The Principles and Practice of Effective Seismic Retrofitting

This is a very rough draft of a book on retrofitting being written by Howard Cook in collaboration with structural engineers who are members of the Structural Engineer's Association of Northern California. It is being written to help contractors and engineers understand how to properly retrofit a home in a cost-effective manner. No one is being paid for this and it is being written solely as a means to help the public avert the coming disaster.

An Overview

This book has been a long time in coming. It has the potential to save thousands of homes and many lives as well as provide a much-needed ~~r~~eference book for building professionals. This book is the result of extensive study related to the subject of seismic retrofitting, which is a field as wide as it is vast. Home foundation bolting, cripple wall bracing, shear wall construction, the reaction of building to large earthquakes, are some of the subjects addressed in this book.

The existing retrofit guidelines, such as the very dated Appendix chapter A3 of the International Existing Building Code and Standard Plan A, do not incorporate modern developments in wood frame retrofit construction, new hardware developments, or earthquake retrofit engineering knowledge gained from the Northridge and Loma Prieta Earthquakes. They also neglect to address the variety of framing configurations found under old houses are not even addressed by these guidelines. Unfortunately, this has resulted in millions of dollars being spent on infective retrofits done by well-meaning contractors who did the best they could with very little knowledge. See FALSLE SECURITY

These deficiencies are because at the time these guideline were written sufficient field experience was lacking. Now is the time to bring the most up-to-date information to light.

Seismic Behavior of Level and Stepped Cripple Walls, a publication of the Consortium of Universities in Earthquake Engineering (CUREE) states: "In the Northridge Earthquake more than half of the 40 billion dollars in property losses were due to failures of wood frame construction, primarily as a result of the damage or collapse of residential, single-family homes, multi-family apartments or condominiums." (Page 10) The San Francisco Bay Area is riddled with earthquake faults. Geologists expect one of these, the Hayward Fault, to erupt with a 7.2 magnitude earthquake. Over $170 billion dollars in property damage is expected with over 150,000 housing units deemed uninhabitable. If the Bay Area's proportion of residential damage matches the Northridge earthquake's damage, this translates into $85 billion dollars of wood frame residential damage. This book hopes to reduce this terrifying statistic.

Homeowners are not unaware of these facts. In response to homeowner demand, many contracting firms in the Bay Area now specialize in residential wood frame seismic retrofit work. Over twenty million dollars has been spent on residential retrofits in Berkeley alone through their retrofit incentive program. Unfortunately, all the work done was performed without a code or guidelines to follow nor with special licensing for contractors. Contractors with little or no understanding of effective retrofit principles design and install most of the residential retrofits in the San Francisco Bay Area. Engineers are also at a loss without good guidelines and construction details.

While a very large number of homes are being retrofitted or have already been retrofitted in the Bay Area, the policy of all Bay Area building departments is known as the “do no harm” policy. This is based on the California Building Code for new construction, the code used by all building departments in California, which states that building departments shall approve any work that might increase the “lateral-force-resisting strength or stiffness of an existing structure” as long as such work does not obviously damage the building. The “do no harm policy” all too often translates into a “do no good” policy. This book hopes to correct this.

Does retrofitting work?

210 Elm Street in Santa Cruz saved by retrofitting

In 1989, at the corner of Center and Elm streets in downtown Santa Cruz, architect/owner Michael O'Hearn unwittingly created a laboratory for the study of residential wood frame retrofitting.

The two identical Victorian style homes at 214 and 210 Elm Street were built100 years ago by the same builder, with identical materials and using the same construction techniques.

O'Hearn retrofitted #210 but before he had time to retrofit #214 the 7.1 Loma Prieta earthquake hit on Oct. 17, 1989.

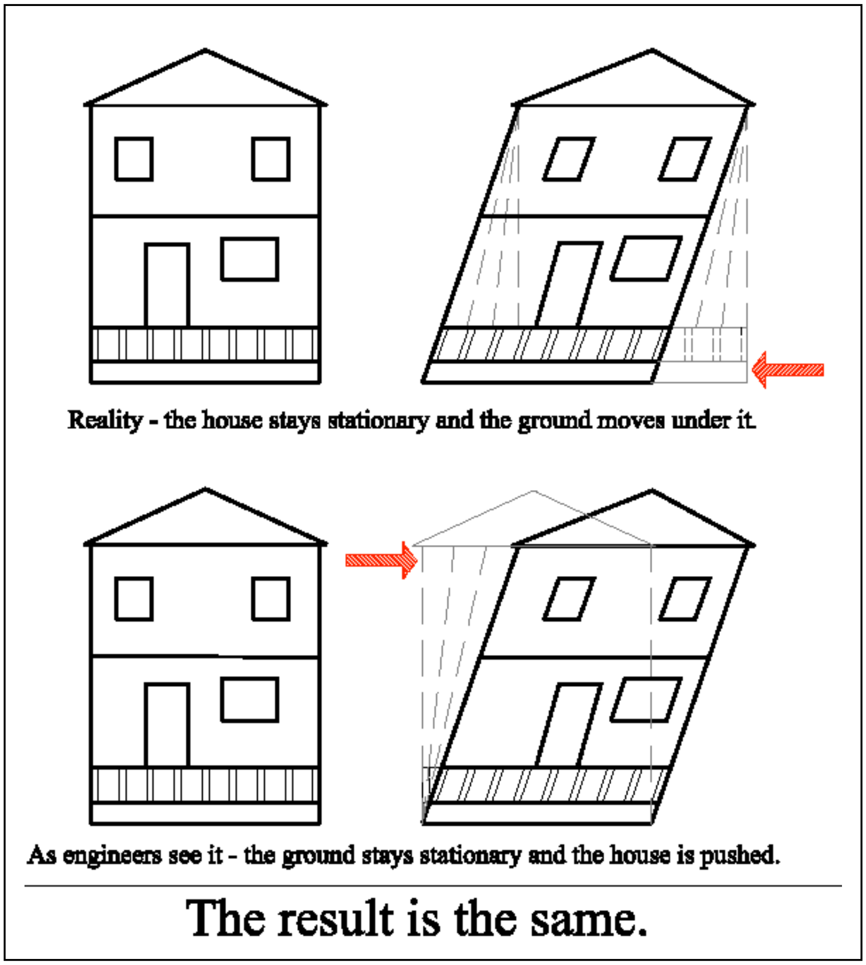
In a sense, 214 Elm Street was the "control element" in this amazing experiment. "The building came apart in four sections," O'Hearn said: "The one we had retrofitted (210 Elm St.) Cost us $5,000 to repair. The other one (214 Elm St.) cost us $260,000 to repair. The whole building had to be jacked up, repaired, and slid back on a new foundation." Both of these repairs would cost significantly more in today’s dollars.

O´Hearn offers this advice, "For homes more than 20 years old located in areas of seismic activity, I strongly urge owners to consider seismic retrofit. It's a lot cheaper to retrofit a house now than to repair it after an earthquake.”

