Briefing Paper 3

Seismic Response of Wood-Frame Construction

Part B: The Role of Wood-Framed Diaphragms

Introduction

This Briefing Paper 3, *Seismic Response of Wood-Frame Construction*, consists of three parts that discuss how earthquakes affect wood-framed construction, including specifics regarding their earthquake-resisting elements, and identifies construction features required for good seismic performance. Part A provides a brief overview of how earthquakes affect wood-frame construction and explains the load path in wood construction. This Part B describes diaphragm chords and collector elements, lateral-force transfer within diaphragms, and lateral-force transfer from diaphragms to shear walls or frames. Part C discusses wood-framed, shear-wall construction including stiffness issues and hold-downs.

Diaphragms, Chords, and Collectors

Wood-frame buildings use wood construction for the roof and floors, and many low-rise concrete and masonry wall buildings use a wood-framed roof. These elements, called horizontal diaphragms, are constructed in modern buildings using wood structural panels (e.g., plywood, or oriented strand board) fastened with nails or staples to the various vertical-load-carrying wood framing members (e.g., sawn lumber joists and purlins, truss-type joists, or glulam or paralam beams) spanning between supporting walls or frames.

A diaphragm transfers lateral forces by acting like a horizontal beam (Figure 1). It spans between shear walls or frames located in the story below the diaphragm. During an earthquake, the diaphragm is subjected to horizontal forces that are based on its own mass and the tributary mass of the walls attached along its edges (for information on calculating tributary mass, see Briefing Paper 1, Part B). The exact amount of the force depends on the design ground acceleration and the type of resisting system being used. Wood-frame shear wall systems will generally produce smaller diaphragm design loads than buildings with heavier concrete or masonry walls.

Just like a vertical-load-carrying beam, the ends of the diaphragm must transfer the lateral forces

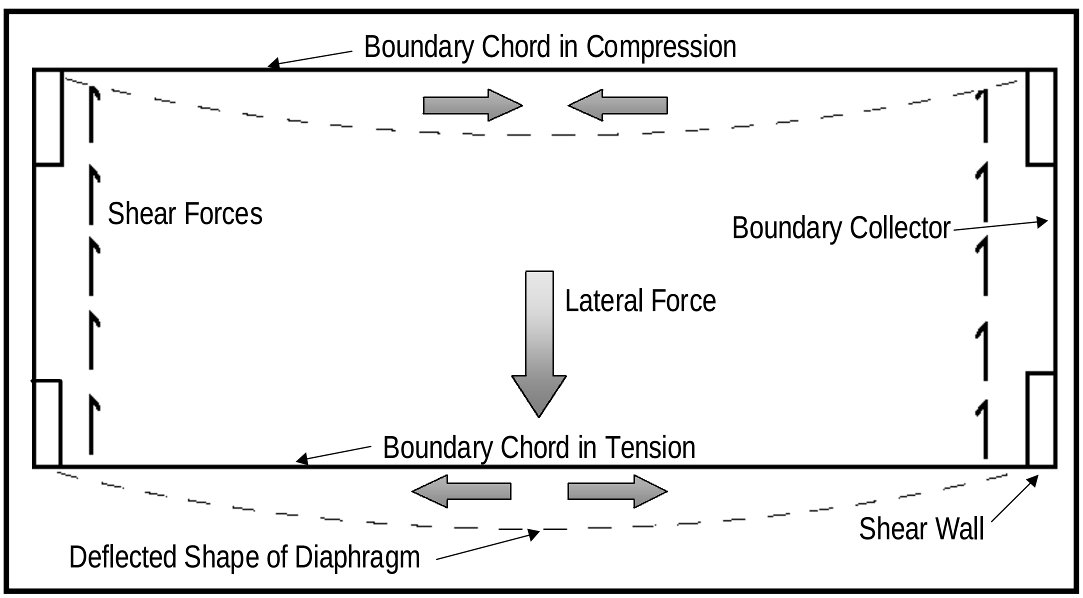

Figure 1. Plan view of diaphragm showing elements and deflected shape under lateral loading.

to the resisting shear walls or frames. The connection between the diaphragm edge or "boundary" and the walls or frames must transmit the shear forces. As described in Briefing Paper 1, Part D, this connection is provided by a load path member called a collector, which collects forces from along the diaphragm edge and carries them to the adjacent shear wall or frame (Figure 1). The specific type of collector member used will vary, depending on the construction of the walls below the diaphragm edges. In a building with a wood-framed diaphragm and concrete or masonry walls, the collector is normally a wood ledger that is bolted to the wall. When the walls below are wood-stud framing, the collector is usually the double top plate of the stud wall. At interior shear walls, the collector is most often a wood beam located in the plane of the roof or floor. In each of these cases, the collector transmits earthquake forces along its length and also carries vertical dead and live loads. Accounting for both the lateral and vertical loads is necessary when designing the connections and determining the size of the collector.

