6.4 Mechanical, Electrical, and Plumbing Components

6.4.2 Storage Tanks and Water Heaters

6.4.2.2 Flat Bottom Tanks and Vessels

This category covers any type of flat bottom tank or vessel resting on a concrete pad at the base. These tanks may be made of steel, stainless steel, polyethylene, polypropylene, fiberglass reinforced plastic (FRP), or concrete.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for flat bottom tanks and vessels are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) Chapter 13, or Chapter 15 for large tanks that are not within buildings.

For tanks considered nonstructural components, ASCE/SEI 7-10 Chapter 13 requires anchorage for tanks in Seismic Design Categories D, E, and F weighing over 400 pounds. Lighter tanks may be exempt if the component Importance Factor $I_p = 1.0$.

- ASCE 7-10 requires consideration of component supports and component anchorage, as follows:
  - The component supports for the tank or vessel include the clips or brackets and attachment of the brackets to the tank or vessel wall,
  - The component anchorage includes the attachment or anchors of the tank or vessel to the structure (e.g., anchor bolts to a concrete slab or bolts to a steel deck or platform).
- Flat bottom tanks and vessels that are exempt from the anchorage requirements noted above are still required to be positively anchored to the structure or ground. The anchorage need not be designed or detailed on the construction documents. Flexible connections between the equipment and associated pipes or conduits must be provided or alternate means for protecting the connection shall be implemented.

Requirements for flat bottom tanks and vessels classified as nonbuilding structures:

- ASCE/SEI 7-10 Section 15.7 contains extensive design requirements for flat bottom tanks and vessels.

- Tanks and vessels at grade may be permitted to be designed without anchorage. See ASCE/SEI 7-10 Section 15.7.5 for additional information.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings,* (ASCE, 2007) classifies flat bottom tanks and vessels as force controlled, meaning that the principal objective is to prevent the component from sliding or overturning. Piping associated with the tank or vessel must meet the force and deformation requirements of the standard.

Tanks and vessels at grade are subject to the provisions of the standard when:

- The performance level is Immediate Occupancy
- The performance level is Life Safety in high seismicity areas, if
  - The item is part of an emergency power system,
  - The item weighs more than 400 pounds and is 6 feet or more in height,
  - The item is unanchored, weighs over 100 pounds, is 6 feet or more in height, and is subject to overturning. These items may be exempt if they have a factor of safety greater than 1.5 against overturning when design loads are applied.
  - The item weighs over 20 pounds and is mounted over 4 feet above the floor.

Typical Causes of Damage

- Unanchored tanks may slide or overturn; poorly anchored tanks may damage the hold down, damage the tank wall, and potentially slide or overturn. However, these tanks and vessels may be designed to resist seismic forces solely by friction between the tank bottom and the subgrade, if the tank meets certain restrictions. See the section on Seismic Mitigation Considerations, below.
- The shell of the tank or vessel may be damaged by fluid-structure interaction.
- Connections of supply lines or fuel lines may be damaged; contents may slosh or spill.

DAMAGE EXAMPLES

Figure 6.4.2.2-1 Damage to ductile connection at base of a 5000 cubic meter diesel fuel tank in the 2001 magnitude-8.4 Peru Earthquake. All eight connections were damaged; damage included bolt elongation, deformation of tank wall, and cracked concrete pad (Photo courtesy of Eduardo Fierro, BFP Engineers).

Figure 6.4.2.2-2 Tank with “elephant’s foot” buckle at the base in the 1964 magnitude-9.2 Anchorage, Alaska earthquake (Photo courtesy of PEER, Steinbrugge Collection, No. S2508)

Figure 6.4.2.2-3 Tank with “elephant’s foot” and “elephant knee” in Port-au-Prince in the 2010 magnitude-7 Haiti Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

Figure 6.4.2.2-4 Anchored tank damaged at base when anchorage failed; tank slid and ruptured attached piping in 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

Seismic Mitigation Considerations

- The structural response of these tanks, especially large tanks, is influenced strongly by the fluid-structure interaction (sloshing). The magnitude of these forces depends on the geometry (height, H, to diameter, D, ratio) of the tank. See ASCE/SEI 7-10 Chapter 15, Section 15.7.6 for additional information.
- Small-diameter tanks and vessels are more susceptible to overturning and vertical buckling. As a general rule, a greater ratio of height to diameter (H/D) produces lower resistance to vertical buckling. Where H/D is greater than 2, the liquid tends to behave as a "rigid mass" and the loads due to sloshing are small.
- There are several alternatives for designing flat bottom tanks and vessels for seismic resistance
    - Provide adequate connections around the base of the tank. Do not weld to tanks with flammable contents.
    - For steel tanks, the lateral force may be resisted by friction between the tank bottom and the subgrade. See ASCE/SEI 7-10 Sections 15.7.5.5 and 15.7.6 for a description of the design approach and limitations.
- Provide flexible connections for fuel lines and piping or implement alternate measures to protect the pipe-to-tank connection.
- The detail shown is for a rigid connection; larger tanks require ductile details such as those shown in Figure 6.4.2.2-1.

