6.3 Architectural Components

6.3.1 Exterior Wall Components

6.3.1.3 Prefabricated Panels

This category covers any type of prefabricated exterior panel that is attached to the perimeter structural framing. These may be lightweight metal panels, glass fiber reinforced concrete panels (GFRC) supported by cold-formed steel framework, stone or tile supported by steel frames, or precast concrete panels that may have adhered or anchored veneer.

Provisions

BUILDING CODE PROVISIONS

ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) focuses on providing adequate strength in the connections and providing a mechanism to accommodate building deformations.

- Fasteners in the connections (bolts, welds, and items embedded in concrete or masonry) are designed for amplified forces to prevent premature failures in potentially brittle connection elements.
- Prefabricated panels must be designed to accommodate the expected deformations of the structure. Story drift can be resisted by rocking or sway mechanisms. In a rocking mechanism, the corners of the panels are permitted to move vertically when the building deforms horizontally. In a sway mechanism, the panel is attached rigidly to one level, while attachment points on other levels of the structure allow lateral movement by sliding or bending of ductile steel elements.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies prefabricated exterior panels as both acceleration and deformation sensitive.

- Prefabricated exterior panels are subject to the requirements of ASCE/SEI 41-06 when:
  - The performance level is Immediate Occupancy or Life Safety in high, moderate, and low seismicity areas.
  - The performance level is Hazards Reduced in high, moderate, and low seismicity areas and prefabricated panels are located over areas of public access or egress.

- Acceptance criteria focus on performing a drift analysis to determine if the panels can accommodate the expected story drifts, and the anchorage of the panels under seismic loading.

Typical Causes of Damage

- Both lightweight and heavier panels may be damaged by deformations of the building frame. GFRC systems and other cladding units that have a cold-formed steel support frame are more tolerant of building deformations, due to the inherent flexibility of the steel support frame.
- Heavier cladding panels may be damaged by direct acceleration.
- Unless the panel connections are specially detailed to allow the panel to move independently of the building, both the connections and the panel may be damaged as they attempt to restrain the lateral movement of the building. Panels may be racked, damage adjacent panels, connections may fracture, and panels may become dislodged or displaced.
- Separations (joints) between adjacent panels are intended to limit contact and resulting panel misalignment and/or damage under all but extreme building response, In strong shaking, some contact between adjacent cladding units is expected.
- Deterioration or corrosion of the mechanical connections is a significant concern; corroded connections may fail prematurely. Maintaining watertight joints is important for the longevity of the anchors.

DAMAGE EXAMPLES

Figure 6.3.1.3-1 Failure of precast panel at parking garage that resulted in fatality in the 1987 magnitude-5.9 Whittier, California earthquake (Photo courtesy of Degenkolb Engineers).

Figure 6.3.1.3-2 Precast panel failure at the top floor of a hospital in the1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of OSHPD).

Figure 6.3.1.3-3 Precast panel damage at a building corner in the 1994 Northridge Earthquake (Photo courtesy of OSHPD).

Figure 6.3.1.3-4 Interior view of precast panel showing response of three sets of push-pull connections in the 1994 Northridge Earthquake (Photo courtesy of OSHPD).

Figure 6.3.1.3-5 Close-up photo of two fractured connection bolts in a prefabricated panel in the 1994 Northridge Earthquake; corrosion of the rods may have contributed to the failure. (Photo courtesy of OSHPD).

Figure 6.3.1.3-6 Residential building with precast concrete corridor and balcony railing panels. Some panels were damaged and subsequently many were removed to prevent falling. Location in Rancaqua, Chile 154 miles northeast of the epicenter; estimated PGA of 0.3g during the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Antonio Iruretagoyena, Rubén Boroschek & Associates).