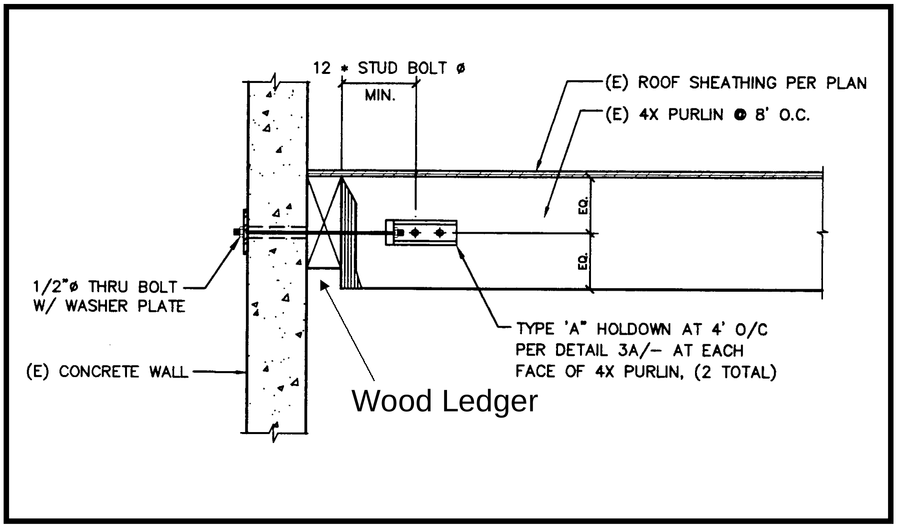

Figure 2. Collector element--wood ledger connecting roof/floor diaphragm to wall

As the diaphragm bends due to lateral forces (Figure 1), it creates either a tension or compression force in the chord member. This force is greatest at the middle of the appropriate span between the walls or frames. In wood-frame stud-wall construction, the double top plates of the wall perform the chord function. Because tension occurs in the chord, any splices in a top plate must be specifically designed to resist tension, or the chord will pull apart. If the top plate is cut to accommodate piping or other penetrating items, the portion removed can seriously reduce the plate's ability to function as a chord. Holes, large notches and other interruptions of the top plate should be properly reinforced to maintain the capacity to resist chord forces. Steel straps are often used to provide replacement capacity. However, straps often do not work well in compression, so that thicker top plates or supplemental blocking installed between studs and immediately below the top plates may also be necessary.

In wood stud wall buildings, the double top plate normally serves as both a boundary collector and a chord. This is because diaphragm forces acting parallel to the wall use the plate as a collector, and forces acting perpendicular to the wall use it as a chord. This dual purpose makes the wall top plate a critical element in the load path of wood-frame construction.

Force Transfer within a Wood Diaphragm

The sheathing fastened to the top surface of a wood-framed floor or roof diaphragm is a membrane that provides the diaphragm with the shear capacity to transmit lateral forces to the walls and frame elements (Figure 3). The shear capacity is primarily determined by the thickness of the sheathing and the size and spacing of the fasteners attaching the edges of each individual piece of sheathing to the framing below. However, the sheathing layout pattern and the use of wood blocking below the edges also affects the capacity. The layout of the short side of the sheathing edges is usually staggered between adjacent rows to provide greater capacity. When all edges occur over framing, the diaphragm is called fully blocked. A blocked diaphragm contains more fasteners, thereby increasing its resisting capacity. Unblocked

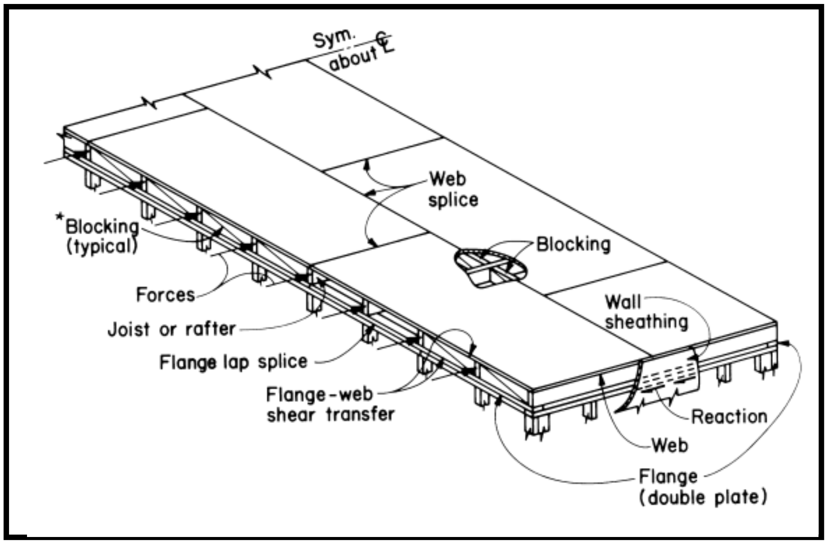

Figure 3. Sheathing in typical wood diaphragms.

diaphragms do not have a nailing surface below the long edges of the sheathing and consequently they have less capacity. The minimum thickness (width) of the framing below sheathing edges with closely spaced nails is also important. These framing members receive fasteners from two abutting panel edges, and the framing must be wide enough to prevent its splitting when two rows of fasteners are used.

