed on the tank exterior to the desired thickness. The surface should be prepared for foaming in accordance with the foam manufacturer's directions. An elastomeric type coating is needed to protect the foamed plastic from the weather. There is a potential fire hazard when polyurethane is used in this manner; see Data Sheet 1-57, *Plastics in Construction,* for guidelines.

Board stock polyurethane also can be used as exterior insulation, along with glass fiber and cellular glass boards. A metal jacket is placed over the insulation for protection. Mechanical means such as circumferential metal bands or welded studs are necessary to keep the jacket and insulation boards on the tank during severe windstorms. Use 2-1/2 in. (64 mm) thick glass fiber board, or 4 in. (100 mm) thick cellular glass board to obtain an R value of about 10.

For other R values, use:

Heat Loss U.S. Customary Units = Tabulated x (10/R) or Heat Loss SI units = Tabulated x (1.76/R)

To obtain R values for various types of insulation used on tanks, multiply the value in Table 10 by the thickness of insulation in inches (mm).

Table 10. R Values Per Inch (mm) of Insulation

Insulation Type	*R (hr-ft^2-°F/Btu-in)*	*R (m^2-°C/W-mm)*
Polystyrene (expanded)	3.6	0.025
PVC foam	5.9	0.041
Foamed glass	2.9	0.020
Glass fiber	4.5	0.031
Urethane, < 6 lb/ft^3 (< 96 kg/m^3)	7.1	0.049
Urethane, 7-10 lb/ft^3 (112-160 kg/m^3)	4.6	0.032
Urethane, 15 lb/ft^3 (240 kg/m^3)	3.4	0.024

3.8.2 Circulating Heating Systems

There are two types of circulating heating systems; gravity and forced. With either system, cold water from a connection to the discharge pipe or near the bottom of a suction tank flows through a cold water pipe to a heater. It then rises into the tank through a separate hot water pipe.

Manually-controlled gravity systems require close supervision to prevent freeze-ups and attain economical operation. Automatic controls, while initially more expensive, require less supervision, which results in more economical operation. The heat-sensing element of the automatic control must be placed at a point where it will sense the true temperature of the tank water.

Forced systems (Figure 16) using an electric motor-driven circulating pump are always automatically controlled. This results in more economical operation than with manually controlled gravity systems. A reliable electric supply is required. A forced circulation system is necessary if the tank is a considerable distance from a heated building, and the circulating pipes are below grade. The pump should have a rated head of at least 5 psi (34.5 kPa) above the friction loss in the pipes at rated capacity, and a rated capacity of at least 10 gpm (0.038 m^3/min).

Steam-Heated Water Heaters. FM Approved steam heaters consist of an iron or steel shell through which water circulates around steam tubes or coils. It is not generally necessary to wrap steam heaters that are heated with circulating steam and water. With some heaters, the water passes through the tubes or coils.

These heaters are wrapped with insulating material and have straight tubes. When the bolted heads are removed from the heater, the tubes can be cleaned by thrusting a tool through them.

Locate a steam-heated water heater in a valve pit, heater house or building at or near the base of the tank structure. When the building is below the tank, the steam heater should be located in the top story. When the tank heater is the only source of heat in a valve pit or other enclosure, leave enough of the heater or steam pipe bare to keep the temperature in the enclosure above freezing.

Do not use hot water as the medium in a heater designed for steam.

If two or more heaters are used (Figure 17), place them on the same level, and connect them in parallel with symmetrical piping, with relief and control valves in each water line. Provide a globe valve in each steam supply line.

Steam-heated water heaters require steam at a constantly available pressure of 10 to 50 psi (69 to 345 kPa) (0.69 to 3.45 bar). Intermittent steam supply from a source that is automatically controlled by the air temperature in a building is not suitable for tank heating. The supply pipe should be at least 1 in. (25 mm) in diameter and run directly from the boiler header if possible. Provide a globe valve in the steam line near the heater and a steam gauge between this valve and the heater.

Arrange the condensate-return pipe to quickly relieve heaters of condensate. Provide a steam trap equipped with an automatic air vent and, preferably, a water gauge near the heater whenever the return is not by gravity or to a vacuum system. Provide a 3/4 in. (19 mm) or larger bypass, with a normally shut globe valve around the trap. Provide a globe valve on each side of the trap between the bypass connections.

Gravity return may be used only when the heater is located well above the boiler water level. The steam pressure at the condensate end of the heater plus the static head of water in the return pipe must be greater than the steam pressure at the boiler. A pressure vacuum gauge and siphon should be installed near the condensate end of the heater.

When the heater is connected to a steam supply of very low pressure, 0 to 5 psi (0 to 34 kPa) (0 to 0.34 bar) or vacuum system, the layout should have the approval of the heating equipment manufacturer. The following equipment is needed:

1. A pressure vacuum gauge with siphon in the steam supply and condensate pipes near the heater and a plugged globe valve in a short test pipe connected to the condensate-return pipe near any trap.

2. A steam trap and vacuum pump if the water is not high enough above the boiler water level to completely drain all return piping. The trap should be specially designed for a vacuum system, and automatically liberate air and prevent air binding.

3. If reverse flow may occur, provide a 3 ft (0.9 m) U in the cold water circulating pipe, or convert the gravity circulating system to a forced system.

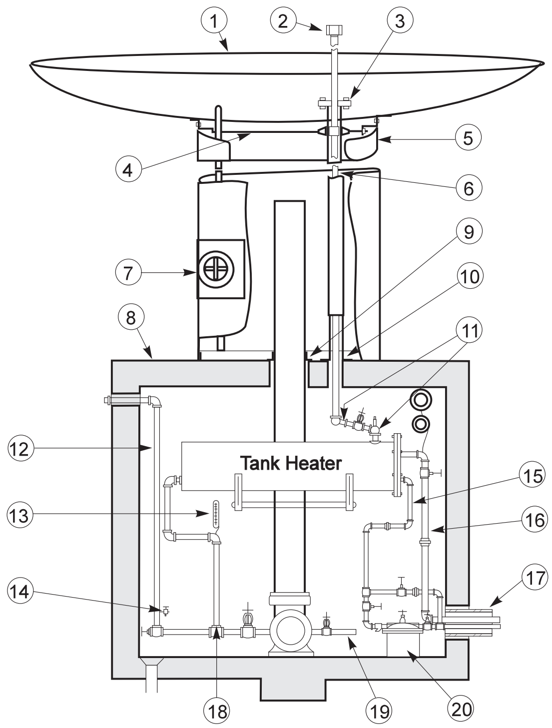
Electric- Gas-, and Oil-Fired Water Heaters. If an adequate steam supply is not available from the plant's main boilers, an FM Approved electric, gas-, or oil-fired water heater of sufficient strength to resist expected water pressure may be used. A coal-fired heater may be converted to the oil or gas-firing type. These heaters must be equipped with combustion and over-pressure safeguards.

Locate the water heater or boiler in a noncombustible house at the base of a tank that has an independent tower or in the boiler room if the tank is on a building. Arrange fuel oil storage and piping, and fuel gas piping according to applicable standards.

Carry the products of combustion from gas or oil-fired water heaters outdoors through a flue or chimney sized in accordance with the manufacturer's recommendations. Equip flues from gas-fired water heaters with a draft hood. Avoid discharge of gas and smoke against steel parts of the tank structure.

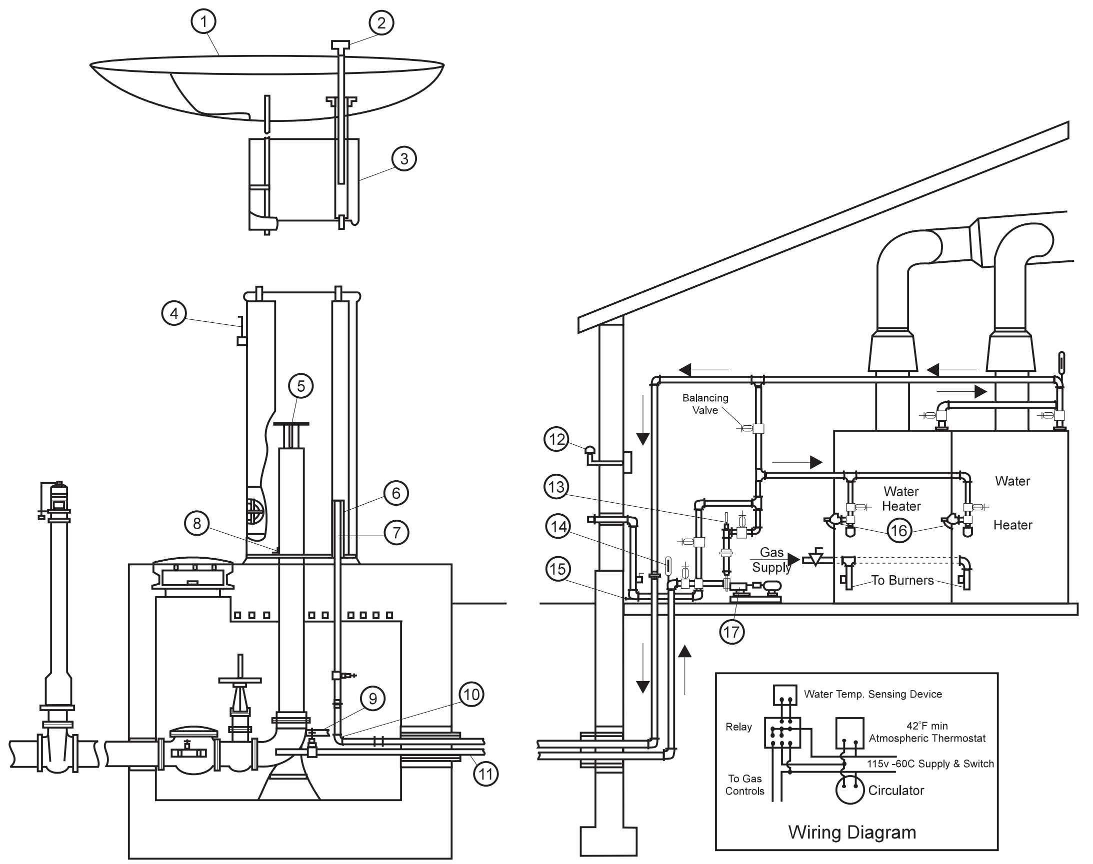
Provide openings in the walls of the heater house or room containing a fuel-fired heater to provide sufficient fresh air for complete combustion of the fuel at all firing rates. Provide at least 1 ft^2 (0.09 m^2) of free opening for every 2 million Btu/hr (586 kW) of fuel burned. Locate openings so that they will not be obstructed by snow.

Water Circulating Pipes. The water circulating pipes used in gravity heating systems for wooden tanks should be at least 2 in. (50 mm) in diameter; for steel tanks, they should be sized in accordance with Table 11. The pipe should be of a type shown in Table 5.



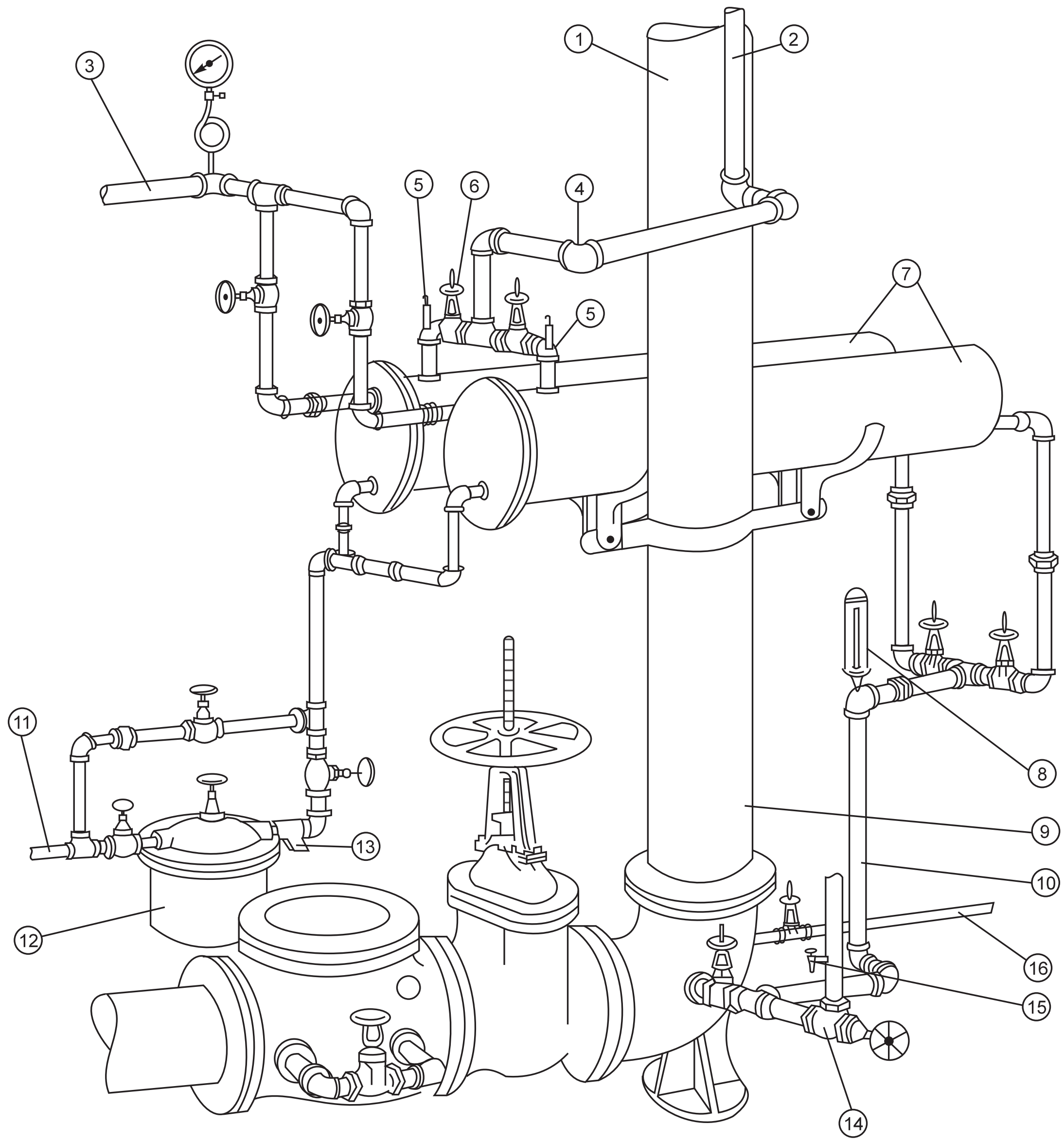
1. Steel gravity tank
2. Hot water outlet
3. Outer pipe
4. Brace rods, at least 1/2 in. (13 mm) in diameter and not more than 25 ft (7.6 m) apart
5. Large steel-plate riser
6. Hot water circulating pipe
7. Manhole cover
8. Hollow-center pier
9. Welded connection
10. Watertight joint
11. Four-elbow joint
12. Drain pipe
13. Thermometer
14. Drain cock, 1/2 in. (13 mm)
15. Condensate return
16. Steam supply pipe
17. Conduit for steam pipes and connection from mercury gauge
18. Cold water circulating pipe
19. Pipe from mercury gauge
20. Steam trap

Fig. 15. Gravity circulation heating system with steam heater for tank with large steel-plate riser



1. Steel gravity tank
2. Hot water outlet
3. Large steel-plate riser
4. Thermometer
5. Discharge pipe protective cover plate
6. Outer pipe
7. Hot water circulating pipe
8. welded connection
9. Pipe from mercury gauge
10. Four elbow swing joint
11. Cold water circulating pipe
12. Large steel-plate riser
13. Water temperature sensing device (actuates heat sources)
14. Cold water thermometer
15. Drain valve
16. ASME rated pressure relief valve
17. Water circulating pump

Fig. 16. Forced circulation heating system with gas heaters for tank with large steel-plate riser



1. Pipe riser
2. Hot water circulating pipe
3. Steam supply pipe
4. Four-elbow swing joint
5. Relief valves
6. Approved OS&Y gate valves
7. Steam-heated water heaters
8. Thermometer
9. Pipe riser or discharge pipe from large steel-plate riser
10. Cold water circulating pipe
11. Condensate return
12. Steam trap
13. Strainer
14. Drain valve
15. Drain cock
16. From mercury gauge

Fig. 17. Piping arrangement for multiple steam water heaters for gravity circulation system

Table 11-US. Size of Water-circulating Pipes for Steel Gravity Tanks (U.S. Customary Units)

100-year DMT Zone, °F	Size (in.) for Tank Capacity (U.S. gal) Shown									
	15,000	20,000	25,000	30,000	40,000	50,000	60,000	75,000	100,000	150,000
5	2	2	2	2	2	2	2	2	2	2-½
0	2	2	2	2	2	2	2	2	2	2-½
-5	2	2	2	2	2	2	2	2	2-½	2-½
-10	2	2	2	2	2	2	2	2	2-½	2-½
-15	2	2	2	2	2	2	2	2-½	2-½	2-½
-20	2	2	2	2	2	2	2-½	2-½	2-½	3
-25	2	2	2	2	2	2-½	2-½	2-½	2-½	3
-30	2	2	2	2	2-½	2-½	2-½	2-½	3	3
-35	2	2	2	2	2-½	2-½	2-½	2-½	3	3
-40	2	2	2	2-½	2-½	2-½	2-½	3	3	3
-45	2	2	2	2-½	2-½	2-½	2-½	3	3	3

Table 11-SI. Size of Water Circulating Pipes for Steel Gravity Tanks (SI Units)

100-year DMT Zone,°C	Size (mm) for Tank Capacity (m^3) Shown									
	57	76	95	114	151	189	227	284	379	568
-15	51	51	51	51	51	51	51	51	51	64
-17.8	51	51	51	51	51	51	51	51	51	64
-20.6	51	51	51	51	51	51	51	51	64	64
-23.3	51	51	51	51	51	51	51	51	64	64
-26.1	51	51	51	51	51	51	51	64	64	64
-28.9	51	51	51	51	51	51	64	64	64	76
-31.7	51	51	51	51	51	64	64	64	64	76
-34.4	51	51	51	51	64	64	64	64	76	76
-37.2	51	51	51	51	64	64	64	64	76	76
-40	51	51	51	64	64	64	64	76	76	76
-42.8	51	51	51	64	64	64	64	76	76	76

A single hot-water outlet located between the one-half and one-third water depth of modern tanks (elliptical, spherical, or spheroidal shapes) has provided adequate hot water distribution. For older tanks (with flat or hemispherical bottoms) where water depths are greater, two outlets at the one-third and two-third depths have been used successfully.

If a column-supported gravity tank has a pipe riser, place the hot water pipe near the riser inside the frost-proof casing. Pitch the pipe upward at all points unless a circulating pump is installed. Provide a swing joint in the pipe just above the heater. An adequately supported brass expansion joint may be used just below the gate valve near the tank bottom if the riser expansion joint is accessible from a platform. The swing joint should have four elbows if the connection to the heater is a vertical pipe; if horizontal, three elbows will suffice. Provide OS&Y gate valves in the pipe near the heater, and also just below its connection to the tank inside the frost-proof casing. If there is no suspended platform and walkway at the tank bottom, make the upper gate accessible from the tower ladder by an extension stem. If a gravity tank has a large steel-plate riser, extend the hot-water pipe from the heater through the bottom or side of the riser just above the heater. Then, run the hot water pipe inside a type of pipe shown in Table 5 of sufficient size to provide a 3/4 in. (19 mm) space between the hot water and the outer pipes. The outer pipe may contain air (as indicated in Figures 14 and 15) or water. If it contains water, provide a 3/8 in. (10 mm) drain hole near the base and make provision for expansion. The outer pipe and the water or air-filled space between it and the hot-water pipe are needed to minimize heat loss from the hot-water pipe to the water in the riser. Connect the cold-water circulating pipe into the riser of a gravity tank with a pipe riser, or into the discharge pipe from a large steel-plate riser or suction tank at a point ahead of the main control valves so that there will be circulation throughout the entire portion of the riser or discharge pipe that is subject to freezing. Install an OS&Y gate valve in the cold-water circulating pipe at this connection to control the flow.

Connect a 2 in. (50 mm) drain pipe (discharging at a visible point) to the cold-water return pipe between the heater and the cold-water control valve. This will permit water to be flushed from the tank through the hot-water pipe, heater, and drain for cleanout.

Provide a thermometer, graduated to at least 30°F (-1.1°C), in the cold-water circulating pipe where it will register the temperature of the coldest circulating water in the system.

A cold or hot-water circulating pipe that would lose considerable water if broken outside a tank should have an accessible OS&Y gate valve just outside the tank plate. Brace and support circulation piping throughout at points not more than 25 ft (7.6 m) apart.

Avoid long runs of nearly horizontal pipe and pockets or an excessive number of fittings in the hot water circulating pipe. These occasionally cause a gravity system to start circulating in the wrong direction, and may result in excessive pounding when the circulation rights itself. If this occurs after a system is installed, it may be overcome by installing a pocket with several elbows in the cold-water circulating pipe to increase the friction loss, or converting to a forced system with a circulating pump and bypass.

Provide a relief valve in the water chamber or pipe between the hot and cold water valves of any water heater.

This valve should be adjusted to open at 120 psi (827 kPa) (8.3 bar). However, the opening pressure should not be greater than the allowable working pressure of the heater, or less than the maximum static or filling pressure to which it may be subjected. If the heater is near stock that may be damaged by water, pipe the relief discharge to a safe point.

Manual Operation of Gravity Circulation Systems. To place the heating system in service, open wide valves A, B and C (Figure 18) in the water circulating pipes. Turn on the steam or start fuel-fired heaters. When first admitting steam, blow all air from steam heaters, pipe, and traps with the air valve or vent on, or in the steam trap if an inverted bucket trap is not provided.

Read the thermometer in the cold-water return pipe daily during freezing weather. This reading shows the temperature of the coldest water if the heat is turned on and the water is circulating properly.

Regulate the heat supply to maintain the temperature of the cold water between 42 and 50°F (5.6 and 10°C). It is unnecessary and uneconomical to maintain higher temperatures.

Determine whether the water is circulating by simultaneously feeling the hot water pipe with one hand and cold water pipe with the other. An appreciable difference indicates good circulation. Unusually high temperatures in the cold water pipe near the heater indicate that the water is not circulating properly.

Steam pressure may be regulated by throttling the steam valve by hand.

