Briefing Paper 3

Seismic Response of Wood-Frame Construction

Part C: The Role of Wood-Framed Shear Walls

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 an overview of how earthquakes affect wood-frame construction and explains the load path in wood construction. Part B describes diaphragm chords and collector elements, lateral-force transfer within diaphragms, and lateral-force transfer from diaphragms to shear walls or frames. This Part C discusses wood-framed, shear-wall construction including stiffness issues and hold-downs.

The purpose of shear walls is to provide both the strength and stiffness necessary to resist lateral loads.

This discussion of shear walls (Figure 1) is limited to wood-stud wall framing using wood structural panel sheathing, because this is the predominant type of shear wall used to resist seismic forces in wood-frame buildings. Wood-stud shear walls resist lateral loads from earthquakes and wind, but only the earthquake-resisting aspects are emphasized herein. Other types of sheathing materials are allowed by the code, and steel-stud framing is also an alternative; however, these are not discussed. Also, steel frames used as resisting elements are not discussed.

The purpose of shear walls is to provide both the strength and stiffness necessary to resist lateral loads from the diaphragm immediately above and from the wall in the story above, and to transmit these horizontal loads down one story into either a shear wall in the story below or to the building foundation. Shear walls also usually carry vertical loads from the roof and floors above. However, a vertical-load-bearing wall is not always a shear wall. An exterior bearing wall may have wood structural sheathing applied to the exterior face for architectural purposes and may appear like a shear wall, but not be designed to resist earthquake forces. In engineered buildings, only those walls that are properly connected to the diaphragm and that have been provided with adequate resistance to sliding and uplift forces qualify as shear walls. Buildings using "conventional light-frame construction provisions" as their basis do not contain shear walls; instead they use what are called "braced wall panels." These braced wall panels perform the same function as shear walls, but they are not required to be analyzed for the forces they must resist.

Shear-Wall Strength and Stiffness

Wood-framed shear walls consist of double top plates, studs, and sole or sill plates, sheathed with wood structural panels on one or both sides. The sheathing and its attachment to the framing perform the same function as in a horizontal diaphragm; that is, they resist lateral loads in the plane of the wall. Because shear walls must have all sheathing edges blocked, the wall's strength capacity depends only on the sheathing

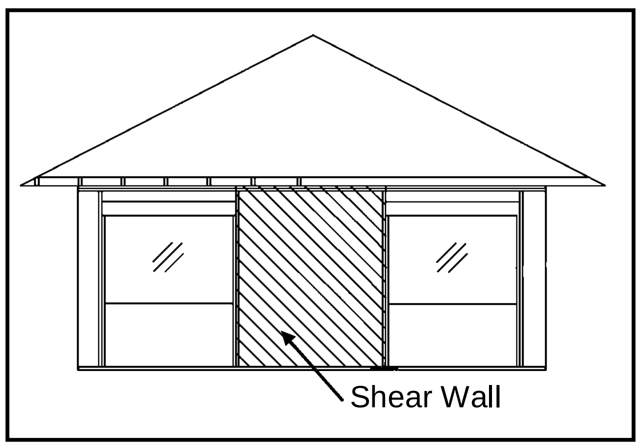

Figure 1 . Wood shear wall along exterior wall line.

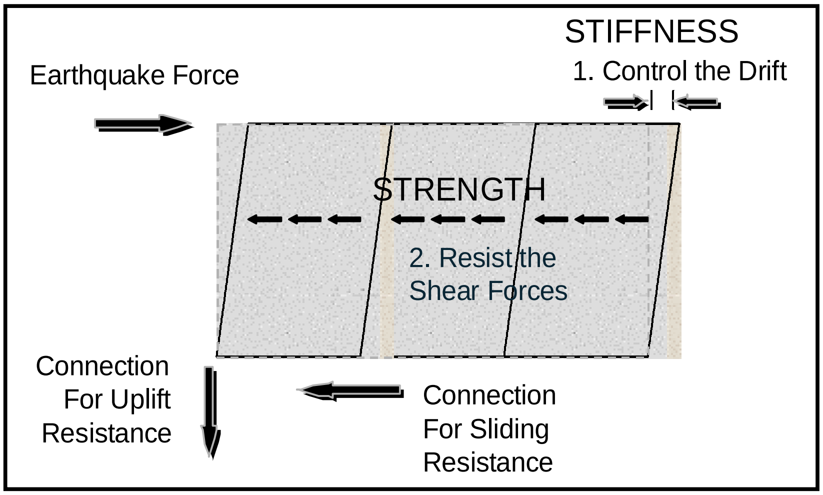

Figure 2. The two functions of shear walls are to provide stiffness and strength.

grade and thickness, and the fastener size and spacing.