Openings through diaphragms occur where duct shafts, stairs, and skylights are located. These openings interrupt the flow of forces through the diaphragm. If the openings are large enough, special straps along their edges are required to complete the load path and transfer forces around the opening. A stair or other opening along a diaphragm boundary edge can sometimes interrupt a collector or chord member, so special attention must be given to the load path when openings occur along edges.

Wood diaphragms also provide bracing for out-of-plane forces on walls. The out-of-plane earthquake forces are a result of the diaphragm pushing or pulling on the walls in response to building drift and also from the bending of the diaphragm itself. Adequate resistance for out-of-plane forces is important in every building. It is particularly critical when the walls are concrete or masonry, and the diaphragm is wood construction. The out-of-plane loads caused by concrete or masonry walls attached to the diaphragm are large, and if inadequate connections are provided, the walls may pull away from the roof or floor. As shown in Figure 4, this can result in a collapse of the roof or floor in that region, and the wall itself may also fall. To prevent this type of failure, additional load path connections are needed to secure the diaphragm to the walls. Diaphragm beams and purlins perpendicular to the wall must be anchored directly to the concrete or masonry wall. In addition, the anchor connection to the wood members must be symmetrical. Therefore, if the anchor is mounted to the side face of a beam, an identical anchor should be placed on the opposite beam face. Where beams perpendicular to the wall

Figure 4. Concrete Tilt-Up Wall Building with Failure at the Wall-to-Roof Connection

are widely spaced, additional lines of blocking may be needed to provide a load path for the out-of-plane wall anchorage.

Wall anchors produce additional stress within the diaphragm because the out-of-plane anchorage force must be resisted by the nailing of diaphragm sheathing along the line of the anchored beams. An unblocked diaphragm normally requires extra fasteners along panel edges occurring over those anchored beams. The code also requires continuous cross ties between walls on opposite sides of the building to resist out-of-plane loads. Where beams are not a single continuous piece across the entire diaphragm, the individual beams must be spliced to provide this continuous tie. These splices may be constructed using steel plates with bolts through the beams and may also require welded connections where beams intersect interior steel columns.

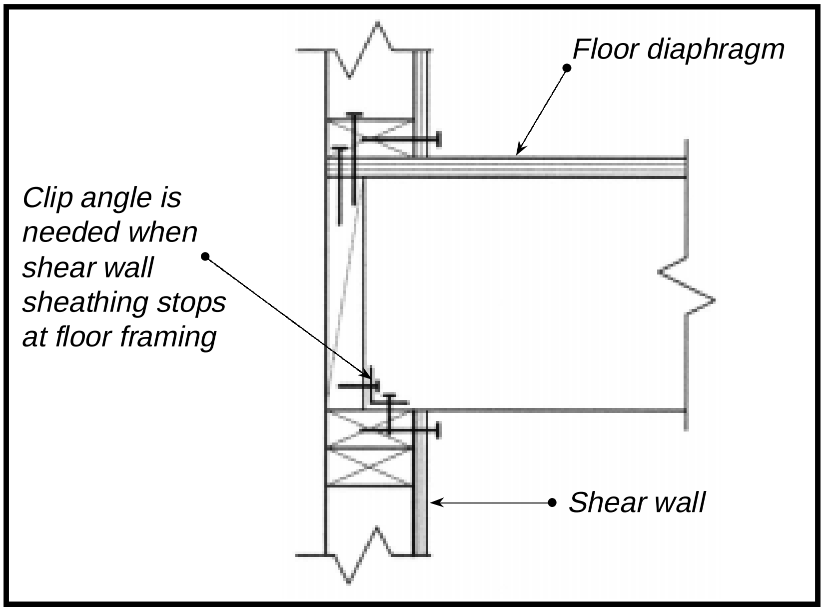

Figure 5. Connection of Floor Rim Joist or Blocking to Top Plate of Wall Below

Transfer of Diaphragm Forces to Walls or Frames

The sheathing fasteners along the diaphragm boundary edges transfer forces out of the diaphragm to the collectors or directly to shear walls or frames. This makes those locations particularly important for providing a complete load path. However, this is only one piece of the load path between the horizontal diaphragm and the vertical resisting elements below. The boundary edge framing member (edge beam, rim joist, or blocking) below the sheathing must also be attached to a shear wall top plate, or a wood nailer attached to the top of a frame beam to complete the transfer of forces. Several methods can be used for this connection, depending on how the designer details the shear transfer. Rim joists and edge blocking can be connected to wall plates using sheet metal angles and nails, as shown in Figure 5•3. Alternatively, the wall sheathing can be fastened to both the diaphragm edge member and the wall top plate. Regardless of the specific details used, this part of the load path must be provided.

Resources for Additional Reading

ATC, 1995, *Guidelines for the Design of Horizontal Wood Diaphragms*, Applied Technology Council, Report ATC-7, Redwood City, California.

About this Briefing Paper Series

Briefing papers in this series are concise, easy-to-read summary overviews of important issues and topics that facilitate the improvement of earthquake-resistant building design and construction quality.

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ATC/SEAOC Joint Venture
c/o Applied Technology Council
555 Twin Dolphin Drive, Suite 550
Redwood City, California 94065