Retrofitting structural supports will help wood-framed homes survive earthquakes and storm damage

SEISMIC BRACING

by David Benaroya Helfant

Editor's Note: In many ways, last year's 7.1 Loma Prieta earthquake confirmed – with frightening realism – what seismologists, engineers, and builders already knew: One-to two-story, wood-framed structures are fairly resilient if they are on solid ground, bolted to their foundations and braced to withstand the lateral racking forces that come with a strong or prolonged temblor.

Unfortunately, most homes built prior to 1940 aren't bolted, and few if any, are adequately braced. The evidence appears in countless photos: stately Victorians and solid-looking bungalows literally on their knees. The reasons for these losses are evident at first glance: some houses simply left their foundations during those 15 seconds, while others bear the telltale bulges low on the siding that mean collapsed cripple walls.

Although a small number of contractors in earthquake country have been trying to eke out a living doing residential seismic retrofitting in the last few years, this moderately strong earthquake brought a new sense of urgency to Northern California residents and millions of others with older unsecured homes who live along active faults.

Unfortunately, there's a lot more eagerness than information surrounding seismic retrofitting. Foundation bolting seems pretty straightforward until you hit the first cripple wall that is too short to accommodate an upright hammer drill, or a foundation that is suspiciously easy to punch holes in. (The first condition requires a steel plate lag-screwed to the edge of the sill and bolted to the inside face of the stem wall; the latter condition can require a new foundation.)

However, information both for professionals and homeowners is becoming available. One such source is Earthquake Safe: A Hazard Reduction Manual for Homes from which the following article and illustrations are adapted. This 54-page booklet covers seismic basics including descriptions of mudsill bolting, bracing, and foundation drainage.

We chose seismic bracing schemes to concentrate on here. (Bracing follows foundation bolting in a typical retrofit but often gets less attention.) But keep in mind that these procedures are only part of a complicated whole that includes siting complications, soil and foundation types, building shape and mass, structural details, and drainage. To be thorough in reducing the hazards of living where the earth shifts, you'll need to take all of these factors into account.

The unbraced cripple walls of this West Oakland home succumbed to the 7.1 quake of Oct. 17, leading to their collapse at the rear of the house. Shearwall bracing and substructure diagonal braces would have given this home a better chance.

Frightening and destructive earthquakes have rocked the San Francisco Bay Area, Coalinga, Calif., Alaska, Mexico City, Armenia, and Japan in the 1980s. Earthquakes have also been felt in the Midwest, the South, and in New England. Recent information suggests that there are potentially active fault systems in New York City as well as other parts of the mid-Atlantic region.

In fact recently revised earthquake hazard maps show that in the United States alone over 50 million people live in areas of greater-than-average seismic risk, while perhaps a half a billion share the risk world wide.

While the idea of earthquake proofing is naïve, the need to protect the structures we design and build is valid and real. Applying what engineers have learned about the effects of quakes can go a long way toward reducing the risk of serious structural failure.

Reducing the Hazards

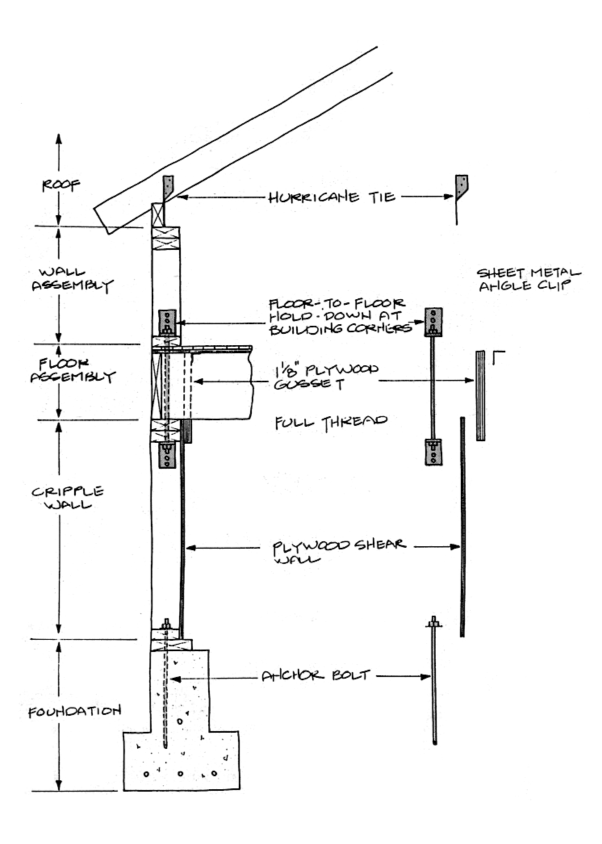
Earthquakes are typically experienced as lateral motion: waves traveling through the earth that produce a roller coaster effect. But sudden up-thrusts can also result. The intensity of a quake and its duration are major factors in how destructive it is.