Earthquake Standards. APA, The Engineered Wood Association, 1997

Three Components of a Cripple Wall Retrofit

Retrofit principles are discussed as if earthquake forces push against a house because it is much easier to conceptualize. In fact as the ground moves suddenly under a house it has an effect similar to riding in the back of a pick-up truck that accelerates very quickly and stops suddenly, and then quickly does the same thing in reverse.



The purpose of retrofitting is to keep the house on the foundation when pushed on as shown above. This is done by onverting un-braced cripple walls into earthquake resistant shear walls. Retrofit shear walls consist of three different retrofit components:

1. The cripple wall's framing needs to be braced with plywood or oriented strand board (OSB).
2. The braced cripple walls need to be bolted to the foundation.
3. The floor of the house needs to be attached to the braced cripple walls.

Below is a photograph of an unreinforced cripple wall viewed from outside the house.

Example 1: **A typical cripple wall**

Converting a cripple wall into a shear wall involves the modification of three structural components. The following illustrations clarify what these three structural components are and why they need to be strengthened. If any one of these three components are not made into an earthquake resistant shear wall, a house can suffer serious structural damage. The structural failures these illustrations portray have been exaggerated for clarity purposes.

1. Bracing the Cripple Walls with Plywood

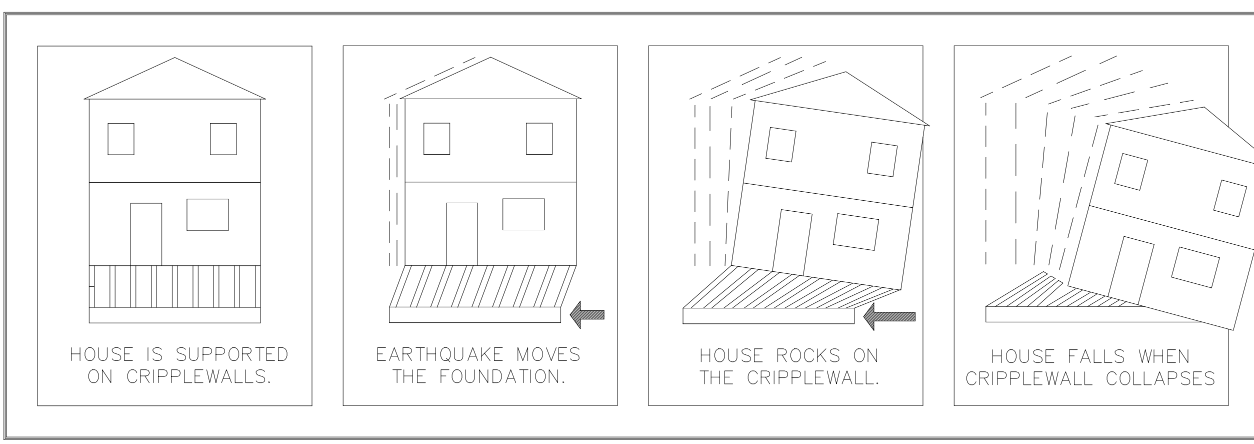
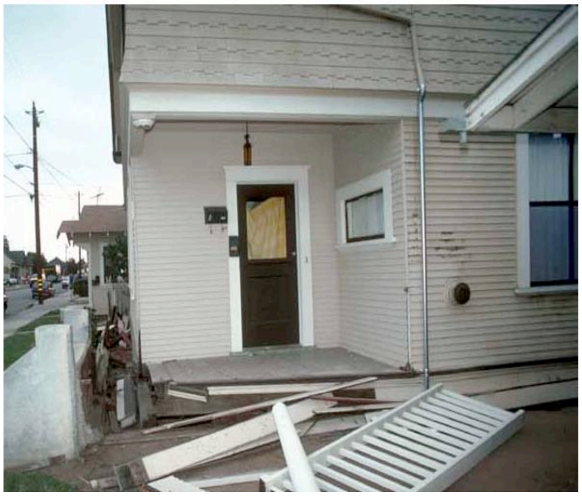


Figure. 1: Damage to house due to lack of cripple-wall bracing

Figure 1 shows what can happen to a house if the cripple wall has not been converted into a shear walls.   History has shown that un-braced cripple walls are the first structural component to fail in an earthquake unless they are converted into shear walls.



Example 2: Cripple wall failure.

Example 3: Cripple wall failure from improperly installed plywood siding.

2. Bolting the Braced Cripple Walls to the Foundation

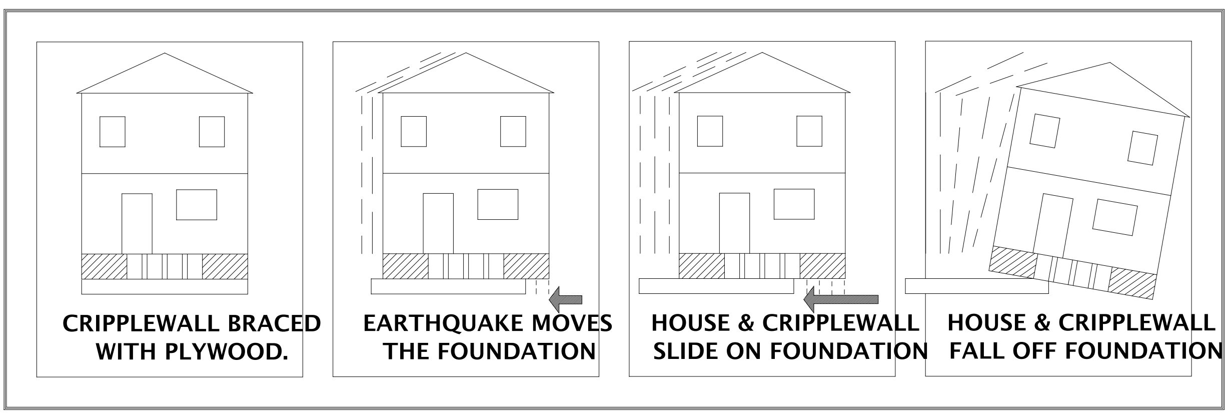


Figure 2: Failure caused by lack of foundation bolts

Figure 2 illustrates what can happen if plywood-braced cripple walls are not bolted to the foundation. It is not necessary to put plywood on the entire wall. House bolting alone without bracing the cripple wall with plywood does nothing to protect a house. A shear wall is an assembly and requires all three components.   Knowing how many linear feet of shear wall to install involves the use of an engineering formula called the <u>*base shear formula*</u>, which will be described later in this chapter.

