3 SHEAR WALLS

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SHEAR WALLS

This section provides an introduction to shear walls and how they resist earthquake and wind forces. This section also shows how to properly construct the shear walls and the parts that make them up. With this knowledge, contractors can build proper shear walls and inspectors can recognize the errors untrained contractors make.

GETTING THE BIG PICTURE

WHAT IS A SHEAR WALL?

Shear walls are vertical elements of the horizontal force resisting system. They are typically wood frame stud walls covered with a structural sheathing material like plywood. When the sheathing is properly fastened to the stud wall framing, the shear wall can resist forces directed along the length of the wall. When shear walls are designed and constructed properly, they will have the strength and stiffness to resist the horizontal forces. (Fig. 3.1)

WHERE SHOULD SHEAR WALLS BE LOCATED?

Shear walls should be located on each level of the structure including the crawl space. To form an effective box structure, equal length shear walls should be placed symmetrically on all four exterior walls of the building. Shear walls should be added to the building interior when the exterior walls cannot provide sufficient strength and stiffness or when the allowable span-width ratio for the floor or roof diaphragm is exceeded. For subfloors with conventional diagonal sheathing, the span-width ratio is 3:1. This means that a 25-foot wide building with this subfloor will not require interior shear walls until its length exceeds 75 feet unless the strength or stiffness of the exterior shear walls are inadequate. (Fig. 3.2)
Shear walls are most efficient when they align vertically and are supported on foundation walls or footings. When shear walls do not align, other parts of the building will need additional strengthening. Consider the common case of an interior wall supported by a subfloor over a crawl space and there is no continuous footing beneath the wall. For this wall to be used as shear wall, the subfloor and its connections will have to be strengthened near the wall. For new construction, thicker plywood or extra nailing and connections can be added. For retrofit work, existing floor construction is not easily changed. That's the reason why most retrofit work uses walls with continuous footings underneath them as shear walls. (Fig. 3-3)
Another type of alignment problem occurs when the ends of shear walls do not align from story to story. This condition creates the need for extra framing members and connections in the walls for holdown devices. Holdown devices must transfer the uplift from the shear wall to framing members that can resist it. When full height studs are not available, special connections must be added. These connections must assemble enough of the structure’s framing to resist the uplift. (Fig. 3-4, 3.5)

**WHAT TYPES OF FORCES DO SHEAR WALLS RESIST?**

*Shear walls resist two types of forces: shear forces and uplift forces.* Connections to the structure above transfer horizontal forces to the shear wall. This transfer creates shear forces throughout the height of the wall between the top and bottom shear wall connections. The strength of the lumber, sheathing and fasteners must resist these shear forces or the wall will tear or shear apart (Fig. 3-6).
Uplift forces exist on shear walls because the horizontal forces are applied to the top of the wall. These uplift forces try to lift up one end of the wall and push the other end down. In some cases, the uplift force is large enough to tip the wall over. Uplift forces are greater on tall short walls and less on low long walls. Bearing walls have less uplift than non-bearing walls because gravity loads on shear walls help them resist uplift. Shear walls need holdown devices at each end when the gravity loads cannot resist all of the uplift. The holdown device then provides the necessary uplift resistance.
WHAT ARE THE FUNCTIONS OF A SHEAR WALL?

Shear walls must provide the necessary lateral strength to resist horizontal earthquake forces. When shear walls are strong enough, they will transfer these horizontal forces to the next element in the load path below them. These other components in the load path may be other shear walls, floors, foundation walls, slabs or footings.

TWO FUNCTIONS OF A SHEAR WALL

Shear walls also provide lateral stiffness to prevent the roof or floor above from excessive side-sway. When shear walls are stiff enough, they will prevent floor and roof framing members from moving off their supports. Also, buildings that are sufficiently stiff will usually suffer less nonstructural damage. (Fig. 3.9)

HOW SHEAR WALLS PROVIDE STRENGTH

The strength of the shear wall depends on the combined strengths of its three components: lumber, sheathing and fasteners. Later in this section you will learn how each component effects the strength and how strength is lost by improper installations. When all of the components are properly in place, the shear wall can provide its intended strength.

For shear wall sheathing, the 1994 Uniform Building Code (UBC) permits the use of gypsum wallboard, cement plaster, fiberboard, wood particleboard, plywood and oriented strand board. Previous editions of the UBC also allowed wood lath and plaster, horizontal and diagonal sheathing for shear walls. All of these sheathing materials provide different strengths. The UBC shows these strengths in pounds per foot of wall length.