Soil conditions and subsurface soil structure also dramatically affect the amount of vibration that is transferred to a building during an earthquake. For example, bedrock or stiff soil transfers much less vibration up through the foundation to a structure than do other soils. And the siting of the building can have a major effect.

Then there's the building itself. Four kinds of structural elements have to be examined on any house to determine what strengthening strategies are necessary. The first is the foundation that supports the building. Second are the horizontal members, such as the floors, that support and transfer the weight of the building and its contents to the walls or vertical members. The third are the columns, support walls, pilasters, posts and other vertical members which transfer the weight down to the foundation. The fourth structural element is all the points of connection between members. It is these points of connection that require special attention in earthquake country (see Figure 1 on next page).

Although I've seen newspaper ads that promise foundation anchoring in a day for $5 a bolt, it takes about a week for our crew to complete its work and costs the client between $4,000 and $7,000 for a typical 2,000-square-foot, two-story house. However, this includes a very thorough inspection and a program of bolting and bracing that leaves few vital connections without some form of strengthening.

This brings up the question of codes and standards. To date, code bodies and state governments have not dealt with existing



Adapted from drawings by Michael S. Noelle

Figure 1. *Tools of the seismic retrofitter: Hurricane ties connect roof rafters and top plates; hold-downs connect between floors; plywood gussets and angle clips go in joist spaces; plywood shear panels strengthen cripple walls, and anchor bolts keep the mudsill tight to stemwalls.*

homes. As a result, many municipalities don't have procedures in place for dealing with seismic retrofitting. In our work, we use the new construction requirements of the 1988 Uniform Building Code (Chapter 23) as the standard.

Reinforcing a building to reduce earthquake hazard should begin at the foundation with a careful examination of the concrete, and the connection between it and the mudsill. If the sill isn't bolted to the foundation, that has to be remedied.

The next concern is with the structure immediately above the mudsill. In many cases, this is a short cripple wall. Severe racking and moment failure of cripple walls are the major sources of structural damage to homes in serious earthquakes. The remedy for these stresses is the installation of bracing.

Existing Bracing

Most wood-frame residences have some kind of bracing nailed to the framing. One-by-six sheathing, either under exterior siding or standing alone, is common in older homes. However, board sheathing is the weakest form of wall bracing. One-by-six let-in-braces, which run on a 45° angle between top and bottom plates and are cut into the edges of the plates and studs, lend greater strength. But plywood shearwall that connects mudsill, cripple studs, and plates is the strongest wood-frame construction technique.

Mesh-reinforced stucco contains some shear strength, but these values vary a lot with the type and amount of mesh reinforcement, the way it's attached to the frame, and the thickness and quality of the stucco itself. Also, most of stucco's shear value is lost when it cracks. It shouldn't be thought of as a substitute for shear panels.

Shearwall Basics

In seismic construction, 1/2-inch CDX plywood is the standard for one-story homes.. Houses that are two-stories or more typically require 5/8-inch plywood, with 3/4-inch plywood used for three-story or taller homes.

In an existing building, you can often retrofit the shearwall onto the cripple studs from the inside of the crawlspace. This saves the expense of tearing off existing exterior siding and replacing it with new once the plywood has been nailed up. However, you won't be able to avoid this procedure on houses that are built on slabs or that don't have a crawlspace large enough to let you handle plywood.