3. Attaching the Floor of the House to the Braced Cripple Walls

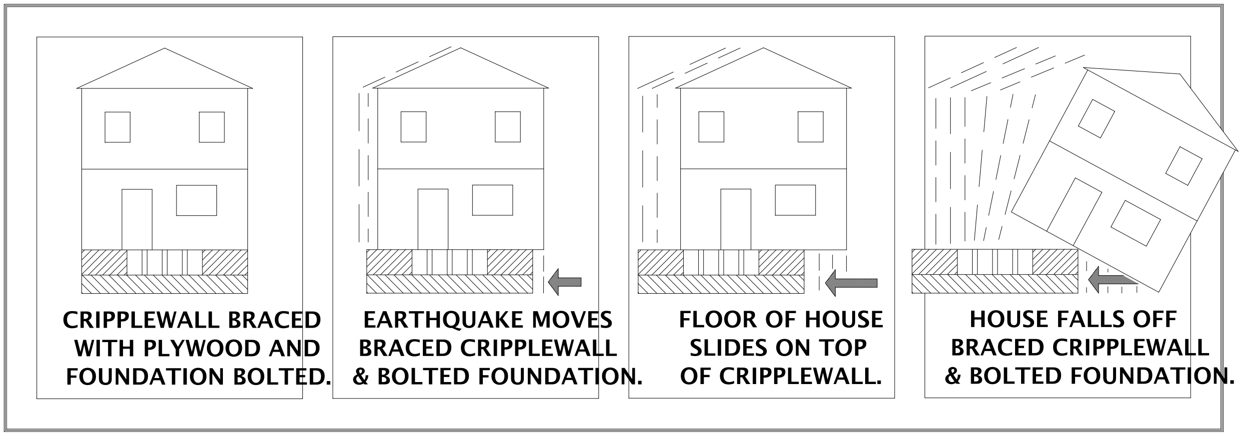


Figure 3: Failure due to no connection of floor to cripple wall

Figure 3 illustrates what can happen if the floor is not attached to the bolted and plywood braced cripple walls. This floor to cripple wall connection is strengthened with hardware called <u>*shear transfer ties*</u>.

Example 4: Bracing a failing cripple wall.

If the first shock does not knock a house down, an after shock might. Notice in the above photo how the failure of the cripple walls on the front and back caused the side cripple walls to lean.

The three previous diagrams give the impression that cripple wall retrofits are simple to install. There are actually an almost infinite variety of cripple wall configurations that are much different from what is illustrated here. This arises from the fact that when old houses in the Bay Area were built, no building codes or standardized methods of construction were in place. At the same time immigrants from many countries built these houses and they all had different approaches. Just as every house is more or less unique, the design and installation of a retrofit is also more or less unique. This is the why retrofit engineering principles and methods of applying these principles make it possible to retrofit a house no matter how it is built. While many different methods and configurations exist in our housing stock in California, an understanding of the LOAD PATH is the first step to being able to properly retrofit any home.

The Load Path

The load path is the path earthquake forces travel through various structural components and their connections as these forces travel from the floor to the foundation. When evaluating a wood frame structure it is necessary to trace the “load path” and make sure future lateral movement of the floor is restrained all the way from the floor down into the bolts and into the foundation. All seismic retrofit is based on understanding how a load path works and is the single most important concept one must understand. When evaluating a house from inside the crawl space, look up at the floor first and then follow the load path down to the foundation. Any weak areas that cannot resist a lateral movement are a potential failure point.

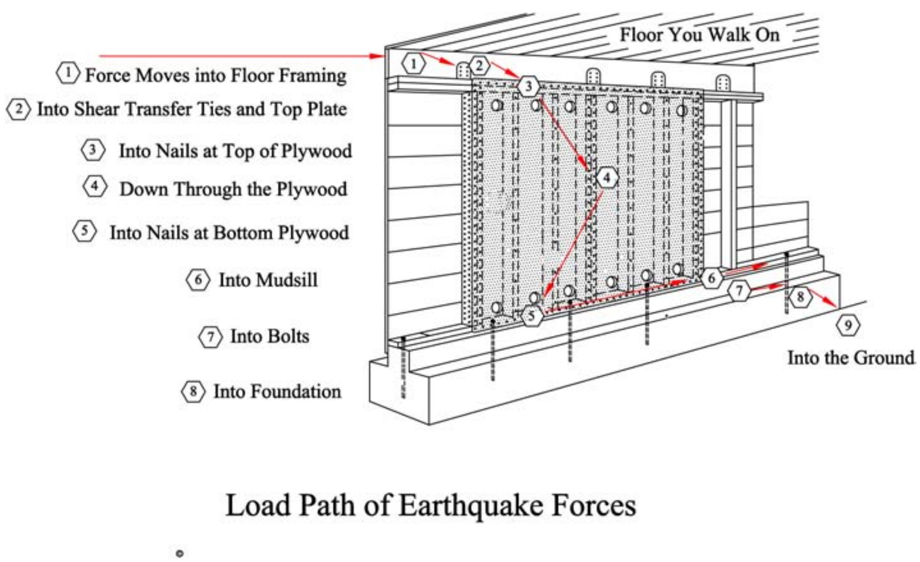


Figure 4-The load path

This illustration represents a fully braced cripple wall. Most cripple walls are very short and do not have much overturning. Overturning will be dealt with in a future chapter. When a wall is braced like this it is known as a shear wall.

1) Earthquake pushes against the floor you walk on as illustrated by the blue arrow.

2) The floor you walk on is nailed to the floor framing. The floor framing in turn is pushed in the same direction as the floor and it tries to slide on the upper top plate.

3 This sliding movement pushes against the shear transfer ties.

4) The shear transfer ties transfer this sliding force into the upper top plate,

5) The upper top plate transfers this sliding force into the nails at the top edge of the plywood.

6) These nails transfer the sliding force down through the plywood into the row of nails at the bottom of the plywood.

7) The nails at the bottom of the plywood transfer the sliding force into the mudsill,

8). The mudsill transfers the force this sliding force into the bolts.

9) The bolts transfer the force into the foundation.

10) The foundation transfers this sliding force into the ground where it is finally dissipated.

This chain of movement from the floor to the foundation through various structural components is the load path. If any component within the chain is missing or weak, the retrofit can fail. A retrofit can be defined as attaching the floor you walk on to the foundation in such a way that the floor is retrained from movement when pushed on by an earthquake.

Example 6: Failure in load path.

This home fell six feet because somewhere the load path from the floor to the foundation failed. Notice the position of the stair landing relative to the floor and how the house is otherwise intact. The interior walls, plumbing, and electrical systems suffered catastrophic damage. If an effective load path had been in place to transfer earthquake movement into the foundation, this house would have remained fully habitable.

The Base Shear Formula

Perhaps the most critical decision regarding a retrofit is knowing how many linear feet of plywood, bolts, and shear transfer ties a house will need. Doing more than is required can strain a budget; not doing enough can cause the retrofit to fail. This information is determined by using a simple formula called the base shear formula which establishes how much earthquake force the base of a house will be subjected to. Elementary multiplication is all you need to know to use this formula.

The base shear formula is:

$$V = 0.2\ (W)$$

> *V* represents the shear force that will be generated at the base of a building. That is what we want to know.
>
> 0.2 represents anticipated force of ground acceleration from a major earthquake. This number is based upon proximity to known earthquake faults. However, for simplicity's sake, 0.2 is used for the Bay Area and it slightly exceeds the code requirement for most geographic locations.
>
> *W* represents the weight of the building. Single story homes weigh approximately 50 pounds per square foot. Two story homes weigh approximately 80 pounds per square foot of the first floor area.