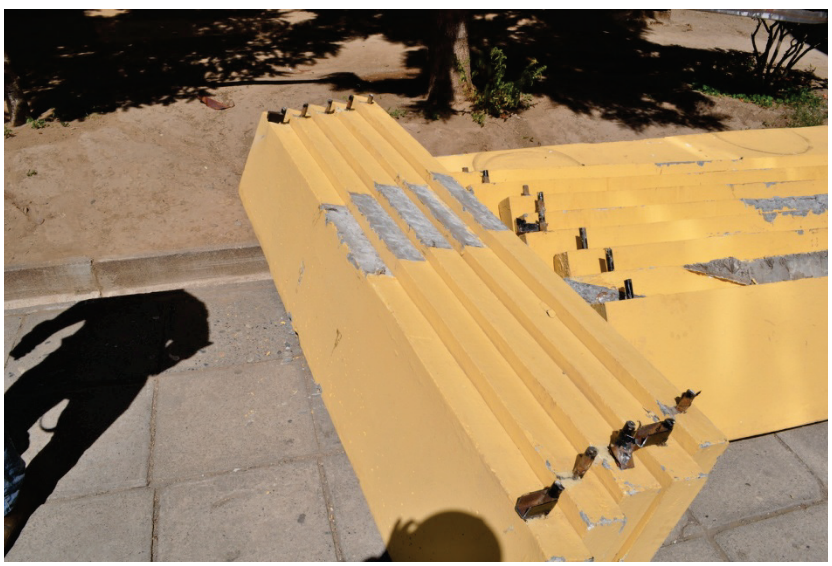


Figure 6.3.1.3-7 Numerous precast panels removed to prevent falling; detail from residential building in Rancagua, Chile above. These panels had a bearing seat at the center and supported on steel dowels at either end (Photo courtesy of Eduardo Fierro, BFP Engineers).

Seismic Mitigation Considerations

- Precast panel connections and panel joints require specialized design based on the expected inter-story drift of the structural system supporting them or 0.5 inch, whichever is greater. The connections must be detailed with sufficient ductility and rotation capacity to prevent failure. Typically, the panels are seated on two bearing connections at either the top or bottom floor and then have "push-pull" connections at the adjacent floor which resist out-of-plane loading but move laterally in the plane of the panel. In this way, the panels move with the floor where the bearing connections are located and the drift is accommodated by the rod at the "push-pull" connection. In order to work effectively, the "push-pull" connection must be able to accommodate the expected drift without extensive inelastic action. For sliding-type connections, this has traditionally been accomplished by using an oversize hole or slot large enough to accommodate the design drift in each direction, but recent testing has shown that this configuration can bind and restrict movement and not work as well as anticipated. For connections utilizing threaded rods, the length of the rod should be sufficient to prevent extensive yielding of the rod in bending, since this may result in premature fracture of the rod due to low-cycle fatigue.
- Prefabricated panels can be installed in a manner that forces the building deformations to occur over a distance substantially less than the story height. For example, "banded" precast concrete wall systems often feature spandrels at each floor level and with glazing and precast column covers spanning from the top of one spandrel to the bottom of the spandrel on the floor above. When the building displaces laterally, the spandrels move with the floors, acting as rigid bodies. The story drift has to be accommodated by the glazing and column covers.
- While both the rocking and sway mechanisms, as illustrated in Figures 6.3.1.3-8a through c, are effective methods of accommodating story drift, mixing mechanisms in adjacent panels may potentially close the joints between units, resulting in a collision between adjacent panels. To avoid this, the joints between panels have to be sized to allow for panel rotation and translation.Architectural Design for Earthquake, A Guide to Nonstructural Elements, (Charleson, 2007) has a detailed discussion of issues related to exterior cladding. Sliding connections with slotted or oversized holes are commonly used in New Zealand as an alternative to push-pull connections.
- DN-21, *Behavior of Architectural Precast Panels in Response to Drift* (PCI, 2011) contains an extensive discussion of the different mechanisms used to accommodate story drift.

