6.4 Mechanical, Electrical, and Plumbing Components

6.4.7 Electrical And Communications Equipment

6.4.7.5 Photovoltaic (PV) Power Systems

This category covers photovoltaic (PV) power systems and solar car charging stations, commonly mounted on roofs or on separate freestanding racks.

Provisions

BUILDING CODE PROVISIONS

While not explicitly covered in ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), PV power systems are subject to the seismic requirements for nonstructural components. If mounted on a building, the provisions of Chapter 13 for nonstructural components apply. PV power systems mounted on racks at grade are subject to the provisions of Chapter 15, Nonbuilding Structures. The principal objective 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. Lighter components may be exempt if the component Importance Factor $I_p = 1.0$.
- Items that are exempt from the anchorage design requirements must still be positively anchored to the structure. The anchorage need not be designed or detailed on the construction documents. Exempt items must also be provided with flexible connections between the equipment and associated raceways, bus ducts, or conduits.
- Ballasted PV systems use friction due to the weight of the system to resist lateral loads. These systems must use an alternative analysis approach, since ASCE/SEI 7-10 requires that component attachments be bolted, welded, or otherwise positively fastened without consideration of frictional resistance produced by the effects of gravity. The alternative analysis should account for the coefficient of friction between the PV system and the supporting structure, the slope of the supporting structure, and the tendency of the PV panels to slide in the direction of the roof slope during shaking. Seismic performance depends on providing adequate distance between the PV system and the edge of the supports, so that the panels do not slide off, and in providing flexible connections to electrical system to accommodate the expected displacements.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2006) does not expressly cover PV systems, but they may be classified as electrical equipment, that is both force and displacement controlled. PV systems are subject to the provisions of the standard when the performance level is Immediate Occupancy. They requirements also apply when the performance level is Life Safety in high and moderate seismicity areas, and the equipment is over 6 feet in height and weighs more than 20 pounds. When applicable, PV systems meeting any of the following criteria must comply with the requirements of ASCE/SEI 41-06:

- The items 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 or roof.

Refer to the notes on Building Code Provisions (above) for acceptance criteria.

Typical Causes of Damage

As the installation of these fixtures on U.S. rooftops is relatively new, there are few documented examples of earthquake damage to date. This is in part due to the fact that since panels tend to be very light, the most severe design loading for roof-mounted photovoltaic panels is typically wind. Nevertheless, if these have not been properly designed to meet seismic loading, the panels may become dislodged and fall from the racks or fall off of pitched roofs or piping may be damaged, resulting in leakage. Wiring may also become dislodged and disable the systems.

Seismic Mitigation Considerations

- Solar power is a rapidly changing field; these products and systems are evolving. Where existing photovoltaic systems may weigh between 2.5 to 3.0 pounds per square foot and consist of glass covered modules that are roof mounted on aluminum or galvanized steel track, newer products include lighter panels without glass, solar roof tiles that interlock with standard S-shaped clay or concrete roofing tiles, or peel and stick panels which weigh under 2 pounds per square foot that may be applied directly to the roof surface. Several of these newer systems are integrated with the roofing materials and may not require special seismic consideration as long as the additional weight is accounted for. Ballasted photovoltaic systems are also available that do not require

anchorage or penetration of the roofing membrane. Check the internet for proprietary systems.

