6.3 Architectural Components

6.3.1 Exterior Wall Components

6.3.1.4 Glazing

Glazing includes glass curtain walls on multistory buildings, large storefront windows, as well as small, operable wood framed windows. Glass may be annealed, heat-strengthened, tempered, laminated or in sealed, insulating glass units. Glazing can be installed using either wet or dry glazing methods. Any of these may pose a significant falling hazard if not designed to accommodate seismic forces and displacements.

Provisions

BUILDING CODE PROVISIONS

ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010) focuses on providing a mechanism to accommodate building deformations, or sufficient ductility to accommodate drift without a failure of the glazing system.

- The building code has specific requirements on the type of glazing that may be used in different areas. Tempered glass is required within 10' above a walking surface under some circumstances; check applicable code requirements. Wired glass with a grid of steel wire embedded in the pane is an option for some situations where fire and impact rating are not also required. ANSI A97.1 *Safety Glazing Materials Used in Buildings* (ANSI, 2004) is the standard that defines different kinds of safety glass.
- The design of glazing assemblies depends on the calculated inter-story drift for the building, and the type of glass.

RETROFIT STANDARD PROVISIONS

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

- Glazed exterior wall systems 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, or
  - The performance level is Hazards Reduced in high, moderate, and low seismicity areas and the glazing is located over areas of public access or egress.

- Acceptance criteria focus on performing a drift analysis to determine if the glazing can accommodate the expected story drifts, and the anchorage of the panels under seismic loading. The evaluation approach is similar to that used in ASCE/SEI 7-10.

Typical Causes of Damage

- Glazing assemblies are sensitive to both accelerations and deformations and are subject to both in-plane and out-of-plane failures. Glazing is particularly vulnerable in flexible structures with large inter-story drifts; large storefront windows are also vulnerable.
- The performance of glazing in earthquakes generally falls into one of four categories:
    - The glass remains unbroken in its frame or anchorage
    - The glass cracks but remains in its frame or anchorage while continuing to be a weather barrier
    - The glass shatters but remains in its frame or anchorage in a precarious position, liable to fall out at any time
    - The glass falls out of its frame or anchorage. Glass can fall in shards, shatter into small pieces, or broken panes may be held in place by film. Many of the glazing performance issues in earthquakes are a result of poor installation techniques. These include failure to provide clearances, use of improper shims, and failure to hold dimensional tolerances.

DAMAGE EXAMPLES

Figure 6.3.1.4-1 Shard of broken untempered glass that fell several stories from a multistory building in the 1994 Northridge Earthquake (Photo courtesy of Wiss, Jenney, Elstner Associates).

Figure 6.3.1.4-2 Scenes in Ferndale, California following the 2010 magnitude-6.5 Eureka Earthquake. 50% of the glazing on Main Street was cracked (Photos courtesy of Bret Lizundia, Rutherford & Chekene).

Figure 6.3.1.4-3 Glazing damage was observed in many residential and commercial buildings and hospitals throughout central Chile following the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Eduardo Miranda, Stanford University).

Figure 6.3.1.4-4 Glazing damage, due in part to pounding with the structure at right during the 2010 Chile Earthquake (Photo courtesy of Antonio Iruretagoyena, Rubén Boroscheck & Associates).

Figure 6.3.1.4-5 Overhead glazing damage from the 2010 Chile Earthquake (Photo courtesy of Eduardo Miranda, Stanford University).