Fasteners for shear wall construction may be staples, screws or nails. Denser lumber species provide stronger fastener strengths. Values for shear wall strengths assume a dense lumber species like douglas fir-larch or southern pine. Thicker framing members also increase wood structural panel sheathing strengths.
COMBINING DIFFERENT MATERIAL STRENGTHS

Older editions of the building code allowed the combination of strengths for different materials on the same shear wall. If a wall was sheathed inside with gypsum wallboard and outside with portland cement plaster, the allowable shear strength became the combined strength of the two materials. Before this code provision was deleted in the 1976 Uniform Building Code, several buildings were built under this errant concept and are at a fraction of the strength that the original design intended. Buildings designed with gypsum wallboard or portland cement plaster in combination with structural wood panels will have the same problem. Different sheathing materials do not combine strengths. This is true on the same wall. It is also true for different walls of the same level of the building.

Material strengths cannot combine because different sheathing materials reach their ultimate strength at different wall displacements. Shear walls braced with cement plaster and gypsum wallboard reach their ultimate strength at about one-half inch of movement of the top of the wall. After this point, gypsum wallboard buckles off the studs, frequently leaving its fasteners in place. Portland cement plaster has similar behavior. Structural wood panels reach their ultimate strength when the top of the wall moves about 1 1/2 inches. This means that plywood will share seismic loads with portland cement plaster or gypsum wallboard when the top of the wall moves less than one-half inch. When earthquake forces cause more than 1/2-inch displacements, the wood structural panel sheathing will have to resist the entire load. Some earthquakes will cause top of wall displacements greater than 1/2-inch. When they do, the sheathing material that stays on the walls the longest will have to resist the total seismic load. Normally, this sheathing material will be wood structural panel. (Fig. 3.13 & 3.14)
SHEAR WALLS ARE LIKE WOOD I-BEAMS

Wood structural panel shear walls behave like cantilevered wood I-beams. Just as wood I-beams use their flanges to resist bending, wood structural panel shear walls use their end studs. Both wood I-beams and wood structural panel shear walls use their sheathing web to resist shear forces. Because of their size, wood structural panel shear walls must fasten their sheathing to intermediate wall studs to prevent it from buckling. The stiffness of shear walls constructed with wood structural panels depends on four things:

1. The size and species grade of the end studs
2. The thickness and grade of the sheathing
3. The diameter of the sheathing fasteners
4. The amount of slip in any holdown device

Figure 3-15  Comparison of Wood Shear Wall to Wood I-Beam
HOW SHEAR WALLS PROVIDE STIFFNESS

The stiffness of the shear wall, just like its strength, depends on the combined stiffness of its three components: lumber, sheathing and fasteners. The size and grade of end stud(s), thickness and grade of sheathing, and the sheathing fastener diameter determine how flexible a wood shear wall will be. When present, holdown devices also contribute to the overall stiffness of the shear wall. If holdown devices stretch or slip, the top of the shear wall will move horizontally. This horizontal movement adds to the movement allowed by the lumber, sheathing and fasteners. Any additional movement from the holdown will reduce the effective stiffness of the shear wall.

STIFFNESS AND ASPECT RATIOS

Shear walls provide stiffness in large part by the ratio of their height to width. Long short walls are stiffer than tall narrow ones. For a wall of constant height, the stiffness will grow exponentially as the wall length increases. To help control stiffness, the UBC requires a minimum wall length for any given wall height. This allowable dimension ratio changes for each type of sheathing material and its construction. Wood structural panels can have smaller shear wall lengths than cement plaster or gypsum wallboard. When this sheathing is fastened at all of its edges, the UBC also permits smaller shear wall lengths.