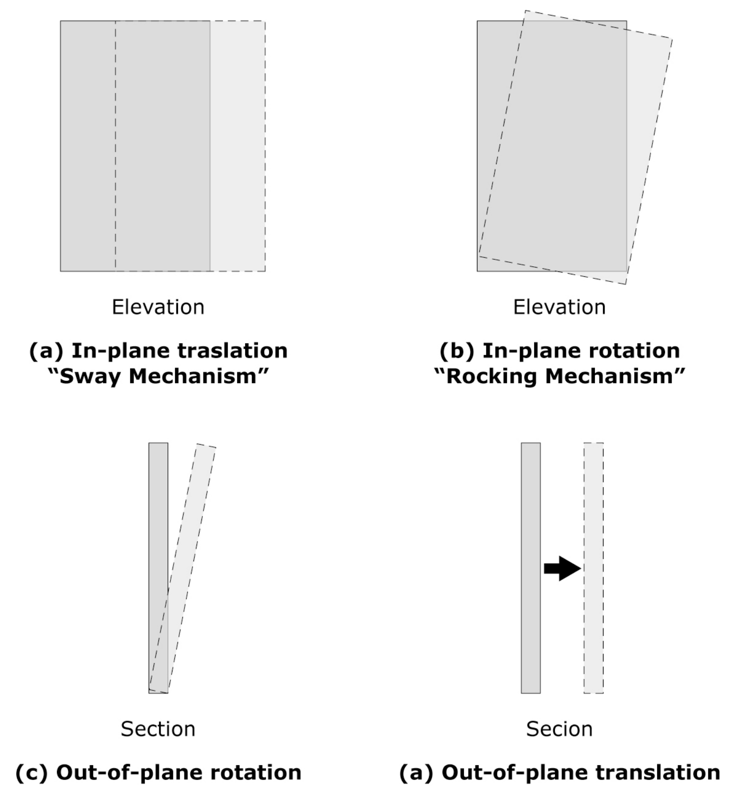


Figure 6.3.1.3-8a Modes of panel response to displacement.

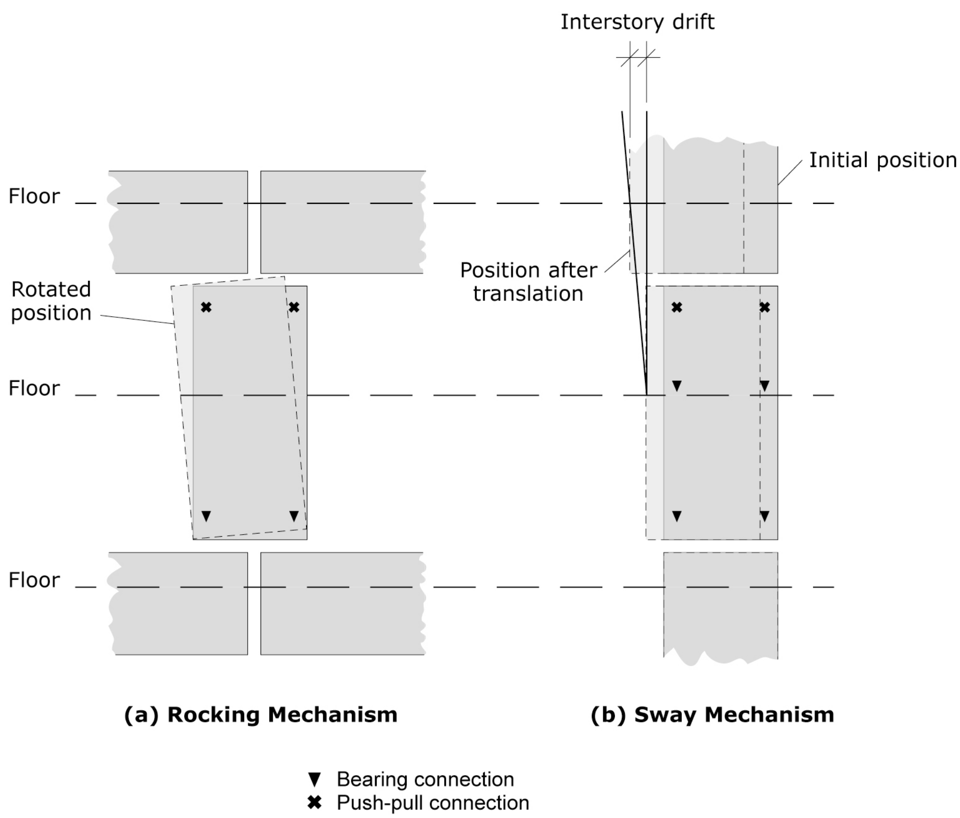


Figure 6.3.1.3-8b Tall and narrow panels designed to accommodate seismic drift.