Overturning and Hold-Downs

The stiffness of a shear wall, which is its ability to resist in-plane deflection, is a more complex issue, but it is the most important attribute for limiting earthquake damage (Figure 2). A shear wall is essentially a cantilever, fixed at its base but able to move laterally, in its plane, at the top. The amount of deflection that occurs at the top depends on the stiffness of the shear wall, which in turn is affected by the height-to-width ratio of the wall. If two identically constructed shear walls of equal height resist the same lateral force, the narrower wall undergoes greater deflection. This is one reason that the 1997 *Uniform Building Code* (UBC) reduced the maximum height-to-width ratio of shear walls from 3.5:1 to 2:1 for buildings located in Seismic Zone 4 (most of California). Other factors that influence stiffness include the shear strength capacity of the sheathing and its attachment, and the potential vertical slip that can occur in the hold-down connections, located at the ends of the wall to resist vertical uplift loads.

The 1997 UBC reduced the maximum height-to-width ratio of shear walls from 3.5:1 to 2:1 for buildings located in Seismic Zone 4 (most of California).

Shear walls receive lateral forces from the diaphragm above through the connections described above. As shown in Figure 2, lateral forces enter the shear wall along the double top plates. The lateral force acts to slide the wall in the direction in which the load is acting, and to lift simultaneously the left end of the wall shown in Figure 2.

To resist sliding, the shear wall bottom (sole) plate of an upper-story wall must be connected along its length with nails long enough to pass through the floor sheathing and to penetrate into the floor framing or blocking below. Shear walls framed on top of a foundation stem wall or concrete slab on grade must have the sill plate bolted to the foundation or slab (see Figure 3). Proper connection of the bottom plate of a shear wall is essential for good earthquake performance.

As described above, the lifting action at the end of a shear wall is a result of the horizontal force acting along the top plate attempting to tip the wall over (overturning force). While one end is being lifted, the other end is being pushed down, so the studs or post at the wall ends are alternately placed in tension or compression, depending on the direction in which the lateral load is applied. To resist the lifting action, shear walls often have anchor straps or brackets called hold-downs attached to the wall studs or posts at each end of the wall (see Figure 3). It is important that these anchors be located at the wall ends because their

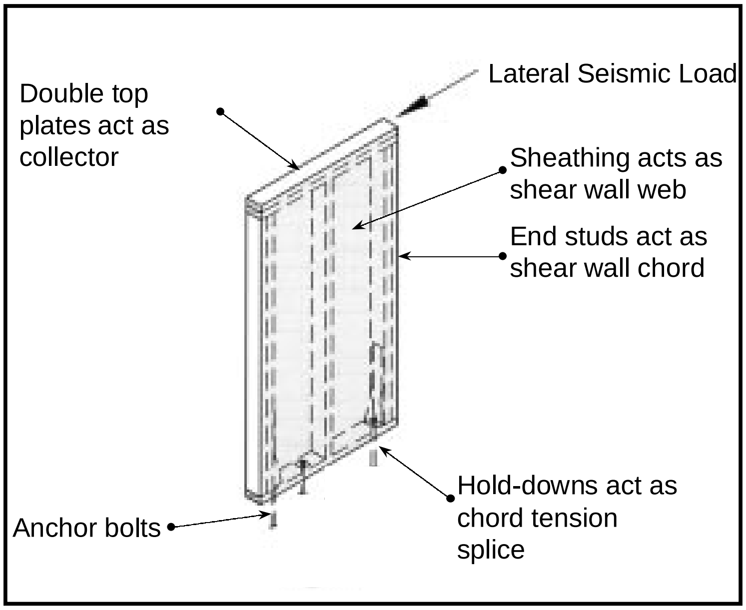

Figure 3 . Typical shear-wall elements.

location defines the length of the shear wall that can be used in the design of the components resisting lateral loads. In upper-story walls, hold-downs must extend through to, and attach to, the wall framing in the story below. Where a wall is not directly below it, the hold-down must attach to a floor beam or wall header to complete the load path leading to the foundation. When walls are framed on a foundation stem wall or slab, the hold-down anchor is embedded in the foundation (Figure 4).

Proper connection of the bottom plate of a shear wall is essential for good earthquake performance.

In addition to providing uplift restraint, hold-downs also limit the in-plane deflection of a shear wall and thereby contribute to its overall stiffness. A certain amount of deflection is expected when a shear wall absorbs earthquake forces, but too much deflection causes damage to other parts of the building that are sensitive to deflection, such as gypsum board or plaster finishes. Improper hold-down installation can result in vertical slip. Vertical movements at the base of the wall allow the top of the wall to deflect horizontally, with the amount of deflection dependent on the height-to-width ratio of the shear wall. If a 1/2-inch vertical slip occurs at the bottom corner of a shear wall that is four feet wide and eight feet tall, it will result in a one-inch horizontal movement at the top. This one-inch deflection is in addition to the horizontal deflection that is expected to occur based on the stiffness of the shear wall itself. Consequently, improper hold-down installation is an important source of earthquake damage. If a hold-down using bolts is incorrectly installed with oversized bolt holes through a wood end post, vertical slip or movement will occur at that location. Vertical slip can also occur if the nut is not tightened on the top end of the threaded rod from a hold-down into the foundation. Mis-alignment of hold-down anchor rods and kinks in steel straps also permit movement as they are straightened when placed in tension by uplift forces.

