

QuakeCheck:

*When the big quake comes, will your home be
“Safe Enough to Stay?”*



Find out why inadequate earthquake ‘retrofits’
leave many older homes vulnerable to quakes, and
whether your home may still need strengthening

by

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Chapter 1 Purpose of This Document

1.1 Introduction

Due to widespread misunderstanding about how earthquakes cause damage, many homes that have been “retrofitted” for earthquake resistance are still vulnerable to damage. The information presented in this document is intended to help homeowners evaluate whether their houses need earthquake strengthening work, whether existing strengthening work is likely to be effective, or whether corrective work is needed beyond “retrofit” work that was already installed.

Though the authors practice mostly in the San Francisco Bay Area, homeowners and contractors from Los Angeles, Portland, Seattle, Salt Lake City, and British Columbia have approached them seeking information about earthquake strengthening. Most of the strengthening methods shown in this document apply to wood-framed houses throughout North America and likely beyond. Unfortunately some of the poor retrofit methods have also been adopted in other regions as well. The laws of physics are the same from one state or country to another; a poor retrofit installation won’t work whether it’s in Alaska, California, South Carolina, Utah, or anywhere else.

1.2 Yes, you should be concerned about Earthquakes!

We hope you are reading this document because you already want to strengthen your home. In case you are not yet convinced, let us address the most common fantasies that people subscribe to about why *their* house may not need retrofitting.

“My house made it through the last earthquake with no damage”

In the San Francisco Bay Area, a disturbing number of people think that the 1989 Loma Prieta Earthquake, that was centered about 60 miles away, compares to a quake that might occur 60 yards away. **Figure 1—1** shows how shaking intensity drops off dramatically as you go farther from the earthquake’s origin. The argument that “my house survived the Loma Prieta/ Northridge/ Nisqually/ fill-in-the-blank earthquake” might hold water if your house was *at the epicenter* of that quake.

Otherwise you may as well add that your house survived Hurricane Sandy, the 2011 tornado season, the 1991 Oakland Hills Fire, and the eruption of Mount St. Helens. Don’t think you’re close to a fault? Many

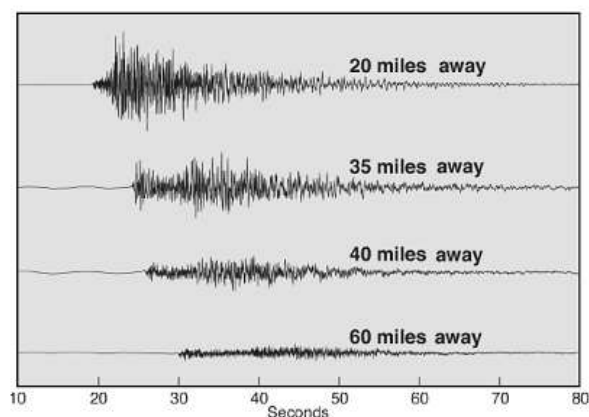


Figure 1-1 This illustration from the US Geological Survey shows the difference in shaking from the same earthquake recorded at seismograph stations varying from 20 to 60 miles from the epicenter. Millions of Californians live within *five* miles of active faults.

recent earthquakes occurred on faults that were previously unknown—including the 1983 Coalinga earthquake, 1987 Whittier Narrows, 1994 Northridge, and 2003 San Simeon quakes.

“My house has withstood the test of time”

All buildings eventually *fail* the test of time. Time has allowed termites, carpenter ants, powder-post beetles, wood bees, and decay to weaken your structure. Tree roots have grown under and heaved the foundation. Gophers have burrowed back and forth under your footings and caused them to settle. Remodeling projects took out sections of walls to open the floor plan or add windows or doors. You replaced the light-weight wood shingles on the roof with new plywood overlain with concrete tile roofing.

Earthquake faults are very patient as we are making our buildings heavier and weaker. In any one area, it may be centuries between earthquakes; ask the people in L’Aquila, Italy, some of whose buildings had stood for 900 years until a quake destroyed them in 2009. Older nations commonly experience earthquakes that destroy 400-year-old buildings, if for no other reason than earthquakes don’t occur very often. An earthquake in 1812 leveled New Madrid in Missouri and changed the course of the Mississippi River; if there had been more than 200 non-native settlers in the area at the time, this would have been a much more remembered event in our euro-centric history.

“My house was built to code”

Which code? Codes keep changing, for a couple of reasons: they don’t include all the requirements needed for good earthquake-resistant construction; and we keep learning more about how buildings react to earthquakes. For example, over the years, the foundation anchors required in active earthquake areas have increased in size and quantity. The current connection requirement has roughly doubled over the last 20 years. If your house was built more than 20 years ago it may only have half of the anchorage that is considered adequate today.

In some cases the current building code allows construction that *immediately* needs retrofitting to meet FEMA and other guidelines for earthquake resistance. In December, 2011, one of the authors submitted a code-change proposal to the International Code Council that clarifies current code requirements. The soonest that this could be adopted is 2015.

“I retrofitted my house 20 years ago”

Best retrofit practices continue to improve. State of the art has changed significantly since the last earthquake, and will certainly keep changing as we learn more about what works best in future earthquakes. Your retrofit could probably use at least a “tune-up.” As mentioned earlier the work may have suffered damage from decay or pests, or tradesworkers installing or repairing utilities under the house.

“The previous owner retrofitted my house just before I bought it”

If the previous owner was an engineer with extensive retrofit experience, then good. But this document was inspired by the alarming frequency that inspectors find defective or inadequate retrofit work. How complete was the retrofit? What materials and hardware were used? Was the house “flipped” by someone skilled only at maximizing profit?

“My house is built on bedrock”

Earthquake shaking is amplified by soft soils; this does not mean shaking is *zero* at rocky sites! Many rocky areas are also hilly; a house on a sloping site is far more vulnerable in an earthquake than one on flat terrain.

“My house was designed by a Famous Architect”

All the more reason to retrofit your house, if you have one of these treasures! Even though Bernard Maybeck, Samuel Maclure, and other great architects of the past designed exquisite houses, they didn’t know much more about earthquake-resistant design than others of the time.

1.3 Acknowledgements & use of Photos

Most of the photos included in this document were provided by members of the Golden Gate chapter of the American Society of Home Inspectors (GGASHI). The photos show actual conditions as found under houses in the greater San Francisco Bay Area. The authors thank all who contributed material used in this document. Note that photos of homes are used for illustrative purposes only, and houses shown may or may not need retrofit work.

1.4 Disclaimer

This information is provided free of charge as a public service. Information presented in this document is general in nature, and is not intended as a substitute for the project-specific advice of an experienced professional. The authors, publisher, contributors, editors shall not accept any responsibility for the misuse or misapplication of any of the recommendations herein, nor for the suitability of any details presented. Specific mention of various hardware products is not a guarantee that they will perform in any particular application during an earthquake or any other event.