Avoid excessive pressure in the heater by shutting off or removing the source of heat when both valves in the circulating pipes are closed. This precaution should be taken even though a relief valve is correctly located and adjusted.

Automatic Operation of Gravity Circulation Systems. The steam supply to a gravity circulation system may be automatically controlled by 1) a solenoid or electric motor operated valve in the steam supply pipe, or by 2) a non-electric temperature regulator with the control valve in the steam supply pipe. Actuate the steam control valve by a temperature-sensing element in the cold-water circulating pipe, or the cold water near the bottom of the tank or about 5 ft (1.5 m) above the base of a large steel-plate riser. Provide a socket thermometer near the sensing element.

A valve operated by non-electric controls, usually a spring or weight and lever, has a wide differential. That is, it operates gradually and requires several degrees difference in water temperature to be fully open or closed.

Electric controls that have a differential of only 1 to 3°F (0.5 to 1.6°C) may be obtained for an electrically-operated valve, which acts more quickly and efficiently. If the temperature-sensing element is in the cold-water circulating pipe, the water must be continuously circulated in freezing weather. This may be accomplished by providing a small aperture in the steam control valve or a small orifice plate in a bypass around the control valve. These will pass sufficient steam when the valve is closed to slowly circulate water in the piping over the temperature-sensing element. When the element is in the cold water near the bottom of the tank or about 5 ft (1.5 m) above the base of a large steel-plate riser, continuous circulation is not necessary.

Install the automatic steam control valve in a full-sized bypass around the manual steam supply valve to the tank heater, with a globe valve on each side of the control valve. Install a drip trap and strainer ahead of the automatic steam control valve.

Gas- and oil-fired gravity circulation water heaters also may be automatically controlled by the temperature of the coldest water in the tank or riser, as noted above.

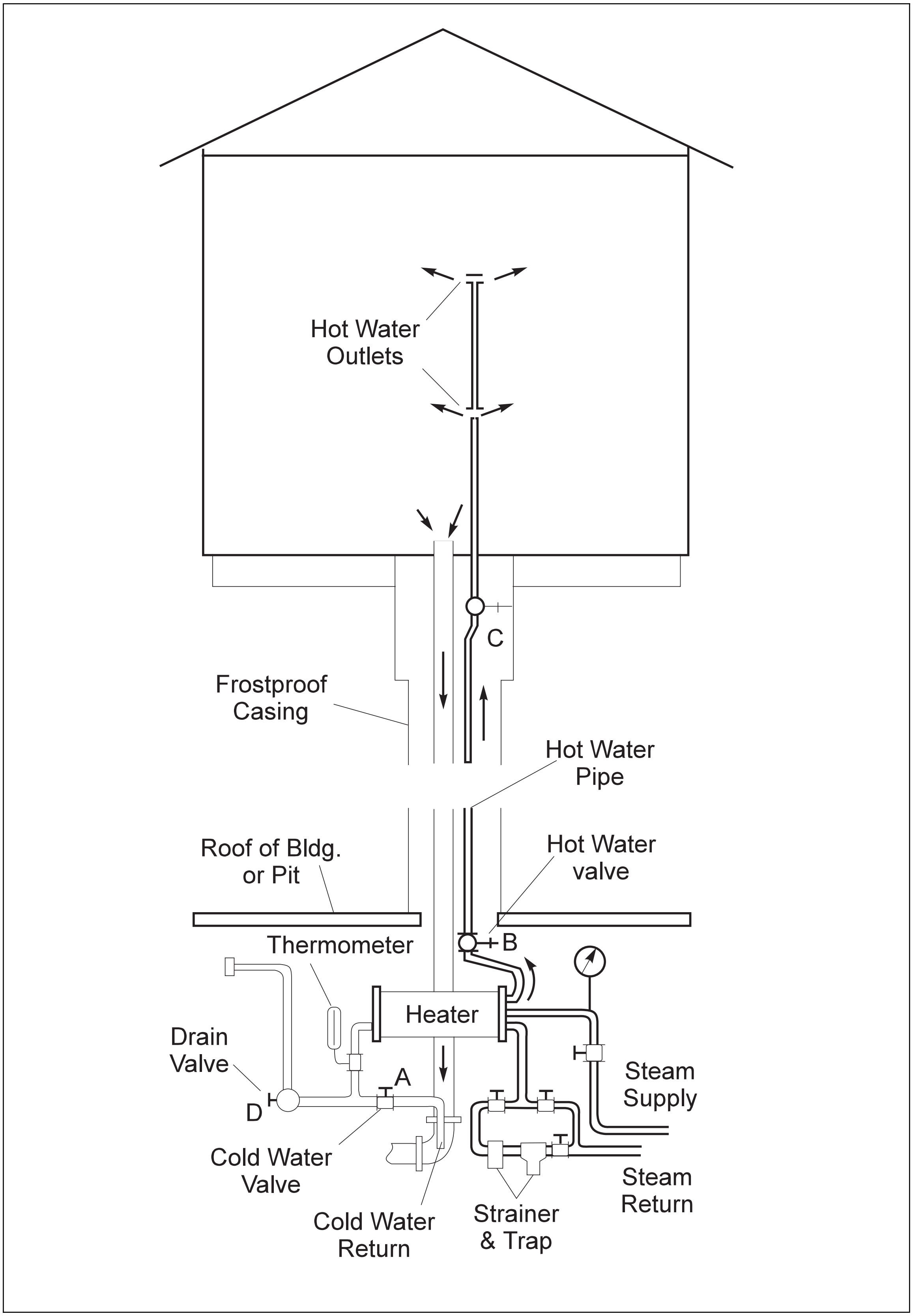


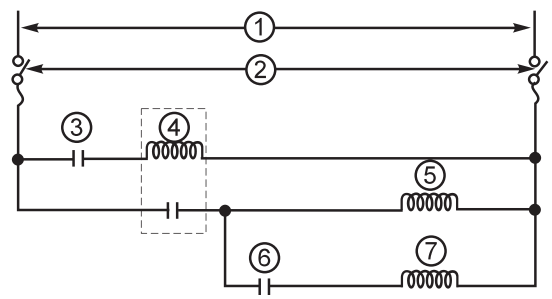
Fig. 18. Schematic diagram of gravity circulation heating system

The electrically-operated control valve should be in the fuel-supply pipe.

Automatic controls should activate the heater when the temperature of the coldest water drops to about 42°F (5.6°C). Place the heating system in service in the same manner as for manual operation of gravity circulation systems.

Control and Operation of Forced Circulation Systems. A forced-circulation system (Figure 16) is the most efficient and economical. With steam heat, the supply is controlled by a solenoid or electric motor-operated valve in the steam-supply pipe. Install this steam-control valve in a full-sized bypass around a manual steam supply valve to the tank heater, with a globe valve on each side of the control valve. Actuate the control valve by a temperature sensing element in the cold-water circulating pipe set at 40°F (4.4°C). It should have a small operating differential, not over 3 to 4°F (1.7 to 2.2°C).

Install a drip trap and strainer ahead of the automatic steam control valve. Arrange an outside thermostat so that the circulating pump will operate when atmospheric temperature drops to 40°F (4.4°C). Arrange the control circuit so that heat will not be supplied unless the circulating pump is operating (Figure 19).



1. Reliable source of electrical power
2. Disconnect switch with fuses
3. Atmospheric thermostat. Set so that contact is closed when atmospheric temperature is 42ºF (4.4ºC) or below. Adjust to minimum differential at operating temperature
4. Relay. Contact open when relay de-energized. Necessary when contacts of atmospheric thermostat will not carry electrical load. Contacts of relay should have proper rating to carry starting current of pump motor 5
5. Motor of water circulating pump
6. Water thermostat. Set so that contact is closed when water temperature is 40ºF (4.4ºC) or lower. Adjust to minimum differential at operating temperature
7. Solenoid or electric motor-operated valve in steam or fuel supply pipe

NOTE: With this circuit the circulating pump operates when the atmospheric temperature is 40ºF (4.4ºC) or below, but no heat is supplied to the water until it cools to 40ºF (4.4ºC). Also no heat is supplied when the circulating pump is not operating.

Fig. 19. Automatic control circuit for forced circulation system for heating water in tanks

Electric, gas-, or oil-fired water heaters also may be used in a forced circulation system. For those heaters, the water-temperature-sensing element activates the heating power supply or the gas or oil burner.

Occasionally, condensation occurs within direct-fired coil type heaters used in forced-circulation systems. This is the result of too great a flow through the heater, and the small resulting water temperature rise. It is corrected by the use of a bypass across the heater(s) (Figure 16) so that only a portion of the circulating cold water passes through them. This gives a higher temperature rise through the unit(s) and eliminates condensation. Improper adjustment of the bypass valves may allow too little water through the heaters and cause them to cycle on their high-limit controls.

Size of Heater. To determine the size of the heater for a circulating system:

1. Obtain the 100-year return period daily minimum temperature (100-year DMT) zone for the locality from the FM Worldwide Freeze Map (see overview of the map in Figures 23 and 24 and details at www.fmglobal.com).

2. Read the total heat loss from the tank in Btu/hr (watts) directly from Table 6 or 8 for a steel gravity tank or Table 7 or 9 for a steel suction tank.

3. If a tank has a large steel-plate riser, add the heat lost from the tank and the riser (as shown in Table 6 or 8) for total heat lost.

4. Select FM Approved heaters or boilers having a capacity sufficient to supply the necessary amount of heat.

5. The heater should have an allowable working pressure at least as great as the maximum pressure to which it may be subjected by the static head from the tank, or the pressure used when filling the tank.

3.8.3 Vertical Radiator Heaters

Vertical radiator heaters (Figures 20 and 22) are acceptable for heating elevated tanks that have large steel-plate risers. The vertical radiator heater should have a sleeve surrounding the radiator element to properly circulate heated water. With this arrangement, cold water enters the lower end of the sleeve, is heated by the radiator, rises, and discharges into the tank through the tee outlet.

The radiator element should consist of a vertical steam pipe contained within a watertight condensing chamber of copper water tubing, cast-iron pipe, or brass (85% copper) pipe. It must be large enough to give 3/4 in. (19 mm) clearance around the steam pipe and any couplings used, but never less than 4 in. (102 mm) in diameter.

The steam pipe inside the condensing chamber should be large enough to convey the quantity of steam required, but not less than 1-1/2 in. (38 mm) in diameter, and extend to within 1 ft (0.3 m) of the top of the condensing chamber.

The sleeve that surrounds the radiator element should have its lower end open and extending from a point about 4 ft (1.2 mm) above the base of the large steel-plate riser to a tee outlet at about one-third the height of the tank.

Make the sleeve of the pipe at least 2 in. (50 mm) greater in diameter than the radiator element. The extension above the radiator element and the outlet of the tee should be 2 1/2 in. (63 mm) or larger in diameter.

The steam-supply pipe to the condensing chamber should be large enough to convey the quantity of steam required, but not less than 1-1/2 in. (38 mm) in diameter. If steam is supplied by a boiler located far from the tank, provide a trap arrangement (as shown in Figure 21) for the steam supply and condensate-return pipes. If the steam supply is from a separate boiler above grade near the tank (Figure 22), the steam pipe inside the condensing chamber should have several 1/4 in. (6.3 mm) holes below the water level of the boiler, and be pitched upward from the top of the boiler to the connection in the condensing chamber. In either case, the condensate-return pipe should be at least 3/4 in. (19 mm) in diameter.

Support and brace the radiator, sleeve, and sleeve extension above the radiator at points no more than 25 ft (7.6 m) apart.

Provide an angle-socket thermometer in the riser, 5 ft (1.5 m) above the bottom, and as far from the heater as possible. This thermometer should have at least a 6 in. (150 mm) stem, and be calibrated as low as 30°F (-1.1°C).

A vertical radiator heater should be supplied from a reliable source of steam at 10 psi (69 kPa) (0.69 bar) or above. Provide a steam gauge with siphon at an accessible location.

Operation and Control. Steam pressure may be regulated by throttling the steam control valve manually, or by an automatic steam control valve. Automatic operation may be by an electrically-activated valve if the electric supply is reliable, or a non-electric control valve.

Locate the temperature sensing element for an automatic control near the thermometer in the side of the large riser.

Place an automatic steam control valve in a full-sized bypass around the manual steam valve, and install globe valves in the bypass on either side.

Provide a drip trap and strainer ahead of the steam control valve.

Regulate the heat supply to maintain the temperature of the cold water between 42 and 50°F (5.6 and 10°C).

Size. The condensing chamber of a vertical radiator heater should have sufficient area to maintain the temperature of the coldest water at not less than 42°F (5.6°C).

To determine the size of the condensing chamber needed:

1. Obtain the 100-year return period daily minimum temperature (100-year DMT) zone for the locality from the FM Worldwide Freeze Map.

2. From Table 6 or 8, determine the total loss from the tank equipment in Btu/hr (watts).

3. From Table 12, determine the transfer in Btu/hr/ft^2 (watts/m^2) at the steam pressure available at the heater.

4. Divide this figure into the total heat loss per hour to determine the number of square feet (m^2) of heating surface needed.

5. From Table 13, determine the diameter and length of pipe necessary to give the needed number of square feet (m^2).

Example: Determine the required size of the condensing chamber in a vertical radiator heater for an uninsulated steel gravity tank of 75,000 gal (284 m^3) capacity in Duluth, Minnesota. The tank is on a 100 ft (30 m) tower and has a large steel-plate riser, 3 ft (0.9 m) in diameter. Steam pressure available at the heater is 15 psi (103 kPa) (1.03 bar). The steam pipe is 1-1/2 in. (38 mm) in diameter.

From the FM Worldwide Freeze Map, Duluth, Minnesota is within a -35°F (-37.2°C) zone, meaning the 100-year DMT is between -35°F (-37.2°C) and -40°F (-40°C). Since temperature data is not precise, Tables 6 through 9 have been developed for use based on the 100-year DMT zone; interpolation should not be used. Therefore, from Table 6 and a -35°F (-37.2°C) 100-year DMT zone, the heat loss is approximately 683,000 Btu/hr (199 kW) for the tank and 214,500 Btu/hr (77.5 kW) for the riser - a total loss of 897,500 Btu/hr (276.5 kW). From Table 12, the heat transfer at 15 psi (103 kPa) (1.03 bar) is 22,000 Btu/hr/ft^2 (69.4 kW/m^2). Therefore, 40.8 ft^2 (3.79 m^2) of surface are needed. The condensing chamber should have a 3/4 in. (19 mm) clearance around the steam-supply pipe or be at least of 4 in. (100 mm) diameter, so that a 4 in. (100 mm) pipe is the smallest that could be used. Reading from Table 13, it is found that a 4 in. (100 mm) pipe approximately 35 ft (10.7 m) long would give the required number of square feet (m^2) of heating surface.

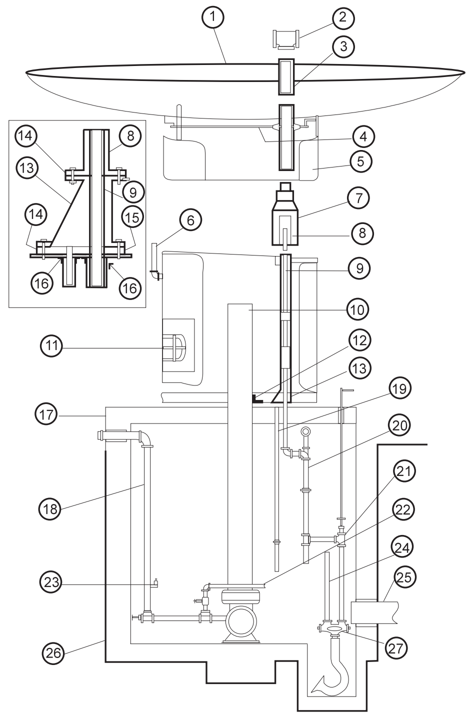
3.8.4 Steam Coil Inside Tanks

A steam coil near the bottom inside a steel or wooden suction tank (Figures 6 and 11) is an acceptable method of heating.

The coil should be of a type shown in Table 5 and at least 1-1/4 in. (32 mm) in diameter. Sturdily support the coil at least 1 ft (0.3 m) above the tank bottom. Pitch to drain at least 1 in. in 10 ft (8.3 mm/m) (0.008%), and make provision for expansion.

Connect the coil through a pipe to a reliable steam supplying the quantity of steam required, preferably at 10 psi (69 kPa) (0.69 bar) or above. Connect the condensate pipe to a steam trap that vents the air automatically.

Provide a globe valve and steam gauge with siphon in the steam-supply pipe as close to the coil as practicable.

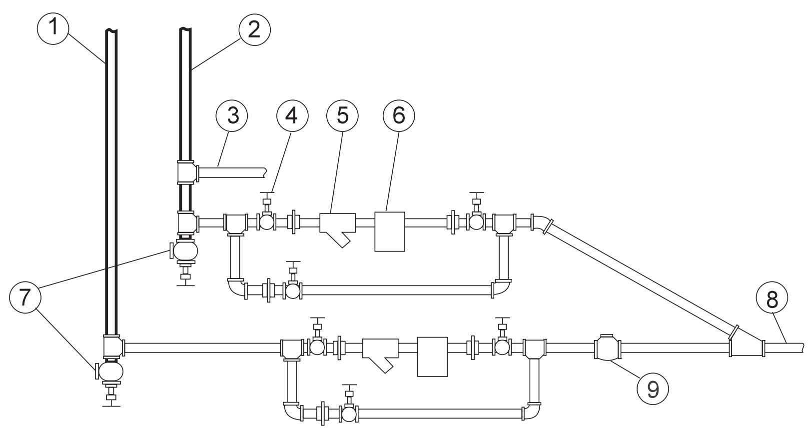


1. Steel gravity tank
2. Hot water outlet
3. Extension above sleeve
4. Brace rods at least ½ in. (13mm) in diameter, not more than 25 ft. (7.6m) apart
5. Large steel-plate riser
6. Thermometer. Locate temperature sensing element for automatic control near this point
7. Sleeve around radiator element
8. Condensing chamber
9. Steam pipe open to top
10. Discharge pipe
11. Manhole cover
12. Welded connection
13. Standard eccentric cast-iron reducer or welded assembly, at least 6 to 4 in. (150 to 100mm)
14. Composition asbestos gasket
15. Tapped flange
16. Extra-heavy coupling welded in place
17. Hollow-center pier
18. Drain pipe
19. Condensate return
20. Steam supply pipe
21. Steam control valve for water ejector
22. Pipe from mercury gauge
23. Drain cock, ½ in. (13mm)
24. Discharge pipe from water ejector
25. Conduit for steam pipes and connection from mercury gauge
26. Waterproof outer covering
27. Water ejector. Electric motor-operated, automatically controlled sump pump may be substituted

Fig. 20. Vertical radiator heater for gravity tank with large steel-plate riser (steam supplied from plant boiler)

Provide a thermometer, graduated at least as low as 30°F (-1.1°C), whose sensitive element is located 5 ft (1.5m) above the bottom of the suction tank. If a long distance thermometer is used, support the external tubing at about 12 ft (3.5 m) intervals.

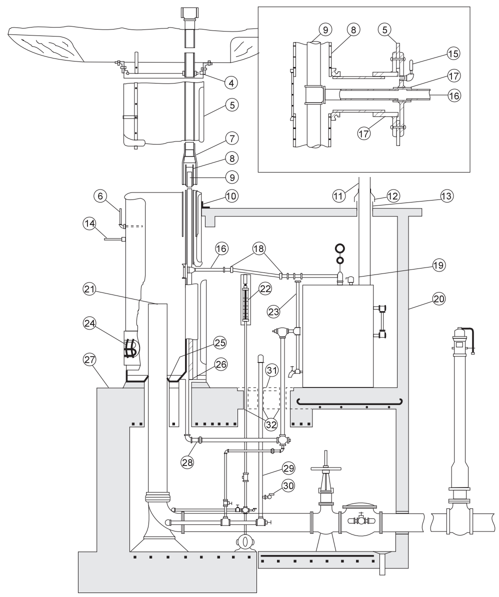
In the past, steam coils have been provided in some gravity tanks. This arrangement is not convenient to determine water temperatures. Provide a long distance thermometer whose sensitive element is located 3 ft (0.9 m) below the overflow pipe or the top of the riser from the plant service piping, and indicating dial is located in a substantial weatherproof cabinet near grade or roof level.



1. Condensate return pipe
2. Steam-supply pipe
3. To steam supply
4. Globe valve
5. Strainer
6. Steam trap. Outlets open for discharging air and water, except when automatically closed by stream. Locate traps above water line of boiler or discharge to independent tank
7. Hose valve and cap. Used for flushing water through steam pipe in vertical radiator to remove obstructing material
8. Return pipe to boiler feed pump or independent tank or hot well.
9. Brass check valve

Note: Piping shown diagrammatically. Bypass piping should be installed at same level as main return piping from stream supply pipe and vertical radiator heater. Copper water tubing may be used for supply and return piping if desired

Fig. 21. Arrangement for removing condensate from vertical radiator heaters when steam supply is from plant boilers



1. Steel gravity tank
2. Hot water outlet
3. Extension above sleeve
4. Brace rods, at least 1/2 in. (13mm) in diameter, not more than 25 ft (7.6mm) apart
5. Large steel-plate riser
6. Thermometer
7. Sleeve around radiator element
8. Condensing chamber closed at top
9. Steam pipe open at top
10. Flashed joint
11. Vent or stack
12. Apron
13. Thimble
14. Temperature-sensing element for automatic control of boiler when desired. Locate at least 1 ft (0.3 m) away from heater
15. Air vent
16. Steam supply pipe
17. Extra-heavy coupling welded to plate
18. Four-elbow swing joint
19. Damper if needed
20. Noncombustible heater house
21. Discharge pipe
22. Mercury pipe
23. Hartford pipe loop
24. Manhole cover
25. Welded connection
26. Drain holes, 1/4 in. (6.3 m) in diameter
27. Hollow-center pier and valve pit
28. Condensate return
29. Drain pipe
30. Drain cock, 1/2 in. (13 mm)
31. Iron grating
32. Caulking where pipes pass through sleeves in concrete floor

Fig. 22. Vertical radiator heater for gravity tank with large steel-plate riser (steam supplied from separate boiler at base of tank)

Operation and Control. Steam pressure may be regulated by throttling the steam control valve manually, or by an automatic steam control valve. Automatic operation may be by an electrically activated valve if the electric supply is reliable, or by a non-electric control valve.