- Photovoltaic panels supported on framing systems are typically flush mounted or tilt mounted. These systems typically have anodized aluminum or galvanized steel track channels mounted to brackets or standoffs which are mounted to roof framing or structural supports. The panels or modules are then screwed directly to the track, typically four per panel. For installation on a wood framed roof, the system layout works best when the track is mounted perpendicular to the rafters; blocking may be required between the rafters where the track is mounted parallel to the rafters. Care must be taken to see that the roof penetrations are well sealed so the photovoltaic power system does not cause roof leaks. Friction fittings should not be used to resist seismic loading; positive connections should be provided between all the component parts.
- Photovoltaic power systems may be installed on top of carports for charging electric cars. Before mounting an expensive solar system on top, it must be ensured that the carport or patio structures have been designed for seismic loading.
- The State of California has published DSA IR 16-8 *Solar Photovoltaic and Thermal Systems Acceptance Requirements* (California Department of General Services, 2010a) to address requirements for California schools. This document describes solar systems supported on framing systems and foundations, ballast panel systems, and adhered panel systems.
- Installation guidelines are available on the internet for proprietary flush mount kits and tilt up kits. For example, UniRac, Inc. has installation manuals for two proprietary systems called SolarMount and Clicksys (see http://unirac.com/mounting-solutions). These installation manuals have wind and snow load tables with wind loading from 90 mph to 170 mph. Although there is no explicit mention of seismic provisions, the detailing will be adequate if designed sufficiently for wind. A review of the tabulated wind design loads shows these systems are engineered for 10 psf to over 100 psf uplift; thus a well engineered wind design for a photovoltaic system typically weighing less than 3 psf should not require additional seismic detailing. Another company, Professional Solar Products (http://www.prosolar.com/prosolar-new/pages/installation-guides-subpage2.htm) has hardware with installation guides for tilt up kits designed for 30 psf or 100 mph winds.
- Like any components exposed to the weather, components and connectors for photovoltaic systems should be corrosion resistant materials such as stainless steel or

anodized aluminum. Where roof penetrations are required, these should have appropriate flashing and caulking to prevent leakage.

MITIGATION EXAMPLES

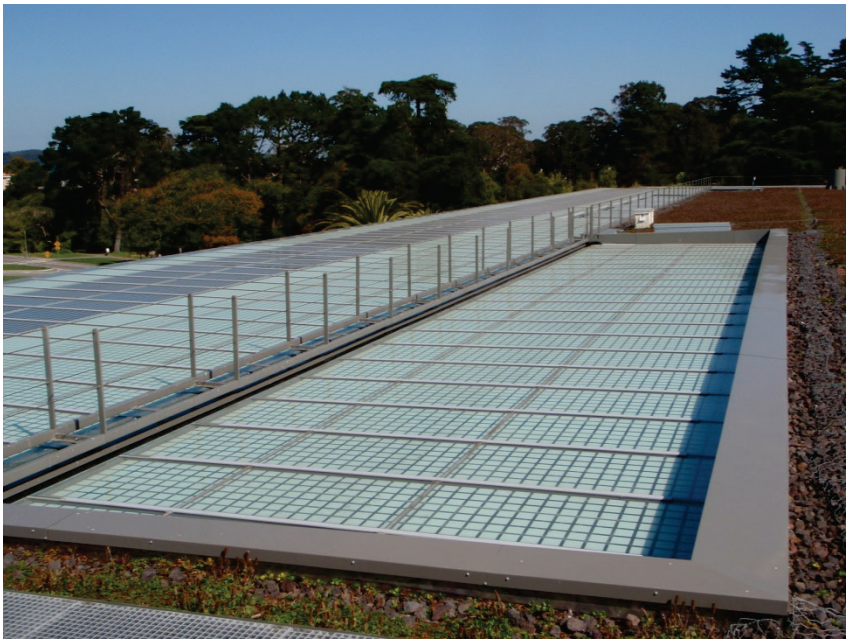


Figure 6.4.7.5-1 60,000 photovoltaic cells are incorporated into the glass canopy surrounding the Academy of Science, San Francisco, California (Photos courtesy of Cynthia Perry, BFP Engineers). The photovoltaic system provides 10% of the electricity needed for the facility. Panels must be securely attached to resist wind loads but also because these cantilevered members may be subject to vertical as well as horizontal seismic forces.

Figure 6.4.7.5-2 Ground mounted photovoltaic system that also provides shade to injured animals at the Marine Mammal Center in Sausalito, California (Photo courtesy of Cynthia Perry, BFP Engineers). Each solar panel is screwed to the strut at four locations; two rows of struts are bolted to 6 steel tubes which are anchored at the base with four bolts apiece.