The walls that require the greatest amount of shearwall are those that bear the greatest portion of the structural load from floor joists and roof rafters. However, you should start with each corner of the building. The standard rule of thumb is to install shearwall 6 to 8 feet, measured horizontally, in each direction from each corner of a one-story house of 1,000 square feet or less. This will account for about 40% to 50% of the substructure wall area. For two-story houses, you'll need 8 to 16 feet in each direction (50% to 70%). Plan to shear-wall the entire substructural area in homes that are three stories or larger.

To calculate the shearwall needs of a home more precisely, you can turn to the UBC design criteria for new construction. It's based on a number of factors: soil conditions (rated S1 to S4), seismic risk zone (0 to 4), occupancy use "importance," total building

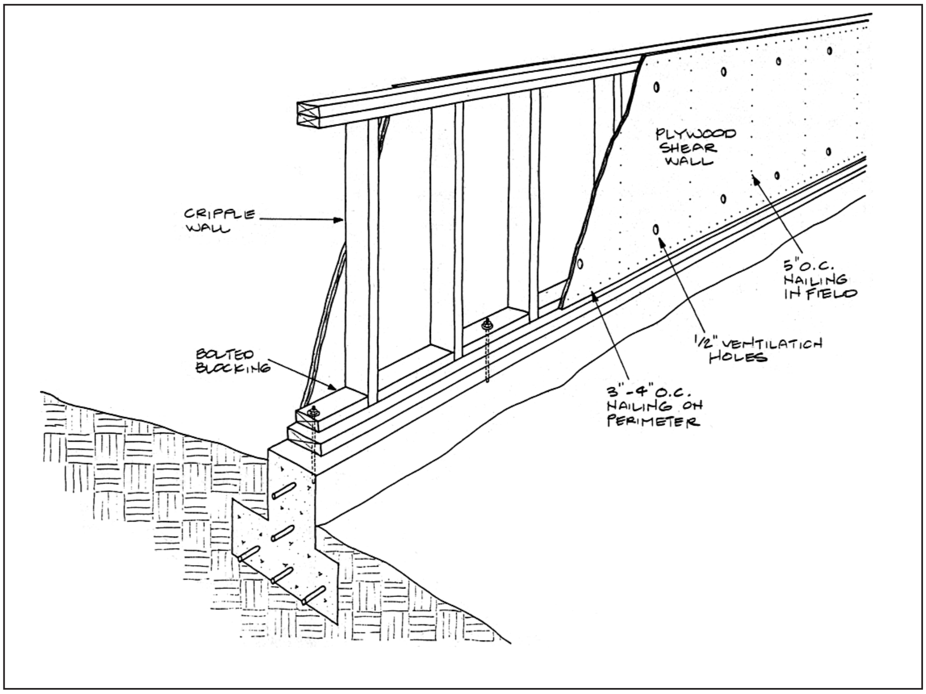


Figure 2. *The primary form of seismic bracing on cripple walls is plywood shear panel with a very close nailing schedule. When the mudsill is wider than the wall framing, blocks have to be anchor bolted down through the sill to provide the vital connection to the foundation.*

weight, and architectural and framing details. If you are familiar with calculating loads to find building weight and can make some educated guesses about general soil conditions, it's not difficulty to apply these criteria.

However, there are some conditions that pose special risks, and require a foundation or structural engineer. These include:

- Questionable soil (fill, high water table, history of slides, etc.);
- Steep sites;
- Brick foundations, or concrete that is badly deteriorated, severely cracked, or lacking reinforcement.
- Pier-type foundations;
- Unusual distribution of building mass or large openings in the structure such as garages that have living space above (these are called softstories).

A Simple Installation

Shearwall has to be nailed to a fully blocked, flush surface. The plates above the cripple studs, the edges of the studs themselves, and the mudsill must all be in the same plane, and the edges of the plywood must be supported continuously by this framing (see Figure 2).