<table>
<thead>
<tr>
<th>Material</th>
<th>Allowable Shear, lbs/ft</th>
<th>Maximum Height-To-Width Ratio</th>
<th>Minimum Width for 8 Foot High Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>gypsum lath &amp; plaster</td>
<td>100</td>
<td>1½:1</td>
<td>5 feet-4 inches</td>
</tr>
<tr>
<td>gypsum wallboard-unblocked</td>
<td>100-145</td>
<td>1½:1</td>
<td>5 feet-4 inches</td>
</tr>
<tr>
<td>gypsum wallboard-blocked</td>
<td>125-250</td>
<td>2:1</td>
<td>4 feet-0 inches</td>
</tr>
<tr>
<td>Fiberboard</td>
<td>125-175</td>
<td>1½:1</td>
<td>5 feet-4 inches</td>
</tr>
<tr>
<td>portland cement plaster-unblocked</td>
<td>180</td>
<td>1½:1</td>
<td>5 feet-4 inches</td>
</tr>
<tr>
<td>portland cement plaster-blocked</td>
<td>180</td>
<td>2:1</td>
<td>4 feet-0 inches</td>
</tr>
<tr>
<td>diagonal sheathing-conventional</td>
<td>300</td>
<td>2:1</td>
<td>4 feet-0 inches</td>
</tr>
<tr>
<td>diagonal sheathing-special</td>
<td>600</td>
<td>3½:1</td>
<td>2 feet-4 inches</td>
</tr>
<tr>
<td>wood structural panels &amp; particleboard</td>
<td>140-870</td>
<td>3½:1</td>
<td>2 feet-4 inches</td>
</tr>
</tbody>
</table>

Table 1 – Allowable Aspect Ratios

- Allowable shear values for gypsum lath and wallboard must be reduced 50% in Seismic Zones 3 and 4.
- The 1997 Uniform Building Code reduces the maximum allowable height-to-width ratios to 1:1 for conventional diagonal sheathing and 2:1 for special diagonal sheathing, wood structural panels and particleboard in Seismic Zones 3 and 4.
LESIONS FROM THE NORTHRIDGE EARTHQUAKE

After each major earthquake, scientists and engineers study the performance of structures so that building codes may be evaluated and improved as needed. After the 1994 Northridge Earthquake, the City of Los Angeles and Structural Engineers of Southern California formed a joint task force to re-evaluate several seismic provisions of the building code for wood frame buildings. The task force recommended significant changes to the design and construction of wood frame shear walls. These changes included lowering the allowable height-to-width ratios and shear strength values.

The following table shows the former (UBC) and new (LABC) code provisions that the City of Los Angeles and many Southern California communities adopted following the Northridge Earthquake.

<table>
<thead>
<tr>
<th>Shear Wall Sheathing Material</th>
<th>Allowable Shear, lbs./ft</th>
<th>Maximum Height-To-Width Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UBC</td>
<td>LABC</td>
</tr>
<tr>
<td>gypsum lath &amp; plaster</td>
<td>100</td>
<td>30</td>
</tr>
<tr>
<td>gypsum wallboard-unblocked</td>
<td>100-145</td>
<td>30</td>
</tr>
<tr>
<td>gypsum wallboard-blocked</td>
<td>125-250</td>
<td>30</td>
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<tr>
<td>fiberboard</td>
<td>125-175</td>
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<td>portland cement plaster-blocked</td>
<td>180</td>
<td>90</td>
</tr>
<tr>
<td>plywood -3 ply panels</td>
<td>200-770</td>
<td>150-200</td>
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<tr>
<td>plywood &amp; OSB- 3/8 inch</td>
<td>200-730</td>
<td>150-200</td>
</tr>
<tr>
<td>particleboard</td>
<td>140-870</td>
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<td>diagonal sheathing-conventional</td>
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<tr>
<td>diagonal sheathing-special</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>wood structural panels</td>
<td>200-870</td>
<td>150-650</td>
</tr>
</tbody>
</table>

Table 2- Reduced Code Values
SUCCESS OF PLYWOOD SHEATHING

The most important lesson that the Northridge Earthquake taught us about wood frame shear walls was the good performance of plywood sheathing. Shear walls sheathed with plywood performed significantly better than other sheathing materials such as gypsum wall board or portland cement plaster. The apartment building shown below in Figure 3.19 had minimal damage from the Northridge Earthquake because of its extensive use of shear walls sheathed with plywood.

The best plywood sheathing is Structural 1 grade with a minimum of four-ply panel construction. Three-ply plywood panel construction tore at its inner ply seam. For this reason, prescriptive standards often specify five-ply plywood for shear wall sheathing.

Fig. 3.16 - Drywall Failure

Fig. 3.17 - Stucco Failure

Fig. 3.18 - Narrow Panel Failure

Fig. 3.19 - Success of Full Plywood Coverage