Locate the temperature sensing element near the thermometer in the side of the tank.

Place an automatic steam control valve in a full-sized bypass around the manual steam valve, and provide globe valves in the bypass on either side.

Table 12-US. Approximate Heat Transfer from Coils and Pipe Radiators (U.S. Customary Units).*
(Coldest water just safely above freezing)

Steam Pressure, psi	*Heat Transfer (Steam to water), Btu/hr/ft^2*
10	19,500
15	22,000
20	24,500
30	29,500
40	34,500
50	39,000

*Not to be used in calculating the area of coil needed in a circulating heater.

Table 12-SI. Approximate Heat Transfer from Coils and Pipe Radiators (SI Units).
(Coldest water just safely above freezing)

Steam Pressure,		*Heat Transfer (steam to water),*
kPa	*bars*	*kw/m^2*
69	0.69	62
103	1.03	69
138	1.38	77
207	2.07	93
276	2.76	109
345	3.45	123

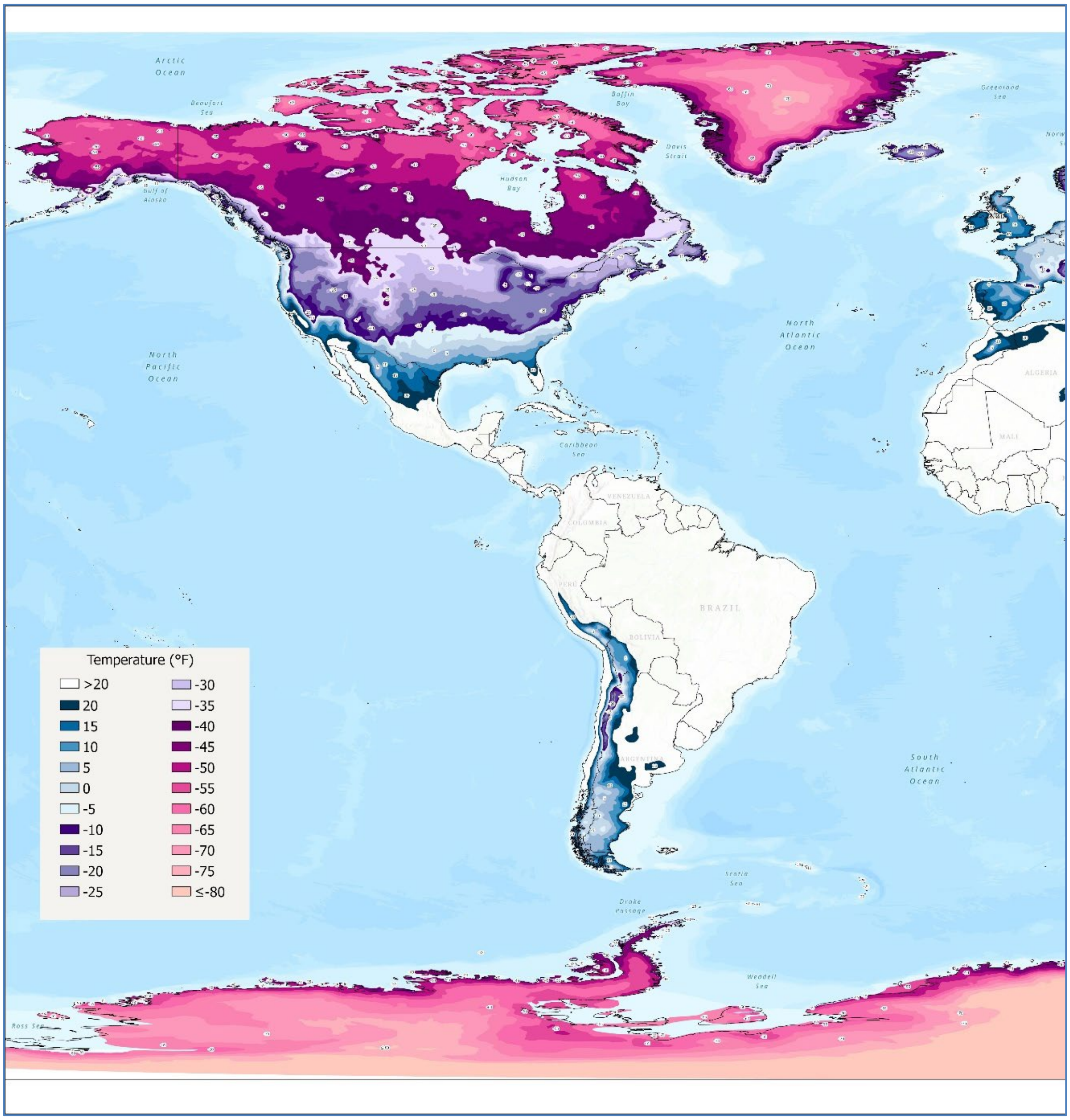


Fig. 23. Overview of 100-year return period daily minimum temperature (100-year DMT) zones, western hemisphere

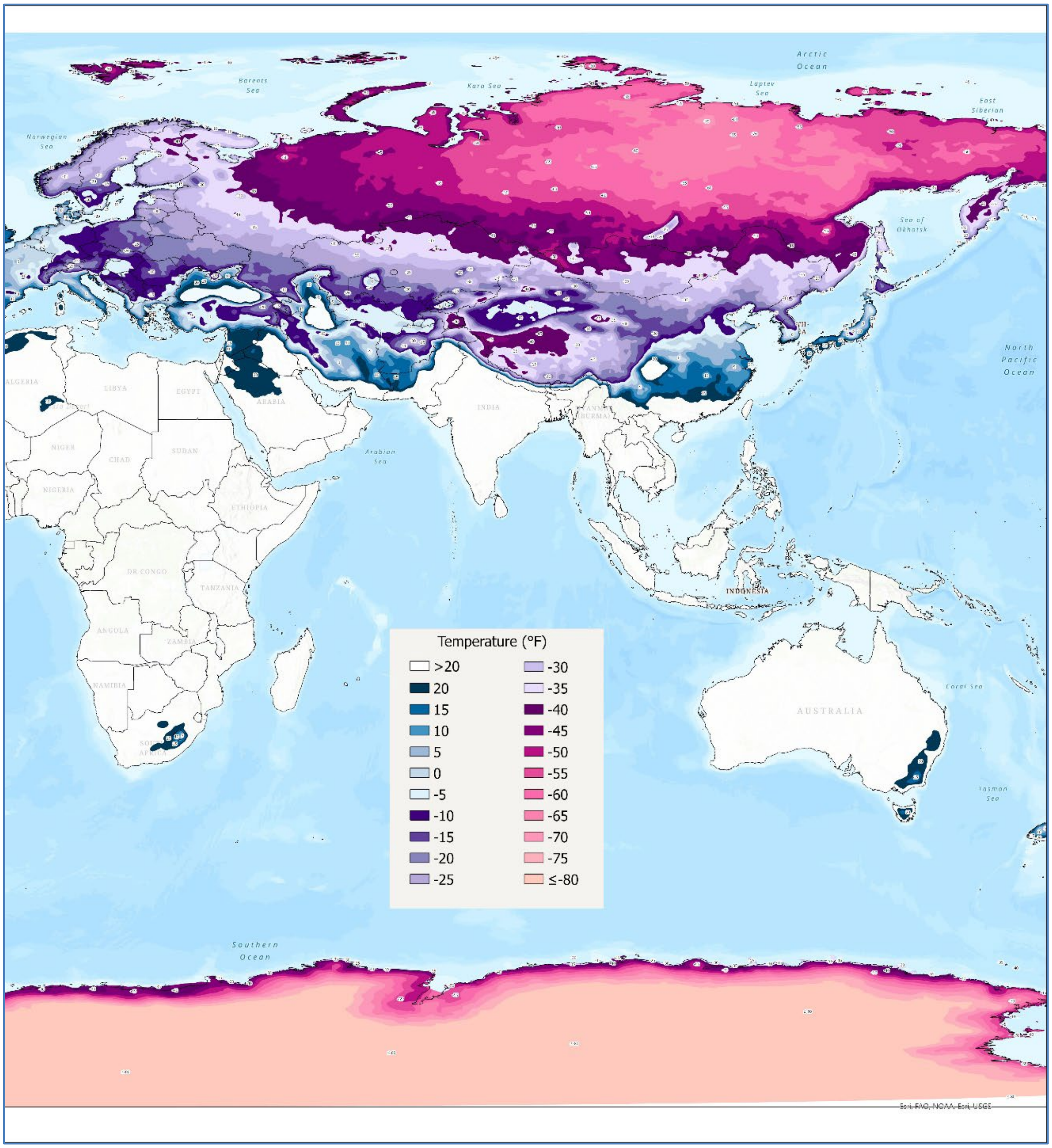


Fig. 24. Overview of 100-year return period daily minimum temperature (100-year DMT) zones, eastern hemisphere

Table 13-US. Heating Surface in Coils or Pipe Radiators, Ft² (U.S. Customary Units)

Length, ft	Size of pipe, in.										
	¾	1	1-¼	1-½	2	2-½	3	3-½	4	5	6
1	0.275	0.346	0.434	0.494	0.622	0.753	0.916	1.048	1.175	1.445	1.739
10	2.7	3.5	4.3	4.9	6.2	7.5	9.2	10.5	11.8	14.6	17.4
15	4.1	5.2	6.5	7.4	9.3	11.3	13.7	15.7	17.6	21.8	26.1
20	5.5	6.9	8.7	9.9	12.5	15.0	18.3	21.0	23.5	29.1	34.8
25	6.9	8.6	10.9	12.3	15.6	18.8	22.9	26.2	29.3	36.3	43.5
30	8.3	10.4	13.0	14.8	18.7	22.5	27.5	31.4	35.3	43.6	52.1
35	9.6	12.1	15.2	17.3	21.8	26.3	32.0	36.7	41.1	50.9	60.8
40	11.0	13.8	17.4	19.8	24.9	30.1	36.6	41.9	47.0	58.2	69.5
45	12.4	15.6	19.5	22.2	28.0	33.8	41.2	47.2	52.9	65.5	78.2
50	13.8	17.3	21.7	24.7	31.1	37.6	45.8	52.4	58.7	72.7	87.0
55	15.1	19.1	23.8	27.2	34.2	41.4	50.4	57.6	64.6	80.0	95.7
60	16.5	20.8	26.0	29.6	37.3	45.2	55.0	62.8	70.5	87.3	104.3
65	17.9	22.5	28.2	32.1	40.4	49.0	59.5	68.1	76.4	94.6	
70	19.2	24.2	30.4	34.6	43.5	52.7	64.1	73.3	82.3	101.9	
75	20.6	26.0	32.6	37.1	46.6	56.5	68.7	78.5	88.2		
80	22.0	27.7	34.7	39.5	49.8	60.2	73.2	83.8	93.0		
85	23.4	29.4	36.8	42.0	52.9	63.0	77.8	89.0	99.9		
90	24.7	31.2	39.0	44.5	56.0	67.8	82.4	94.3	105.8		
95	26.1	32.9	41.2	46.9	59.1	71.5	87.0	99.5			
100	27.5	34.6	43.4	49.4	62.2	75.3	91.6	104.8			

Table 13-SI. Heating Surface in Coils or Pipe Radiators, m² (SI Units)

Length, m	Size of Pipe, mm										
	19	25	32	38	50	63	75	89	100	125	150
0.1	0.083	0.105	0.132	0.151	0.19	0.23	0.28	0.31	0.35	0.44	0.53
3.0	0.25	0.33	0.40	0.46	0.58	0.70	0.85	0.98	1.10	1.36	1.62
4.6	0.38	0.48	0.60	0.69	0.86	1.05	1.27	1.46	1.64	2.03	2.42
6.1	0.51	0.64	0.81	0.92	1.16	1.39	1.70	1.95	2.18	2.70	3.23
7.6	0.64	0.80	1.01	1.14	1.45	1.75	2.13	2.43	2.72	3.37	4.04
9.1	0.77	0.97	1.21	1.37	1.74	2.09	2.55	2.92	3.28	4.05	4.84
10.7	0.89	1.12	1.41	1.61	2.03	2.44	2.97	3.41	3.82	4.73	5.65
12.2	1.02	1.28	1.62	1.84	2.31	2.80	3.40	3.89	4.37	5.41	6.46
13.7	1.15	1.45	1.81	2.06	2.60	3.14	3.83	4.39	4.91	6.09	7.27
15.2	1.28	1.61	2.02	2.29	2.89	3.49	4.25	4.87	5.45	6.75	8.08
16.8	1.40	1.77	2.21	2.53	3.18	3.85	4.68	5.35	6.00	7.43	8.89
18.3	1.53	1.93	2.42	2.75	3.47	4.20	5.11	5.83	6.55	8.11	9.69
19.8	1.66	2.09	2.62	2.98	3.75	4.55	5.53	6.33	7.10	8.79	—
21.3	1.78	2.25	2.82	3.21	4.04	4.90	5.96	6.81	7.65	9.47	—
22.8	1.91	2.42	3.03	3.45	4.33	5.25	6.38	7.29	8.19	—	—
24.4	2.04	2.57	3.22	3.67	4.63	5.59	6.80	7.79	8.64	—	—
25.9	2.17	2.73	3.42	3.90	4.91	5.85	7.23	8.27	9.28	—	—
27.4	2.29	2.90	3.62	4.13	5.20	6.30	7.66	8.76	9.83	—	—
29.0	2.42	3.06	3.83	4.36	5.49	6.64	8.08	9.24	—	—	—
30.4	2.55	3.21	4.03	4.59	5.78	7.00	8.51	9.74	—	—	—

Provide a drip trap and strainer ahead of the steam control valve.

To place the heating system in service, turn on the steam or start the fuel-fired heaters. If an inverted bucket trap is not provided, blow all air from the steam pipe and trap by the air valve or vent in the steam trap when first admitting steam.

Regulate the heat to maintain the temperature of the cold water between 42 and 50°F (5.6 and 10°C).

Size. The surface area of the steam coils should be sufficient to maintain the temperature of the coldest water at not less than 42°F (5.6°C).

To determine the area of steam coils needed:

1. Obtain the 100-year return period daily minimum temperature (100-year DMT) zone for the locality from the FM Worldwide Freeze Map (see overview of the map in Figures 23 and 24 and details at www.fmglobal.com).

2. From Table 7 or 9, determine the total loss from the tank in Btu/hr (watts).

3. From Table 12, determine the transfer in Btu/hr/ft^2 (W/m^2) at the steam pressure available at the coil.

4. Divide this figure into the total heat loss per hour to determine the number of square feet (m^2) of heating surface needed.

5. From Table 13, determine the diameter and length of pipe needed to give the necessary number of square feet (m^2).

Example: Determine the required size of a steam coil for heating an uninsulated 100,000 gal (379 m^3) steel suction tank located at Chicago, Illinois. The steam pressure available at the coil is 20 psi (138 kPa) (1.38 bar).

Reading from the FM Worldwide Freeze Map, Chicago is in the -20°F (-28.9°C) temperature zone, so the 100-year DMT is between -20°F (-28.9°C) and -25°F (-31.7°C). Since temperature data is not precise, Tables 6 through 9 have been developed for use based on the 100-year DMT zone; interpolation should not be used. Referring to Table 7 the heat loss is about 556,000 Btu/hr (165 kW). From Table 12, the heat transfer at 20 psi (138 kPa) (1.38 bar) is 24,500 Btu/hr/ft^2 (77 kW/m^2). Therefore, 23 ft^2 (2.14 m^2) of surface are needed. From Table 13, it is found that any of the following would be satisfactory:

- 53 ft of 1-1/4 in. pipe (16 m of 32 mm pipe)
- 47 ft of 1-1/2 in. pipe (14.5 m of 38 mm pipe)
- 37 ft of 2 in. pipe (11.25 m of 50 mm pipe)
- 31 ft of 2-1/2 in. pipe (9.5 m of 63 mm pipe)
- 25 ft of 3 in. pipe (7.75 m of 75 mm pipe)

Steam Coil Inside Frost-Proof Casings. A steam coil inside a frost-proof casing should extend the full height of the casing and be of a type shown in Table 5, at least 1-1/2 in. (38 mm) in diameter. It should be sturdily supported at intervals of not over 25 ft (7.6 m).

The steam pipe should be supplied through a trap and drip arrangement similar to that shown in Figure 21.

The surface area of the steam pipe should be sufficient to supply the heat lost through the frost-proof casing.

To determine the surface area of steam pipe needed:

1. Determine the 100-year return period daily minimum temperature (100-year DMT) zone for the locality from the FM Worldwide Freeze Map, which represents the temperature at the warm side of the zone (do not interpolate).

2. Subtract this temperature at the warm side of the zone from 42°F (5.6°C).

3. Multiply the difference by the number of feet (m) of riser, the area of outside surface of frost-proof casing in ft^2/lin ft (m^2/m) and the heat transmission in Btu/ft^2/hr (W/m^2) per degree difference in temperature for the particular frost-proof casing provided (e.g., as given in Figures 12 and 13). Note: the heat conductivity or transmission is the reciprocal of the “R” insulating value (i.e., 1/R).

4. Divide this total heat loss by 510 (which is the heat loss from a bare steam pipe to air of 3 Btu/hr/ft^2 of pipe per °F difference in temperature, times the difference in temperature between steam at atmospheric pressure and the air in the casing at 42°F - a difference of 170°F). (In SI units: use 894, which is 9.46 W/hr/m^2/°C times 94.5°C.)

5. From Table 11, determine the diameter of pipe necessary to give the needed surface area when the pipe extends the full height of the frost-proof casing.

3.8.5 Air-bubbler Systems

Air-bubbler systems have been used successfully to keep marinas and reservoirs ice free all winter. These systems work because water at 40°F (4.4°C) is denser than water at 32°F (0°C) and natural bodies of water and earth reservoirs are in contact with surfaces below the frost line (unlike fire protection tanks). The bubbler system forces the denser 40°F (4.4°C) water to rise. As it rises, it warms the upper layers of water which will sink as they get more dense. However, marinas and reservoirs generally contain much more water than fire protection water storage tanks and they extend below the frost line. Therefore, they have much more available heat than do typical fire protection tanks.

3.8.6 Maintenance of Tank Heating Equipment

The heating system should be cleaned and overhauled as necessary after the heating season is over, with major maintenance being performed during the summer. The system should again be serviced, and verified to be working, in the fall before the heating season starts.

Every five years, disassemble radiator heaters and clean out all pipes. Replace badly corroded pipe with copper water tubing, brass (85% copper), or cast iron pipe.

Every five years, clean the exterior of steam coils that are used to heat suction tanks. Steel or iron coils should be taken apart and cleaned inside. Replace seriously corroded coils with copper tubing or brass (85% copper) pipe.

Coil-type gas heaters (Figure 16) may require periodic removal of scale or lime deposits since some solids exist in most water supply systems. As the water is heated, these solids tend to drop out. This condition can normally be detected when a change of approximately 5°F (2.8°C) in the normal temperature rise through the heater occurs. This scale is comparatively easy to remove if cleaned before the coils become clogged. Special solvents are available for this purpose. Manufacturers of FM Approved coil-type water heaters have a preventive maintenance system for deliming; their recommendations should be followed.

3.8.7 Tank-Heating Troubles

Table 14 lists tank heating troubles and their possible causes. Suggested remedies are covered below. Additional causes are mechanical breakage and deterioration of insulation, which would be obvious on visual inspection. If the water in a tank cannot be maintained at 42°F (5.6°C) or above, the causes of trouble that can be checked easily should be checked first.

Troubles and Remedies:

1. Plant boiler fires are banked at night, during weekends or other plant shutdowns. Have sufficient steam for tank heating during these periods, or provide a separate heater for the tank.

2. Steam supply is intermittent because the main boiler is controlled by room temperature. Arrange boiler controls so that a thermostat on the tank heater in addition to the room thermostat controls steam supply, or provide a separate heater for the tank.

3. Steam for the heater supplied from a small building distribution pipe. Connect the tank-heating system directly to a header at the boiler.

4. Tank heater is too small. Replace with a proper size heater, or install an additional heater.

5. Plant boiler is too small for the combined steam demand of plant and tank. Provide additional boiler capacity or, for circulating systems, provide a separate tank heater. For vertical radiator heaters or steam coils inside tanks, provide a separate boiler for the tank.

6. Normal steam pressure is too low. For circulating systems, provide a separate tank heater; for vertical radiator heaters or steam coils inside tanks, provide a separate boiler for the tank.

7. Steam-supply pipe is too small or obstructed by corrosion. Install pipe of proper size to deliver the quantity of steam required or replace corroded pipe.

8. Steam or water circulating valve is closed or throttled, or valve disk disengaged from stem. Open or repair valves.

9. Vertical radiator heater is partially plugged with scale. Flush out the heater through a hose connection on steam piping (Figure 20). If scale is not removed, disassemble the heater and clean or replace pipe. It may be possible to increase steam pressure to obtain necessary heat so that repairs can be deferred until warm weather. If repairs are deferred, keep careful check on water temperatures.

10. Hot water pipe is not sloped upward throughout. Remove pockets by pitching the pipe upward, or change to a forced circulation system.

11. Hot water outlet is above the surface of water or too near the bottom of the tank. Locate hot water outlets as specified under Water Circulating Pipes. Keep the tank filled. Check to see that hot water pipe is not corroded through near the tank bottom.

12. Condensate collects in pocket(s) in steam supply pipe. Pitch the steam pipe to eliminate pocket(s) or provide an independent trap for each low point.

13. Hot water pipe is connected to the low point of the tank heater shell or the steam supply pipe is connected to the lower end of the coil. Reverse pipe connections: hot water pipe to the high point of the heater and steam supply pipe to the top of the coil. For vertical radiators, connect steam supply pipe to the large outlet of the radiator, that is, to inner pipe.

14. Hot water pipe is connected directly to tank riser. Arrange hot water circulating pipe in accordance with Figures 6, 8, or 13 to 16.

15. Steam supply is connected directly to pipe riser. Provide a method of tank heating in accordance with this data sheet.

16. Temperature sensing element of thermometer or thermostat is improperly located. Install in correct location, depending upon method of heating tank.

17. Steam trap and/or heater are air bound. Provide steam traps that automatically remove air from piping.

18. Steam trap is too small or discharge is impeded. Have carrying capacity of traps and return system checked by an expert, and install larger traps or return line if necessary.