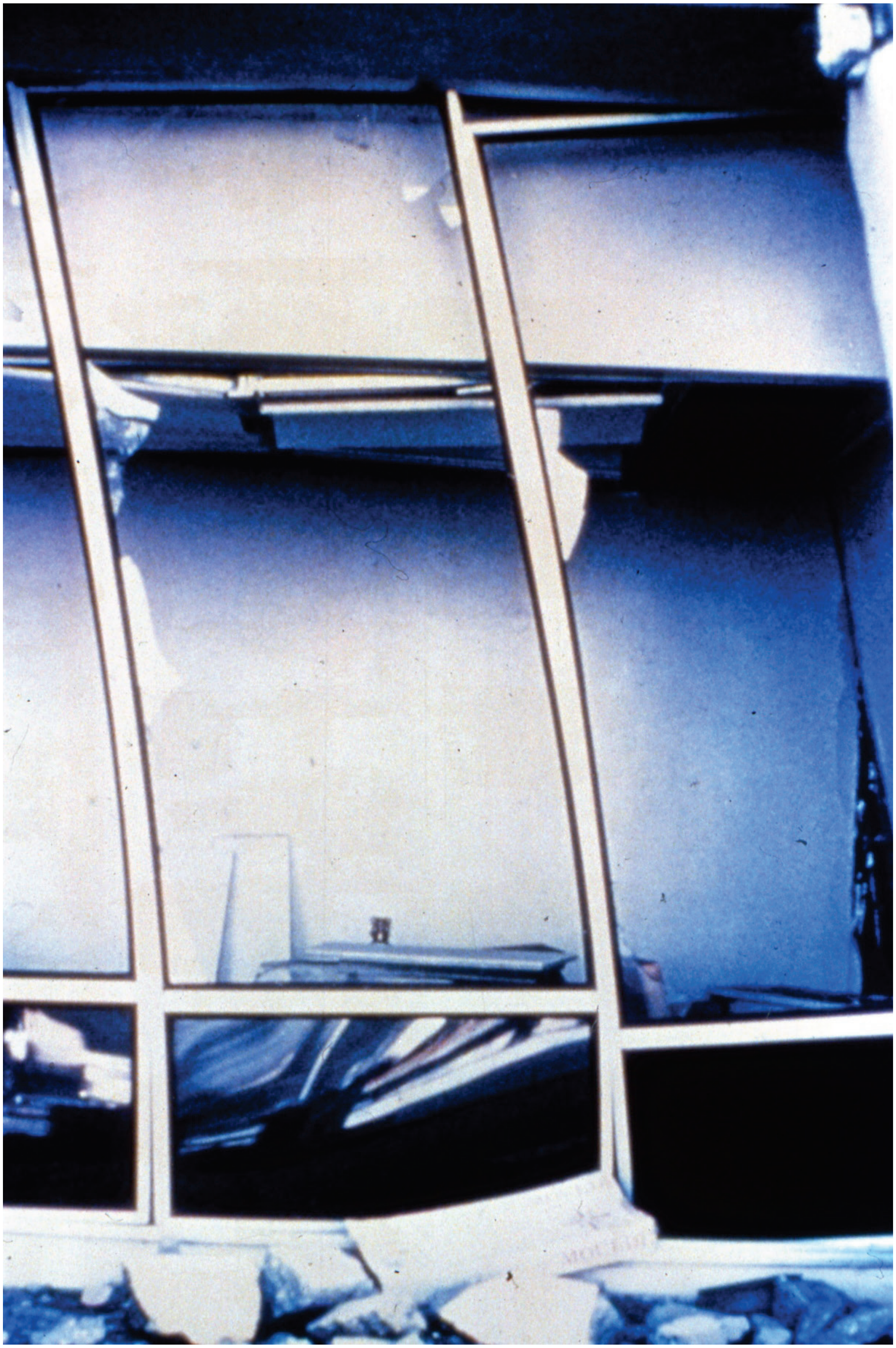

Figure 6.3.1.4-6 Broken glass and bent window mullions in flexible building which experienced large inter-story drift in the 1994 Northridge Earthquake (FEMA 310, 1998).

Seismic Mitigation Considerations

- The current glazing design provisions are the result of extensive testing. A full description of the test program can be found in FEMA 450-2, *NEHRP Recommended Provisions and Commentary for Seismic Regulations for New Buildings and Other Structures, Commentary. 2003 Edition* (BSSC, 2004).
- Glazing that remains in place and acts as a weather barrier (even if cracked) satisfies both immediate occupancy and life-safety performance objectives. If the glass shatters or falls, the level of hazard depends on the post-breakage characteristics of the glass and the height from which it falls.
- The term safety glass refers to tempered or laminated glazing and is required by code in a number of applications such as glazing in or adjacent to exits, within 10' of a walking surface, etc. Use of tempered glass will greatly reduce the seismic hazard because tempered glass breaks into small dull fragments instead of large hazardous shards. However, since the tempered glass fragments tend to fall from the frame or anchorage in clusters, they are potentially harmful to humans if they fall from greater heights. Laminated glass will typically remain in place when broken and will prevent people or objects from falling through the opening. Storefront windows are often vulnerable as the windows occupy a large structurally unsupported area at the ground floor, often resulting in soft story or torsion problems. Use of laminated glass for storefront windows reduces the seismic risk and also increases protection from burglary and vandalism.
- Plastic films that help hold glass fragments together even if the pane breaks are available. These films may reduce seismic risk associated with dislodged fragments, which pose a safety risk, particularly if they fall from great heights. Strategic application of plastic films where glazing is directly over an exit way, within 10' of an exit way, or along interior corridors may provide sufficient risk reduction if other areas surrounding the building have limited public access. Plastic films may be a cost effective way to retrofit an existing pane of glass and are often installed for other reasons, such as security or reducing solar heat gain. Extending the film over the edge of the surrounding frame is advisable not only to hold broken fragments in place but also to prevent the entire pane from falling out. Avoid placing beds, desks, chairs or couches that are typically occupied many hours a day near large plate glass windows.
- Liberal use of landscaping strips or areas with restricted pedestrian access may help to reduce the seismic risk beneath large glass panes or tall curtain walls.