Figure 6.4.7.5-3 Residential photovoltaic system in Berkeley, California mounted over the transition between two different roof slopes (Photos courtesy of Heber Santos). Short standoff used on tar and gravel flat portion (upper left); aluminum flashing and mounting bracket used on sloped portion with composition tile roofing (upper right). The profile of one type of proprietary mounting track is seen at lower left.

Figure 6.4.7.5-4 Flush mount photovoltaic system on barrel shaped roof of gymnasium at Head-Royce School, Oakland, California (Photo courtesy of Cynthia Perry, BFP Engineers).

MITIGATION DETAILS

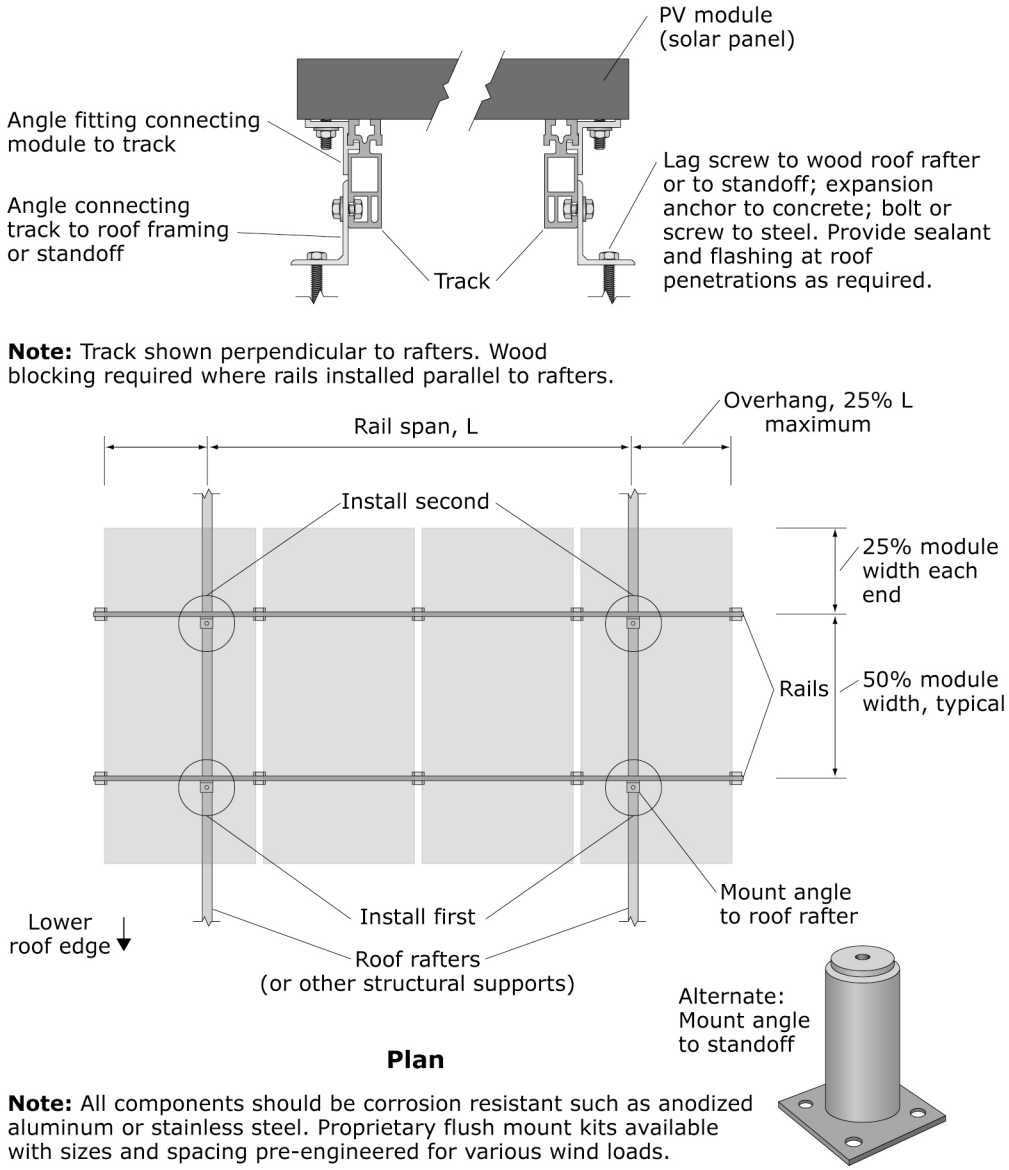
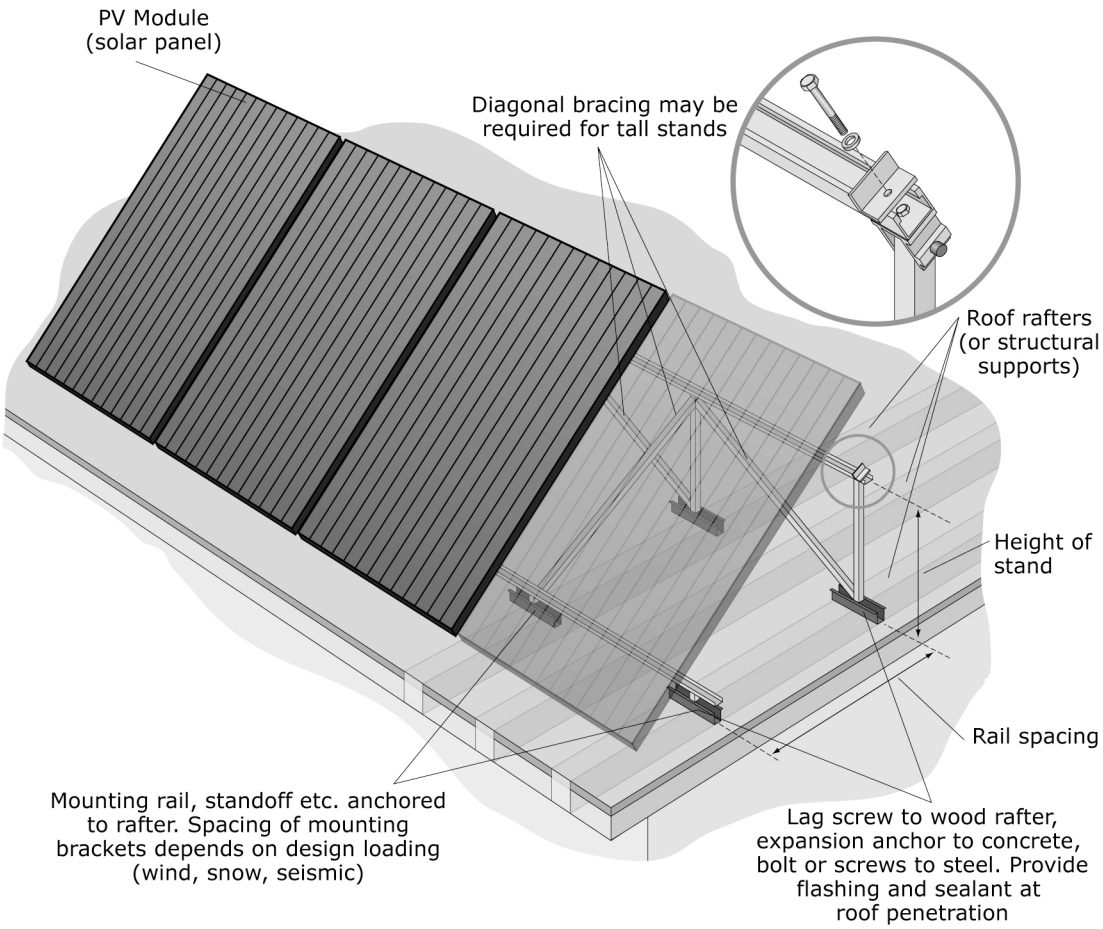


Figure 6.4.7.5-5 Typical details for flush-mounted photovoltaic power modules (ER).



Note: All components should be corrosion resistant such as anodized aluminum or stainless steel. Proprietary tilt-up kits available with sizes and spacing pre-engineered for various wind loads.

Figure 6.4.7.5-6 Typical tilt up details for anchored photovoltaic power modules (ER).