Example: We have a two-story house with a first story that is 25 feet by 40 feet. The first story is thus 1,000 square feet (25 x 40 = 1,000). If we multiply this times 80 pounds, we determine that the building weighs 80,000 pounds. Using this information and the base shear formula we can determine the amount of earthquake force expected to strike this building. We will want to design a retrofit that will resist this amount of force.

In this example we would use the base shear formula as follows:

V = 0.2 x weight of house
V = 0.2 x (area in square feet <u>of the first floor</u> x weight per square foot for a two-story home)
V = 0.2 x 1,000 sq. ft. x 80 pounds per sq. ft
V = 0.2 x 80,000 pounds
Base Shear = 16,000 pounds

The earthquake force that is anticipated to strike this home at its base (foundation area) during a major earthquake is 16,000 pounds of force.

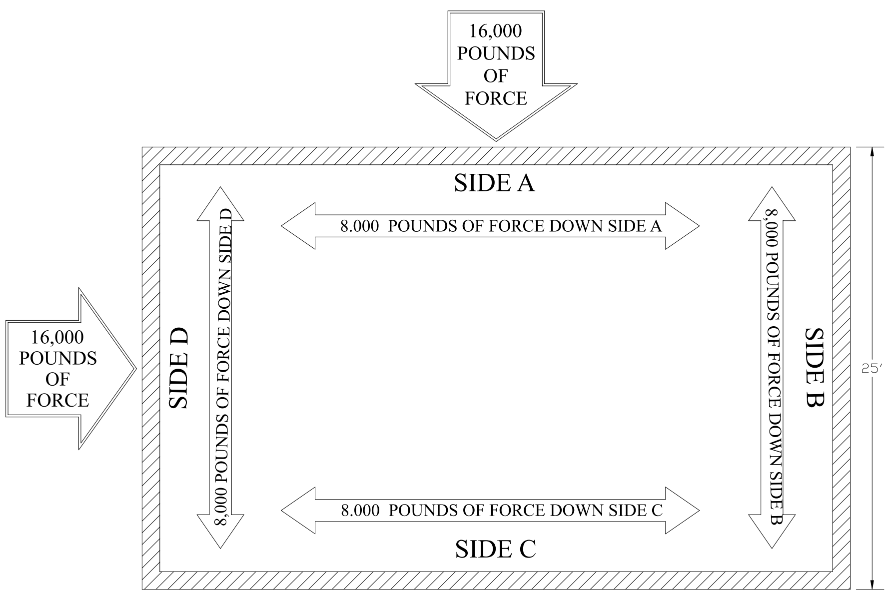


Diagram 8: Earthquake force against base of house

This means a properly designed retrofit for this house must have enough bolts to resist a minimum of 16,000 pounds of force where the mudsill sits on the foundation, AND enough plywood on the cripple walls to resist a minimum of 16,000 pounds force and keep the cripple walls from collapsing, AND enough shear transfer ties to resist a minimum of 16,000 pounds of force where the floor framing sits on top of the cripple wall.

If 16000 pounds of force is applied to the house from any direction, the two sides of the house that are parallel to this force must resist it. So in our example each must resist 16,000/2 or 8,000 pounds on each side. This information establishes the quantity of bolts, plywood, and shear transfer ties that are needed to strengthen these potential failure points. All bolts, nails, plywood, shear transfer ties are rated in terms of the amount of earthquake force they can resist measured in pounds. For example, a 1/2-inch bolt with a mudsill plate and plate washer can resist 1,200 pounds of force. Each linear foot of properly installed plywood bracing using the flush cut method can resist 600 pounds of force. Good shear transfer ties can also resist around 600 pounds of force. A retrofit is simply a matter of providing enough of these components to resist the outcome of the base shear formula.

The earthquake resisting capacities of the different types of bolts, plywood, and shear transfer ties; as well as installation guidelines are discussed in the rest of this book.

If you wish to study earthquake engineering in fuller depth, the following publications will be very usedful.

Foundation Bolt Quantity

The house in our example could be attacked by 16,000 pounds of earthquake force in any direction. To determine the number of 1/2-inch bolts we will need, divide 16,000 pounds by 1, 200 pounds. This is the capacity of a ½ inch bolt to resist earthquake forces. The answer is 13.3 bolts. We round this up to 14 bolts. This means we need a total of 14 bolts to protect the house in the north-south direction and 14 bolts to protect it in the east-west direction. To protect this house we will need to install 7 bolts along each foundation wall. Bolts only need to be installed at plywood shear wall locations because practically all of the earthquake forces is absorbed by the plywood and transferred to the bolts located at the base of the shear wall.

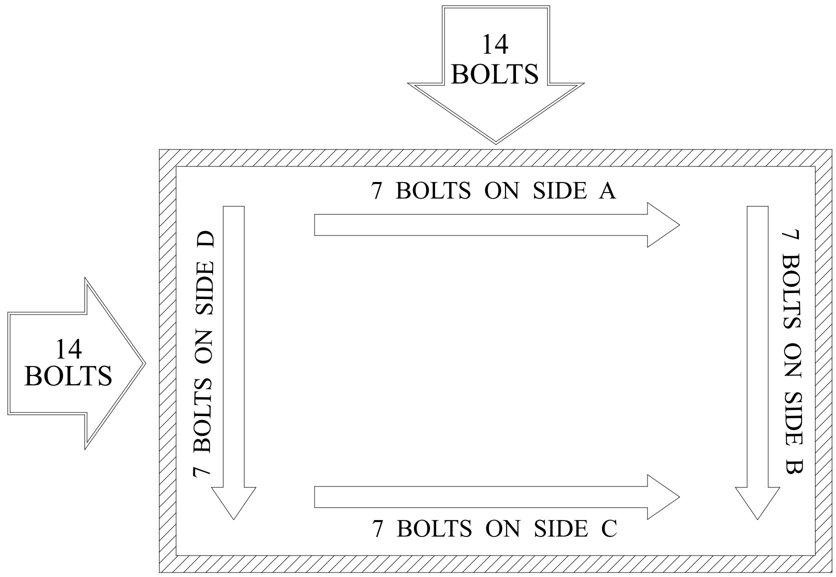


Diagram 9: Required number of bolts

Plywood Bracing

Next we need to address the bracing of the cripple walls. Each linear foot of good quality plywood can resist 600 pounds of earthquake force. If we divide 16,000 by 600 we get 26.6. We may round this up to 28 because cripple walls are usually framed in 2-foot increments. This means we need 28 linear feet of plywood in the east-west direction and 28 linear feet of plywood in the north-south direction, or 14 feet of plywood on each side of the house.