19. Sediment or scale plugs heater, pipes, or accessories. Flush heater, pipes, or accessories through drains provided.

20. Heater coil leaks. Replace or repair defective coil.

21. Steam or hot water pipe is exposed or improperly located. Provide sufficient insulation, particularly when pipes pass through rooms that may be unheated. Repair frost-proof casings to cover all parts of pipe. Locate pipes inside frost-proof casing.

22. Circulation starts in wrong direction. If no trouble has occurred previously and the hot-water valve is wide open, the hot-water pipe is probably partially obstructed and should be cleaned out or replaced. For new piping and with hot-water valve wide open, throttle the cold-water valve when heating starts, then open it wide. It may be possible to correct this latter condition by incorporating a 3 ft (0.91 m) U in the cold-water return line. The additional friction loss through the fittings of the U tends to make the flow start in the correct direction. Convert a gravity circulating system to a forced system.

3.8.8 Restoring Protection After Freeze-Ups

It is dangerous to withdraw water from a tank if the surface is completely covered with a thick layer of ice. Ice less than 2 in. (50 mm) thick will probably break as the water recedes and do no harm. Make sure that this occurs before the level has fallen more than a few inches, or a vacuum may cause the tank to collapse. If a large mass of ice falls suddenly after the water is withdrawn, it may seriously damage the tank.

If it becomes necessary to drain the tank but water cannot be withdrawn from the riser, the water must be siphoned through the tank hatch using suction-type or other non-collapsible hose. Dispose of the water where it will not cause damage by flooding or icing.

If it is necessary to thaw ice, steam or warm air is preferred. Do not allow direct heat from an open flame or sparks from any source to come in contact with combustible construction, building contents, frost-proof casing, or insulation. Replace broken fittings or pipe. If welding is used, the standard precautions should be taken.

If the ice in a tank having a circulating heating system is more than 2 in. (50 mm) thick, break it up from the tank hatch, or at least make a large opening. Try to flush the heater through the drain pipe or from the plug at the bottom of the heater. If neither of the circulation pipes is frozen solid, thoroughly flush both pipes and heaters. Maintain good steam pressure on the heater continuously with a large difference in temperature between the hot and cold water pipes.

Check the accuracy of the cold water thermometer; if the surface water temperature does not rise and ice does not start melting within 12 hr, drain the tank by siphoning and inspect the heater pipe inside. It is likely to be corroded through or broken off near the base, allowing local circulation without appreciably heating the tank water. Replace the inside heater pipe if it is found defective. Make sure the heater is large enough and that adequate steam pressure is constantly available.

If a tank has a frost-proof casing yet the circulation pipes are frozen solid and no breaks are evident, admit steam or heated air into the base of the frost-proof casing. If fittings are broken or the pipe split, leakage will occur when the ice melts. Advance precautions should be taken to prevent damage.

When a tank or large riser has a coil or radiator, first break up thick ice on the water surface. If the heater cannot be made effective by maintaining steam pressure and liberating all air from the coil, and if water cannot be drawn from the tank through the riser, siphon the water from the tank and determine whether the coil and pipes need replacement.

Where a tank is without a heating system (other than external heat in a frost-proof casing for the riser), manually break up ice more than 2 in. (50 mm) thick through the tank hatch. Thinner ice will settle and break as the water level falls. If the riser is not frozen, drain about one fourth of the tank and refill with water at a temperature not below 40°F (4.4°C). Do not overfill the tank unless it has an inside overflow pipe that discharges the water harmlessly. Watch for additional freezing and provide heat if possible, or repeat the emptying and refilling process as needed.

If an automatic gas- or oil-burning heater, circulating pump, or other complicated equipment cannot be made to operate satisfactorily and keep the tank free of ice, call in an expert, preferably from the manufacturer.

4.0 REFERENCES

4.1 FM

Data Sheet 1-2, *Earthquakes*
Data Sheet 1-28, *Wind Design*
Data Sheet 1-54, *Roof Loads and Drainage*
Data Sheet 1-57, *Plastics in Construction*
Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*
Data Sheet 2-8, Earthquake Protection for Water-Based Fire Protection Systems
Data Sheet 2-81, Fire Protection System Inspection, Testing and Maintenance
Data Sheet 3-4, *Embankment-Supported Fabric Tanks*
Data Sheet 3-6, *Lined Earth Reservoirs for Fire Protection*
Data Sheet 3-7, *Fire Protection Pumps*
Data Sheet 9-18, Prevention of Freeze-Ups

Approval Guide, an online resource of FM Approvals

Approvals Standard Class Number 4020, *Approval Standard for Steel Tanks for Fire Protection*
Fire Pump Testing and Maintenance Checklist. FM publication P8217.
Pocket Guide to Inspecting, Testing and Maintaining Fire Protection Equipment. FM publication P0418

4.2 NFPA Standards

National Fire Protection Association (NFPA). NFPA 22, *Standard for Water Tanks for Private Fire Protection,* 2013.

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4.3 Others

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APPENDIX A GLOSSARY OF TERMS

Allowable stress design (ASD): A method of designing structural members such that computed stresses produced by normal gravity design loads (e.g., the weight of the tank and roof, roof live or snow loads and hydrostatic loads from the weight of contained water) do not exceed allowable stresses that are typically below the elastic limit of the material (e.g., in steel these are typically well below the yield stress, F_y). Although it is becoming less common for buildings, for tanks normal allowable stresses are usually increased by one-third when design includes extreme environmental loads such as earthquakes. (Also called working stress design or elastic design).

Anchor Bolts: large bolts fastened to the shell of the tank and embedded up to several feet in a reinforced concrete foundation. They are typically used to resist seismic forces. They also may be needed with unusually tall, narrow tanks to resist wind forces.

Break Tank: a tank which is not of adequate capacity to supply the sprinkler and hose demand. It relies on automatic filling while the fire pump draws it down, in order to provide a suitable capacity.

Elastic design: see Allowable Stress Design.

Exterior surfaces: Weather-exposed exterior accessible surfaces of the tank shell, roof, pedestal, legs, accessories, and appurtenances.

FM Approved: References to ‘‘FM Approved’’ in this data sheet mean the product and services have satisfied the criteria for FM Approval. Refer to the *Approval Guide*, an online resource of FM Approvals, for a complete listing of products and services that are FM Approved.

Fire Pump Suction Tank: a water tank which is typically flat bottomed and has a water level at the same approximate elevation as the sprinkler system and slightly above that of the fire pump. The tank supplies the water volume and the pump provides the necessary pressure for the sprinkler system.

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

Foundation anchors: See anchor bolts.

Gravity Tank: a tank which supplies a volume of water for fire protection but has an elevation considerably higher (typically on the order of 100 ft (30 m)) than that of the sprinkler system so as to provide the water to it at the needed pressure.

Inaccessible areas: Areas of the finished structure that cannot be accessed to perform surface preparation or coating application. For example, contact areas between roof plates and roof members, and the underside of bottom plates of ground-supported tanks.

Interior dry surfaces: Interior accessible surfaces of the finished structure that are not exposed to the stored water or its vapor nor to the weather. For example, the interior of the pedestal.

Interior wet surfaces: Interior accessible surfaces of the tank shell, roof, bottom, accessories and appurtenances that are exposed to the stored water or its vapor.

Load and resistance factor design (LRFD): A method of designing structural members such that computed stresses produced by service design loads multiplied by load factors do not exceed the theoretical nominal member strength multiplied by a strength reduction (resistance) factor. (Also called strength design or ultimate strength design).

Pressure tank: A relatively small (e.g., 20,000 gal [76 m^3]) horizontal cylindrical steel tank having a water capacity typically two-thirds of the total listed tank capacity with the remaining volume of the tank filled with pressurized air supplied by a compressor. The tank supplies the water volume and the necessary pressure for the sprinkler system.

Strength design: See load and resistance factor design.

Top capacity level (TCL): The high water level when the water surface is at the inlet of the overflow or at the top of the weir box (if a weir box exists).

Tower: an elevated structure, made of steel, or concrete which supports a gravity tank.

Ultimate Strength Design: See load and resistance factor design.

Wind surface roughness exposure category: A classification (B, C, or D) reflecting the characteristics of ground surface irregularities upwind of a site. As the number of obstructions increases, the effects of wind forces are reduced due to friction. Exposure Category B has the largest number of obstructions (e.g., in an urban area) and Exposure Category D has the least number of obstructions (e.g., adjacent to large areas of open water or unbroken ice).

Working stress design: See allowable stress design.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

July 2022. Interim revision. The new FM GlobalWorldwide Freeze Map, available online at www.fmglobal.com, has been developed using recent worldwide temperature data. The map now uses 100-year return period daily minimum temperature (100-year DMT) zones to identify areas having a significant weather-related freeze hazard. This temperature measure differs from that previously used (the lowest one-day mean temperature [LODMT]). Data Sheet 9-18, *Prevention of Freeze-Ups*, has also been revised to align with the new FM Global Worldwide Freeze Map. Revisions are made such that guidance is appropriate for the new 100-year DMT zones and reflects Data Sheet 9-18, *Prevention of Freeze-Ups*, changes. Some editorial changes are made as well. Significant revisions include:

A. Added Section 1.1, Hazards

B. Revised Section 2.2.6, Protecting Tanks and Tank Piping Against Freezing

C. Revised Recommendation 2.3.9 to restore precautions, inadvertently deleted in the previous revision, to follow when tanks are drained

D. Added freeze-related Recommendation 2.3.10, and revised freeze guidance in Recommendations 2.3.11 and 2.3.12

E. Revised Section 3.7.2, Frost-proof Casings

F. Revised Section 3.8, Tank Heating Equipment

G. Revised Section 3.8.2, Circulating Heating Systems

H. Revised Section 3.8.3, Vertical Radiator Heaters

I. Revised Section 3.8.4, Steam Coil Inside Tanks

J. Revised heat loss guidance in Table 6 through Table 9, and water-circulating pipe guidance in Table 11

K. Replaced Figures 23 and 24 with an overview of the FM Global Worldwide Freeze Map

L. Added a reference to Data Sheet 9-18 in Section 4.1

July 2021. Interim revision. Revised Recommendation 2.3.9 to allow underwater evaluation of the interior of tanks when appropriate, matching provisions in the July 2021 revision of Data Sheet 2-81, *Fire Protection System Inspection, Testing and Maintenance* (Recommendation 2.10.1.4). Additionally, minor editorial changes were made.

October 2015. This data sheet has been extensively revised. The following major changes were made:

A. Added pressure tanks to Section 1.0 and deleted or relocated (to Section 2.1) items unrelated to the scope of this data sheet.

B. Throughout Section 2.0, rearranged recommendations to clarify the type of tank to which they apply. Also relocated recommendations from Section 3.0 that were not previously included in Section 2.0, and updated recommendations to meet current requirements in FM Approvals Standard 4020, *Approval Standard for Steel Tanks for Fire Protection*, and other applicable standards. Significant new Section 2.0 recommendations that were relocated from Section 3.0 include the following:

1. Tank construction Recommendations 2.2.1.17 and 2.2.1.18 (previously in Section 3.1.1)

2. Section 2.2.5 foundation and anchor information (previously in Section 3.5.1)

3. Section 2.2.6 insulation and heating recommendations (previously in Sections 3.7 and 3.8)

4. Inspection and maintenance Recommendations 2.3.6, 2.3.7, 2.3.8 and 2.3.10 (previously in Section 3.1.6)

5. Section 2.3.13 heating system inspection/maintenance recommendations (previously in Sections 3.8 and 3.8.6).

C. Created Section 2.1, Introduction, with text relocated from Section 1.0.

D. Added design and inspection information for pressure tanks to Section 2.2.1, Section 2.3, and Section 3.3.

E. Consolidated and revised design information for break tanks in Section 2.2.2; also revised break tank inspection/maintenance requirements in Section 2.3, and information in Section 3.2.

F. Added information on design loads applicable to all tanks to Section 2.2.3 and Section 3.1.3 (the information is based on and parallels that given in FM Approval Standard 4020).

G. Revised recommendations on the coating of new steel water tanks and accessories in Section 2.2.4, Section 3.1.6, Table 2, and Table 3 to match current American Water Works Association (AWWA) requirements.

H. Revised the presentation of United States and Europe lowest one-day mean temperature maps (new Figures 23 and 24) and modified text in Section 3.7.2 and Section 3.8 based on the new presentation. The data in the Figure 23 and Figure 24 temperature maps is unchanged but is now presented in terms of temperature zones rather than isothermal lines. Also revised Section 3.8.1 regarding insulation of tanks.

I. Added design criteria for tanks not covered by FM Approval Standard 4020 to Recommendation 2.2.1.2 and Section 3.1.8, and general information on suction and gravity tanks to Section 3.1.1. Revised information regarding FM Approval of tanks to Recommendation 2.2.1.4 and Section 3.1.2. Added information on suction tank flexible liners to Section 3.1.7 and tank foundations to Section 3.5.1.

J. Clarified suction and break tank anti-vortex plate locations and configurations in Recommendation 2.2.1.14, Recommendation 2.2.2.7, and Section 3.6.5.

K. Updated Section 4.0, References, and Appendix A, Glossary.

L. Added Appendix E as an aid for the preliminary design of cylindrical ground-supported steel suction tanks prior to submittal of design documents to FM Approvals for review. Appendix E summarizes and clarifies FM Approval Standard 4020 and AWWA design requirements for these tanks.

M. Tables 1, 2, and 3 and Figures 4 through 24 have been renumbered. Tables 2 and 3 and Figures 23 and 24 were also revised as noted above. Except for minor editorial changes, other renumbered tables and figures have not been revised.

N. Added Tables 15 through 23, Figure 2, Figure 3, and Figures 25 through 31.

In addition to the above, various minor changes have been made as indicated in red text throughout the document.

May 2010. Replaced all references to Data Sheet 2-8N, *Installation of Sprinkler Systems (NFPA)*, with references to Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*.

September 2009. Recommendation 2.2.8 and Section 3.6.5 were modified to be consistent with FM Global *Approval Standard for Ground Supported, Flat Bottom Steel Tanks for Fire Pump Suction* (Class Number 4020/4021).

January 2008. Clarification was made to Section 3.6.5, Suction Tank Pipe Connection.

May 2006. Figure 4 was revised.

September 2004. References to FM Global earthquake zones have been modified for consistency with Data Sheet 1-2, *Earthquakes.*

May 2001. Maps are redrawn for improved resolution and mapping accuracy.

January 2001. This revision of the document has been reorganized to provide a consistent format.

September 1998. Completely revised.

March 1994. Revised Document.

APPENDIX C NFPA STANDARD

Sprinkler tanks also are covered in NFPA 22, *Standard for Water Tanks for Private Fire Protection.* There are no major conflicts.

APPENDIX D JOB AIDS

Table 14. Causes of Tank-Heating Troubles

	Number	Possible causes	*Tank-heating troubles:* Ice on surface of water	Pipe or riser frozen	No circulation when heat on	Cannot heat coldest water to 42°F	Bad water hammer	Boiler flooded	Heater plugs
Insufficient heat	1	Plant boiler fires banked at night, during week ends, etc.	x	x		x			
	2	Steam supply intermittent because boiler controlled by room temperature.	x	x		x			
	3	Steam for heater supplied from small building distribution pipe.	x	x	x	x			
	4	Tank heater too small.	x	x		x			
	5	Plant boiler too small for combined steam demand of plant and tank.	x	x	x	x			
	6	Normal steam pressure too low.	x	x	x	x			
	7	Steam supply pipe too small or obstructed by corrosion.	x	x	x	x			
	8	Steam or water circulating valve closed or throttled or valve disk disengaged from stem.	x	x	x	x			
	9	Vertical radiator heater partially plugged with scale.	x			x			
Improper installation	10	Hot-water pipe not sloped upward throughout.	x	x	x	x			
	11	Hot-water outlet above surface of water or too near bottom of tank.	x	x	x	x			
	12	Condensate collects in pocket in steam-supply pipe.	x	x	x	x	x		
	13	Hot-water pipe connected to low point of tank heater shell or steam-supply pipe connected to lower end of coil.	x	x	x	x			
	14	Hot-water pipe connected directly to tank riser.	x	x					
	15	Steam-supply pipe connected directly to pipe riser.					x		
	16	Sensitive element of thermometer or thermostat improperly located.	x	x					
	17	Air binding of steam trap and/or heater.	x	x		x			
	18	Steam trap too small or discharge impeded.	x	x		x			
Miscellaneous	19	Sediment or scale plugs heater, pipes, or accessories.	x	x	x	x			x
	20	Leak in heater coil.	x					x	
	21	Steam or hot-water pipe exposed or improperly located.	x	x	x	x			
	22	Circulation starts in wrong direction.					x		

APPENDIX E DESIGN OF NEW CYLINDRICAL, GROUND-SUPPORTED, STEEL SUCTION TANKS

New ground-supported, flat-bottom, cylindrical steel (bolted or welded) suction tanks are to be designed per the current version of FM Approvals Standard 4020, *Approval Standard for Steel Tanks for Fire Protection,* as well as other standards referenced by that document. Design documents (drawings, calculations, etc.) should then be submitted to FM Approvals for review and approval.

The use of this appendix is not required, but is provided as an aid for initial design or review of new tanks. Major (but not all-inclusive) FM Approvals Standard 4020 (May 2011) provisions for bolted or welded ground-supported, flat-bottom, cylindrical steel suction tanks are included. The final determination of whether a tank will be FM Approved rests with FM Approvals and will be based on the complete requirements in the latest revision of FM Approvals Standard 4020.

It is not possible to make a blanket determination as to whether a suction tank designed using other standards will meet all FM Approvals Standard 4020 provisions. It has been noted during past reviews that there can be significant differences. Thinner shell plates resulting from higher allowable tension and compression stresses in some international standards by comparison to those allowed by FM Approvals Standard 4020, and lack of adequate earthquake uplift anchorage details are two common examples.

Except for design of anchor chairs in Section E.7.2.3, the nomenclature used in Appendix E is given in Table 15. This nomenclature largely corresponds to that in FM Approvals Standard 4020 but there are a few differences. Where variables not in Table 15 are used, or when further clarification is needed, it is provided in the text.

Table 15. Appendix E Nomenclature[1]

Variable	*Definition*
A_g	Gross area of a bolt in the unthreaded body, in.^{2} (mm^2)
A_r	Root area of a bolt based on the minimum diameter at roots of threads, in.^{2} (mm^2)
A_S	Tensile stress area of a bolt at the threaded portion, in.^{2} (mm^2)
C_c	Coefficient used to determine the convective period, sec/√ft
C_i	Coefficient used to determine the impulsive period
C_v	Coefficient used to determine the vertical period
D	Tank diameter, ft (m)
F_a	Allowable axial compression stress (Allowable Stress Design), including the one-third increase if appropriate, for the steel member, plate, etc. under consideration, psi (MPa)
F_t	Allowable tension stress (Allowable Stress Design), including the one-third increase if appropriate, for the steel member, plate, etc. under consideration, psi (MPa)
F_{tn}	Allowable tension stress (Allowable Stress Design), including the one-third increase if appropriate, for Shell Ring "n," psi (MPa)
F_u	Published minimum ultimate tensile stress of the steel under consideration, psi (MPa)
F_y	Published minimum yield stress of the steel under consideration, psi (MPa)
G	Specific gravity of the contained fluid (1.0 for water)
H	Maximum height of liquid in the tank from the base to the TCL, ft (m)
H_n	Water height measured down from the TCL to the bottom of Shell Ring "n," ft (m)
H_{sh}	Total height of the tank shell, ft (m)
I	Importance factor
J	Earthquake uplift factor at the base of the tank used to determine whether there is uplift during a seismic event
J_n	The value of "J" determined at the bottom of Shell Ring "n" that is a height "z" above the tank base
K	Effective length factor (usually between 0.5 and 2.0) for a column or other compression member
L	Laterally unsupported length of a column or other compression member, in. (mm)
L_u	Maximum unbraced length of a beam compression flange as defined by AISC
M_{EQ}	Earthquake overturning moment at the tank base, ft-lb (N-m)
M_{EQn}	Earthquake overturning moment at the bottom of Shell Ring "n" that is a height of "z" above the tank base, ft-lb (N-m)
M_{RES}	Moment, from tank dead load, resisting overturning at the base of the tank, ft-lb (N-m)
M_w	Wind overturning moment at the tank base, ft-lb (N-m)
M_{wn}	Wind overturning moment at the bottom of Shell Ring "n" that is a height of "z" above the tank base, ft-lb (N-m)

Table 15. Appendix E Nomenclature[1] (cont'd)

Variable	*Definition*
N	Number of foundation bolts resisting shear or tension
P_{aw}	Average wind pressure acting over "h_{max}" (usually equals P_w), psf (kPa)
P_w	Uniform horizontal design wind pressure, psf (kPa)
R	Tank radius, units vary - see text, ft (m) or in. (mm)
R_c	Earthquake force reduction factor for convective action (Allowable Stress Design)
R_i	Earthquake force reduction factor for impulsive (or vertical) action (Allowable Stress Design)
S	Minimum required section modulus of a wind girder, $in.^3$ (mm^3)
SA_c	Earthquake horizontal spectral acceleration for the convective mode, expressed as a fraction of gravitational acceleration (g)
SA_i	Earthquake horizontal spectral acceleration for the impulsive mode, expressed as a fraction of gravitational acceleration (g)
SA_v	Earthquake spectral acceleration for the vertical mode, expressed as a fraction of gravitational acceleration (g)
S_{D1}	Soil-adjusted, 5% damped, design earthquake spectral response acceleration at a period of 1 second, expressed as a fraction of gravitational acceleration (g)
S_{DS}	Soil-adjusted, 5% damped, design earthquake spectral response acceleration at a short (0.2-second) period, expressed as a fraction of gravitational acceleration (g)
T_a	Allowable tension force per foundation anchor (Allowable Stress Design) including the one-third increase if appropriate, lb (N)
T_c	Period of vibration for the convective earthquake mode, seconds
TCL	Top capacity level - the water level defined by the lip of the overflow
T_i	Period of vibration for the impulsive earthquake mode, seconds
T_r	Required design tension force per foundation anchor necessary to resist overturning from wind or earthquake forces, lb (N)
T_s	Control period (= S_{D1}/S_{DS}) of the design earthquake response spectra, seconds
T_v	Period of vibration for the vertical earthquake mode, seconds
V_a	Allowable shear force per foundation anchor (Allowable Stress Design) including the one-third increase if appropriate, lb (N)
V_{EQ}	Design earthquake lateral force at the bottom of the tank (base shear), lb (N)
V_r	Required design shear force per foundation anchor necessary to resist shear forces from wind or earthquake, lb (N)
V_{RES}	Frictional force, between the tank bottom plate and its support, resisting the lateral (horizontal) force from wind or earthquake loads, lb (N)
V_w	Total wind lateral force, lb (N)
W'_D	Total dead (no roof live [or snow] load) weight (mass) at the bottom of the tank from the tank shell plus that portion of the tank roof supported by the shell, lb (kg)
W'_{Dn}	Same as W'_D except calculated at the bottom of Shell Ring "n" that is a height of "z" above the tank base, lb (kg)
d	Diameter of a bolt, in. (mm)
d_a	Actual (provided) freeboard, ft (m)
d_{hn}	Diameter of bolts in the horizontal lap splice at the bottom of Shell Ring "n," in. (mm)
d_{sl}	Calculated required sloshing wave height, ft (m)
d_{vn}	Diameter of bolts in the vertical lap splices of Shell Ring "n," in. (mm)
$d_{vn[hole]}$	Bolt hole diameter in the Shell Ring "n" vertical lap splices, in. (mm) - usually equals d_{vn} + 1/16 in. (1.6 mm)
h	A height as specified in the text - units vary, ft (m) or in. (mm)
h_c	Height, above the tank base, of the convective liquid mass, ft (m)
h'_c	Height of the convective liquid mass for obtaining the convective moment below the base plate for use in design of mat and pile foundations, ft (m)
h_i	Height, above the tank base, of the impulsive liquid mass, ft (m)
h'_i	Height of the impulsive liquid mass for obtaining the impulsive moment below the base plate for use in design of mat and pile foundations, ft (m)