Mitigation Details

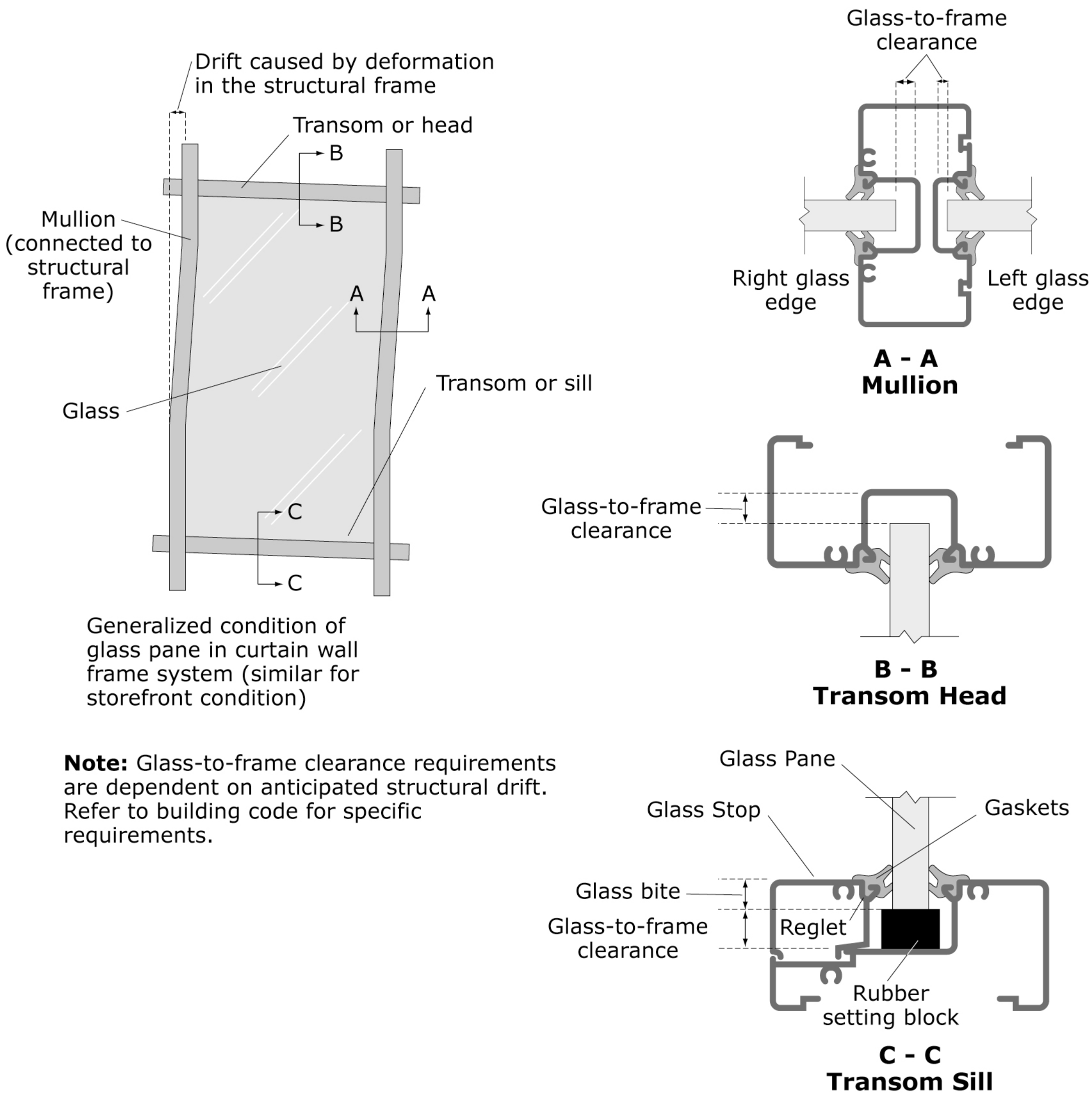

Figure 6.3.1.4-7 Glazed exterior wall system (ER).