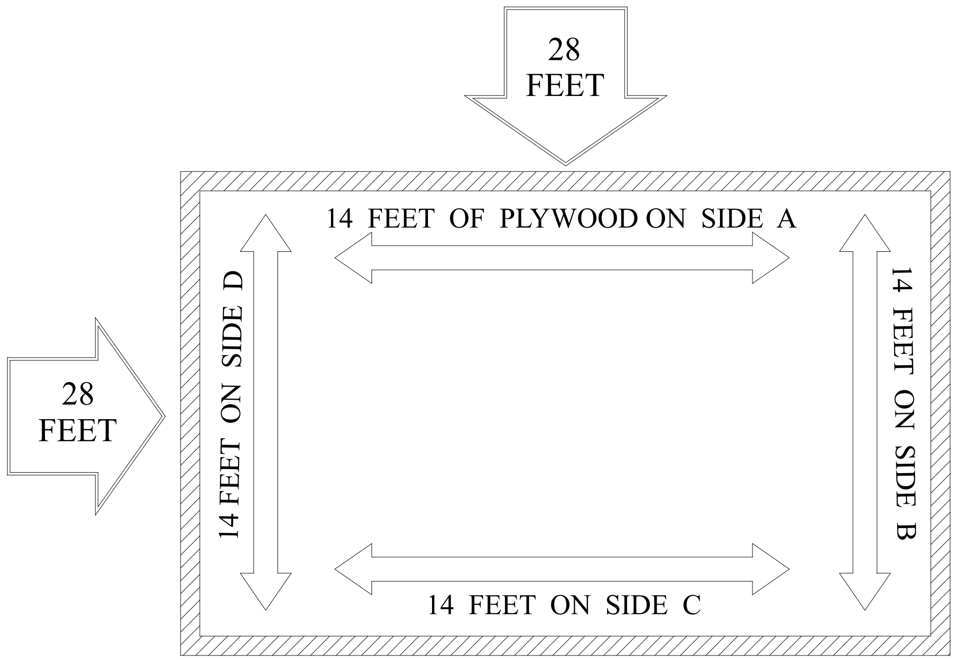
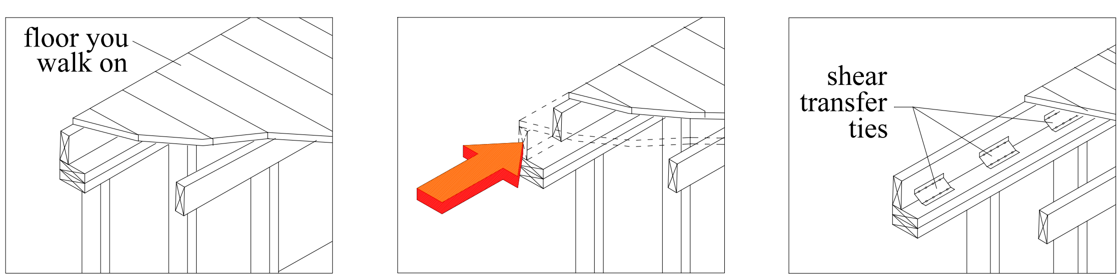


Diagram 10: Required linear footage of plywood

Shear Transfer Ties

The same method is used to determine the required number of shear transfer ties. Good shear transfer ties can resist approximately 600 pounds of earthquake force. 16,000 divided by 600 equals 26.6. We round this up to 28 an even number so we can have an equal number of shear transfer ties on each side of the house. This means we need 28 shear transfer ties in the east-west direction and 28 in the north-south direction; or 14 shear transfer ties along each side of the house. The purpose shear transfer ties is to prevent movement of the floor framing on the cripple wall top plate as illustrated below.



Movement prevented by shear transfer ties.

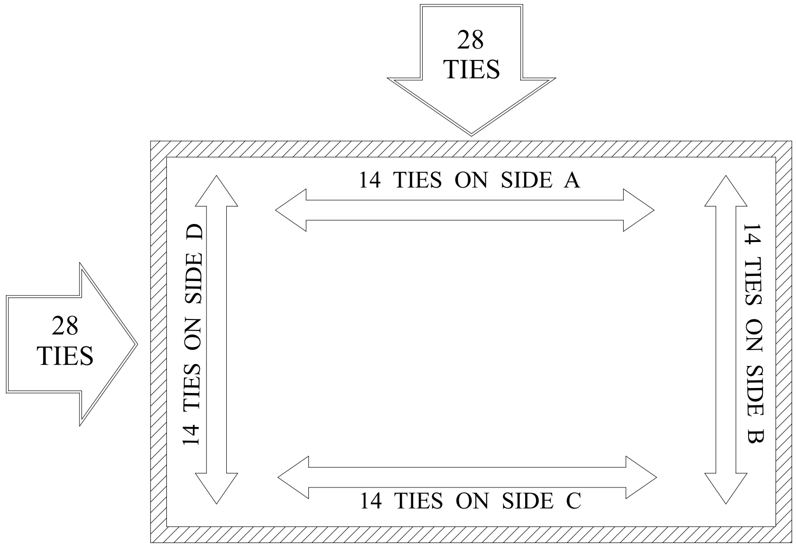
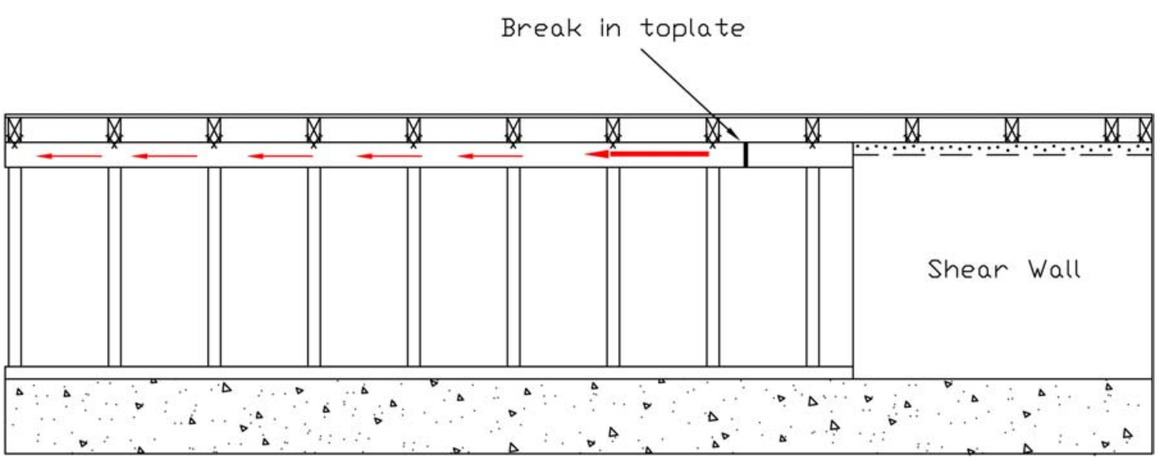


Diagram 11: Required number of shear transfer ties

Top plate splice

It is very important to make sure any breaks in the top plate are spliced together.