That raises a common problem. In many older homes, the mudsill is wider than the studs and plates which are nailed to it. To compensate for this, you have to install flat blocking on top of the mudsill that is flush with the wall framing. This should be bolted through the mudsill into the concrete foundation with an 8 1/2 or 10-inch anchor bolt (depending on the number of stories). You should bolt at least every other block, making sure that you don't skip the ones that fall at the intersection of two panels. At the corners, install a hold-down rather than an anchor bolt. This will bolt the block down to the foundation and tie in the corner post as well.

Make sure all your bolting – including hold-downs – is complete before cutting and nailing up shearwall. Once you cut a panel, snap chalk lines to mark studs, diagonal bracing, and any blocking in the wall. Before installing the plywood, it is a good idea to paint the mudsill and the studs with a wood preservative to help guard against termites and dry rot. Also coat the plywood on both sides at least 6 inches up from the bottom edge.

Although nobody is likely to see your work, a flat, tightly nailed panel is most effective. Begin by tacking one corner of the plywood, and then working diagonally down the sheet, smoothing out any kinks, bumps, or warps ahead of you as you go. When you're finished nailing, the panel should resonate like a drum when you slap it between studs.

The nailing schedule for the perimeter of the plywood is 3 to 4 inches on-center; you can reduce this to 5 inches for intermediate studs. While this may seem like overkill, the more nails you drive, the stronger the bracing becomes because the strength of the plywood shearwall is, in part, a function of the shear value of the nails used.

You want the nail to penetrate approximately 50% of the depth of the studs, so a 6d (2-inch) or 8d (2 1/2 inch) nail is appropriate using 1/2-inch shearwall over 3 1/2-inch studs. Nail guns are fine, but some municipalities do not allow clipped head nails. In general, full-headed nails are better.

Once you've finished nailing off the plywood, go back with an electric drill and punch a row of 1/2-inch-diameter vent holes 5 inches down from the top plate and the same distance up from the mudsill. Lay these out 16 inches on-center between framing members. This will provide sufficient air circulation for any moisture that builds up providing there is good storm drainage along the exterior of the footings and gutters and downspouts are properly drained. If good site drainage isn't in place, you can have more than a moisture problem in the crawlspace, since water-saturated soil exerts tremendous additional pressure on foundations during an earthquake.

Bracing Floors

After the cripple walls have been shear-walled, you'll want to look at the first-floor framing. Good floor diaphragms have blocking between the joists at all plates and at 8-foot intervals in their spans. Joists that lack blocking are subject to tipping and can collapse during a serious earthquake. If the joist span is 10 feet or less, a line of blocking at mid-span and one at each end is sufficient.

Now turn to the floor-to-plate connection. First, make sure the joists are properly blocked at the perimeter with a rim joist or end blocking. If they are, install a sheet metal angle clip – a Simpson L90 or an equivalent connector – on top of the cripple wall in each bay. One leg of this connector nails to the top plate; the other nails to the rim joist. Use another, smaller clip in a vertical attitude that connects the joist end and the rim joist.

If blocking is needed, you can use it to make a solid connection between the floor system and the framing below. Cut a block from 1 1/8-inch plywood that fits snugly between the joists. The top of it should butt the underside of the subfloor, and the bottom should lap the top plates of the cripple wall by at least 4 inches. Face nail this block-gusset to the cripple wall top plates at the bottom, and toe nail the sides into the joists. At the top, screw a sheet-metal angle clip to the face of the plywood and into the subfloor above using #10 screws (see Figure 3 on facing page).

If the floor joists sit directly on top of the mudsill – no cripple walls – the connection you use will again depend on blocking. If joist blocking at the sill is sufficient, use sheet metal angle clips to tie the mudsill and joist ends to the rim joist, and angle iron to connect the joists to the foundation (see Figure 4 on facing page).