This book presents the authors’ views, interpretations of research performed by others, and what they consider “economical best practices” as of November, 2012. Solutions, recommendations, and opinions presented do not necessarily reflect those of any of the contributors, nor any professional societies to which the authors belong.

The laws of physics governing earthquake behavior will not change, but our codes will. So will our understanding of what works best to resist earthquakes. This document will almost certainly need updating or revision after the next earthquake, and should be held in suspicion after about 2018 or the next damaging west coast earthquake, whichever occurs first.

Chapter 2 How Earthquakes Damage Houses **and What can be Done About It**

How does an earthquake affect your home? Most of the structural damage caused by earthquakes is due to shaking from side to side. In a major quake, buildings shake back and forth dozens or even hundreds of times, placing heavy stress on structural connections. If your house is not adequately anchored and braced, a strong quake can slide it off the foundation, cause walls to buckle and collapse, or cause structural connections to fail.

What can be done to prevent damage? It is not practical to prevent all damage, but most homes can be adequately upgraded or “retrofitted” to prevent catastrophic failure. In general, the most essential and cost effective upgrades are in the area below the first floor. The costs and procedures vary depending on the style and size of the house, its age, location, local regulations, and other factors, but the following guidelines apply to a large percentage of older homes.

Older homes typically need upgrades in three categories:

1. Connections between the wood structure and the concrete foundation.
2. Bracing of the walls just above the foundation. In many Bay Area homes these are the short “cripple-walls” between the first floor and the foundation, typically accessible in an unfinished “crawl space.” In other homes, they may be partial or full-height walls around a basement. Many homes built since 1940 have perimeter foundation walls that support the floor framing directly, with no cripple walls—these houses still need the connections described in the next item. Single-story homes built on slab foundations, with no subarea or crawl space, are usually in less danger than homes with raised floors.
3. Attachment of the first floor framing to the braced walls or foundation below.

The details of an upgrade depend on the architectural style, type of construction, degree of access to the foundation, and other factors. Here are the most common situations:

Cripple-wall house: **Figure 2-1** shows a wood-framed house supported on a perimeter foundation with a crawl space or basement below the first floor, and cripple walls between the foundation and floor. A majority of homes built before 1950 are in this category and this type of construction is still common. The difficulty and cost of an upgrade is affected by the degree of access below the floor. Where clearance



Figure 2-1 Typical house with cripple walls.

If there are more than about three steps up to the first floor of your house, it likely has cripple walls.

below the floor is limited, it may be necessary to open exterior walls or excavate soil under the house for access.

Crawl space with no cripple walls:

The photo in **Figure 2-2** shows the entry to a house supported on a perimeter foundation with a crawl space below the first floor, but without cripple walls. In such houses, the floor framing is supported directly on the mudsill. This style became common in the 1940s and is still widely used. As in houses with cripple walls, access to the subarea may significantly affect cost and difficulty.

These homes require special attention to connections between the floor framing and the mudsills.

In some parts of the country it is common for the foundation walls around a basement or crawlspace to extend all the way up to the first floor framing. In this case you may have a tall crawlspace without cripple walls.

Houses with slab foundations: In some houses the foundation is integral with the concrete floor and there is no space below the floor. This style was widely used starting in the 1950s and it is the predominant style for new homes, especially in tract developments. Since most homes on slab foundations were built after at least minimal connections from wood framing to the foundation were common, this type of house has a lower retrofit priority than ones with raised floors.

Composite Buildings: Many houses, especially those on hillsides, have more than one style of construction, either due to site conditions or to additions after original construction. The house shown in **Figure 2-3** has a slab foundation on one side and full-height concrete block walls on the other.



Figure 2-2 Typical house with crawl space and NO cripple walls.

If there are foundation vents around your house but it only has one or two steps up to the main floor level, it probably does not have cripple walls.



Figure 2-3 Mixed foundation systems.

This house has a lower-level garage on the right with full-height wood-framed walls, and a crawlspace on the left with no cripple walls.

Other weaknesses include a split-level floor at the entry, and a “weak-story” at the garage. Another hazard is the brick chimney. All of these are special cases beyond the scope of this document.

Other Weaknesses

The following categories of structural weaknesses are described in FEMA Publication P-593, “*Seismic Rehabilitation Training for One and Two-Family Dwellings*” (download from <http://www.fema.gov/library/viewRecord.do?id=4554>) Some houses may have problems not listed. Conditions under Items 2 & 3 in the following list are the most common hazards, and generally recognized as the easiest to repair at reasonable cost. These are discussed in greatest detail in subsequent sections.

1. **Foundation weaknesses:** Brick masonry, stone, post-and-pier construction.
2. **Inadequate mudsill anchorage:** Until the 1937 building code, no fasteners were specified for this crucial connection. Requirements have increased significantly since then.
3. **Cripple-wall bracing:** Cripple-walls are the short wood-framed walls that support the main floor of your house above the foundation. Until the 1980’s these walls were often too weak to resist earthquake forces adequately. If the cripple-walls collapse, portions of the house will fall several feet to the ground. This usually results in extreme damage and leaves your home uninhabitable.
4. **Brick chimneys:** Masonry chimneys can be very dangerous. They are usually extremely expensive to brace effectively.
5. **Open front buildings:** Often found in row-houses in San Francisco, where the entire front wall of one or more floors consists of a single garage door opening, or perhaps a garage door opening with adjacent access doors.
6. **Weak wall lines:** Houses where one or more sides do not have enough solid wall length to resist earthquake forces perform badly in earthquakes. Weak wall lines are often found in the front and rear walls of houses on narrow lots and houses with large window or door openings that dominate a wall or walls. Buildings with great views to the Bay, ocean, or elsewhere often have weak wall lines.
7. **Split-levels:** When two segments of a house have different floor levels without sufficient connections between them, the segments can separate and collapse.
8. **Hillside homes:** Houses built on significant slopes perform badly in earthquakes. Houses built on the downhill side of the street usually fare worse than those uphill from the street.
9. **Post connections:** Where posts provide the only support for segments of a home, secure connections at the top and bottom of each post are essential. If perimeter walls surround many short interior posts, the typical existing connections are usually sufficient; in this case it is best to focus on bracing around the perimeter of the house.
10. **Outside stairs, decks, canopies:** The main concern with exterior stairs, porch roofs, or canopies is that they will collapse and trap you inside the house.
11. **Masonry veneer:** Brick or stone veneer (exterior wall facing) increases earthquake hazards for two reasons: it can fall off and injure or kill people, and it increases the earthquake forces on a building. Brick or stone veneer less than four feet above ground level is generally not considered a serious hazard, although if it is near a building exit you may wish to remove it or securely attach it to the building.