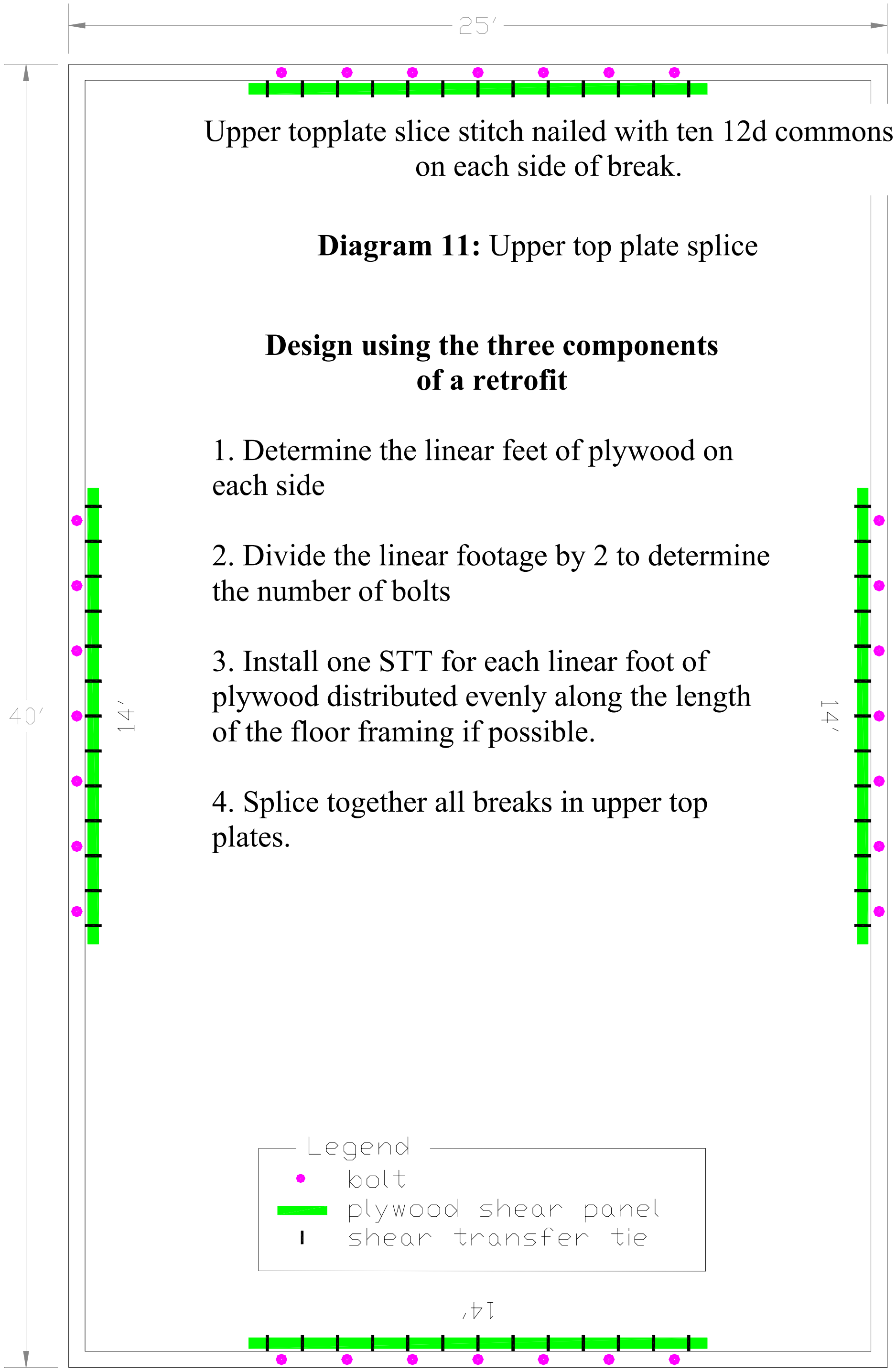
The illustration below shows how earthquake forces pull on the upper top plate as "travel" back towards the shear wall. Once they confront the break in the upper top plate they cannot reach the shear wall and are left to damage the house. A steel strap is used to bridge these gaps which is called a continuity tie.



Below is what our final retrofit would look like.

Upper topplate slice stitch nailed with ten 12d commons on each side of break.

Diagram 11: Upper top plate splice



Design using the three components of a retrofit

1. Determine the linear feet of plywood on each side

2. Divide the linear footage by 2 to determine the number of bolts

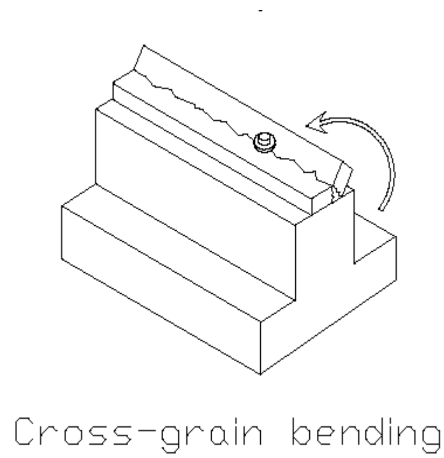
3. Install one STT for each linear foot of plywood distributed evenly along the length of the floor framing if possible.

4. Splice together all breaks in upper top plates.

Diagram 12: **Complete retrofit**

It is important that the proper number of bolts with plate washers be installed at shear wall locations behind the plywood. This should be done not only to resist the tendency of cross grain bending, but also to provide a bolt strength capacity equal to the strenght of he plywood.

Cross grain-bending failure in test shear wall



This type of force is difficult for wood to resist.

Publications Used is Seismic Retrofit Engineering

In order to properly design and implement wood frame seismic retrofits it is important to be familiar with the research that has been done in this field. Most of this research has been published in six different documents: The International Building Code published by the International Conference of Building Officials, The Simpson Strong-Tie Catalog published by the Simpson Strong-Tie company, NER-272 published by the National Evaluation Service, Inc., The National Design Specification for Wood Construction published by the American Wood Council, APA Report numbers 138 and 154, and APA Technical Note N370C published by the American Plywood Association. Below the reader will find a short description of these documents and how they can best be used in the design and construction of wood frame seismic retrofits.

The Uniform Building Code

This document defines the laws required in new construction for the state of California as well as for many other jurisdictions throughout the country. This code was first published in 1927 and the edition currently in use in the 1997 edition. In common parlance it is usually referred to as the “1997 Building Code”, “The Building Code” or simply “The Code.” This is an important document because it provides designers with basic information and formulas that can be used in seismic retrofit work. It specifies how new walls are to be framed and tells the designer how strong shear walls will be if they are built in a certain way. When any city or state building inspector looks at construction work he makes sure that it complies with this code. The Uniform Building Code is not much use in designing seismic retrofits because it applies to new construction. Only one short chapter, chapter 34 entitled Existing Structures gives guidelines for seismic retrofit work.