MITIGATION EXAMPLES

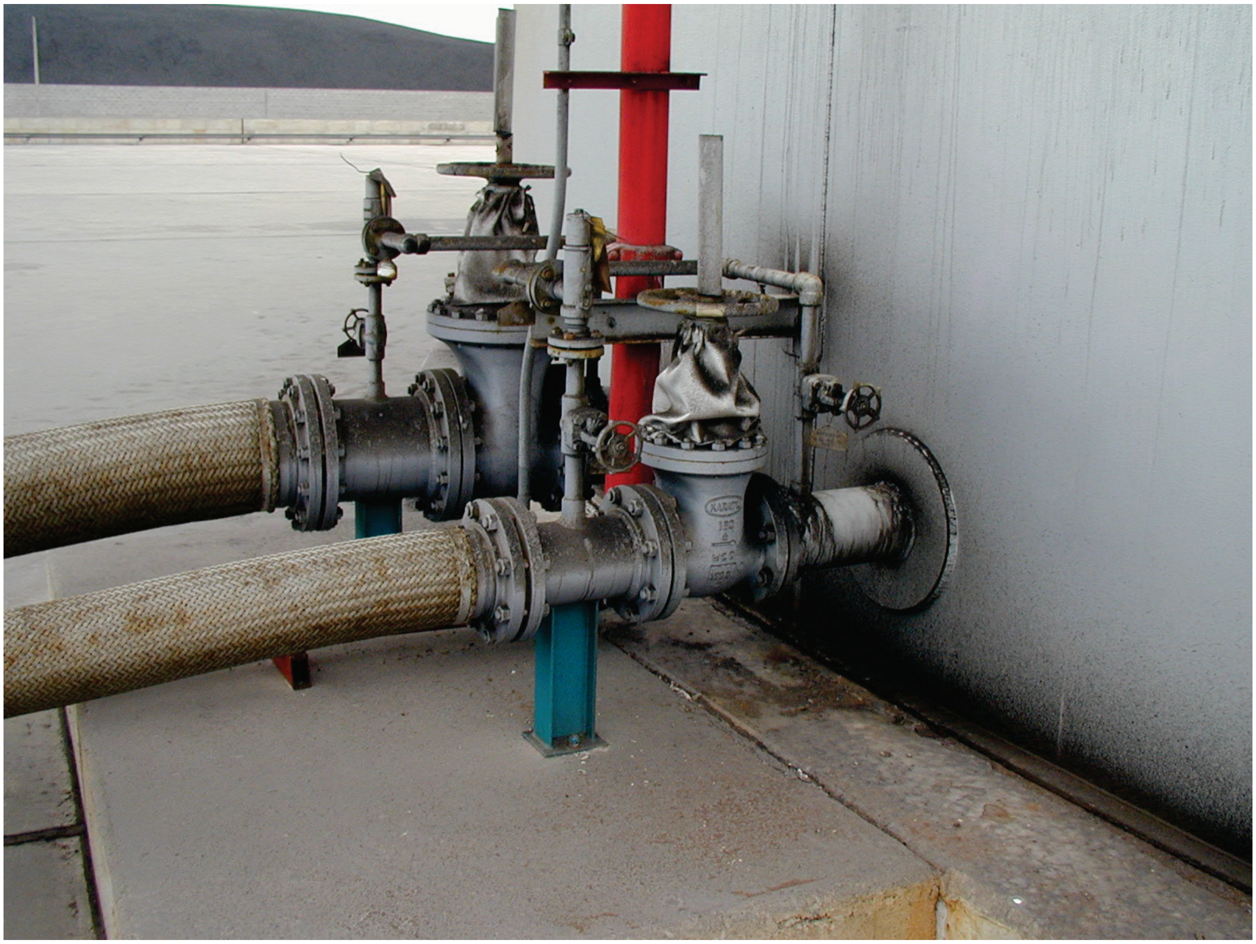

Figure 6.4.2.2-5 Flexible connections prevented piping damage in 2001 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

Figure 6.4.2.2-6 Anchors at base of fiberglass reinforced plastic tank (Photo courtesy of Jeffrey Soulages, Intel).

Figure 6.4.2.2-7 Examples of rigid base anchorage for small circular tanks (Photos courtesy of Maryann Phipps, Estructure).

MITIGATION DETAILS

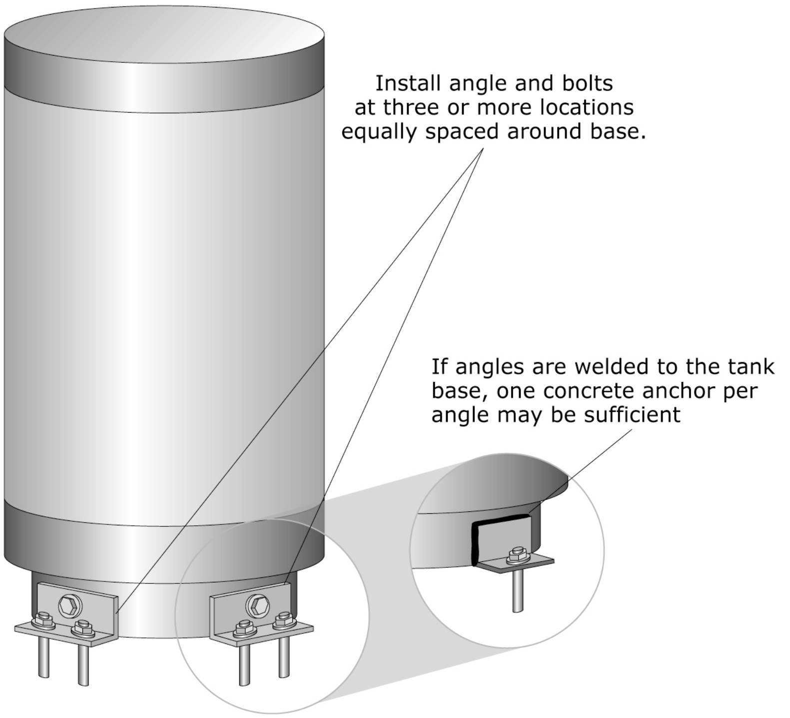

Figure 6.4.2.2-8 Flat bottom tank (ER).