Chapter 3 The Basics of an Earthquake Retrofit

3.1 STEP 1: CONNECTING THE STRUCTURE TO THE FOUNDATION.

3.1.1 Anchors in Modern Homes

The first element in earthquake reinforcement is a secure connection between the foundation and the “*mudsill*” (also called the “*foundation sill*” or “*sill plate*.”) This is the board installed directly on the foundation; it is the base to which the rest of the structure is attached. In modern construction, the mudsill is secured with bolts or other hardware cast into the foundation when the concrete is poured. Heavy square steel washers and nuts are installed on the bolts to secure the mudsill to the foundation; this system prevents the mudsill from sliding.

Anchor bolts in a new foundation. Figure 3-1 shows a wall under construction. Note the large square washers or “bearing plates” on the anchor bolts. These are required by current building codes, and are best practice to use when installing retrofit foundation anchors.

The mudsill is a different color from the other lumber because it is treated with chemicals to resist moisture and structural pests.

The vertical “studs” will support the wall surfaces and the structure above.



Figure 3-1 Mudsill connection to the foundation in a house under construction. This crucial connection transfers earthquake forces to the foundation.

3.1.2 Weak Anchoring of Older Homes.

Most Bay Area homes built before the 1940s do not have foundation bolts, which were not required by the building codes of the time. These buildings can readily slide off the foundation in an earthquake. Nearly all homes built from the 1940s through the 1970s have bolts or other anchors. This is an improvement over times when no connections were required at all, but the anchors usually are too small, too far apart, or otherwise inadequate by today’s standards. Homes of this era typically need an upgrade to ensure they are reliably anchored. **Figure 3-2** shows some older types of mudsill connections, described as follows.

Reinforcing steel or steel rods used as anchors in a 1940s home. In homes from the 1940s and early 1950s, sections of reinforcing steel were sometimes used instead of bolts. After placing the mudsills over the steel rods extending from the foundation, the steel was bent over

the mudsill. (Sometimes bolts were even bent over on top of the mudsill instead of installing a nut and washer.) This does not provide a reliable connection.

Anchor bolt used from about 1950 through about 1995. The bolt shown in **Figure 3-2** is typical of the era when bolts were first widely installed. It is smaller (1/2" diameter) than bolts used in current construction and it lacks the large square washer or "bearing plate" needed to help ensure the mudsill will not split during earthquake loading. Older bolts like this often do not extend far enough into the concrete foundation, and may be partially rusted through.



Figure 3-2 Mudsill connections used in the past. From left to right: Steel rod, pin, or bolt bent down over mudsill; bolt with standard round washer and nut; proprietary sheet-metal strap embedded in concrete and wrapped around and nailed to mudsill.

Proprietary anchors: Various labor-saving products have been used (and some are still available) to avoid having to carefully align bolt holes in mudsills with the corresponding foundation bolts. The narrow metal strap shown above right is an early version of one of these. Even when installed correctly, these sorts of anchors performed badly in recent quakes.

3.1.3 Upgrading the Anchors.

Bolts and other anchors can usually be added at relatively modest cost. The type of hardware that can be used depends on the accessibility of the foundation and on the type of construction.

Retrofit Bolts: Where there is enough space above the foundation, bolts can be added by drilling downward through the mudsill and into the concrete, as shown in **Figure 3-3**. The heavy-duty drills used in retrofit work need about two feet of clearance in order to drill straight down into the foundation.

Bolts can be secured into the concrete with epoxy resin or other adhesives; other anchors (described in some of the references under Further Information) are also effective.



Figure 3-3 Retrofit bolt installation at a cripple wall.

Mudsill connectors for low-clearance installation: Where there is not enough room for drilling from above, standard bolts will not work. Several types of connectors are available that can be secured to the side of the foundation with bolts into the concrete and structural screws into the edge of the mudsill. **Figure 3-4** shows a “Universal foundation Plate” (UFP10) manufactured by Simpson Strong-Tie Company. This hardware is specifically engineered for this situation, and has undergone testing to establish its load capacity.



Figure 3-4 A Simpson “UFP10” used where bolt holes could not be drilled from above (yellow electrical cable and gray conduit to left are not related to the connector).

3.1.4 Common mistakes in retrofit anchoring.

Improper hardware. Among the most common defects in retrofit work is the use of hardware that “seems to fit” but which is not suitable for the application. Thousands of retrofits rely on the wrong hardware for the job. **Figure 3-5** shows some examples.

Steel “angle-irons:” Steel angle stock as shown on the left in the figure below are “home-made” connectors that do not have a rated load capacity. In this case, they are installed with a single bolt into the foundation and they will do almost nothing to prevent the house from sliding off the foundation. Connectors rated to resist loads such as Simpson’s “UFP10” should be used in cases like this, as shown above. In some cases angle-irons may cause damage if left in place. Since 2006, FEMA has recommended against using this sort of connection even in engineered designs, except for certain connections along uphill footings in hillside homes.

“Hurricane ties:” Sheet metal anchors as shown in the middle below are designed for resisting upward loads; they have very little resistance to the side-to-side forces of an earthquake. Unfortunately, they are fairly common, especially in retrofits from the 1990s, before more appropriate hardware was widely available. The best approach is usually to leave these in place and install anchors designed for the situation, such as the UFPs shown above.



Figure 3-5 The steel angles, “hurricane ties” and flat steel straps shown are not appropriate connectors to resist earthquake forces.

Flat steel straps: The sheet metal strap shown on the right in **Figure 3-5** is normally used to connect framing components that meet end-to-end. It was never intended by the manufacturer to resist sliding forces. A retrofit “expansion bolt,” adhesive anchor, or proprietary foundation anchor would provide a much better connection from the foundation to the mudsill. Plywood bracing panels are also needed in this situation (see the following section).

Improper installation of bolts. To be effective, bolts must be properly positioned and must have adequate embedment into the foundation. There are seemingly endless ways to get it wrong; **Figure 3-6** shows a few.

Bolts installed at an angle: The bolt in the left-hand photo below is installed at an angle because there was not enough room above the mudsill to allow drilling straight down. The heavy-duty drills used in retrofit work need about two feet of clearance in order to drill straight down into the foundation. This connection is very weak. The UFP10 anchors shown above were developed to solve this problem.

Incorrect size, location, and improper washers: The middle photo below shows several defects: the bolt is too small; it is too close to the end of the mudsill; and it does not have an adequate washer under the nut. Bolts should be placed at least 12 times their diameter from the end of the mudsill section and at least 1½ diameters from the edges. For 5/8” bolts (the most common size) this means 7-1/2” from the end and 1” from the edge.

Faulty pest repair work: The section of mudsill shown below right was installed as a repair on a foundation where bolts were already present. Since the house could not be lifted to permit dropping the new mudsill over the bolts, the installers cut slots into the sill so they could slide it in sideways. The slot substantially weakens the mudsill. Also, the bolt is probably not embedded deeply enough in the concrete, and it lacks an adequate washer. This installation would not meet any code, whether it is supposed to resist earthquake forces or not.