The Simpson Strong-Tie Catalog

This document describes the different types of hardware made by the largest construction hardware manufacturer in United States. This company manufactures practically all of the hardware used in seismic retrofit work. It is therefore very important that the designer be able to accurately read this catalog. It tells the designer the size and length of nails that are to be used in each piece of hardware and more importantly, it tells the designer how much earthquake force a specific piece of hardware is designed to resist. For example, on page sss of the 2004 catalog under the fastener column is specifies that the H10 hardware should be installed with 8-10d x 1 1/2 fasteners. This means that this hardware should be installed with eight 10 penny nails 1 1/2 inches long. Under the “F1” column it reads 585. This means that the hardware will resist 585 pounds of lateral force (the type of force generated by earthquakes) if it is installed as specified by the catalog. However, in some cases it is necessary to use a different sized fastener. In these cases the hardware will still work if compensation is made for the fact that the nail or other fastener is different from that specified in the catalog. This is called a "reduction" or "increase" in capacity of the hardware. For example, if the Simpson L70 hardware is installed with 8-8d x 1 1/2 nails rather than the 10d nails it will have a 12% reduction in strength as per the "Load Reduction Chart" on page 11.

The information found in the Simpson Strong-tie Catalog is vital to engineers and anyone else designing seismic retrofits because 99% of the hardware used in seismic retrofit work can be found in this catalog. Their hardware is so common the Simpson Strong-Tie Catalog is probably the most publication a designer needs to be familiar with.

NER-272

This document is also called National Evaluation Report Number 272 and governs “Power-driven staples and nails for use in all types of building construction”. It lists the earthquake resisting capabilities of nails and staples for all the manufacturers of nails and staples which are also members of the International Staple, Nail and Tool Association. After the Simpson Strong-Tie Catalog, it is probably the most consulted publication used in the design of seismic retrofits. This document contains "Design Values and Allowable Load Tables" for individual nails staples as well as for nailed or stapled shear walls that may not be listed in the Uniform Building Code. This documents gives engineers and designers a work to consult when they need to determine the earthquake resistance of a non-conventional design built using nails or staples not listed in the Uniform Building Code. For example, this document may contains a table that lists a lateral load values for staples that cannot be found in the Uniform Building Code or in the Simpson Strong-Tie catalog. . This document also gives engineers various formulas to calculate the earthquake resistance of staples or nails that are not listed in one of the tables. Engineers are expected to understand how to use these formulas while architects and contractors are not expected to. If a load value for a nail or staple cannot be found in NER-272 then you must consult an engineer. Knowledge of what is contained in this document, as well as the ability to understand and use the formulas contained therein, is important for seismic retrofit design. Along with hardware found in the Simpson Strong-Tie Catalog, nails and staples are a vital part of any retrofit. Anyone wishing to do this kind of work needs to be very familiar with it.

National Design Specification for Wood Construction

This document is from the American Wood Council and the American Forest and Paper Association. It was first published in 1944 and the most recent edition was published in 1997. It is accredited by the American National Standards Institute and is a listing where "the most reliable data available from laboratory tests and experience with structures in service have been carefully analyzed and evaluated for the purpose of providing, in convenient form, a national standard of practice." It defines itself as” the method to be followed in structural design.” This document is primarily of use in seismic retrofit work because it addresses connections that are not found in the Simpson Strong-Tie Catalog or in NER-272. Chapters 2,8,9,11, and 12 are the most useful ones to be familiar with. These chapters come under the headings "Design Values for Structural Members", "Bolts", "Lag Screws", "Wood Screws", and "Nails and Spikes." For example, if the designer wants to know how far from the edge he can place a bolt from the end of the mudsill this information can be found on page 58 of the 1997 NDS. The shear values for nails found in the chapter on "Nails and Spikes" is much more complete than the one found NER-272. This document also contains engineering formulas that are used by engineers when they come up against a wood frame connection that is not listed in a table. The use of these formulas should be left to engineers.

APA Publications

The Engineered Wood Association, also known as the American Plywood Association, publishes APA reports. The *APA-The Engineered Wood Association* is the world authority on the construction of plywood shear walls. At their large research facility in Tacoma Washington they combine the research efforts of APA scientists with the knowledge gained from decades of fieldwork and testing done by member plywood manufacturers. For this reason anything they publish regarding shear wall construction carries great weight and familiarity with their research is essential for anyone involved with wood frame seismic retrofit work. The results of their research can be found in all existing building codes including the IBC and the IRC.

APA Report 154

This APA report examines many of the types of shear walls that must be built in seismic retrofit work. This is because the design criteria found in the Uniform Building Code often do not work on existing buildings. The Uniform Building Code is meant for new construction with standard framing rather than old construction with non-standard framing. This document states its objective as follows:
The purpose of the testing reported herein was to develop design information for construction no currently listed in tables or recommended design shears, and to present supporting data for changes recently incorporated into Table 1 (This table is found in the front of this document as is also the same shear wall capacity table found in 23-II-I-1 of the Uniform Building Code). Six tests of series are reported:

1. Unblocked shear walls
2. Stapled shear walls
3. Sheathing over metal framing
4. Double-sided walls
5. Panels over gypsum sheathing
6. Effects of stud spacing and width

Results of past testing, both previously published and unpublished, are summarized in Appendix A.

The results of the tests done by the APA laboratories are extremely important in seismic retrofit work for the following reasons:

Oft-times existing retrofit work will contain unblocked shear walls or installing blocking on a new retrofit shear wall may be impossible due to an obstruction.

Stapled shear walls are often advised to keep splitting of framing material to a minimum. Often times short pieces of framing lumber are required in retrofit shear walls and it is desirable to keep the chance of splitting the framing to a minimum.
Double-sided shear walls are often necessary because access to the foundation may be limited. Installing shear walls on both sides of the foundation allows the designer to design extremely high capacity shear walls.

Installing panels over gypsum is often much cheaper than tearing out the existing gypsum and also allows retrofit shear walls to be built without interfering with fire code regulations.

And finally, stud spacing and width is unpredictable on existing homes and knowledge about how the stud spacing a width effects shear wall performance is often necessary.

These important aspects or retrofit work are discussed in detail in APA Report 154 contains tables that document their tests for these various shear wall constructions. It also contains formulas for the engineer.

APA Report 138

The Abstract at the beginning of this report states: “Commonly accepted plywood diaphragm construction is applicable for design shears significantly higher than those previously published. Multiple rows of fasteners in wide framing members are used to develop the higher shear loads sometimes required for buildings in Seismic Zone 4. This report details the design and testing of eleven diaphragms, up to the limiting shear stress of the plywood. The effects of openings in the diaphragm and field gluing of plywood sheathing are also investigated.

At the beginning on the report a table gives allowable design shears for the walls tested. For the most part, the design shears are double the capacity found in the Uniform Building Code. Many atypical shear wall configurations that are not not found in APA Report 154 can be found here. The tests that relate to seismic retrofit work are as follows:

Test 1) Shear walls were tested to determine if a large number of staples would result in a corresponding increase in diaphragm strength and if the use of staples would reduce the tendency for framing members to split.

Test 2) Another test checked to see how increasing the penetration of staples into the framing from 1 5/8 inches to 2 inches would effect shear wall strength.

Test 3) This test checked to see how multiple rows of power driven nails would effect the performance of a shear wall.

Test 4) Consisted of two separate tests to determine the effect of openings such as windows and doors on shear wall performance.