Table 15. Appendix E Nomenclature[1] (cont'd)

Variable	*Definition*
h_{max}	Maximum vertical distance below a wind girder at which another intermediate wind girder must be placed, ft (m)
h_r	Height, above the tank base, to the center of gravity of the tank roof, ft (m)
h_{sh}	Height, above the tank base, to the center of gravity of the tank shell, ft (m)
k_e	Factor representing the portion of provided shear or overturning foundation anchors that are effective (= 0.5 for tanks with no bottom plate and 1.0 for tanks having a bottom plate)
m_b	Dead weight (mass) of the tank bottom plate, lb (kg)
m_c	Weight (mass) of the convective liquid for earthquake design assuming sufficient freeboard, lb (kg)
$m_{c\text{-}IF}$	Modified weight (mass) of the convective liquid for earthquake design when freeboard is insufficient, lb (kg)
m_i	Weight (mass) of the impulsive liquid for earthquake design assuming sufficient freeboard, lb (kg)
$m_{i\text{-}IF}$	Modified weight (mass) of the impulsive liquid for earthquake design when freeboard is insufficient, lb (kg)
m_l	Total weight (mass) of the liquid contained in the tank to the TCL, lb (kg)
m_r	Total weight (mass) of the tank roof (dead load plus the specified percentage of the roof live [or snow] load), lb (kg)
m_{sh}	Total dead weight (mass) of the tank shell, lb (kg)
r	Least radius of gyration of a column or other compression member, in. (mm)
s	Spacing between bolts, units vary - see text, ft (m) or in. (mm)
s_{hn}	Horizontal spacing between bolts in the same row at the horizontal lap splice at the bottom of Shell Ring "n," in. (mm)
s_{vn}	Vertical spacing between bolts in the same row at vertical lap splices in Shell Ring "n," in. (mm)
t	Thickness of a plate or part at a specified location, in. (mm)
t_{av}	Average tank wall thickness over a specified distance, in. (mm)
t_b	Thickness of the tank bottom plate, in. (mm)
t_n	Thickness of Shell Ring "n", in. (mm)
t_s	Thickness of the shell ring at the base of the tank, in. (mm)
w	Width of a specified part, in. (mm)
w_L	Dead weight of water adjacent to the tank shell per length of circumference that is effective for overturning resistance, lb/ft (N/m)
w_t	Dead weight (no roof live [or snow] load) at the bottom of the tank from the tank shell and that portion of the roof supported by the tank shell per length of circumference, lb/ft (N/m)
z	Height, above the tank base, where stress, etc. is being evaluated (typically corresponds to the bottom of Shell Ring "n"), ft (m)
μ_c	Factor for reducing the convective moment with height "z" from the tank base
μ_i	Factor for reducing the impulsive moment with height "z" from the tank base
σ_c	Longitudinal shell compression stress in the ring directly above the point being checked, psi (MPa)

[1]For design of anchor chairs, a different nomenclature is used (see Section E.7.2.3).

E.1 Minimum Suction Tank Accessories and Configuration

The minimum provisions in this section should be satisfied and indicated on the tank drawings.

E.1.1 Suction Tank Accessories and Fittings

Provide the following minimum accessories and fittings, typically fabricated from galvanized steel (see Figure 25):

- A **shell manhole** in the first ring of the tank at least 24 in. (600 mm) diameter if circular or 18 in. x 22 in. (450 mm x 550 mm) if elliptical.
- A **roof vent** covered with corrosion-resistant metal screening, located near the center of the roof and having a screened area at least 1-1/2 times the cross-sectional area of either the fill line or suction line (whichever is larger). This item may be combined with the roof manway. The overflow pipe may not be considered to be a vent.
- A **roof manway** (minimum opening diameter or side dimension of 20 in. [500 mm]) near the center of the roof with a removable cover over a 4 in. (100 mm) curb. This item may be combined with the roof vent.

- A lockable hinged **roof hatch** (minimum opening diameter of 24 in. [600 mm] or dimensions of 15 in. x 24 in. [380 mm x 600 mm]) located near the outside ladder. To prevent water infiltration the cover should overlap a 4 in. (100 mm) curb or a gasket should be provided.
- A minimum 2 in. (50 mm) diameter **fill line** capable of filling the tank in less than 8 hours. Locate the fill line in a different quadrant (at least 90° away) or, alternatively, at least 15 ft (4.6 m) horizontally from nearest point of the suction line intake anti-vortex plate.
- A **suction line** with a steel anti-vortex plate (minimum 0.25 in. [6 mm] thick having a diameter or each plan dimension at least twice the diameter of the suction line) securely attached to the pipe or the tank bottom (see Section 3.6.5 for more information).
- An **overflow pipe** covered with corrosion-resistant metal screening and at least one pipe size larger than the fill line, having a capacity at least equal to the fill line pumping rate. Provide a weir box or other appropriate intake at the inlet.
- An exterior **water level gauge** or a monitored high water/low water electric alarm. Locate the high water alarm not more than 2 in. [50 mm] above the overflow inlet and the low water alarm not more than 12 in. (300 mm) below the overflow inlet.
- An **exterior ladder,** beginning at 8 ft (2.4 m) above the tank bottom, located to provide access to the roof hatch.

Corrosion-resistant metal screening should have either 3/8 in. (10 mm) or ½ in. (12 mm) openings. Very fine mesh, such as an insect screen, should not be used since it is susceptible to blockages that reduce the available vent area. Also note that internal ladders and internal overflow piping are discouraged, and are not allowed in cold weather locations (generally where the lowest one-day mean temperature is 5°F [-15°C] or less).

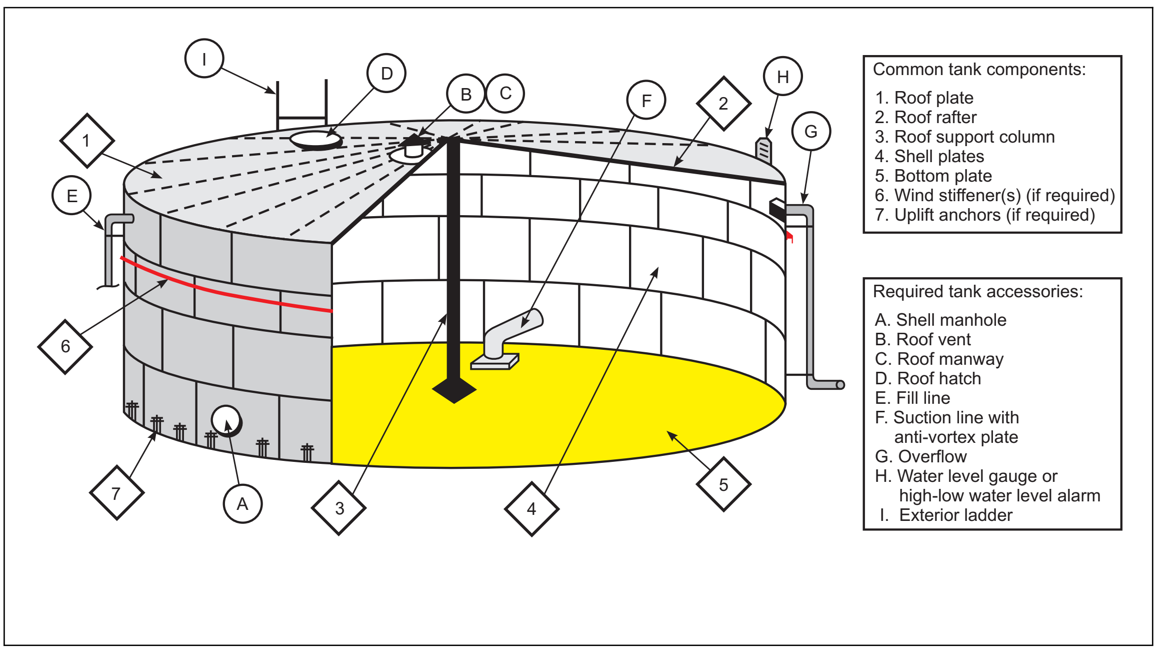

Fig. 25. Steel suction tank components and accessories

E.1.2 Minimum Steel Thicknesses

Provide the following minimum steel thicknesses unless a larger thickness is required based on calculated stresses:

A. Shell plates and bottom plates: 0.25 in. (6.4 mm) for welded tanks, 0.094 in. (2.4 mm) for bolted tanks

B. Flat roof steel plates for roof slopes less than 20 degrees (1:2.75): 0.094 in. (2.4 mm); corrugated roof sheets placed perpendicular to roof beams can be thinner

C. Roof support members: 3/16 in. (5 mm)

E.1.3 Reinforcement of Openings

Reinforce openings in the tank shell that are greater than 4 in. (100 mm) in diameter and subject to hydrostatic pressure in accordance with AWWA D100 or AWWA D103.

E.1.4 Arrangement of Roof Members

Arrange roof members in accordance with the following:

A. Provide minimum freeboard of 2 in. (50 mm) such that roof members and support clips are above the overflow water level and not in contact with the water. For tanks in FM 50-year through 500-year earthquake zones, follow freeboard requirements in Section E.6.1.

B. When roof members are arranged in a radial pattern (supported by interior columns and the tank shell), limit spacing between the members at the tank shell to 6 ft 3 in. (1.9 m).

E.2 Allowable Steel Stresses

E.2.1 General

Base all design stress limits on Allowable Stress Design (ASD) using the published minimum yield stress (F_y) and minimum ultimate tensile stress (F_u) of the steel; do not increase design stresses based on higher F_y or F_u determined from mill test reports.

E.2.2 Roof Members and Supporting Column Stress Limits

Design steel roof members and roof support columns per the American Institute of Steel Construction (AISC) *Steel Construction Manual* and AISC 360 *Specification for Structural Steel Buildings,* using Allowable Stress Design (ASD), or equivalent international codes, with the following additions.

For roof members, limit allowable ASD bending stresses from local codes to the following:

A. The larger of 15,000 psi (103.4 MPa) or $0.4F_y$ when the compression (top) flange of a simply-supported rafter is not laterally supported.

B. The larger of 15,000 psi (103.4 MPa) or $0.6F_y$ when the compression (top) flange of a simply-supported rafter is laterally supported at intervals not exceeding L_u as defined by AISC; do not consider friction between roof plates and the top flange of rafters as lateral support unless otherwise allowed by FM Approvals.

For roof support columns, limit the column slenderness ratio (KL/r) to 175 and limit the allowable ASD axial compression stress (F_a) from local codes to that found in Table 16.

E.2.3 Steel Shell Plate Stress Limits

E.2.3.1 The published minimum yield stress (F_y) of steel used for shell plates should not be less than 27,000 psi (186.2 MPa) nor more than 70,000 psi (483 MPa) unless otherwise allowed by FM Approvals.

E.2.3.2 The tension stress in steel shell plates resulting from hydrostatic and hydrodynamic pressure (causing hoop tension across vertical joints) or overturning from wind or earthquake (causing tension across horizontal joints) should not exceed the ASD allowable tension stress (F_t) given in Table 17 unless otherwise allowed by FM Approvals.

In welded tanks, the allowable stress in tension is, for all Class 1 and Class 2 materials, based on 15,000 psi (103.4 MPa) multiplied by a weld joint efficiency reduction factor found in Table 15 of AWWA D100-11. Do not use a weld joint efficiency reduction factor greater than 0.85 unless allowed by FM Approvals. For bolted tanks, although the actual values should be used, a reasonable first estimate of the bolt diameter to spacing ratio ("d/s" in Table 17) is about 0.2 in vertical splices and about 0.1 in horizontal splices (see Figure 26).

E.2.3.3 The vertical axial compression stress in steel shell plates resulting from gravity loads (i.e., dead load and roof live or snow load), from appropriate combinations of gravity loads with wind overturning, or from

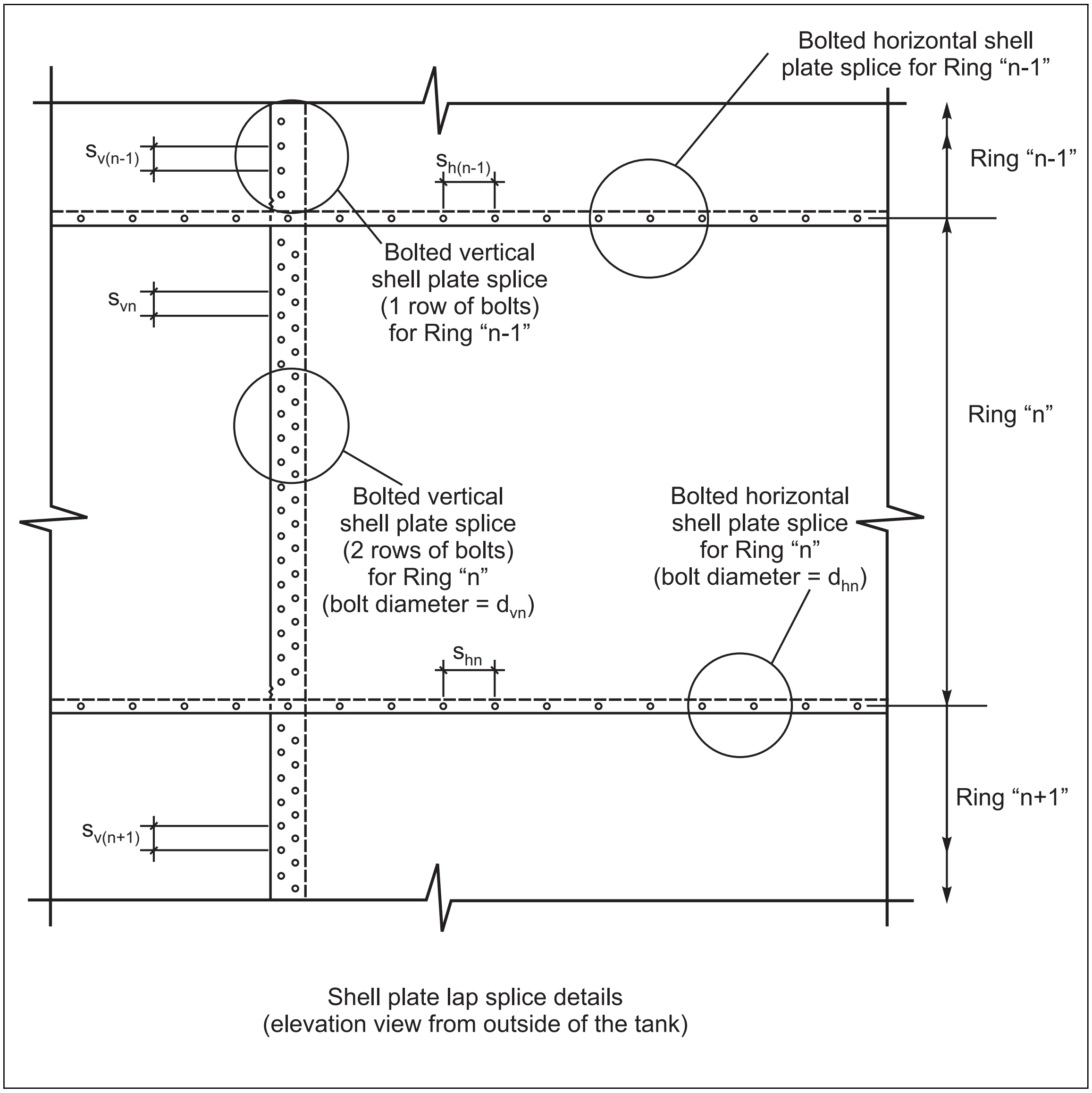

Fig. 26. Shell plate lap splice details (elevation view from outside the tank)

appropriate combinations of gravity loads with overturning and vertical accelerations from earthquake should not exceed the ASD allowable axial compression stress (F_a) given in Table 18 unless otherwise allowed by FM Approvals.

Increasing allowable compression stresses to account for the stabilizing effect of hydrostatic forces on shell buckling is allowed by some codes, but is not allowed in most cases by FM Approvals Standard 4020 (which bases allowable stresses on AWWA D100 or AWWA D103). Hydrostatic stabilization is therefore not included in Table 18.

It is not uncommon, particularly for tanks in earthquake zones, that steel shell plate thicknesses determined using other standards will need to be increased such that vertical compression stresses are below those allowed by FM Approvals Standard 4020.

E.2.4 Uplift Anchorage Stress Limits

Other design requirements related to wind or earthquake uplift anchorage are found in Recommendations 2.2.5.2.6 and 2.2.5.2.7.

E.2.4.1 Embedded Steel Uplift Anchor Bolt Stress Limits

Cast-in-place carbon steel anchors having a bolt head or nut, with or without an additional plate, at their embedded end are the preferred style of uplift anchorage (see Figure 27 and Figure 30), particularly when uplift tension results from earthquake forces. Hooks at the embedded end are not allowed for earthquake uplift anchors.

The maximum allowable tension stress (which already includes the 1/3 seismic or wind increase) is $0.33F_u$ but not more than $0.6F_y$ on the minimum bolt tensile stress area (A_s) at threads, nor, for upset bolts, on the minimum gross bolt area (A_g). Upset bolts have an increased diameter at the threaded portion such that the root diameter at threads is larger than the diameter of the unthreaded portion. For mild steel having F_y = 36,000 psi (248.2 MPa) and F_u = 58,000 psi (400 MPa), the wind or earthquake stress limit (including the 1/3 seismic or wind increase) can be taken as 20,000 psi (137.9 MPa). Bolt tensile stress areas, which are tabulated in various publications, are typically about 4% to 8% larger than the area determined using the minimum root diameter at threads (A_r).

E.2.4.2 Post-Installed Concrete Uplift Anchor Stress Limits

Post-installed concrete anchors (e.g., expansion anchors) are acceptable to resist wind uplift forces, but are not recommended for use as earthquake uplift anchorage. If used to resist earthquake forces they must be qualified for use in seismic zones, be installed with rigorous quality control (see Data Sheet 1-2), and be acceptable to FM Approvals.

The failure capacity in tension of post-installed concrete anchors must be at least four times the calculated ASD tension force in the anchor.

E.2.4.3 Uplift Anchor Strap Stress Limits

Steel anchor straps that are embedded in the concrete foundation and welded to the tank shell can be used to resist wind uplift forces, but are not allowed for use as earthquake uplift anchorage. The tension stress on the minimum cross-sectional area of the strap should not exceed the values given for bolts in Section E.2.4.1.

E.2.4.4 Steel Uplift Anchor Chair Stress Limits

Where uplift results from earthquake forces, use a steel anchor chair (see Figure 27, Figure 30, Figure 31 and Section E.7.2.3) to transfer the earthquake uplift forces from the tank to the foundation bolts. Anchor chairs are preferred, but not required, for transferring wind uplift forces.

Limit steel stresses in bending for the top plate of uplift anchor chairs and for the shell plate near the chairs to 25,000 psi (172.4 MPa) as suggested in the American Iron and Steel Institute (AISI) publication T-192 *Steel Plate Engineering Data*: Volume 2 - Useful Information on the Design of Plate Structures, Part VII Anchor olt Chairs. This value already includes the 1/3 wind or seismic increase.

Fig. 27. Tank uplift anchorage chair

Table 16. ASD Allowable Axial Compression Stress (F_a) in Steel Columns[1]

	Allowable Axial Compression Stress[2] *(F_a)*			
	Where F_y = 36,000 psi (248 MPa)		Where F_y = 50,000 psi (345 MPa)	
KL/r	psi	Mpa	psi	Mpa
5	21,392	147.50	29,656	204.47
10	21,155	145.86	29,256	201.71
15	20,891	144.04	28,803	198.59
20	20,599	142.03	28,300	195.12
25	20,283	139.84	27,749	191.32
30	19,941	137.49	27,153	187.21
35	19,577	134.98	26,513	182.80
40	19,190	132.31	25,832	178.11
45	18,781	129.49	25,111	173.13
50	18,351	126.52	24,351	167.89
55	17,900	123.42	23,553	162.39
60	17,430	120.17	22,717	156.63
65	16,940	116.80	21,846	150.62
70	16,431	113.29	20,938	144.36
75	15,902	109.64	19,993	137.85
80	15,355	105.87	19,012	131.09
85	14,789	101.97	17,994	124.07
90	14,205	97.94	16,938	116.78
95	13,601	93.78	15,842	109.23
100	12,978	89.48	14,706	101.40
105	12,335	85.05	13,527	93.27
110	11,672	80.48	12,341	85.09
115	10,988	75.76	11,292	77.85
120	10,282	70.90	10,370	71.50
125	9,554	65.88	9,557	65.90
130	8,836	60.92	8,836	60.92
135	8,194	56.49	8,194	56.49
140	7,619	52.53	7,619	52.53
145	7,103	48.97	7,103	48.97
150	6,637	45.76	6,637	45.76
155	6,216	42.86	6,216	42.86
160	5,833	40.22	5,833	40.22
165	5,485	37.82	5,485	37.82
170	5,167	35.63	5,167	35.63
175	4,876	33.62	4,876	33.62

[1] This table gives ASD allowable axial compression stresses (F_a) for roof support columns based on the column slenderness ratio, KL/r, where “L” (the laterally unsupported column length) and “r” (the least radius of gyration of the column) are both in the same units. Take the effective length factor “K” as 1.0 unless analysis shows a different value is permitted or required.