Figure 3-6 These photos show several examples of bad anchor bolt installations:
Left: Retrofit bolt installed at an angle; Center: Bolt that is too small, installed without a proper washer and too close to the end of the mudsill; Right: Mudsill slotted to install in the course of repairing decay or pest damage. • PH. Matt. PR

3.2 STEP 2: BRACING THE WALLS

3.2.1 Wall Bracing and Shear Panels

Anchoring the mudsill to the foundation is important, but bolting by itself is not a complete retrofit. The next step is bracing the cripple walls; this is usually accomplished with plywood bracing or “shear panels.” Quality materials and proper installation are essential to ensure that bracing is effective. Critical factors include the grade and thickness of the plywood; the size and placement of the nails; and ensuring that there is adequate wall framing to attach the plywood to.

A properly installed plywood bracing panel must be securely nailed to solid framing at all edges, as shown in **Figure 3-7**. Any seams in the panel—such as the horizontal one here—must have framing installed behind them so that all panel edges can be securely nailed. (Plywood comes in 4-foot widths, but you may have to cut narrower strips in order to fit them into the work area.)



Figure 3-7 Plywood bracing panels nailed along all edges. Note the horizontal joint with nailing above and below the joint. The six holes provide ventilation to help prevent moisture build-up and associated damage

3.2.2 Mudsill blocking.

The mudsills in older Bay Area homes are often wider than the wall studs, so it is not possible to install plywood without some modification that provides a continuous, flat surface behind it. The most common method is to install blocks between the studs on top of the mudsill, then nail the bottom edge of the plywood to the blocks. This is a crucial connection that requires special care.

Screw connections: The block shown in Figure 3-8 is connected to the mudsill with special screws. This provides a solid connection that also keeps the block from lifting off the mudsill. (Lifting results from the bracing panel rocking back and forth, not from vertical earthquake forces.)



Figure 3-8 Mudsill blocks connected with structural screws.

Bolted mudsill blocks: Another way to prevent blocks from lifting off the mudsill is to bolt them to the foundation, as shown in Figure 3-9. It is still essential to connect the block to the mudsill in addition to the bolt, such as with the screws shown in Figure 3-8.

3.2.3 Common defects in wall bracing.

It is all too common to find bracing that is not properly installed. The most common defects are the use of screws where nails are needed, missing or improperly installed nails, inadequate blocking at the mudsills, and gaps in bracing panels.



Figure 3-9 Mudsill block with proper attachment to foundation and mudsill. TM-R D&W

Screws used to connect plywood: Bracing panels must be fastened with nails, not screws. Almost all screws (especially drywall screws as shown below in Figure 3-10) are brittle and will break after an earthquake shakes the plywood back and forth a few times; nails are much more ductile and do not fail as easily. Depending on other aspects of the installation, it may be possible to leave the screws in place and add nails between them as a repair.

Nails too close to plywood edges: Nails must be installed at least 3/8" away from the panel edges, and preferably further. Nails that are too close to the edges can tear out of the plywood during an earthquake. In the right-hand photo in Figure 3-10, the bottom edge of the plywood is "toe-nailed" to the mudsill, which is an especially poor connection.



Figure 3-10 Defective plywood connections: Left—drywall screws; Right—toe-nails along bottom edge of plywood into the mudsill. TM-R D&W, Matt C

Nails missing at plywood panel edges:

Missing nails at the edges of the panels shown in **Figure 3-11** render them essentially useless in resisting earthquake forces. Bracing panels must have nails installed along all edges. It is sometimes necessary to install additional studs or blocks for this purpose. The plywood shown should be removed to allow installation of new framing.



Figure 3-11 Plywood must be nailed to framing along each panel edge. TM—Max Cullen/W

Split mudsill blocks:

The left photo in **Figure 3-12** below shows a block that split badly when it was nailed to the mudsill. The split block has much less strength than it needs. Splitting is especially common where blocks

are cut short to fit between studs—the shorter the block, the more likely it is to split. One way to avoid this problem is to cut the bottom ends of the studs so that longer blocks can be installed across two or more stud spaces.

Lack of secure block connection: In the right-hand photo in **Figure 3-12** no nails are visible in the block, indicating that it is not properly attached to the mudsill. Nails may have been driven into the ends of the block through the studs, but such a connection is much weaker than nailing directly to the mudsill.



Figure 3-12 Mudsill block problems: Left—Split block; Right—lack of visible connection from block to mudsill. TM—RPaul Rude

Slots or notches in plywood: The left-hand photo in **Figure 3-13** shows plywood that was slotted to fit around existing wires and piping. The slots significantly weaken the plywood. When possible, shear panels should be installed where there are no pipes, wires, or ducts in the way. If openings must be made through plywood for utilities, they should be as small as possible and blocking should be installed to permit nailing around them, as in the center photo. The connection shown in the center photo could be improved by sandwiching the pipe between the blocks so that the plywood is completely supported by framing.

Repairing notches or slots: In a perfect world, nothing would obstruct the plywood installation. In reality, avoiding obstructions is often impractical or adds great expense to the work. Slotted shear panels can be strengthened by gluing plywood patches over the slots, as shown in the right-hand photo in **Figure 3-13**. (Plywood is manufactured by gluing wood veneer together; it can be patched the same way.) The screws in the photo are only there to hold the repair patch in place until the glue dries. Repairs require proper plywood and adhesives.



Figure 3-13 Slots severely weaken plywood bracing panels. If existing utilities cannot be avoided, slot length should be minimized (center) or a plywood patch glued to the plywood to reinforce it.

Repairs: The right-hand photo shows a diagonal patch that was installed with construction adhesive to reinforce the notch at the upper-left corner of the plywood panel. TM, Paul R. TM, Thor

3.3 STEP 3: ATTACHING THE MAIN FLOOR FRAMING TO THE STRUCTURE BELOW

Once the mudsill is bolted to the foundation and the cripple walls (if present) are braced, the next step is attaching the floor framing to the supporting structure.

Floor framing connections to the top of the cripple wall do not always have adequate strength. Joists running parallel to the cripple wall generally have the weakest original connections. Some cripple walls in Bay Area homes built around the 1900's through 1930's have no top-plates. In this case, additional framing members are needed to make adequate connections.

In cases where there is no cripple wall and the floor framing bears directly on the mudsill, connection from floor framing to the mudsill is crucial.

Floor framing connections to braced walls: The floor joist at the right side of the photos below (resting on top of the cripple-wall top plate) was typically only connected with a few “toenails” which provide very little strength to keep it from sliding along the top of the braced wall. The photos in Figure 3-14 show joists before and after proper connections were made. Special tools are almost always needed to drive nails in such restricted areas.



Figure 3-14 Connections from floor framing to the braced walls.

Left photo: The floor joist on the right side of the photo could slide along the top of the braced cripple wall without better connection

Right photo: The sheet metal connectors will transfer earthquake forces from the floor joist to the braced wall.

Choose the right connector:

In the left-hand photo in **Figure 3-15**, the twisted “hurricane ties” at the top of the wall have very little strength to resist side-to-side earthquake forces. (The large hole in the plywood also weakens this bracing panel.)