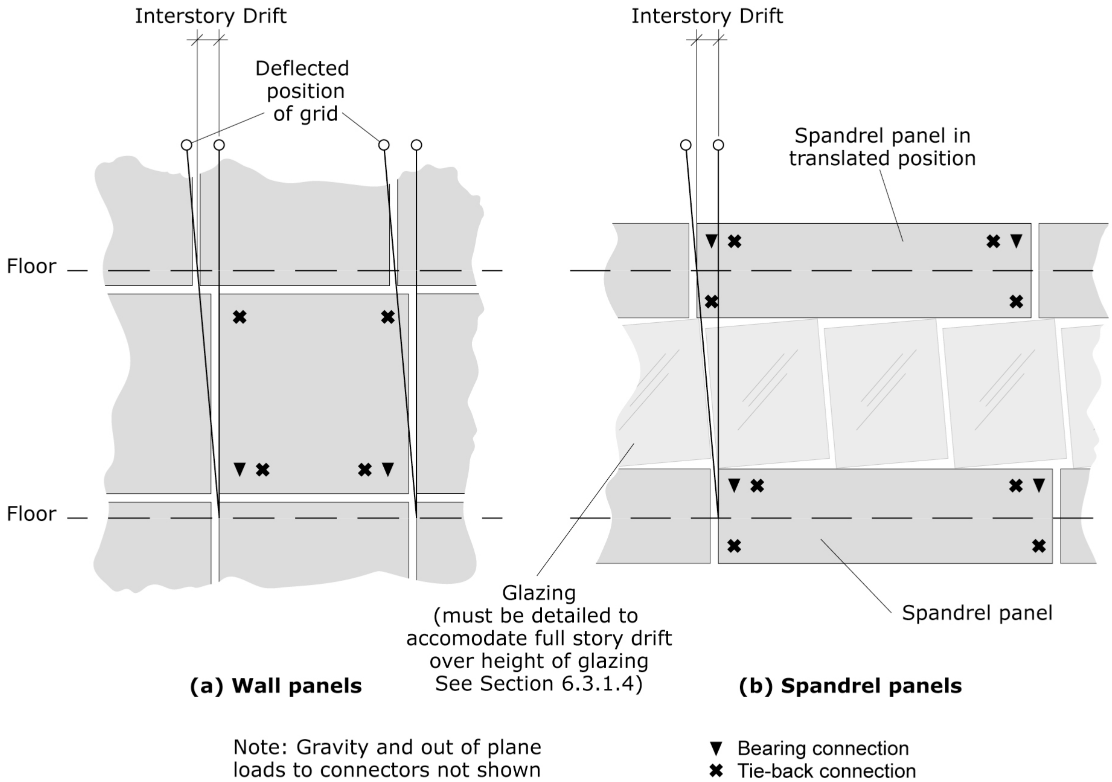
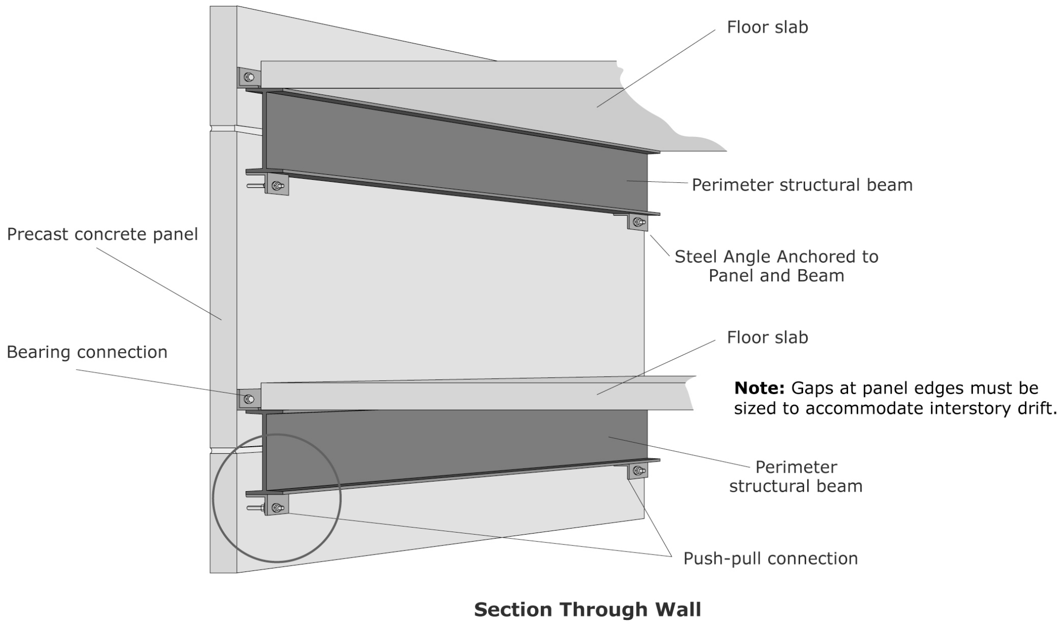


