6.4 Mechanical, Electrical, and Plumbing Components

In the following sections, the seismic performance of individual mechanical components will be discussed. However, it is critical to remember that mechanical components act and interact together as systems. While each component is examined individually, the performance of that component and the system as a whole depends on the performance of many individual components. Depending on the performance objectives of the structure, these interactions may be inconsequential, or should be studied in greater depth. For example, the following would be considered for a rooftop fire water tank, mounted close the edge of the building overlooking a busy sidewalk:

- If the performance objective is limited to protect the occupants of the sidewalk from the tank falling on them, the seismic evaluation may focus on the adequacy of the tank legs, bracing, and anchorage to the roof structure.
- If the performance objective is to prevent the contents of the tank from flooding the floor below, then the evaluation must not only consider the anchorage of the tank but the connections and bracing of the rooftop piping associated with the tank.
- If the performance objective is to provide a reliable fire suppression system that may function after an earthquake, the tank must be considered as part of a complete system that includes fire sprinkler risers, mains, branches and sprinkler drops. The possibility of interactions between the fire protection piping and adjacent structural or nonstructural elements, such as sprinkler heads and hard ceilings, should also be considered.

Having a clear view of the performance objectives will guide the selection of the proper degree of investigation and the mitigation measures needed.

6.4.1 Mechanical Equipment

6.4.1.1 Boilers, Furnaces, Pumps, and Chillers

This category includes equipment such as boilers, furnaces, humidifiers, pumps, chillers and similar that are anchored to a concrete floor or housekeeping pad. These items are either rigidly anchored or have vibration isolation.

In recent shake table testing of a full scale 5story building performed at UC San Diego (see Section 6.1.3), a vibration isolated cooling tower and a self-contained air handling unit, were subjected to severe earthquake motions. The cooling tower and air handling unit were both anchored to the roof of the building per code requirements. Both units were energized and the time of the testing and both were undamaged after all the testing was concluded. There was, however, one issue. As the shaking level increased, water in the cooling tower sloshed and spilled resulting in loss of water. After each test, the cooling tower was refilled with water. At the largest shaking level, the cooling tower lost half of its water capacity because of spillage. This loss of water would affect the cooling tower's ability to maintain its full cooling capability until the water capacity was restored.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for boilers, furnaces, pumps, and chillers are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) Chapter 13. The principal objective of the code provisions is to prevent the component from sliding or overturning.

- ASCE/SEI 7-10 requires anchorage design for all equipment in Seismic Design Categories D, E, and F if the equipment weighs over 400 pounds, or if the item weighs over 20 pounds and is mounted over 4 feet above the floor. Lighter items may be exempt if the component Importance Factor, I_p, is 1.0.
- Items that are exempt from the anchorage design requirements noted above are still required to be positively anchored to the structure. The anchorage need not be designed or detailed on the construction documents. They must also be provided with flexible connections between the equipment and associated pipes, ducts, or conduits unless alternate measures are used to protect the connection.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies boilers, furnaces, pumps, and chillers as force controlled. These components are subject to the provisions of the standard when the performance level is Immediate Occupancy, or Life Safety in high, moderate and low seismicity areas, if:

- The item weighs more than 400 pounds,
- The item is unanchored, weighs over 100 pounds and is subject to overturning. These items may be exempt if they have a factor of safety greater than 1.5 when design loads are applied.
- The item weighs over 20 pounds and is mounted over 4 feet above the floor.
- The equipment is a boiler or furnace.

Acceptance criteria for boilers, furnaces, pumps, and chillers focuses on providing adequate anchorage.

Typical Causes of Damage

- The primary concern is that equipment may slide, tilt or overturn. Anchorage should be made to a structural element with sufficient capacity to resist the anchorage forces, such as a concrete slab or housekeeping pad. Heavy equipment may be anchored to an unanchored or poorly reinforced housekeeping pad and the pad may shift or break.
- Movement of equipment may cause loss of connections to fuel and exhaust lines, relief valves, electrical lines, piping, or ductwork. Fluids such as fuel or refrigerant may leak.
- Even when the equipment is adequately anchored, distribution systems (pipe, conduit, or ducts) connected to the equipment may fail if they experience large movements relative to the equipment. For example, ¾- and 1-inch diameter copper piping (exempt from seismic bracing requirements due their small diameter) has failed where they connect to braced equipment. Providing flexible connections between the equipment and distribution systems will help protect against such failures.
- Function and operability of equipment may be compromised; this is especially critical for hospitals and other essential facilities that must maintain post-earthquake operations.