The connectors at the top of the wall in the right-hand photo are also “hurricane ties”, but they connect to both sides of the joist and have a much higher rating for side-to-side forces. When this sort of connector is used, blocking between the joists is essential.



Figure 3-15 “Hurricane Ties” used to connect floor framing. The connectors in the left-hand photo have almost no capacity to resist side-to-side earthquake forces. The connectors in the right-hand photo have a much greater load rating.

Chapter 4 Other Concerns in Earthquake Reinforcement

4.1 So-called “Soft Story” Conditions

4.1.1 What is a soft story? (Introducing a new term: “SWOF”)

“Soft story” and “weak story” have very specific definitions in the building code. “Soft” and “weak” refer to stiffness and strength, respectively, which are different structural characteristics. These terms describe buildings where the entire structural system in one particular story is significantly weaker or more flexible than the story above. Cripple walls usually are both soft *and* weak. In earthquake retrofit work, engineers may use the category of “soft, weak, or open-front” buildings, or SWOFs. The “open-front” part of the term usually applies to mixed-use buildings with glass-fronted shops at the lower level and apartments above. In most cases when you hear the term “soft story” describing a house, the speaker is probably referring to a very large opening in an outside wall.

Garage doors create the most common SWOF:

In single-family homes the most common culprit leading to a SWOF condition is the opening for a garage door on the lower level of a multi-story home. The house shown at the top in **Figure 4-1** has very narrow walls on either side of the garage door. In most cases, even if you could strengthen the walls themselves, the foundation beneath them would not be strong enough to resist earthquake forces concentrated by the narrow walls. A garage door or other large opening does not always create a SWOF condition, depending on the configuration of the structure. Recent structural engineering studies show that a SWOF condition may not be the biggest concern in some buildings, and that even engineers sometimes mis-diagnose buildings as SWOFs.

The bottom photo shows severe earthquake damage. The added weight of a second floor above would almost certainly have caused complete collapse.



4.1.2 How can a SWOF be reinforced?

Soft-story conditions usually exist because of a large opening that must remain unobstructed. Maintaining the use of a garage door (or keeping the view from a large picture window) significantly limits the choices for strengthening the building.

Structural steel is often used to strengthen weak walls: Openings can be braced with a steel “moment frame” anchored to a new section of foundation. Such a frame appears in the left-hand photo of **Figure 4-2**. Custom-made moment frames are quite expensive. Some manufactureres (such as Simpson Strong-Tie Co, and Hardy Frames, Inc.) sell “pre-fabricated” moment frames; custom sizes almost always need to be ordered for retrofit work.

In cases where there is not enough room for a moment frame, a single “moment-column” can usually provide the necessary strength (right-hand photo in **Figure 4-2**). This system must be designed for much higher forces than moment-frames or shear walls because they rely on a single element with no “back-up.” Even with the greater strength requirement, moment-columns are often less expensive to install than moment frames.

Installation costs for both systems depend on the height of the opening, weight of structure above, the orientation of the floor framing members above the garage, existing obstructions, and other factors. Strengthening a soft-story is an expensive solution using the methods currently available. One of the authors of this document is pursuing a method that would allow lighter-weight moment columns, with related reduction in foundation size.



Figure 4-2 Two ways to strengthen a soft-story.

Left: A “moment-frame” made of steel and painted brown installed at the center garage door opening. (The bare wood framing and diagonal braces just inside the openings provide temporary support for the floor above).

Right: A “moment-column” fits between two garage doors. The column is embedded in a very substantial reinforced concrete “grade beam.” TMB, FEMA

4.2 Porches

Many older homes with large porches do not have a foundation below the front wall, where anchors and bracing are needed to resist earthquakes. Instead, the foundation follows the outline of the porch. This is especially common in homes built in the 1920s or earlier. In these situations it may be necessary to install a new section of foundation to ensure adequate earthquake resistance. **Figure 4-3** shows exterior and crawlspace views of such a house.



Figure 4-3 Front wall without foundation. The photo at right was taken in the crawlspace looking toward the front of the house. The foundation follows the porch outline; there is no foundation below the front wall of the house.

Porches—especially those with concrete surfaces—can be very heavy. The roof of a large porch is also heavy. In many older homes, the framing of the porch and roof has only minimal connection to the house, and little or no bracing. If the porch or porch roof collapses it can block the exit, increasing the hazard to occupants.

Concrete porches: The wrap-around porch in the top photo of **Figure 4-4** has a thick concrete slab supported on wood framing. The outer cripple walls under the porch need bracing along with the house walls.

The porch roof in the bottom photo of **Figure 4-4** shook back and forth and collapsed when it tore away from the house. Porch roofs that are not at least partly contiguous with the main roof of the house are most susceptible to collapse (note the porch roof outline left on the front wall in the photo—the roof had only been “planted” on to the front wall). Heavy roof construction (tile or slate, or several layers of old roofing) also increase the hazard.



Figure 4-4 Porches:

Top—wrap-around concrete porch.

Bottom—collapsed porch roof.

4.3 Corrosion Due to Chemicals in Treated Lumber:

A POTENTIAL TIME BOMB?

In most homes built since the 1970s, the mudsills and other lumber installed directly on concrete foundations are typically of preservative pressure-treated or “PT” lumber. The need for treatment is that concrete wicks moisture from the ground that causes lumber to deteriorate. (Prior to 1970 it was still economical to use “foundation grade” redwood, before we cut most of the redwoods down.) Earlier types of PT contained highly toxic chemicals. Formulations were changed starting in the 1990s to reduce the potential hazard to humans. The wood-treating industry switched to the new chemicals completely in 2004. Unfortunately, some of the newer formulations contain chemicals (particularly copper) that cause rapid corrosion in metal parts.

Figure 4-5 shows a severely corroded bolt; this photo was taken just five years after installation in pressure-treated lumber.

Corrosion can cause structural connections to fail. In the case of bolts or other anchors, failure could allow the structure to slide off the foundation in an earthquake. Corrosion of nails in shear panels or exterior sheathing could result in total failure of wall bracing. The severity of the problem varies with the specific formulation, the type of hardware installed, moisture conditions, and other factors. Because this is a relatively recent development, the potential for failure is still uncertain—but based on reports from contractors and field observations, the outlook is not good. Anchors and nails are usually concealed in a completed building, so it can be difficult to evaluate the extent of damage.



Figure 4-5 Fastener corrosion caused by preservative treatment, approximately five years after construction.

Current codes require that nails and hardware in copper-containing PT lumber be made of stainless steel or have a heavy galvanized coating that resists corrosion. However, there is no simple procedure for repair of hardware that is already damaged by corrosion. Where anchors are accessible in a crawl space or basement, they can be supplemented with new hardware. Where anchors are concealed inside walls, repair would require disturbing finished surfaces. More often than not, the nails of shear panels are completely concealed; inspection and repair could require extensive demolition.