[2] The allowable axial compression stresses in the table can be multiplied by 1.333 for those load cases that include forces from wind or earthquake.

Table 17. ASD Allowable Tension Stress (F_t) in Steel Shell Plates[1]

<table>
<tr><th>Tank Type</th><th>Splice Configuration</th><th>Allowable Tension Stress[2] (F_t)</th><th>Comments</th></tr>
<tr><td rowspan="2">Welded</td><td>Complete penetration grooved butt weld</td><td>12,750 psi
(87.9 MPa)</td><td rowspan="2">Allowable F_t applies to all Class 1 (F_y = 27,000 - 34,000 psi [186.2 - 234.4 MPa]) and Class 2 (F_y > 34,000 psi [> 234.4 MPa]) steels.</td></tr>
<tr><td>Lap joint with full-thickness continuous fillet welds on each edge of the joint</td><td>11,250 psi
(77.6 MPa)</td></tr>
<tr><td rowspan="3">Bolted</td><td>One row of bolts</td><td>$(0.06 + 1.8[d/s])F_y$
but $\leq 0.4F_u$</td><td rowspan="3">The bolt diameter (d, in. or mm) and spacing (s, in. or mm) are d_{vn} and s_{vn} for hoop tension across vertical joints in Shell Ring “n” and d_{hn} and s_{hn} for overturning tension across horizontal joints at the bottom of Shell Ring “n” (see Figure 26).</td></tr>
<tr><td>Two rows of bolts</td><td>$(0.33 + 0.9[d/s])F_y$
but $\leq 0.4F_u$</td></tr>
<tr><td>Three rows of bolts</td><td>$(0.42 + 0.6[d/s])F_y$
but $\leq 0.4F_u$</td></tr>
</table>

[1] This table is applicable to steel cylindrical suction tanks and is based on AWWA D100 (welded tanks) and AWWA D103 (bolted tanks) using conditions that commonly occur in suction tanks. See the AWWA documents for more information.

[2] The ASD allowable tension stresses in the table can be multiplied by 1.333 when the load case includes forces from wind or earthquake.

Table 18-US. ASD Allowable Vertical Axial Compression Stress (F_a) in Steel Shell Plates[1] (U.S. Customary Units)

t/R	*Allowable Axial Compression Stress[2], F_a, (psi)*			*t/R*	*Allowable Axial Compression Stress[2], F_a, (psi)*		
	Bolted Tank	Welded Tank			Bolted Tank	Welded Tank	
		Class 1 Steel[3]	Class 2 Steel[3]			Class 1 Steel[3]	Class 2 Steel[3]
0.0001	199	175	175	0.0033	5,874	8,210	8,919
0.0002	397	351	351	0.0034	6,029	8,284	9,389
0.0003	594	527	527	0.0035	6,183	8,358	9,877
0.0004	789	706	706	0.0036	6,336	8,432	10,115
0.0005	983	886	886	0.0037	6,487	8,506	10,203
0.0006	1,176	1,069	1,069	0.0038	6,637	8,579	10,292
0.0007	1,367	1,255	1,255	0.0039	6,786	8,653	10,380
0.0008	1,557	1,445	1,445	0.0040 to 0.0123	Bolted Tank: $2.0\ (10)^6\ ([t/R] - 33.33\ [t/R]^2)$ Welded Tank, Class 1 Steel[3]: $5{,}775 + 738\ (10)^3\ (t/R)$ Welded Tank, Class 2 Steel3: $6{,}925 + 886\ (10)^3\ (t/R)$		
0.0009	1,746	1,639	1,639				
0.0010	1,933	1,838	1,838				
0.0011	2,119	2,041	2,041				
0.0012	2,304	2,251	2,251				
0.0013	2,487	2,467	2,467				
0.0014	2,669	2,690	2,690				
0.0015	2,850	2,920	2,920				
0.0016	3,029	3,158	3,158				
0.0017	3,207	3,405	3,405				
0.0018	3,384	3,660	3,660				
0.0019	3,559	3,925	3,925				
0.0020	3,733	4,200	4,200	0.0124	14,549	14,926	17,911
0.0021	3,906	4,485	4,485	0.0125	14,583	15,000	18,000
0.0022	4,077	4,782	4,782	0.0126	14,616		
0.0023	4,247	5,090	5,090	0.0127	14,647		
0.0024	4,416	5,410	5,410	0.0128	14,677		
0.0025	4,583	5,742	5,742	0.0129	14,706		
0.0026	4,749	6,088	6,088	0.0130	14,733		
0.0027	4,914	6,447	6,447	0.0131	14,759		
0.0028	5,077	6,821	6,821	0.0132	14,784		
0.0029	5,239	7,209	7,209	0.0133	14,807		
0.0030	5,400	7,612	7,612	0.0134	14,829		
0.0031	5,559	8,032	8,032	0.0135	14,850		
0.0032	5,717	8,137	8,467	>0.0135	15,000	15,000	18,000

[1] ASD allowable axial compression stresses (F_a) in the vertical direction for cylindrical steel tank shell plates are based on AWWA D100 (welded tanks) and AWWA D103 (bolted tanks) and the tank t/R (shell thickness to tank radius) ratio, where “t” and “R” are both in the same units. Equations are given for most t/R ratios above 0.004 since these t/R ratios are less common.

[2] The allowable axial compression stresses in the table can be multiplied by 1.333 when the load case includes forces from wind or earthquake.

[3] The published minimum yield stress (F_y) for Class 1 steel is 27,000-34,000 psi and for Class 2 is greater than 34,000 psi.

Table 18-SI. ASD Allowable Vertical Axial Compression Stress (F_a) in Steel Shell Plates[1] (SI Units)

t/R	*Allowable Axial Compression Stress[2], F_a, (MPa)*			*t/R*	*Allowable Axial Compression Stress[2], F_a, (MPa)*		
	Bolted Tank	Welded Tank			Bolted Tank	Welded Tank	
		Class 1 Steel[3]	Class 2 Steel[3]			Class 1 Steel[3]	Class 2 Steel[3]
0.0001	1.37	1.21	1.21	0.0033	40.50	56.61	61.50
0.0002	2.74	2.42	2.42	0.0034	41.57	57.12	64.74
0.0003	4.10	3.64	3.64	0.0035	42.63	57.63	68.10
0.0004	5.44	4.86	4.86	0.0036	43.69	58.14	69.74
0.0005	6.78	6.11	6.11	0.0037	44.73	58.64	70.35
0.0006	8.11	7.37	7.37	0.0038	45.76	59.15	70.96
0.0007	9.43	8.65	8.65	0.0039	46.79	59.66	71.57
0.0008	10.74	9.96	9.96	0.0040 to 0.0123	Bolted Tank: 13790 ([t/R] - 33.33 $[t/R]^2$) Welded Tank, Class 1 Steel[3]: 39.82 + 5088 (t/R) Welded Tank, Class 2 Steel[3]: 47.75 + 6109 (t/R)		
0.0009	12.04	11.30	11.30				
0.0010	13.33	12.67	12.67				
0.0011	14.61	14.08	14.08				
0.0012	15.89	15.52	15.52				
0.0013	17.15	17.01	17.01				
0.0014	18.40	18.55	18.55				
0.0015	19.65	20.13	20.13				
0.0016	20.89	21.78	21.78				
0.0017	22.11	23.48	23.48				
0.0018	23.33	25.24	25.24				
0.0019	24.54	27.06	27.06				
0.0020	25.74	28.96	28.96	0.0124	100.31	102.91	123.50
0.0021	26.93	30.93	30.93	0.0125	100.55	103.42	124.11
0.0022	28.11	32.97	32.97	0.0126	100.77		
0.0023	29.28	35.09	35.09	0.0127	100.99		
0.0024	30.45	37.30	37.30	0.0128	101.20		
0.0025	31.60	39.59	39.59	0.0129	101.39		
0.0026	32.75	41.97	41.97	0.0130	101.58		
0.0027	33.88	44.45	44.45	0.0131	101.76		
0.0028	35.01	47.03	47.03	0.0132	101.93		
0.0029	36.12	49.70	49.70	0.0133	102.09		
0.0030	37.23	52.49	52.49	0.0134	102.25		
0.0031	38.33	55.38	55.38	0.0135	102.39		
0.0032	39.42	56.10	58.38	>0.0135	103.42	103.42	124.11

[1] ASD allowable axial compression stresses (F_a) in the vertical direction for cylindrical steel tank shell plates are based on AWWA D100 (welded tanks) and AWWA D103 (bolted tanks) and the tank t/R (shell thickness to tank radius) ratio, where “t” and “R” are both in the same units. Equations are given for most t/R ratios above 0.004 since these t/R ratios are less common.

[2] The allowable axial compression stresses in the table can be multiplied by 1.333 when the load case includes forces from wind or earthquake.

[3] The published minimum yield stress (Fy) for Class 1 steel is 186.2-234.4 MPa and for Class 2 is greater than 234.4 MPa.

E.3 Tank Roof and Shell Design for Gravity Forces

Design the tank to resist dead loads (see Recommendation 2.2.3.2) plus roof live (or snow) loads (see Recommendation 2.2.3.4). Allowable stresses are found in Section E.2.2 for roof members and supporting columns, and in Section E.2.3.3 for tank shell plates.

Shell axial compression from vertical gravity loads alone is not likely to control the required shell thickness. For the common condition where the roof is comprised of radial beams (i.e., like the spokes in a wheel) supported at the interior by one column at the center of the tank and at the perimeter by the tank shell, the roof load on the shell may be estimated as 2/3 of the total dead weight of the roof plate plus 1/2 of the total dead weight of the roof radial members plus 2/3 of the total roof live (or snow) load.

E.4 Tank Shell Design for Hydrostatic and Hydrodynamic Forces

Determine the required thicknesses of steel shell plates needed to resist hoop tension caused by pressure of the tank contents per the requirements in this section. Base the thickness of each shell ring on the hydrostatic (and hydrodynamic, where applicable) pressure at the bottom of the shell ring being designed (i.e., the hydrostatic and hydrodynamic pressures at the bottom of the shell ring are assumed to act undiminished on the entire shell ring above).

E.4.1 Hydrostatic Hoop Tension Forces

Welded Tanks. For welded tanks, the required shell plate thickness of Ring "n" to resist hydrostatic forces can be determined from:

U.S. Customary Units

$$t_n = \frac{2.6(H_n)(D)(G)}{F_{tn}}$$

SI Units

$$t_n = \frac{4.9(H_n)(D)(G)}{F_{tn}}$$

See Table 15 for the definition and units of the variables in the equations above. For this section, note the following:

A. H_n is the water height measured down from the TCL to the bottom of Shell Ring "n" (at the tank base, H_n equals the maximum height of the water in the tank [H]).

B. F_{tn} is the normal allowable tension stress for gravity loads (no 1/3 increase) for a welded tank, including the joint efficiency reduction factor, for Shell Ring "n" (see Section E.2.3.2).

Bolted Tanks. For bolted tanks, the required shell plate thickness of Ring "n" to resist hydrostatic forces can be determined from:

U.S. Customary Units

$$t_n = \left[\frac{2.6(H_n)(D)(G)}{F_{tn}}\right]\left[\frac{(s_{vn})}{(s_{vn} - d_{vn[hole]})}\right]$$

SI Units

$$t_n = \left[\frac{4.9(H_n)(D)(G)}{F_{tn}}\right]\left[\frac{(s_{vn})}{(s_{vn} - d_{vn[hole]})}\right]$$

See Table 15 for the definition and units of the variables in the equations above and Figure 26 for lap splice details. For this section, note the following:

A. H_n is the water height measured down from the TCL to the bottom of Shell Ring "n" (at the tank base, H_n equals the maximum height of the water in the tank [H]).

B. F_{tn} is the normal allowable tension stress for gravity loads (no 1/3 increase) for a bolted tank for Shell Ring "n" (see Section E.2.3.2).

E.4.2 Hydrodynamic Hoop Tension Forces

For tanks located in FM 50 through 500-year earthquake zones where a site-specific S_{DS} greater than 1.4g (unanchored tank) or 1.6g (anchored tank) is being used, increase the shell thicknesses required for hydrostatic pressure (found in Section E.4.1) by multiplying these by the following factor to account for hydrodynamic fluid pressures:

$$\left[0.75 + \left(\frac{0.625}{R_i}\right)S_{DS}\right] \qquad \text{(must be greater than 1.0)}$$

See Table 15 for the definition and units of the variables in the equation above. Note that R_i equals 3.5 for an unanchored tank or 4.0 for an anchored tank (see Table 21).

E.5 Tank Design for Wind Forces

E.5.1 Tank Wind Anchorage

Determine if shear or overturning anchorage at the base of the tank is needed to resist lateral wind forces in accordance with this section.

E.5.1.1 Using the uniform lateral (horizontal) wind pressure (P_w) per Recommendation 2.2.3.5.3, determine the total lateral force (V_w) from wind pressure on the tank as follows:

U.S. Customary Units

$$V_w = (P_w)(D)(H_{sh})$$

SI Units

$$V_w = 1000\,(P_w)(D)(H_{sh})$$

See Table 15 for the definition and units of the variables in the equations above.

E.5.1.2 Determine the frictional force between the tank's steel bottom plate and the supporting ground or concrete mat resisting wind lateral forces (V_{RES}), using only the dead weight of the tank, as follows:

A. When a bottom plate does not exist, $V_{RES} = 0$.

B. When a bottom plate exists:

U.S. Customary Units

$$V_{RES} = \tan 20° \,(m_r + m_{sh} + m_b)$$

SI Units

$$V_{RES} = 9.8 \tan 20° \,(m_r + m_{sh} + m_b)$$

See Table 15 for the definition and units of the variables in the equations above. For this section, note that no roof live (or snow) load should be included when calculating m_r.

E.5.1.3 Provide shear anchorage at the base of the tank when the lateral force from the wind (V_w) exceeds the resisting frictional force (V_{RES}). When shear anchorage is needed, the required ASD shear force (V_r) per anchor is determined using the following formula:

$$V_r = \left[\frac{V_w - V_{RES}}{k_e N}\right]$$

See Table 15 for the definition and units of the variables in the equation above. For this section, note the following:

A. The number of foundation anchors (N) should only include those anchors effective for resisting shear.

B. When the tank does not have a steel bottom plate use $k_e = 0.5$ (i.e., half of the bolts are effective), when a steel bottom plate exists use $k_e = 1.0$ (i.e., all bolts are effective). See Sections 3.1.3.6.1 and E.7 for a discussion of tank anchorage.

E.5.1.4 Determine the overturning moment from wind pressure (M_w) at the tank base assuming the total lateral force from wind pressure (V_w) is applied at the mid-height of the shell:

$$M_w = 0.5\,(H_{sh})(V_w)$$

Which can also be expressed as:

U.S. Customary Units

$$M_w = 0.5D(H_{sh})^2 P_w$$

SI Units

$$M_w = 0.5D(H_{sh})^2(1000P_w)$$

See Table 15 for the definition and units of the variables in the equation above.

E.5.1.5 Determine the moment resisting wind overturning at the tank base (M_{RES}) assuming the dead weight (W'_D) of the tank shell plus that portion of the roof dead weight supported by the tank shell is applied at the center of the tank:

See Table 15 for the definition and units of the variables in the equations above.

U.S. Customary Units

$$M_{RES} = \left(\frac{D}{2}\right)(W'_D)$$

SI Units

$$M_{RES} = 9.8\left(\frac{D}{2}\right)(W'_D)$$

E.5.1.6 Provide overturning anchorage when the moment resisting wind overturning (M_{RES}) is less than 1.5 times the overturning moment from wind (M_w). When overturning anchorage is needed, the required ASD tensile force (T_r) per anchor is determined using the following formula:

U.S. Customary Units

$$T_r = \frac{4M_w}{k_e N D} - \frac{W'_D}{k_e N}$$

SI Units

$$T_r = \frac{4M_w}{k_e N D} - \frac{9.8W'_D}{k_e N}$$

See Table 15 for the definition and units of the variables in the equation above. For this section note the following:

A. The number of foundation anchors (N) should only include those anchors effective for resisting overturning.

B. When the tank does not have a steel bottom plate use k_e = 0.5 (i.e., half of the bolts are effective); when a steel bottom plate exists use k_e = 1.0 (i.e., all bolts are effective). See Sections 3.1.3.6.1 and E.7 for a discussion of tank anchorage.

E.5.2 Tank Shell Wind Compression Stresses

Determine the adequacy of the tank shell, at its base and where the tank shell thickness changes, to resist combined vertical axial compression stresses from dead loads plus wind overturning forces in accordance with this section.

E.5.2.1 Determine the minimum steel thickness of each tank shell ring such that the vertical compression stress (σ_c) at the bottom of the ring from dead and wind loads is less than the ASD allowable vertical compression stress (F_a) based on the shell thickness to tank radius ratio (t/R) and Table 18, including the 1.333 wind increase factor, for that ring.

E.5.2.2 At the base of the tank, calculate the vertical (longitudinal) compression stress (σ_c) from combined dead and wind load as follows:

U.S. Customary Units

$$\sigma_c = \left(\frac{W'_D}{\pi D} + \frac{1.273M_w}{D^2}\right)\left(\frac{1}{12t_s}\right)$$

SI Units

$$\sigma_c = \left(\frac{9.8W'_D}{\pi D} + \frac{1.273M_w}{D^2}\right)\left(\frac{1}{1000t_s}\right)$$

See Table 15 for the definition and units of the variables in the equations above.

E.5.2.3 For rings higher in the shell, where either the thickness or steel yield stress (F_y) change, calculate the vertical (longitudinal) axial compression stress (σ_c) from combined dead and wind load using the equations in Section E.5.2.2 but replacing the values of W'_D and M_w by the values of W'_{Dn} and M_{wn} at the bottom of

Shell Ring "n" (the shell ring being checked) and the value of t_s by the actual thickness (t_n) of Shell Ring "n." The wind overturning moment at the bottom of shell ring "n" that is a distance "z" above the tank base is given by:

U.S. Customary Units

$M_{wn} = 0.5D(H_{sh} - z)^2 P_w$

SI Units

$M_{wn} = 0.5D(H_{sh} - z)^2(1000P_w)$

See Table 15 for the definition and units of the variables in the equations above.

E.5.3 Tank Shell Wind Girders (Stiffeners)

Determine the need for shell wind girders (stiffeners) using the requirements of this section.

Wind girders, when needed, can be many different shapes (e.g., a steel angle, a steel channel) meeting width/thickness (w/t) ratio provisions of steel design codes. In general, for elements held along one edge (e.g., an angle leg, the flange of a channel or Z-shaped member, the stem of a T-shaped member, each half of the flange of an I-shaped or T-shaped member) as long as the width of the element is less than 16 times its thickness the w/t ratio is adequate.

In many cases it will be obvious that intermediate stiffeners are not required. For example, a cylindrical tank with a 40 ft (12.2 m) diameter and an average uniform horizontal wind pressure (P_{aw}) of 18 psf (0.862 kPa) could be nearly 73 ft (22.2 m) tall and not need intermediate wind girders if the shell plate is at least 0.25 in. (6.4 mm) thick. However, if the shell plate was the minimum thickness allowed for bolted tanks (0.094 in. [2.4 mm] thick), a wind girder would be required at only 6.3 ft (1.9 m) below the roof.

E.5.3.1. When tank roof members are positively attached to the shell at a spacing not exceeding 6 ft 3 in. (1.9 m), a wind girder at the top of the tank is not needed. When this spacing is exceeded, provide a wind girder per Section E.5.3.3 unless an engineering analysis shows the tank shell is adequate without one.

E.5.3.2 When the tank shell height (H_{sh}) is greater than the calculated value of the maximum wind girder spacing (h_{max}) from the appropriate equation below, either thicken the tank shell or provide one or more intermediate shell wind girders, with spacing not exceeding h_{max} , per Section E.5.3.3.

U.S. Customary Units

$$h_{max} = \frac{(10.625x10^6)(t_{av})}{(P_{aw})\left(\frac{D}{t_{av}}\right)^{1.5}}$$

SI Units

$$h_{max} = \frac{(8.025)(t_{av})}{(P_{aw})\left(\frac{D}{t_{av}}\right)^{1.5}}$$

See Table 15 for the definition and units of the variables in the equations above. For this section note the following:

A. t_{av} is the average tank wall thickness within the distance h_{max}

B. P_{aw} is the average wind pressure acting over "h_{max}" and usually equals P_w as defined in Recommendation 2.2.3.5.3. Use a minimum P_{aw} of 18 psf (0.862 kPa).

E.5.3.3 When a top or intermediate wind girder (stiffener) is required, the minimum section modulus is determined by the appropriate formula below:

U.S. Customary Units

$$S = 0.0001hD^2\left(\frac{P_{aw}}{18}\right)$$

SI Units

$$S = 67.13hD^2(P_{aw})$$

See Table 15 for the definition and units of the variables in the equations above. For this section note the following:

A. The minimum required section modulus of the wind girder, (S) can be determined including a portion of the tank shell for a distance of the lesser of 16t or $0.78\sqrt{Rt}$ below and, if applicable, above the wind girder.

B. t = tank wall thickness at the girder attachment location, in. (mm).

C. R = tank radius, in. (mm).

D. h = height of the shell being considered, ft (m). For a top girder "h" is the full shell height (H_{sh}). For an intermediate girder, "h" equals the distance from the girder being sized to the next girder below (or, in the case of the lowest wind girder, to the tank base), and "h" cannot be greater than h_{max} from Section E.5.3.2

E.6 Tank Design for Earthquake Forces

Design tanks located in FM 50 through 500-year zones for earthquake forces based on FM Approvals Standard 4020, major aspects of which are outlined in this section.

E.6.1 Determining Earthquake Forces

The information below summarizes some of the key points of the FM Approvals Standard 4020 method for determining earthquake forces for steel flat-bottom ground-supported cylindrical suction tanks.