DAMAGE EXAMPLES

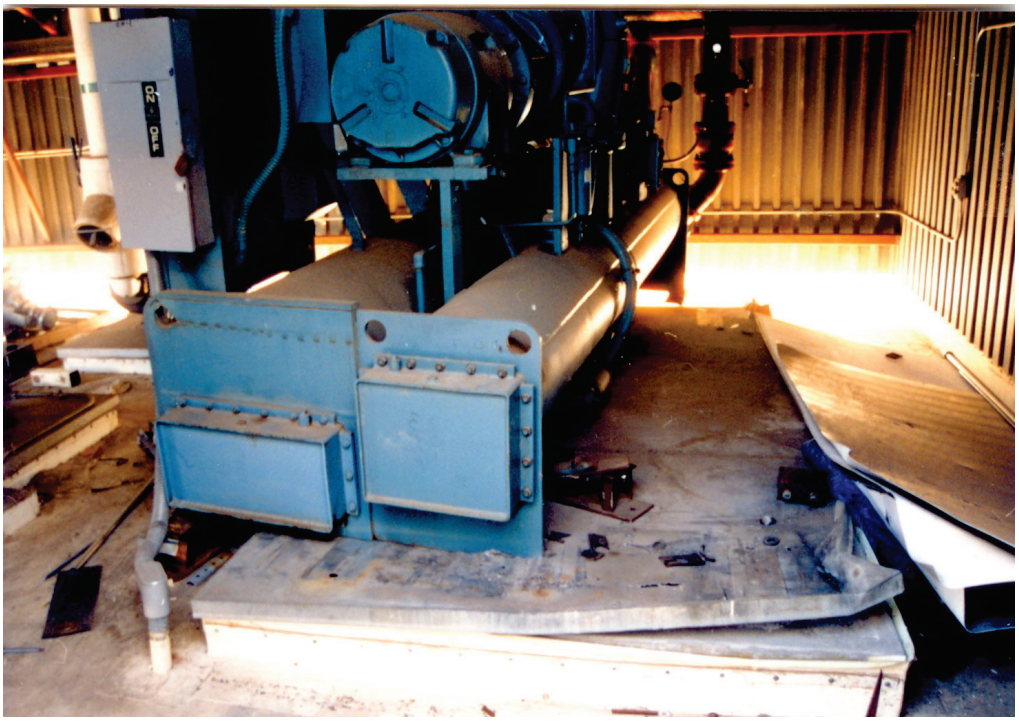

Figure 6.4.1.1-1 Failed chiller mounts due to insufficient uplift resistance in the 1994 magnitude-6.7 Northridge Earthquake ((Photo courtesy of Wiss, Jenney, Elstner Associates).

Figure 6.4.1.1-2 Pumps with rigid anchorage to housekeeping pad in the 2010 magnitude-8.8 Chile Earthquake; housekeeping pad not anchored to base slab and slid horizontally several inches (Photo courtesy of Eduardo Fierro, BFP Engineers).

Seismic Mitigation Considerations

- The details shown depict rigid anchorage of mechanical equipment to a concrete slab or housekeeping pad. Verify that the slab and/or housekeeping pad are adequate to resist the imposed loads. Rigidly mounted equipment should have flexible connections for the distribution systems, such as fuel lines and piping where relative motion or displacements due to story drift are likely to occur between the component and the distribution systems. Where flexible connections are used for larger diameter piping, it may be necessary to evaluate the forces imposed on the equipment nozzles when the flexible connections displace. For pressurized systems, “flexible” connections such as braided pipe or hose have significant lateral stiffness, and may overload the nozzle on the equipment, causing it to fail. Piping loops are also an acceptable way of providing a flexible connection, provided that nozzles are not overloading by the piping reactions.
- For equipment with vibration isolation, restraints ("snubbers") or seismic isolators are required; see Section 6.4.1.3 for equipment with vibration isolation. Snubbers should not be rigidly connected to the equipment, but instead allow for a small amount of ordinary vibration movement while preventing large seismic movements. However, the “air gap”, or distance between the snubber and the component should be limited to less than 0.25 inches, to avoid significant dynamic amplification when the component contacts the snubber. The snubbers should have an elastomeric or resilient surface to lessen the impact effects during strong shaking. Where isolators with integral seismic restraint are used, the isolator should be selected and sized to resist the anticipated seismic shear and uplift and connections to the equipment and supporting structure should be specifically designed to resist these forces.
- HVAC equipment or other items required for use in a hospital or essential facility would be classified as designated seismic systems and may require engineering calculations, equipment certification and special inspections. Check with the jurisdiction for specific requirements.
- To see additional examples for specific equipment and different anchorage conditions, refer to FEMA 412 *Installing Seismic Restraints for Mechanical Equipment* (2002) and FEMA 414 *Incremental Seismic Restraints for Duct and Pipe* (2004).