Occasionally, hold-downs may not be required. One situation occurs when the lateral loads are relatively small compared with the dead load supported by the wall or its end posts. The other situation is when a shear wall is very wide relative to its height. A wide shear wall has the center of its dead load located further from the end of the wall and this distance creates more leverage to resist the uplift at the ends. If the structural analysis shows that the dead load is large enough to resist the uplift

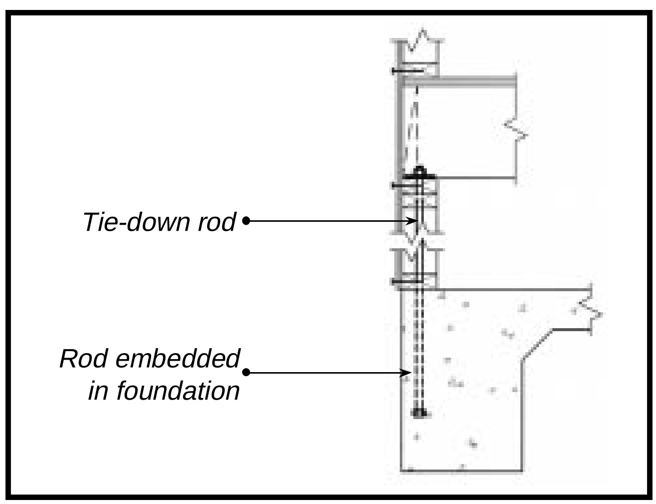

Figure 4 . Hold-down anchorage.

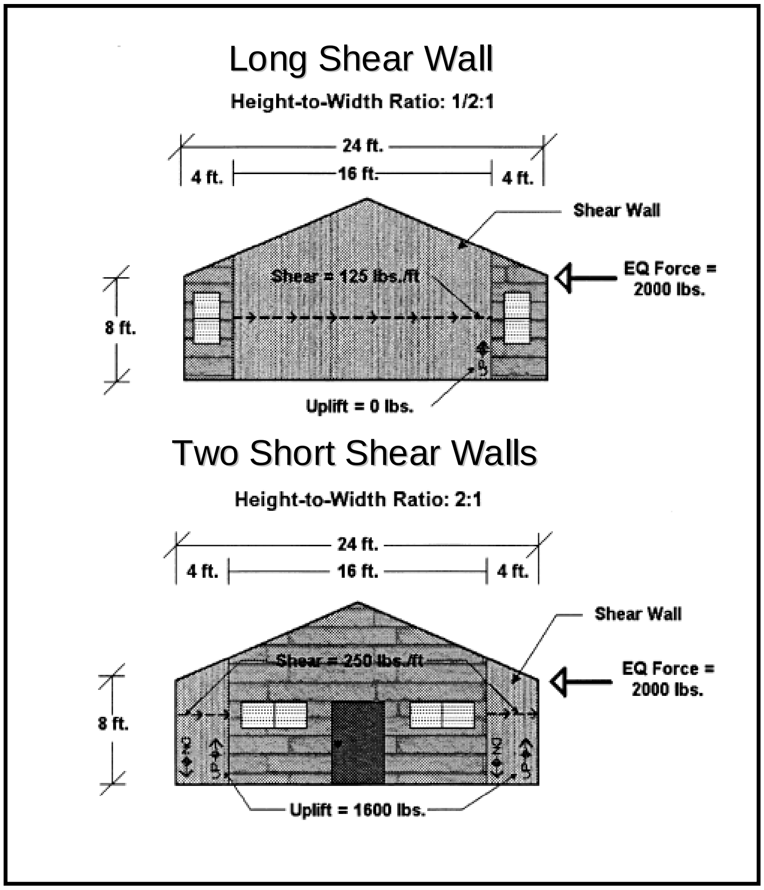

Figure 5 . Comparison of forces in shear walls of different length. There are no uplift forces in the 16-ft long shear wall at the top of the figure, whereas uplift forces at the corners of the 4-ft long shear walls in the lower figure (one wall at each end) equal 1800 pounds for the same lateral earthquake force and uniform deadload (200 lb/ft).

force at the end of the wall, a hold-down is not required. This concept is illustrated in Figure 5.

Reference

ICBO, 1997, *Uniform Building Code*, International Conference of Building Officials, Whttier, 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.

This briefing paper was prepared by the ATC/SEAOC Joint Venture, a partnership of the Applied Technology Council (ATC) and the Structural Engineers Association of California (SEAOC). Funding for the series was provided by the California Seismic Safety Commission, Proposition 122 Retrofit Practices Improvement Program.

Copies of Briefing Papers can be downloaded from ATC's World Wide Web site (www.atcouncil.org), or are available from:

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