A. Determine basic design parameters based on the tank location and configuration, including:

1. From Table 19, values of the short period acceleration (S_{DS}), the one-second acceleration (S_{D1}) and the period $T_s = S_{D1}/S_{DS}$ for the FM earthquake zone in which the tank will be located. Site-specific values may be used as allowed in FM Approvals Standard 4020 and Data Sheet 1-2.

2. From Table 20 and based on the tank H/R (maximum liquid height [H] to tank radius [R], where both are in the same units) ratio, find the ratios and values (variables are defined in Table 15) needed for determining earthquake forces (m_i/m_l, m_c/m_l, C_c, and, if needed, C_i, and C_v) and earthquake overturning moments (h_i/H, h_c/H, h'_i/H, h'_c/H). Interpolate when the actual H/R ratio is between H/R ratios given in the table. Note, the ratios h'_i/H, h'_c/H are only needed for design of concrete slab/mat foundations, which will not be covered in this appendix (see the FM Approvals standard for more information).

3. From Table 21, values of the ASD impulsive/vertical force reduction factor (R_i), the ASD convective force reduction factor (R_c) and earthquake importance factor (I).

B. Based on the tank properties, determine the natural period of vibration, in seconds, for the horizontal convective mode (T_c) using the following equations:

U.S. Customary Units

$$T_c = C_c\sqrt{0.5D}$$

SI Units

$$T_c = 1.811C_c\sqrt{0.5D}$$

See Table 15 for the definition and units of the variables in the equations above. Note that the SI unit equation above has been adjusted so that the same value of C_c from Table 20 can be used for both U.S. Customary units and SI units.

For most ground-supported cylindrical steel suction tanks, calculating the periods of vibration for the impulsive (T_i) and vertical (T_v) modes is not necessary since they will typically be less than the period defined as $T_s = S_{D1}/S_{DS}$. This assumption will be used in this appendix. If exact values for T_i and T_v are needed, see FM Approval Standard 4020.

C. Find, from Table 22 or Figure 28, the horizontal impulsive spectral acceleration (SA_i), horizontal convective spectral acceleration (SA_c) and vertical spectral acceleration (SA_v), as a portion of gravity, based on the natural periods of vibration T_i, T_c and T_v (in seconds), respectively. For steel flat-bottom ground-supported suction tanks, it is conservative, and generally reasonable, to omit calculations for SA_i and SA_v and simply assume them to equal S_{DS} and $0.667S_{DS}$, respectively.

D. Calculate individual dead weights (U.S. Customary units) or masses (SI units) and the distances from the tank base to their centers of mass for the tank roof (both the dead load and the portion of the roof live [snow] load to be used in the analysis), for the tank shell, for the tank bottom plate and for the impulsive and convective fluid. Note that for U.S. Customary units the weights are in pounds while in SI units the masses are in kilograms. Any roof live (or snow) loads included in the earthquake analysis must be converted, for SI units, from kPa to kg/m^2 by multiplying by a factor of (1000/9.8) and then multiplying this by the roof area (m^2).

Because earthquake base shear and overturning moment are dominated by the contained water, it is not necessary to be overly precise in determining the distance from the tank base to the centers of mass of the tank elements. Assuming distances from the tank base equal to the tank shell height (for the roof mass) and equal to half the shell height (for the shell mass) is usually reasonable. For impulsive and convective weights (masses) and distances above the tank base to their centers of mass, the ratios m_i/m_l, m_c/m_l, h_i/H, and h_c/H from Table 20 are used.

When the actual provided freeboard, d_a (ft or m), is less than the expected sloshing wave height $d_{sl} = 0.5{*}D{*}SA_c$ (where "d_{sl}" and the tank diameter [D] are in the same units of length [ft or m]), the roof constrains the liquid and causes a portion of the convective liquid to act as an impulsive liquid. Lack of sufficient freeboard can result in significantly larger horizontal earthquake forces and overturning moments on the tank, since the impulsive acceleration is much higher than the convective acceleration.

When the actual provided freeboard, d_a (ft or m) is less than the required freeboard, d_{sl} (ft or m) increase the impulsive fluid weight and decrease the convective fluid weight, and design the roof to resist the uplift forces. The impulsive and convective water weights must be revised as follows:

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

$$m_{c\text{-}IF} = m_l - m_{i\text{-}IF}$$

See Table 15 for the definition and units of the variables in the equations above.

E. Analyze the tank for earthquake forces per Sections E.6.2 and E.6.3. Equations for the base shear (V_{EQ}) and overturning moment (M_{EQ}) use horizontal ASD design forces found by multiplying: 1) the tank weight and the impulsive fluid weight by the Table 21 impulsive ASD design acceleration, and 2) the convective fluid weight by the Table 21 convective ASD design acceleration. The impulsive and convective components of the base shear and overturning moment are combined by the square root sum of the squares (SRSS) method. Vertical ASD forces are found by multiplying the total tank weight and/or the fluid weight by the Table 21 vertical ASD design acceleration.

Table 19. Seismic Design Parameters S_{DS}, S_{D1} and T_s Based on FM Earthquake Zone[1]

FM Earthquake Zone	*S_{DS} (g)*	*S_{D1} (g)*	*T_s (sec)*
50-year	1.3 g	0.8 g	0.615
100-year	0.9 g	0.45 g	0.5
250-/500-year	0.55 g	0.25 g	0.455

[1] See Table 15 for the definition of variables in the table.

Table 20. Ground-Supported Flat-Bottom Suction Tank Earthquake Design Values as a Function of Tank H/R Ratios[1]

See Note 2			See Note 3			See Note 2			
H/R	m_i/m_l	m_c/m_l	C_i	C_c	C_v	h_i/H	h_c/H	h'_i/H	h'_c/H
0.3	0.176	0.824	9.28	1.153	9.83	0.4	0.521	2.64	3.414
0.5	0.3	0.7	7.74	0.959	7.91	0.4	0.543	1.46	1.517
0.7	0.414	0.586	6.97	0.881	7.04	0.401	0.571	1.009	1.011
1	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	0.82	6.03	0.439	0.69	0.555	0.734
2	0.763	0.237	6.21	0.817	5.87	0.448	0.751	0.5	0.764
2.5	0.81	0.19	6.56	0.817	5.8	0.452	0.794	0.48	0.796
3	0.842	0.158	7.03	0.817	5.75	0.453	0.825	0.472	0.825

[1] Values in this table are the same as those in FM Approvals Standard 4020. See Table 15 for the definition of variables in the table.

[2] These ratios are applicable to both U.S. Customary and SI units. Also note that H, R, h_i, h_c, h'_i and h'_c have the units of ft (m); and m_i, m_c and m_l have the units of lb (kg).

[3] Values in the table for C_i, C_c, and C_v are for U.S. Customary units. However, any SI unit equations in the Appendix E text using these parameters have been adjusted so that the same C_i, C_c, and C_v values from this table can be used.

Table 21. Allowable Stress Design (ASD) Force Reduction and Importance Factors

Item	*Force Direction and Mode*		
	Horizontal		Vertical
	Impulsive	Convective	
ASD force reduction factors R_i (impulsive and vertical modes) and R_c (convective mode)	R_i = 3.5 (unanchored tank) R_i = 4.0 (anchored tank)	R_c = 2.0	Same as horizontal impulsive mode
Earthquake Importance Factor (I)	1.25		
ASD Design Acceleration[1]	$\frac{SA_i}{\left(\frac{R_i}{I}\right)}$	$\frac{SA_c}{\left(\frac{R_c}{I}\right)}$	$\frac{SA_v}{\left(\frac{R_i}{I}\right)}$

[1]For values of SA_i, SA_c and SA_v see Table 22 or Figure 28.

Table 22. Spectral Accelerations SA_i, SA_c, and SA_v as a Function of Natural Period of Vibration[1,2,3]

Value of Natural Period of Vibration (T), seconds	*SA_i (at $T = T_i$), g*	*SA_c (at $T = Tc$), g*	*SA_v (at $T = T_v$), g*
$T < T_s$	S_{DS}	1.5* (S_{DS})	2/3* (S_{DS})
$T_s \le T \le 4$ sec	(S_{D1}/T_i)	1.5* (S_{D1}/T_c)	2/3* (S_{D1}/T_v)
T > 4 sec	($4S_{D1}/T_i^2$)	1.5* ($4S_{D1}/T_c^2$)	2/3* ($4S_{D1}/T_v^2$)

1 The natural period of vibration (T) in the first column represents the appropriate natural period of vibration for the spectral acceleration being determined (i.e., T_i for impulsive, T_c for convective or T_v for vertical)

[2] The response spectra for SA_c and SA_v are 1.5 times and 2/3 times the response spectrum for SA_i, respectively.

[3] For values of S_{DS}, S_{D1}, and T_s see Table 19.

E.6.2 Designing for Earthquake Shear at the Tank Base

E.6.2.1 Tank Earthquake Lateral Force

Determine the total earthquake lateral force (V_{EQ}) at the base of the tank as follows:

See Table 15 for the definition and units of the variables in the equations above. For this section note that:

A. The earthquake base shear (V_{EQ}) has a factor of safety of 1.1.

B. If freeboard is insufficient use the modified weights (masses) of the impulsive liquid ($m_{i\text{-}IF}$) and the convective liquid ($m_{c\text{-}IF}$) instead of m_i and m_c (which assume sufficient freeboard).

C. For these equations m_r should include the total roof dead load plus 25% of the total roof live (or snow) load - for SI units, convert the live or snow loads given in kPa to kg/m^2 by multiplying by a factor of (1000/9.8) and then multiplying this by the roof area (m^2).

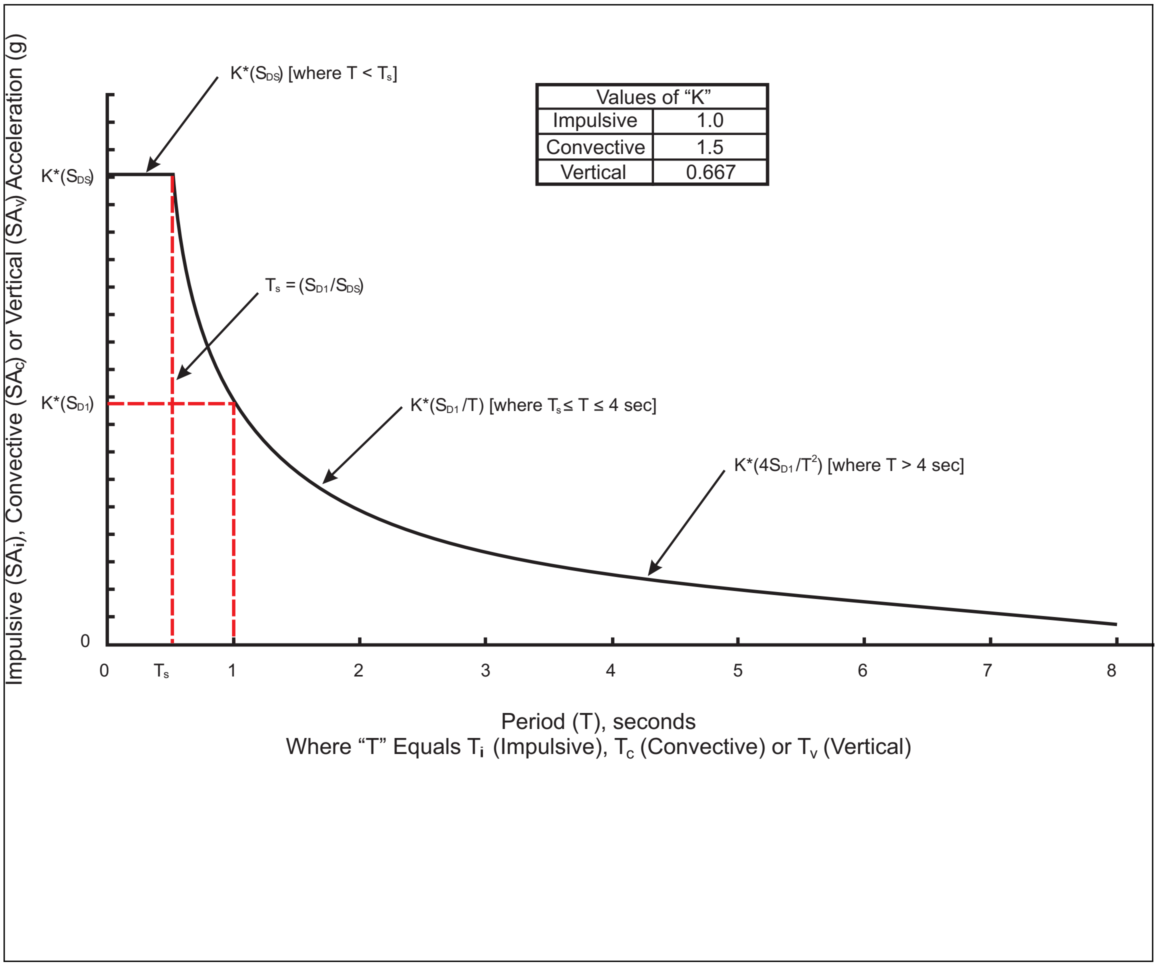

Fig. 28. Graph of spectral accelerations SA_i, SA_c, and SA_v vs. natural periods of vibration T_i, T_c, and T_v

$$V_{EQ} = 1.1\ x\ \sqrt{\left\{\frac{(m_i + m_{sh} + m_r + m_b)\ x\ SA_i}{R_i/I}\right\}^2 + \left\{\frac{(m_c\ x\ SA_c)}{R_c/I}\right\}^2} \quad (U.S. Customary\ Units)$$

$$V_{EQ} = 9.8\ x\ 1.1\ x\ \sqrt{\left\{\frac{(m_i + m_{sh} + m_r + m_b)\ x\ SA_i}{R_i/I}\right\}^2 + \left\{\frac{(m_c\ x\ SA_c)}{R_c/I}\right\}^2} \quad (SI\ Units)$$

D. If checking to see if anchorage is needed, use the R_i value assuming the tank is unanchored.

E.6.2.2 Tank Earthquake Shear Anchorage

Determine if shear anchorage at the base of the tank is needed to resist earthquake forces in accordance with this section.

E.6.2.2.1 Determine the frictional force between the tank's steel bottom plate and the supporting ground or concrete mat resisting earthquake lateral forces (V_{RES}), using the dead weight of the tank and contained water, but no roof live load, as follows:

A. When a bottom plate does not exist, V_{RES} = 0 (in addition, a mat foundation must be used).

B. When a bottom plate exists:

V_{RES} = tan 20° (m_r + m_{sh} + m_b + m_i + m_c) (1.0 - [0.4 x SA_v]) U.S.Customary Units

V_{RES} = 9.8 x tan 20° (m_r + m_{sh} + m_b + m_i + m_c) (1.0 - [0.4 x SA_v]) SI Units

See Table 15 for the definition and units of the variables in the equations above. Note that V_{EQ} is calculated including 25% of the total roof live (or snow) load but when calculating V_{RES}, no roof live (or snow) load should be included.

E.6.2.2.2 Provide shear anchorage at the base of the tank when the lateral force from the earthquake (V_{EQ}) exceeds the resisting frictional force (V_{RES}). When shear anchorage is needed, the required ASD shear force (V_r) per anchor is determined using the following formula:

$$V_r = \left[\frac{V_{EQ} - V_{RES}}{k_e N}\right] \quad \text{(U.S. customary or SI units)}$$

See Table 15 for the definition and units of the variables in the equation above. For this section, note the following:

A. The number of foundation anchors (N) should only include those anchors effective for resisting shear.

B. When the tank does not have a steel bottom plate use k_e = 0.5 (i.e., half of the bolts are effective); when a steel bottom plate exists use k_e = 1.0 (i.e., all bolts are effective). See Sections 3.1.3.6.1 and E.7 for a discussion of tank anchorage.

E.6.3 Designing for Earthquake Overturning Moment

The overturning equations at the tank base in this section are used to design overturning anchorage and ring wall foundations. Tank shell tension and compression stresses are checked at the tank base and upper shell. Where mat or pile foundations are used, they are designed for a larger moment (determined using h'_i and h'_c) - see FM Approvals Standard 4020.

E.6.3.1 Tank Earthquake Overturning Moment at the Tank Base

Determine the earthquake overturning moment (M_{EQ}) at the base of the tank as follows:

$$M_{EQ} = \sqrt{\left\{\frac{[(m_i \ x \ h_i) + (m_{sh} \ x \ h_{sh}) + (m_r \ x \ h_r)] \ x \ SA_i}{R_i/I}\right\}^2 + \left\{\frac{(m_c \ x \ h_c \ x \ SA_c)}{R_c/I}\right\}^2} \ (U.S. customary\ units)$$

$$M_{EQ} = 9.8 \ x \sqrt{\left\{\frac{[(m_i \ x \ h_i) + (m_{sh} \ x \ h_{sh}) + (m_r \ x \ h_r)] \ x \ SA_i}{R_i/I}\right\}^2 + \left\{\frac{(m_c \ x \ h_c \ x \ SA_c)}{R_c/I}\right\}^2} \ (SI\ units)$$

See Table 15 for the definition and units of the variables in the equations above. For this section note the following:

A. If freeboard is insufficient use the modified weights (masses) of the impulsive liquid ($m_{i\text{-}IF}$) and the convective liquid ($m_{c\text{-}IF}$) instead of m_i and m_c (which assume sufficient freeboard).

B. For these equations m_r should include the total roof dead load plus 25% of the total roof live (or snow) load; for SI units, convert the live or snow loads given in kPa to kg/m^2 by multiplying by a factor of (1000/9.8) and then multiplying this by the roof area (m^2).

C. If checking to see if anchorage is needed, use the R_i value assuming the tank is unanchored.

E.6.3.2 Tank Earthquake Overturning Anchorage at the Tank Base

Determine if overturning anchorage at the base of the tank is needed to resist earthquake forces in accordance with this section.

E.6.3.2.1 Determine the dead weight of the tank shell plus the roof supported by the tank shell (no roof live load) per length of circumference (w_t) as follows:

U.S. Customary Units	SI Units
$w_t = \left(\frac{W'_D}{\pi\ x\ D}\right)$	$w_t = 9.8\ x\ \left(\frac{W'_D}{\pi\ x\ D}\right)$

See Table 15 for the definition and units of the variables in the equations above.

E.6.3.2.2 Determine the dead weight of the water adjacent to the shell per length of circumference (w_L) that can be used to resist overturning as follows:

A. When a bottom plate does not exist, w_L = 0 (in addition, a concrete mat foundation must be used).

B. When a bottom plate exists:

$$w_L = 7.9 t_b \sqrt{F_y H G} \text{ but not more than } 1.28 HDG \qquad U.S. Customary\ Units$$

$$w_L = 99 t_b \sqrt{F_y H G} \text{ but not more than } 201.1 HDG \qquad SI\ Units$$

See Table 15 for the definition and units of the variables in the equations above. For this section note that t_b is the thickness of the bottom plate adjacent to the tank shell; see the commentary below for limitations.

In most tanks the bottom plate is uniform throughout, but the bottom plate can be thickened near the tank shell (i.e., creating a bottom plate annulus) allowing it to carry more liquid dead load. See FM Approvals Standard 4020 for specific information regarding annulus thickness and width determination. Even if a thicker annulus is provided, the value of "t_b" in the equations above should not exceed the thickness of the bottom shell ring.

E.6.3.2.3 Based on the value of the earthquake uplift factor "J" at the base of the tank, determine the need for uplift anchorage as follows (variables have been defined previously in this section):

$$J = \frac{M_{EQ}}{D^2\,(w_t + w_L)} \qquad (U.S. customary\ or\ SI\ units)$$

When:

- J ≤ 0.785, there is no shell uplift and uplift anchors are not required.
- 0.785 < J ≤ 1.54, there is shell uplift but anchors are not required unless needed to limit the compression stress at the bottom of the shell (see Section E.6.3.3.2) in lieu of thickening the tank shell plates.
- J > 1.54, the tank must be anchored unless the bottom plate annulus can be thickened to engage more dead load from the contained water and reduce "J".

E.6.3.2.4 When overturning anchorage is needed per Section E.6.3.2.3, the required ASD tension force (T_r) per anchor is determined using the following formula:

$$T_r = \frac{4M_{EQ}}{k_e N D} - \left(\frac{(w_t + w_L)\pi D}{k_e N}\right) \quad (U.S. customary\ or\ SI\ units)$$

See Table 15 for the definition and units of the variables in the equation above. For this section note the following:

A. The number of foundation anchors (N) should only include those anchors effective for resisting overturning.

B. When the tank does not have a steel bottom plate use k_e = 0.5 (i.e., half of the bolts are effective); when a steel bottom plate exists use k_e = 1.0 (i.e., all bolts are effective). See Sections 3.1.3.6.1 and E.7 for a discussion of tank anchorage.

E.6.3.3 Tank Shell Earthquake Compression Stresses

Determine the adequacy of the tank shell (at its base and where the tank shell thickness changes) to resist combined vertical compression stresses from dead loads plus earthquake overturning forces in accordance with this section.

Each tank shell ring must have a minimum steel thickness such that the vertical compression stress (σ_c) at the bottom of the ring from dead and earthquake loads is less than the allowable vertical axial compression stress (F_a) based on the shell thickness to tank radius ratio (t/R) and Table 18, including the 1.333 wind increase factor, for that ring.

E.6.3.3.1 At the base of the tank, when there is no uplift (J ≤ 0.785 from Section E.6.3.2.3) or when the tank is anchored, calculate the vertical (longitudinal) compression stress (σ_c) from combined dead and earthquake load as follows:

U.S. Customary Units:

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

SI Units:

$$\sigma_c = \left(w_t + \frac{1.273M_{EQ}}{D^2}\right)\left(\frac{1}{1000t_s}\right)$$

See Table 15 for the definition and units of the variables in the equations above.

E.6.3.3.2 At the base of the tank, when there is uplift (0.785 < J ≤ 1.54 from Section E.6.3.2.3), calculate the vertical (longitudinal) compression stress (σ_c) from combined dead and earthquake load as follows (note, if J > 1.54 anchorage must be provided and the stress for the anchored tank would be calculated using Section E.6.3.3.1):

U.S. Customary Units:

$$\sigma_c = \left(\frac{w_t + w_L}{0.607 - 0.18667(J^{2.3})} - w_L\right)\left(\frac{1}{12t_s}\right)$$

SI Units:

$$\sigma_c = \left(\frac{w_t + w_L}{0.607 - 0.18667(J^{2.3})} - w_L\right)\left(\frac{1}{1000t_s}\right)$$

See Table 15 for the definition and units of the variables in the equations above.