This problem is mostly limited to relatively new homes, as PT lumber was not widely used prior to the 1970s. In older homes, the *original* mudsills are usually of high quality redwood that is quite resistant to moisture damage and does not increase corrosion appreciably. However, if wood damaged by termites or decay was replaced, PT lumber was often used; foundation replacement work usually involves replacing the mudsill with new PT lumber. More information is posted on the web site of the Simpson Strong Tie company, a connector and hardware manufacturer: www.strongtie.com/productuse/PTWoodFAQs.html



Figure 4-6 Corroding steel and galvanized steel connectors.

Left—note the nail in the red circle, that is corroding where it barely touches the PT lumber. There is a moisture barrier between the PT lumber and the concrete footing; without the barrier, corrosion would proceed even faster. This photo was taken just four years after construction. Note also that the silver-gray, galvanized steel hardware is beginning to corrode; corrosion will continue until all of the galvanized coating—and then all of the steel—is consumed. The steel rusts over its entire surface—not just where it contacts the wood.

Right—according to the building code, connectors $\frac{1}{2}$ " in diameter and larger may be plain steel (like the severely rusted anchor bolt in the photo). It is alarming to imagine what the nails fastening the wall bracing panels look like; the nails are about $\frac{1}{8}$ " in diameter. This photo was taken six years after construction. Melinda Pryor

RECOMMENDATIONS: There are two simple solutions to the corrosion problem. The first is to use stainless steel framing connectors; these are *very* expensive. The better alternative is to use **BORATE TREATED** lumber. Borate treatments are not waterproof, and must not be used for decks, fenceposts, or other members exposed to liquid water—but borate-treated lumber is appropriate for mudsills and other members that are protected from weather.



Figure 4-7 Borate treated lumber is not toxic to humans, and does not increase corrosion in fasteners like other chemicals.

4.4 Masonry Chimneys

Masonry chimneys are very vulnerable to earthquakes; collapse can result in death or serious injury. **Figure 4-8** shows two dangerous chimneys. The safest approach is to have chimneys removed, at least down to the level of the mantle. Where a fireplace must be retained, a metal flue can be installed. Steel braces may reduce the hazard, but most existing braces are inadequate. Bracing that meets current codes is *extremely* expensive to design and install; even braced chimneys may shed individual bricks in a strong quake.



Figure 4-8 Chimneys are hazardous even when they are in good condition. Slamming the front door could cause the disintegrating chimney shown at right to collapse.

One measure of earthquake intensity is whether or not chimneys collapse. The 1994 Northridge Earthquake knocked over the chimney shown in the left photo in **Figure 4-9**. The center photo shows a chimney that was built to recent code (note the twisted reinforcing steel), yet still fell over—as did tens of thousands of similar chimneys in the Northridge Earthquake (and others).

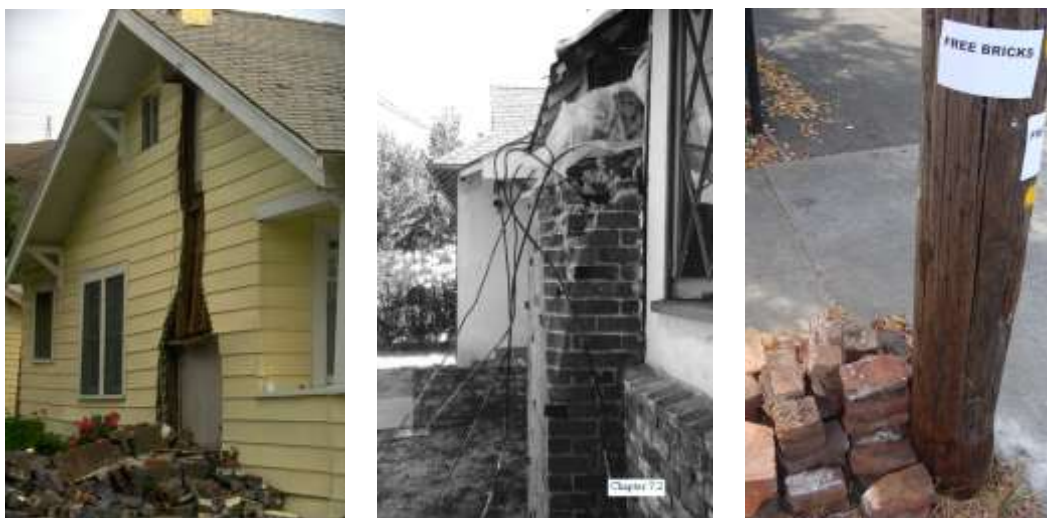


Figure 4-9 Collapsed chimneys; in the left-hand photo notice the bricks that remain at the roof level, ready to fall in an aftershock. Right-hand photo shows a good way to dispose of your chimney before an earthquake can knock it over!

Chapter 5 Special Conditions

5.1 Unusually Shaped Houses

Homes on steep hillsides and those with complex or multi-level floor plans or unusual configurations need specially engineered measures to ensure earthquake resistance.

Figure 5-1 shows two typical hillside homes, one supported by a perimeter foundation and another supported on tall posts. Both of these homes need special bracing measures. Plywood bracing does not work well on sloped or stepped foundations, even if it is installed following the recommendations given earlier.



Figure 5-1 Hillside homes require special consideration; plywood shear walls perform badly in sloping walls as found in the house shown above left. Homes on steep sites can be very dangerous in quakes.

5.2 Careless Remodeling

Any time an older home undergoes major alteration, an upgrade for earthquake resistance should be incorporated into the work. Where walls are opened for other work, an upgrade usually does not add significantly to the cost. On the other hand, when foundations and structural walls are concealed behind new drywall or tile, an upgrade may require removing and replacing the finished surfaces, making it prohibitively expensive. This has become especially common in the recent housing market; when distressed homes are “flipped” for quick resale, sellers rarely want to spend money on structural components that buyers will never see.

The newly remodeled basement shown in **Figure 5-2** has lovely cabinets and finishes—but is there plywood behind the freshly-painted walls? Were any mudsill anchors installed? What design guidelines, if any, were followed in designing the retrofit strengthening work?



Figure 5-2 Installing earthquake strengthening measures will help protect your basement remodel, as well as the rest of your house.

Chapter 6 Getting the Retrofit Work Done

How you approach your retrofit project will depend largely on your own abilities, your budget, and the complexity of the job.

6.1 Doing the Work Yourself

If your house meets the criteria for a “standard” retrofit plan (see the Further Information section) you may be able to install the retrofit components yourself. Retrofitting a simple home that has good access in a crawl space or basement is within the capacity of many homeowners who are willing to get dirty and have at least basic experience with carpentry tools. A retrofit can be a good source of “sweat equity,” as labor is by far the greatest factor in retrofit bid from a contractor.