Figure 6.3.1.3-8c Low aspect ratio panels designed to accommodate seismic drift.

Mitigation Details

Figure 6.3.1.3-9 Precast spandrel panel in San Francisco parking garage supported by bearing connections near top of panel (left) and slotted connections at bottom of panel (right); panels have four connections each. The remnants of a previous nonductile connection detail are visible in the photo at left (Photo courtesy of Cynthia Perry, BFP Engineers).



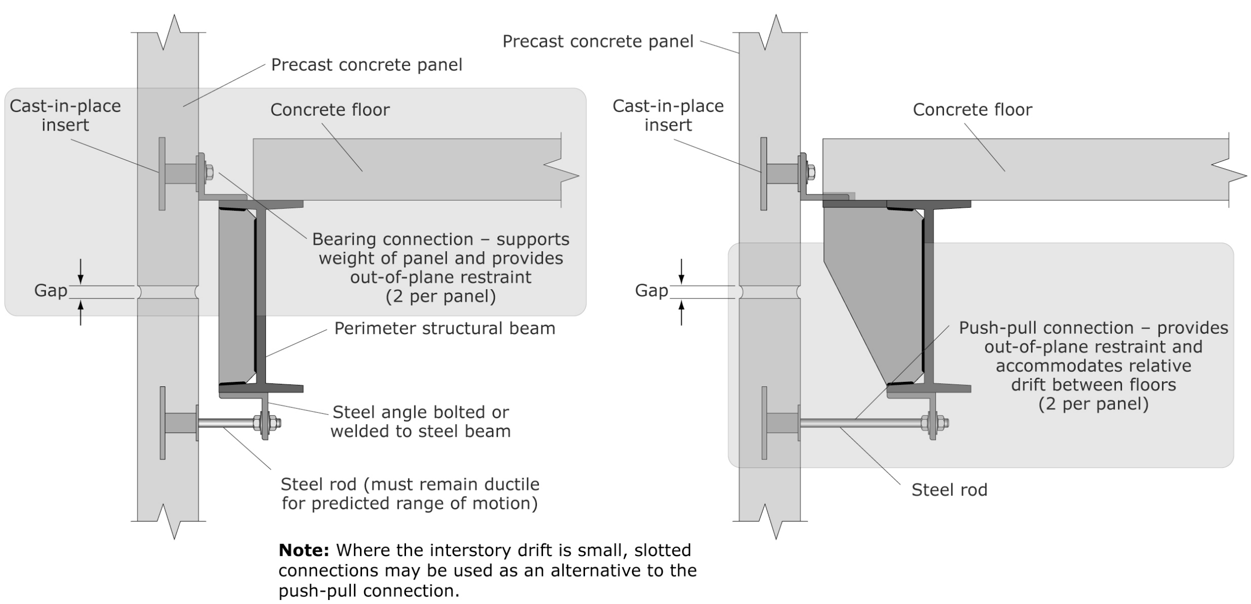


Figure 6.3.1.3-10 Prefabricated panels (ER).