E.6.3.3.3 For rings higher in the shell, where either the thickness or steel yield stress (F_y) change, calculate the vertical (longitudinal) axial compression stress (σ_c) based on the earthquake moment (M_{EQn}) at the bottom of Shell Ring “n” (the shell ring being checked) and the thickness (t_n) of Shell Ring “n.”

E.6.3.3.3.1 The earthquake overturning moment at the bottom of Shell Ring “n” (M_{EQn}) that is a distance “z” above the tank base is found as follows.

U.S. Customary Units:

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

SI Units:

$$M_{EQn} = 9.8 \times \sqrt{\left\{\frac{[(m_i \times h_i \times \mu_i) + (m_{sh} \times h_{sh} \times \mu_i) + (m_r \times \{h_r - z\})] \times SA_i}{R_i/I}\right\}^2 + \left\{\frac{(m_c \times h_c \times \mu_c \times SA_c)}{R_c/I}\right\}^2}$$

See Table 15 for the definition and units of the variables in the equations above. Also note that the values for μ_i and μ_c are found in Table 23.

E.6.3.3.3.2 When the compressive stress at the tank base was originally calculated per Section E.6.3.3.1 (i.e., the tank is anchored or J [at tank base] ≤ 0.785) use that section to calculate the compressive stress at the bottom of Shell Ring “n” by substituting M_{EQn} for M_{EQ} and substituting the thickness of Shell Ring “n” (t_n) for t_s.

E.6.3.3.3.3 When the compressive stress at the tank base was originally calculated per Section E.6.3.3.2 (i.e., 0.785 < J [at tank base] ≤ 1.54) use that section to calculate the compressive stress at the bottom of Shell Ring “n” by substituting J_n for J and substituting the thickness of Shell Ring “n” (t_n) for t_s. The value for J_n is determined from:

$$J_n = \frac{M_{EQn}}{D^2\,(w_t + w_L)}$$ (U.S. customary or SI units)

Table 23. Factors for Reducing Impulsive and Convective Overturning Moments at Height (z) from the Base[1]

Ratio of Heights (Above Tank Base) (z/H)	*Impulsive Factor (μ_i)*	*Convective Factor (μ_c)*
0	1.0	1.0
0.05	0.90	0.95
0.10	0.80	0.90
0.15	0.71	0.84
0.20	0.62	0.77
0.25	0.54	0.71
0.30	0.45	0.64
0.35	0.39	0.59
0.40	0.32	0.53
0.45	0.26	0.48
0.50	0.20	0.42
0.55	0.17	0.36
0.60	0.13	0.30
0.65	0.10	0.25
0.70	0.06	0.19
0.75	0.04	0.15
0.80	0.02	0.10
0.85	0.01	0.07
0.90	0.00	0.04
0.95	0.00	0.00
1.00	0.00	0.00

[1]"H" is the maximum height (ft or m) of water in the tank from base to TCL, and "z" is the height (ft or m) above the tank base where the earthquake overturning moment is needed. Use interpolation for z/H ratios between values given in the table.

E.7 Tank Anchorage for Wind or Earthquake Forces

E.7.1 General

See Section 2.2.5 and FM Approvals Standard 4020 for additional information on tank foundations and anchorage. Some brief summary comments are provided below.

Shear anchorage for wind or earthquake can consist of many different kinds of anchors (e.g., bolts cast into concrete [embedded bolts], post-installed concrete anchors, etc.). These are commonly attached to the tank through holes in an angle or plate at the tank base. Figure 29 shows tank anchorage that is inadequate to resist earthquake shear (or uplift) forces and that may be inadequate to resist wind forces. The clips will simply rotate or bend when subjected to the large forces that can be generated in an earthquake. Design shear anchors for the forces determined in this appendix (Section E.5.1.3 for wind and Section E.6.2.2.2 for earthquake). Anchor capacities in shear are given in manufacturer's literature or in building codes. The one-third seismic increase is generally applicable since shears in this appendix are based on allowable stress design (ASD).

Uplift anchorage for wind can likewise vary. Commonly, embedded or post-installed concrete bolts are provided and anchored through holes in an angle or plate at the tank base. For some tanks strap anchors are embedded into the concrete and welded to the tank shell. Where wind uplift forces are particularly high, a bolt that is attached to the tank shell through a steel chair (see below) may be needed. The uplift (tension) force for wind anchorage is given in Section E.5.1.6 of this appendix and, again, the one-third stress increase is typically allowed for design.

Earthquake uplift anchorage is designed for much more severe conditions than wind uplift anchorage. Anchor bolts embedded into concrete foundations and attached to the tank shell via anchor chairs are used (see Figure 27 and Figure 30). Strap anchors are not allowed. Attaching post-installed concrete anchors to anchor chairs is difficult and post-installed concrete anchors will not typically have adequate capacity to resist earthquake uplift forces. Earthquake uplift anchors are not attached to angles at the base of the tank because: 1) the large forces may damage the connection of the shell to the bottom plate, and 2) it is desirable to provide sufficient length in the section of bolt above the foundation and below the anchor chair so that yielding of the bolt can occur. The uplift (tension) force determined in Section E.6.3.2.4 of this appendix is used to size the bolts and determine ring beam size and details. However, the embedment of the bolt in the concrete, and the size and details of the anchor chair attached to the tank shell are determined using higher forces so that these do not fail before the anchor bolt itself.

When an anchor resists both shear and tension, an interaction equation of the form: $T_r/T_a + V_r/V_a \leq 1.0$ should be used ("T_r" and "V_r" are the required tension and shear force in the bolt, "T_a" and "V_a" are the allowable tension and shear force in the bolt [including the one-third increase if appropriate]). When uplift anchors consist of bolts and chairs and shear anchorage is needed, special details or separate shear anchorage must be provided. Post-installed concrete anchors subject to earthquake shear and/or tension must be qualified for use in earthquake zones as outlined in Data Sheet 1-2.

The remainder of this section is devoted to the design of earthquake uplift anchors and anchor chairs.

E.7.2 Earthquake Uplift Anchorage Design

E.7.2.1 Use the required uplift tension force (T_r) on the anchor (Section E.6.3.2.4) to size the anchor itself. For embedded bolts having a constant cross-section (i.e., not upset), the tensile stress area of the bolt (A_s) must meet both of the following requirements (see Section E.2.4.1 for more information [e.g., no further 1/3 stress increase is allowed]):

$A_S \geq T/0.33F_u$

$A_S \geq T/0.6F_y$

See Table 15 for the definition and units of the variables in the equations above.

If bolts are upset, the gross area (A_g) of the smaller bolt body should also meet the requirements above (i.e., substitute A_g for A_s in the above equations).

If post-installed concrete anchors are allowed, they instead should be sized such that their failure capacity in tension is at least four times the required design tension force (T_r). See Section E.2.4.2.

E.7.2.2 Design of foundations is beyond the scope of this appendix. However, when ring beams are used (see Figure 30), the weight of the ring beam plus the weight of the soil and water it lifts must be adequate to resist the tension force (T_r). If necessary, piles or a mat foundation can be used.

For embedded anchor bolts, design and detail the foundation and the embedded part of the bolt (e.g., concrete strength, foundation reinforcement, bolt embedment depth, etc.) to develop a force equal to A_S x F_u (tensile stress area multiplied by the minimum published ultimate tensile stress of the bolt) without failure. FM Approvals Standard 4020, and standards such as ACI 318, Appendix D, provide more information.

E.7.2.3 Design anchor bolt chairs in accordance with the American Iron and Steel Institute (AISI) publication T-192, *Steel Plate Engineering Data: Volume 2 - Useful Information on the Design of Plate Structures, Part VII Anchor Bolt Chairs;* Section E.2.4.4 of this appendix; and the following.

An example of a welded anchor chair is provided in Figure 31. Nomenclature and dimensions are consistent with those used in AISI T-192 (nomenclature in Table 15 does not, in general, apply). Assuming the thicknesses of the tank shell and bottom plates are held constant, the most efficient ways to limit stresses in the tank shell are by: (1) minimizing the eccentricity of the bolt (dimension "e"), (2) increasing the chair height (dimension "h"), or (3) providing more bolts of smaller diameter. In some cases, the chair height will need to be much larger than the 12 in. (300 mm) dimension given in Figure 31.

E.7.2.3.1 Take the design load "P" (lb [N]) on the anchor chair as the lesser of A_S x F_y (tensile stress area multiplied by the minimum published yield stress of the bolt) or four times the required design tension force (T_r) from Section E.6.3.2.4. (Note: The second requirement will only control if the bolt is oversized. The value of A_S x F_y will typically be about 1.7 to 1.9 times "T_r".)

E.7.2.3.2 Based on AISI T-192, meet the following requirements (see Figure 31):

A. Use a minimum chair height (h) of 12 in. (300 mm); it is recommended that h ≤ 3a, where "a" is the top plate width along the shell.

B. Use vertical side plates with a thickness (j) of 0.04 (h-c), where "c" is the top plate thickness, but not less than 0.5 in. (13 mm).

C. The value of the side plate thickness (j) times the average side plate width (k) should meet the following requirement: jk ≥ P/S, where P is the design load (lesser of A_S x F_y or 4 x T_r as described above) in lb (N) and S is the allowable stress of 25,000 psi (172.4 MPa).

D. Provide an eccentricity (e) from the outside of the shell to the centerline of the anchor bolt of at least 0.886d + 0.572 in. (0.886d + 14.5 mm), where “d” is the anchor bolt diameter, so that the nut will clear the shell by about 0.5 in. (13 mm).

E. Provide a distance (f) from the outside of the top plate to the edge of the hole of at least 0.5d + 0.125 in. (0.5d + 3 mm).

F. Provide a distance between vertical plates of at least d + 1.0 in. (d + 25 mm).

G. Provide fillet welds with a minimum leg size of ¼ in. (6.4 mm) between chair plates and from the chair to the tank (note: for bolted tanks, chairs are usually bolted to the tank instead; design of bolted connections is not covered in this appendix).

E.7.2.3.3 Determine the required thickness of the top plate (c) using the following equation (applies to either U.S. customary or SI units):

$$c = \sqrt{\frac{P}{Sf}\ (0.375g - 0.22d)}$$

Where (see Figure 31):

c = required top plate thickness, in. (mm)
P = design load (lesser of A_S x F_y or 4 x T_r), lb (N)
S = allowable stress (use 25,000 psi or 172.4 MPa)
f = distance from outside edge of top plate to edge of hole, in. (mm)
g = distance between vertical plates, in. (mm)
d = anchor bolt diameter, in. (mm)

E.7.2.3.4 Limit the maximum stress in an anchor bolt chair (S) to 25,000 psi (172.4 MPa) using the following equations (apply to either U.S. customary or SI units):

$$S = \frac{Pe}{t^2}\left[\frac{1.32Z}{k_1} + \frac{0.031}{\sqrt{Rt}}\right] \leq 25{,}000 \text{ psi (172.4 MPa)}$$

With:

$$k_1 = \frac{1.43\ ah^2}{Rt} + \sqrt[3]{4ah^2}$$

And:

$$Z = \frac{1.0}{\frac{k_2\ am}{\sqrt{Rt}}\left(\frac{m}{t}\right)^2 + 1.0}$$

Where (see Figure 31):

S = calculated stress, psi (MPa)
P = design load (lesser of A_S x F_y or 4 x T_r), lb (N)
e = anchor bolt eccentricity, in. (mm)
t = shell thickness at base, in. (mm)
R = tank radius, in. (mm)
a = top plate width along the shell, in. (mm)
h = chair height, in. (mm)
k_2 = constant equal to 0.177 (U.S. Customary units) or 0.00697 (SI units)
m = bottom plate thickness, in. (mm)

E.7.2.3.5 The minimum weld size is almost always adequate, but can be checked using the following equations (apply to either U.S. customary or SI units):

$$w \geq \frac{W}{k_3}$$

With: $W = \sqrt{W_V^2 + W_H^2}$

And:

$$W_V = \frac{P}{a + 2h}$$

And:

$$W_H = \frac{Pe}{ah + 0.667h^2}$$

Where :

w = required fillet weld leg size, in. (mm)
W = total load on weld, lb/in. (N/mm)
k_3 = 9,600 (U.S. Customary units) or 66.3 (SI Units) based on an allowable weld stress of 13,600 psi (93.8 MPa)
W_V = vertical load on weld, lb/in. (N/mm)
W_H = horizontal load on weld, lb/in. (N/mm)
P, a, e, and h are as defined above in Section E.7.2.3.4

E.7.2.3.6 An example of an anchor chair that meets the provisions in this section is presented below.

A. Required tension design force (T_r): 11,500 lb. (51,170 N)

B. Anchor bolt steel:

- F_y = 36,000 psi (248.2MPa) and F_u = 58,000 psi (400 MPa)
- Allowable tension stress (F_t) including 1/3 seismic increase is 20,000 psi (137.9 MPa) per Section E.2.4.1

C. Minimum required tensile stress area: A_s = 0.575 in.^{2} (371 mm^2)

D. Actual bolt used:

- Diameter (d) = 1 in. (25.4 mm)
- Tensile stress area A_s = 0.606 in.^{2} (391 mm^2)

E. Required chair design load is the lesser of the actual A_S x F_y or 4 x T_r: P = 21,816 lb. (97,050 N)

F. Other chair and tank dimensions (defined previously in this section):

a = 4 in. (101.6 mm)
b = 3 in. (76.2 mm)
e = 1.5 in. (38.1 mm)
f = 0.875 in. (22.2 mm)
g = 2 in. (50.8 mm)
h = 12 in. (304.8 mm)
j = 0.5 in. (12.7 mm)
k = 2.5 in. (63.5 mm)
m = 0.25 in. (6.35 mm)
R = 180 in. (4572 mm)
t = 0.25 in. (6.35 mm)

G. From Section E.7.2.3.3, and using a maximum allowable stress (S) of 25,000 psi (172.4 MPa), the minimum thickness of the chair top plate (c) is calculated as 0.73 in. (18.5 mm).

H. From Section E.7.2.3.4, the value of Z is calculated as 0.9743 and the value of k_1 is calculated as 31.48 (U.S. Customary units) or 798.5 (SI units). The resulting calculated stress (S) is 23,810 psi (164.2 MPa), which is less than the maximum allowable stress of 25,000 psi (172.4 MPa).

I. From Section E.7.2.3.5, the vertical load on the weld (W_V) is calculated as 779 lb/in. (136.5 N/mm) and the horizontal load on the weld (W_H) is calculated as 227 lb/in. (39.8 N/mm) with a resulting total load on the weld (W) of 811 lb/in. (142.0 N/mm). The required fillet weld leg size (w) needed to resist this total load on the weld is 0.08 in. (2.15 mm), which is less than the minimum specified fillet weld leg size of ¼ in. (6.4 mm).

Fig. 29. Inadequate suction tank anchorage

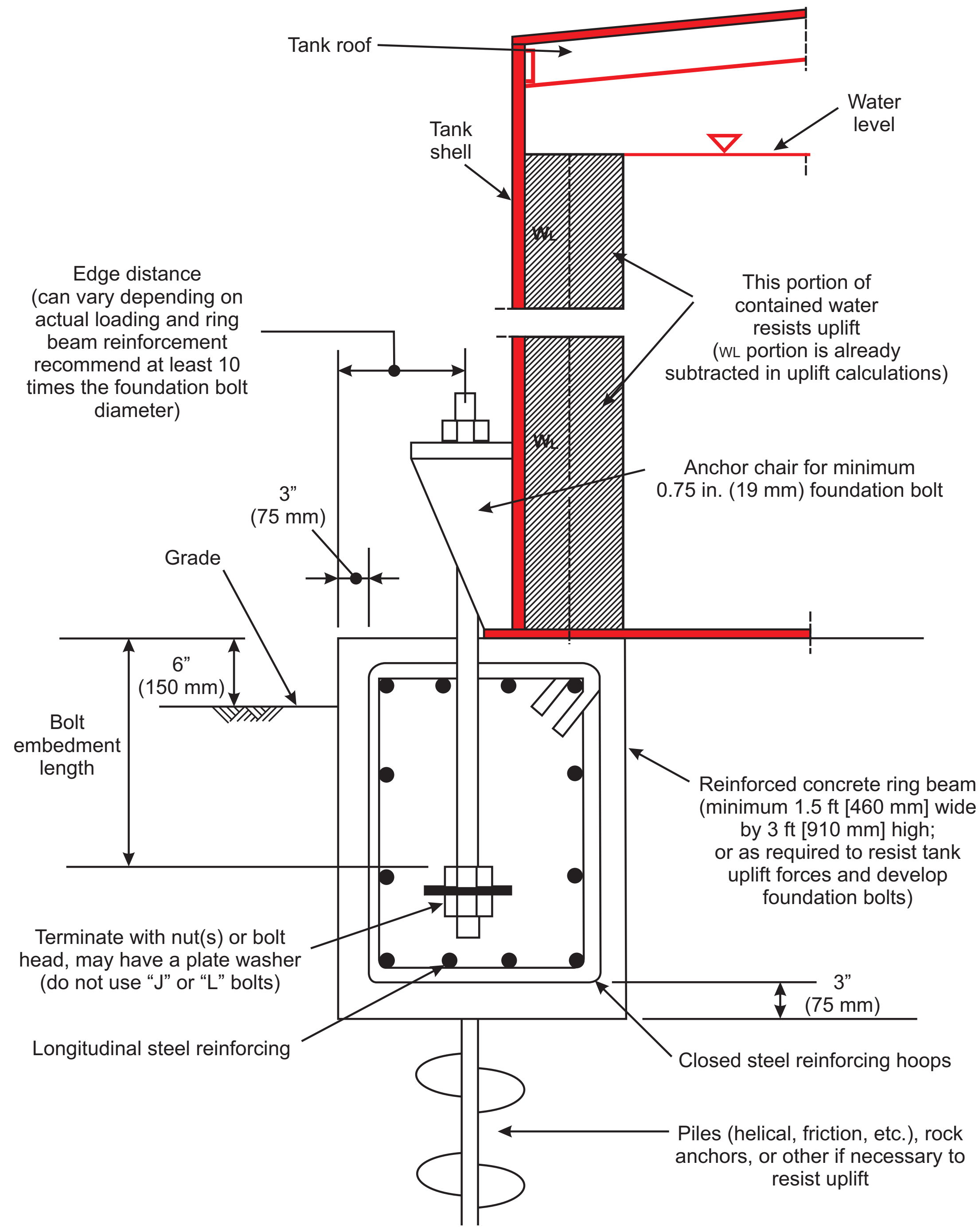

Fig. 30. Conceptual uplift anchorage for suction tank

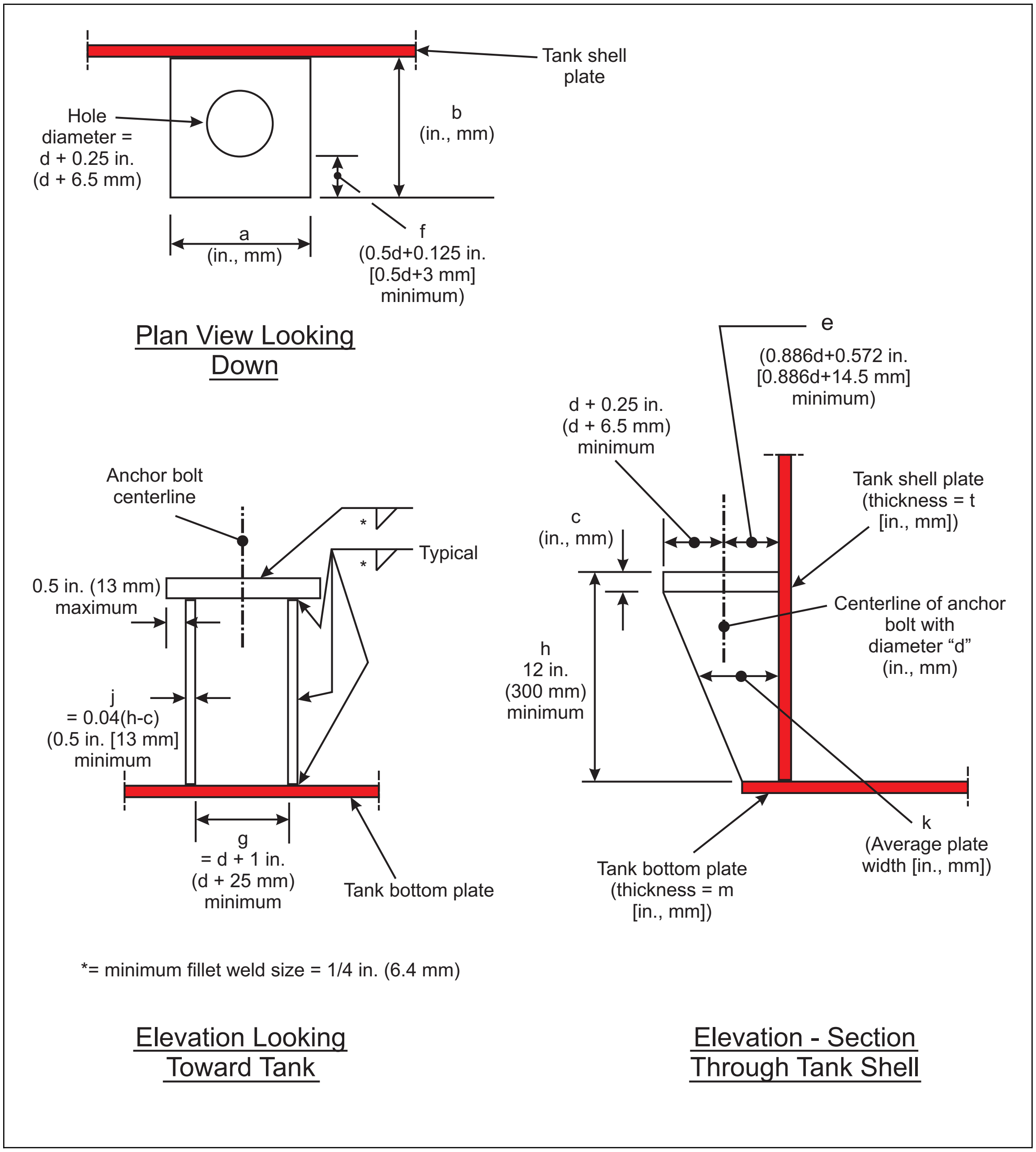

Fig. 31. Steel welded uplift anchor chair