To make sure your time and effort are well invested in a do-it-yourself retrofit, it is essential to obtain professional guidance, preferably a set of engineered plans. Some engineers and contractors will work with you on an hourly basis.

6.2 Hiring a Contractor Directly

There are numerous Bay Area contractors specializing in earthquake strengthening work. Some have their own in-house engineer or have engineers they work with regularly. Others follow “Plan Set A” (see “Further Information”), or simply rely on their own judgment in deciding what needs to be done. An experienced contractor may be able to do a good retrofit without engineering, especially for a simple home with a crawl space and without any of the special features mentioned above. But unless you hire a professional to observe the work during construction, you will have no way to be sure the work is adequate or performed properly.

If you plan to solicit bids from contractors—with or without plans—check with the Contractors State License Board www.cslb.gov for information on your rights, contractors’ responsibilities, and the status of a contractor’s license.

The Association of Bay Area Governments (<http://quake.abag.ca.gov/residents/contents/>) provides extensive information on residential earthquake retrofit work. They also have a listing of contractors who have attended ABAG training sessions (as of 2012, no training has been offered for several years; it is possible that personnel who attended the ABAG training have left the company—ask whether trained workers are still on staff.) For information on contractors, engineers, home inspectors and other professionals visit <http://quake.abag.ca.gov/residents/retrofitprof/>

6.3 Design: The Role of the Engineer

The traditional procedure of any construction project is that a professional designer draws plans for the work and a qualified contractor carries it out according to the plans. Earthquake retrofits

that fall outside the scope of the standard retrofit guidelines should be designed by a civil or structural engineer—a professional specifically trained to analyze the forces an earthquake can generate and devise a means to resist them. Engineers have different specialty areas, just as doctors or attorneys. Make sure the engineer you hire has experience designing retrofits for wood-framed construction. You can check an engineer’s licensing status at the Board of Registration for Professional Engineers and Land Surveyors website: <http://www.bpelsg.ca.gov/>.

Hiring an engineer may entail additional cost, but it carries some important advantages:

- A building permit is required for virtually any structural change to a building, and obtaining a permit requires a set of plans meeting certain standards; consult your local building department for details. For more complicated retrofit construction, the building department may require that an engineer prepares and stamps the drawings.
- If you ask contractors to bid on an “earthquake retrofit” without a set of plans, you have no assurance that they are all bidding on the same work. One contractor may quote a lower price simply because he or she proposes doing a less thorough job than one with a higher price. With a good set of plans, bids are tied to a specific scope of work. Obtaining bids based on plans can save money if it enables you to choose a contractor whose bid is truly better. In some cases, this can pay for a considerable portion of an engineer’s fees.
- In case of a dispute between a homeowner and a contractor, the engineer can offer an authoritative judgment as to whether the work is performed properly.

Chapter 7 Non-Structural Earthquake Hazards

Homeowners can eliminate many earthquake hazards themselves. Most of the following are “non-structural” earthquake hazards that do not require engineered solutions to correct:

- Wild-fires: The scene in **Figure 7-1** was probably much more frightening in person. Imagine the Oakland Hills fire (3000 homes lost), but with broken water-mains, first-responders needed throughout the Bay Area (or LA, Santa Barbara, San Diego etc.). Then add cracks in roads, damaged bridges, and downed trees. Depending on which part of California you are in, there may be a six to ten-month period when a wild-fire is quite likely after an earthquake. If you live on a forested hillside with congested roads, have a mountain bike for each resident and keep it ready for **IMMEDIATE EVACUATION** after an earthquake. If you wait until you smell smoke or see flames, it may be too late.



Figure 7-1 Wild-fires are scary enough without the extra confusion of an earthquake. Plan your escape *now*!

- Manual shut-off valves for natural gas or propane: Do you know where your gas shut-off valve is? When was the last time you “exercised” the valve? (It may have seized up 20 years ago.) Do you know which way to turn it to shut it off? Some valves can be turned either way (usually ¼ turn) but some can only be shut off by turning them clock-wise. If you have a propane tank, there should be a shut-off valve at the tank. There may also be another shut-off valve where the supply pipe enters the house.
- Automatic shut-off valves: Have a plumber install an earthquake-actuated (*not* a flow-actuated) automatic gas shut-off valve at your gas meter or propane tank. For information on California state certification of shut-off valves, see:
<http://www.dgs.ca.gov/dsa/Programs/programCert/gasshutoff.aspx>;
For a list of state-certified valves (as of October 27, 2008—may not get updated) see:
http://www.documents.dgs.ca.gov/dsa/gas_shutoff/List_of_Cert_ESV_rev10-27-08.pdf
- Metal stove-pipes for wood-burning stoves, and the stoves themselves; these should be secured solidly together and to the structure.
- Water-heaters falling over; The Golden Gate chapter of the American Society of Home Inspectors has a short video on their website that shows how to check if water heater bracing is secure, at the following link: <http://www.youtube.com/watch?v=RrUqO2HJIns>
- Heavy roof tiles—a good roofing contractor could advise you on how to keep the tiles from falling during an earthquake.
- Roof-mounted equipment such as air-conditioning units
- Heavy or expensive components subject to damage include water-softeners, pressure tanks, swimming pool filters, air-conditioner condensers, evaporative coolers, propane tanks, and so forth. Broken connections to some of these could cause flooding or other secondary damage.
- Porticos, heavy trellises, and awnings
- Tall, heavy furniture such as bookshelves or file cabinets, dressers, china cabinets, heavy mirrors or paintings, and so forth can fall and cause injuries during earthquakes. For suggested bracing methods see <http://quake.abag.ca.gov/residents/contents/>
- Heavy objects hung from walls, especially large mirrors or other glass items
- Hazardous windows: Non-tempered windows can break into possibly deadly pieces. Windows near beds or cribs are of particular concern. Consider installing a reinforcing film such as 3M’s “Scotch-shield” to such windows.

ABAG has an extensive website that shows how to reduce the above dangers, plus a great deal of information on how to prepare for an emergency.

Further Information

(For more extensive information, see www.quakecheck.org)

Mr. Matteson is currently writing a book exclusively about earthquake retrofits for wood-framed houses. The book is expected to be about 200 pages long, with at least 100 photos and dozens of construction details. The book will expand on all of the topics presented here and include much additional information. Release is anticipated in mid 2013.

If you or your company is interested expediting the earthquake retrofit book's release through direct funding, please contact Mr. Matteson at (510) 230-8601. (Further details at www.quakecheck.org; donations are currently NOT tax deductible.)

The following references present the most current information on residential retrofits:

SECOND EDITION of "Wood-Framed Shear Wall Construction—an Illustrated Guide" by Thor Matteson, SE International Code Council Publication #4020S09

(Available at the ICC website at www.iccsafe.org/Store/Pages/Product.aspx?id=4020X09 or from Builders Booksource in Berkeley: 1817 4th St., Berkeley, CA 94710 510/ 845-6874)

The second edition of the *Shear Wall Construction Guide* is 180 pages long, with over 150 illustrations and photos. Chapter 6 addresses earthquake retrofits.