This 2 1/4x2 1/4x1/4-inch angle stock should be machine bolted to the joist faces, and anchor bolted to the foundation. (If you are using this system with 4x girders, use angle iron on

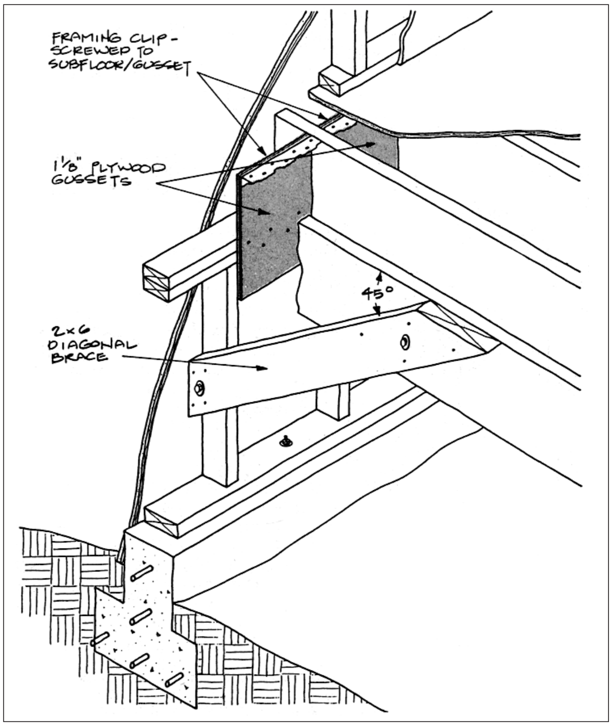


Figure 3. *If the floor system doesn't have solid end blocking or a rim joist, installing plywood "blocks" will keep joists from tipping and act as gussets to connect the floor and cripple wall. Diagonal braces provide moment resistance along the length of the joists.*

both sides of the beams.) You'll have to get the steel from a fabricator, but that gives you an opportunity to order it pre-drilled.

If you need to add blocking where there are no cripple walls, cut 1 1/8-inch plywood gussets that extend from the bottom of the subfloor to about 10 inches below the mudsill. You're going to combine this with a 1/4-inch steel plate that covers much of the plywood and attaches to the mudsill and the concrete.

Install the gussets with an angle clip at the top and toenails into the joists as shown in Figure 3. Use a layer of 30-pound asphalt felt where the plywood laps the concrete. Then, lag screw the pre-drilled, steel plate, which should measure about 12 inches square, through the plywood gusset into the edge of the mudsill, and anchor bolt it into the face of the concrete foundation.

Other Bracing

Installing diagonal braces that run from the joists to the cripple walls provides moment resistance against the hinging action that long runs of joists are prune to in prolonged earthquakes. A typical diagonal brace is a 2x6 nailed and bolted to a cripple stud about halfway between the mudsill and top plate. It extends up on a 45° angle to just under the subfloor and is nailed and bolted to the joist face it parallels, as shown in Figure 3.

Diagonal braces are typically placed in open bays, but can be used on shear-walled sections of cripple wall by installing the braces first, blocking around them to support the edges of the shear panels, and then cutting slots in the plywood so the sheets can be lowered down over the braces.

Another extremely weak intersection in wood-frame buildings is post-to-beam connections. These should be reinforced with steel T-straps. Plywood gussets may also be used along with diagonal 2x4 braces from the main post up to the beam that it supports. Posts should be secured to their piers with steel straps bolted to both the concrete and the wood as shown in Figure 5.

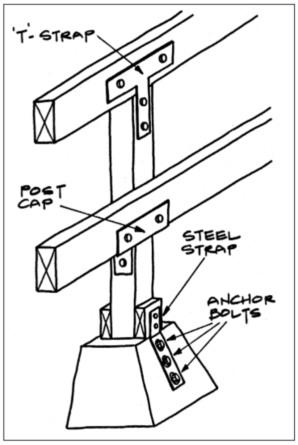


Figure 5. *Post-to-beam and post-to-pier connections are reinforced with steel brackets and machine bolts. Pier systems – rather than grade beams or stem walls – are very vulnerable in earthquakes and difficult to retrofit effectively.*