MITIGATION EXAMPLES

Figure 6.4.1.1-3 Added lateral capacity provided for skid-mounted equipment added following the 2001 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

Figure 6.4.1.1-4 Bolted connection to steel skid with added shear lugs (Photo courtesy of Eduardo Fierro, BFP Engineers).

Figure 6.4.1.1-5 Alternate detail for skid mounted equipment (Photo courtesy of Eduardo Fierro, BFP Engineers).

MITIGATION DETAILS

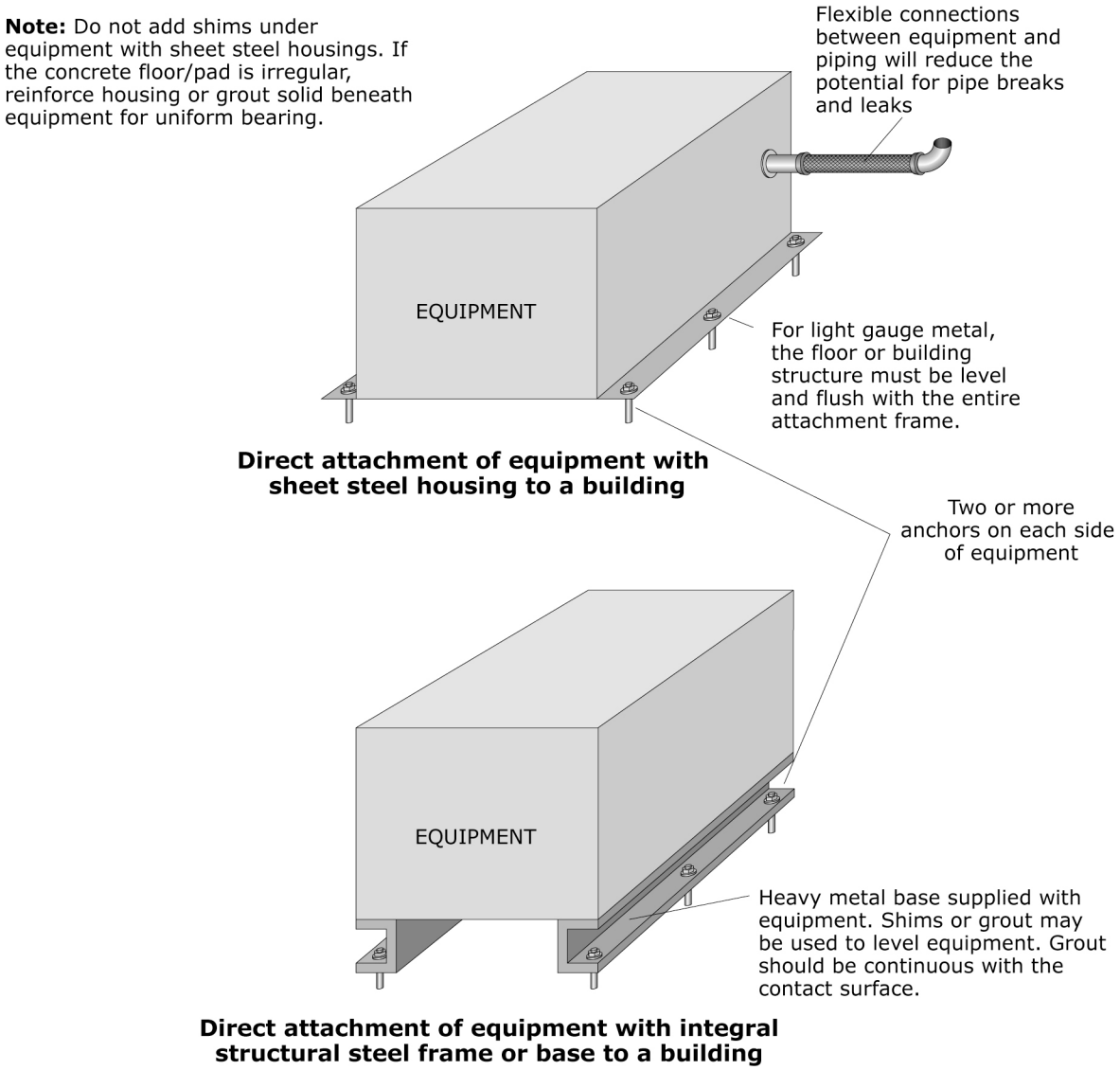

Figure 6.4.1.1-6 Floor-mounted equipment – anchored through integral base (ER).

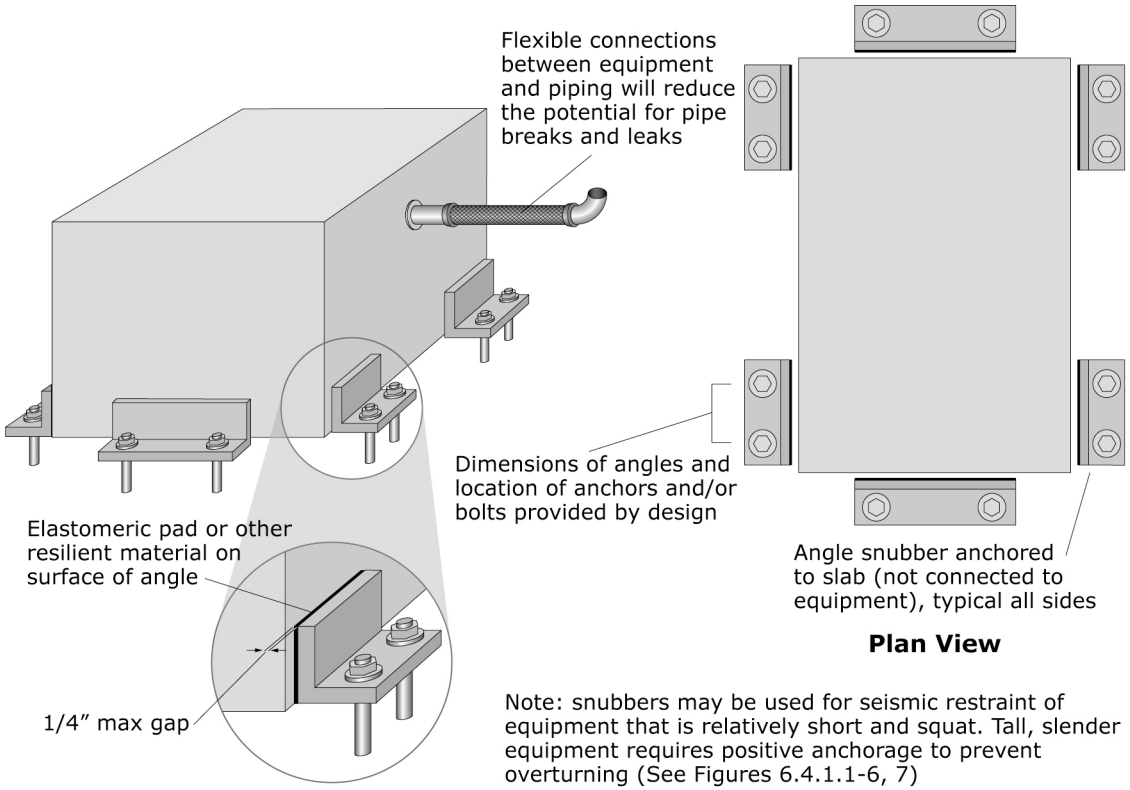

Figure 6.4.1.1-7 Floor-mounted equipment – restrained with snubbers.