The *Shear Wall Construction Guide* addresses many field conditions and obstacles encountered in shear wall construction. It also includes information on collectors, openings through shear walls, wood shrinkage, and other topics related to new or retrofit construction.

FEMA P-593 Seismic Rehabilitation Training for One- and Two-Family Wood-Frame Dwellings--2008

Features a very useful color-coded chart showing common hazards to look for; chart gives references of where to find more info (many of which are listed here)

Current format is essentially Power Point slides; this is a good review if you attended the seminar, but without accompanying discussion it is unlikely a reader will learn retrofit methods by reading the materials alone

Contains good examples of some common mis-applications of hardware to avoid

FEMA P-547 Techniques for the Seismic Rehabilitation of Existing Buildings--2006

An expansion of prior FEMA documents, especially with respect to wood-framed buildings. Chapter 5 applies to residential construction (other chapters address any office buildings, warehouses, hospitals, and the like that you may want to retrofit). Download Part 1 (containing Chapter 5) from FEMA at: <http://www.fema.gov/library/viewRecord.do?id=2393>

The following “standard plans” are either identical to, or minor variations on, the information in FEMA P-547:

- **California Existing Building Code & International Existing Building Code**, Appendix Chapter A3 (essentially the same with respect to wood-framed construction).
- **ABAG—Standard Plan A (also known as “Plan Set A”)**: Consists of two full-size 24” x 36” drawing sheets. More information available at <http://www.abag.ca.gov/bayarea/eqmaps/fixit/plansets.html>. Download the PDF document directly at <http://www.abag.ca.gov/bayarea/eqmaps/fixit/Plan%20Set%20A.pdf>.
- **City of Seattle—Project Impact**: PDF document in 11” x 17” format. Download at: http://www.seattle.gov/dpd/static/20_pages_LatestReleased_DPDP_021980.pdf
- A workbook that accompanies the Seattle plan set expands somewhat on how to implement work under its requirements: <http://www.seattle.gov/emergency/library/mitigation/HR%20Book%202%20-%20assessment.pdf>
- **LA—Standard Plan One**: This document is available for download. It is in PDF format sized at 30” x 40.” You can also order by mail. (If you think these are inconvenient drawing sizes to print from your computer, try unfolding one to read it in an 18” high crawlspace.) http://ladbs.org/LADBSWeb/LADBS_Forms/Publications/anchor_bolting.pdf

Surviving in Earthquake Country—by Peter Yanev

Excellent overview of geologic considerations, behavior of various high-rise and commercial building types, residential hazards (such as hillside homes) to look for. Provides basic retrofit measures similar to those in other publications listed above.

Putting Down Roots in Earthquake Country

Prepared as a joint venture by the US Geological Survey and various state and local agencies, depending on the region. Overview of seismology, shaking maps, fault locations, emergency preparations. Customized for several regions: Northern California, Southern California, Nevada, & Utah. PDF versions are available for free download on the web.

FEMA P 50-1 Seismic rehabilitation guidelines for detached, single-family wood-framed buildings

Chapter 2 applies to residential retrofits. Connections and structural conditions discussed are generally covered in documents listed above.

As of November, 2012, this document was not available on the web. Chapter 2 is available for download at www.quakecheck.org

Glossary of Terms Used in Earthquake Retrofit Work

Anchor. Hardware that connects the structure to the foundation.

Anchor bolt. A bolt used for connecting the structure to the foundation.

Bearing plate. A heavy steel washer installed on foundation bolts to reduce splitting of the mudsill.

Blocking. Sections of lumber installed between framing components such as studs or joists, usually perpendicular to them.

Cripple Wall. In carpentry, “cripple” simply means shorter than normal. The cripple walls of a building are the short walls between the foundation and the floor.

Douglas fir. The most common kind of lumber used for framing in the western US.

Epoxy anchor. A bolt installed in a foundation with epoxy resin.

Footing. A section of concrete foundation, especially the buried portion.

Foundation. The structure installed in or on the ground to support a building. In most Bay Area homes, the foundation is of concrete. Many homes built before about 1910 and a few later ones have brick foundations. Concrete block masonry is less common than concrete; stone foundations are rare on the west coast.

Framing. The structural “skeleton” of a building. In most houses, the framing is of lumber. Some or all of the framing in newer homes may be of steel.

Hold-downs. Steel brackets installed at the ends of a shear panel to prevent the panel from rocking up and down on the foundation (they do not function to keep the house from “jumping off the foundation”). In newer homes, hold-downs may also be used to connect shear walls at upper floors to the foundation. The same hardware may be used to anchor decks to the main house structure, or for other connections.

Joist. A horizontal wood member that supports a floor.

Moment Frame. (Also called “moment-resisting frame.”) A steel frame used to brace around a large opening such as a garage door.

Mudsill. The board installed directly on top of the foundation, and the base to which other framing is attached. Also called the sill plate or foundation plate.

Pony wall. Same as “Cripple Wall”.

Pressure Treated Lumber. Lumber that has had chemicals applied to it under pressure to resist termites, fungus, and other structural pests.

PT. Pressure treated lumber.

Retrofit. Installation of components for earthquake resistance in an existing structure.

Shear Panel. A bracing component for resisting side-to-side earthquake forces, usually consisting of plywood fastened to mudsills, top plates, and wall framing.

Soft Story. The building codes define a “soft story” when the structural system at any particular story has 70% or less of the *stiffness* of the structural system in the story immediately above. Unreinforced cripple walls are typically “soft stories” in wood-framed buildings. See “SWOF.”

Stud. A vertical component of a wall that supports the wall surfaces and the structure above. In older homes, studs are usually of lumber. Newer homes may have steel studs.

SWOF. Short for “*Soft, Weak, or Open Front.*” This term is used for a large category of residential, commercial, and mixed-use buildings. For single-family homes it usually refers to a portion of the building with a garage door opening or picture window that significantly reduces the strength of a particular wall line. Unreinforced cripple walls usually create soft *and* weak story conditions in wood-framed buildings. Large openings may or may not create a soft or weak story according to the strict code definitions. Depending on the location of the opening and the building configuration, large openings can create weaknesses that may lead to significant localized damage or collapse of part of the building.

Top Plate or Wall Plate. A horizontal component, usually of lumber, at the top of a framed wall.

Weak Story. The building codes define a “weak story” when the structural system at any particular story has 80% or less of the *strength* of the structural system in the story immediately above. Unreinforced cripple walls are typically “weak stories” in wood-framed buildings. See “SWOF.”

DONATE to Help Expand Retrofit Training Resources

In addition to regular work, Thor Matteson is either writing or updating a book on earthquake retrofits (over 200 pages long), or he is developing seminars for contractors and homeowners on good retrofit methods. **If you found the information in this document helpful and want to show appreciation, please donate any amount to him via Paypal.com: thor@yosemite.net**