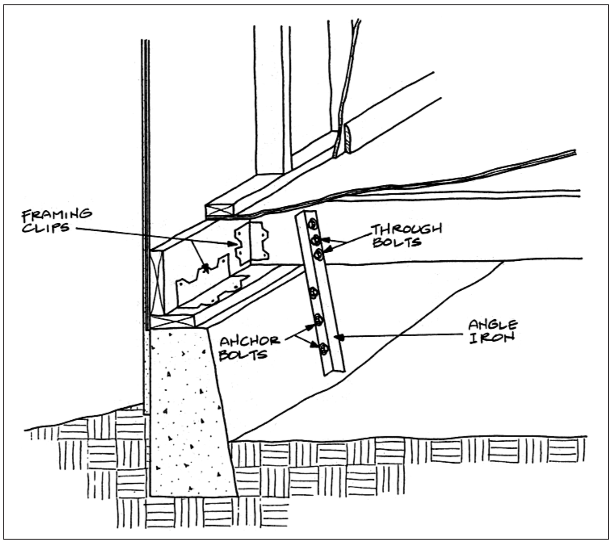


Figure 4. This bracing scheme – for floor joists that bear directly on the mudsill – relies on 1/4-inch angle iron bolted to the joist and the stemwall, and sheet-metal framing clips nailed to the joist, mudsill, and rim joist.

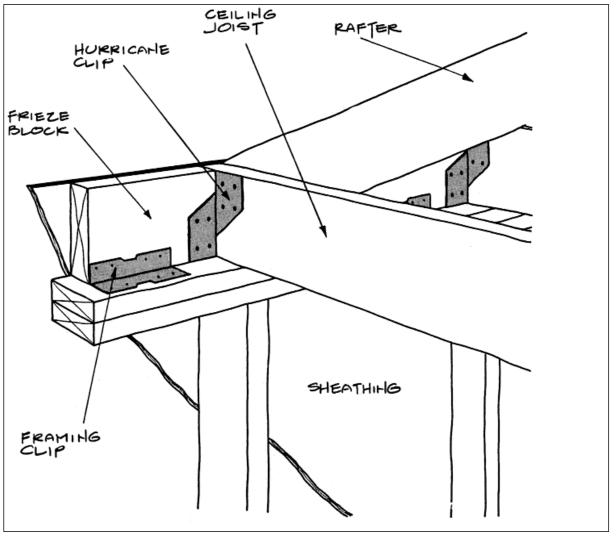


Figure 6. *Although most roofs are well triangulated by sheathing, nailing hurricane ties to plates and rafters/ceiling joists, and framing clips to plates and frieze blocks ensure a connection between the roof system and the remaining framing in the house.*

Although it requires removing and replacing some finish wall material on at least one level, bolting in hold-downs and connecting them with all-thread between floors at building corners is a way of ensuring that platform-framed floors remain attached.

Roofs and Chimneys

Roof systems are triangulated wood structures, and tend to be rigid if carefully framed. However, where rafters and ceiling joists rest on the top plate they should be reinforced with sheetmetal "hurricane ties." Adding sheetmetal angle clips in each bay to tie the blocking to the double plate further increases the attachment between the roof and the vertical framing (see Figure 6).

A cautionary note regarding reroofing: Although most municipal building codes allow three layers of roofing on an existing roof frame, that represents a great deal of weight. Stripping the roof will give you a chance to add the sheetmetal connectors more easily and add more nails to the existing plywood to increase its ability to resist racking.

Brick chimneys often suffer in earthquake country from two general design limitations. First, they are typically built on their own inadequate foundations. Second, they are often not structurally connected to the building.

If there is bad drainage around the foundation, masonry fireplaces invariably sink. As they settle, they tend to rotate and pull away from the building. Proper drainage, a deepened, steel-reinforced foundation, and bracing back to the frame of the building can help.

During earthquakes, however, chimneys still have a tendency to break at the roof line. One solution for this is to take off the brick to the roof line and build a wood chase with a light-weight flue system, or a new, steel-reinforced masonry one. Another precaution well worth taking is to install plywood in the attic adjacent to the chimney so that a collapse won't send bricks through the ceiling and into living space below.

Chimneys that are structurally attached to the eaves of the roof tend to buckle near the center of their vertical run if bad drainage and a shallow foundation have resulted in some subsidence. To protect against this, you can typically brace these chimneys with structural steel and tie them back to the framing at points where they are prone to buckle. ■

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