Test 1 determined that staples can be placed very close together without splitting the wood. This is very useful in seismic retrofit work where the installation of short blocks is often necessary. The report claims “During these tests it was discovered that a large nuer of either 10d or 16d nails, spaced less than 3” o.c. as required to develop high shears, often caused the framing member to split. On the other hand, the use of pneumatically driven staples showed that staples with a 7/16 inch crown could be driven as close as 1” o.c. without causing splitting, either at the time or driving or when the specimen was loaded in shear”

In Test 2 staples were tested with a penetration into the framing of 2” rather than the 1 ¼ inches penetration in separate tests. This was because in Test 1 “In all cases, the failure was staple withdrawal from the framing.” Increasing the staple penetration had the positive effect wherein the tests “revealed only very slight staple withdrawal.”

Test 3 discusses building shear walls with 4 by nominal framing with 3 rows of 10d common 2 x 2-1/4 long nails at 3” o.c. These tests showed that tabulated design shear for these walls are 1410 plf. This is useful in some retrofits because some buildings have existing framing that is made of old growth 4 bys.

Test 4 discusses the effect of openings on shear walls. Because existing site conditions often the designer take into consideration the presence of windows and doors, this is also a very important test to be familiar with.

APA Technical Note N370C

“Allowable shear values for blocked structural panel diaphragms are significantly higher than those for unblocked diaphragms. Where blocked diaphragm values are required, panel edges are typically blocked with 2x lumber framing and fastened and fastened in accordance with recognized schedules in order to achiever desired shear values. There are instances, however, where installation of lucmer blocking may not be convenient. One alternative is to substitute sheet metal strips for lumber blocking at panel joints. The technique has been evaluated by APA-*The engineered Wood Association* and is discussed in the Technical Note”

Use of this technique is often necessary is seismic retrofit work. Oftentimes shear walls must be built while standing on ladders where the installation of blocking is difficult. Other obstructions such as pipes sometimes make the installation of blocks impossible. In addition, the short blocks installed between the studs tend to split. All of these possibilities make familiarity with this Technical Note a must for anyone designing seismic retrofits.

Foundations

As you may recall, the mudsill is the piece of wood at the base of a house that sits directly on top of the foundation. When an earthquake force pushes on the mudsill the bolts keep the mudsill from sliding on the foundation. Mudsill bolting became a Bay Area code requirement in 1958. Before this code requirement, it was a common construction practice to randomly drive nails nearly ¼ inch in diameter through the mudsill until they stuck out the other side. The nails were then set into the wet concrete at time a foundation was built. The mudsill was secured to the foundation in this way, not to resist earthquakes, but to keep the mudsill from moving during construction.

This is why evidence of mudsills sliding in previous earthquakes is rare. Example 7 demonstrates how an unbolted mudsill remained in place even after being subjected to violent shaking. It is still not possible to verify the quantity, size, deterioration, or even presence of these nails, so bolting is still an important part of any retrofit.

Example 7: Mudsill remained in place

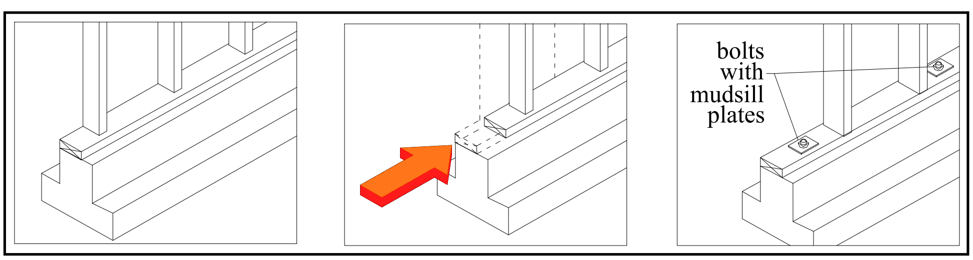


Diagram 14: Force on mudsill

Existing Foundations

The base of the foundation is called the footing. Table XXX in the International Existing Building Code specifies that existing concrete footings have a compressive strength of 1500psi, unless tests show otherwise. This table only requires the concrete be in "sound and in good condition" (this more or less means it is solid when you hit it with a hammer or jab it with a screwdriver).

Past earthquakes have shown that foundations with undersized and shallow footings slide minimally on the ground if at all, even if the force is considerable. If the foundation happens to move, the house moves right along with it and historically this is not a source of earthquake damage.

The reader may skip the next two sub-sections *Tests and Codes* and *Foundation Size* These chapters show why practically all foundations that do not appear to be suffering significant deterioration, have no rebar, and/or have minimal embedment in the soil, have performed quite well in tests and previous earthquakes and do not need further consideration. Unless the reader wants to know the supporting data for these conclusions, these sub-sections can be disregarded. For the same reason all the sub-sections in the chapter: Foundation Anchorage Systems can be skipped except the very important last chapter; *Bolt to Wood Connections*

Tests and Codes

A 1992 test report: Foundation Anchorage Systems, published by the Structural Engineer's Association of Southern California (SEAOSC), came to the following conclusion regarding bolt performance in weak1500psi concrete when compared to stronger modern concrete:

"The difference in the strength of the concrete did not appreciably affect the performance of the foundation anchorage systems. Engineered or proscribed methods for retrofitting foundations of good concrete will also work with foundations of weaker concrete (approximately 1500psi). The predominant failure mechanism in these anchorage connections was the wood sill plate in both the good and weak concrete foundations."

Foundation anchorage systems include epoxy bolts, wedge anchors, and side plates. Side plates are a type of hardware suitable for homes with short or no cripple walls.
In the SEAOSC tests a jack was used to push against mudsills parallel to the foundation in a manner that mimicked the lateral force exerted by an earthquake. When the mudsill pushed against the bolts and side plates, which in turn pushed against the 1500psi concrete, neither the bolt nor the concrete failed. Instead the wood mudsill split at bolt locations. We can only assume from these tests that modern foundation anchorage systems will perform in a similar way. The Simpson StrongTie Company, the nation's leading bolt and side plate manufacturer, will not guarantee the performance of their foundation anchorage systems in 1500psi concrete.

“Values in the International Code Council reports (these are values accepted by the building code) were based on testing performed in either 2000psi concrete or 2500psi concrete, varying on the specific product. Concrete encountered in existing construction is assumed by the Uniform Building Code to have a compressive strength of 1500psi. Due to this assumption, we cannot make any guarantees as to how our products will perform in this condition since we have not done testing in 1500psi concrete. True anchor values in 1500psi concrete would only be established through testing”. Mudsill Anchorage Systems in Cripple Wall Retrofits, Allen, Wendy C.E. Field Engineer, Simpson StrongTie, Dec 2005

It is unfortunate that the performance of foundation anchorage systems in weaker 1500psi concrete is based on only one series of tests. The SEAOSC tests did however show unequivocally that the bolt to wood connection *always* failed before the concrete and therefore deserves strengthening if possible.

In summary: the IEBC assumes all existing concrete in sound condition has a compressive strength of 1500psi and SEAOSC’s tests determined that bolts and side plates installed in 1500psi concrete will perform just as well as in higher psi concrete. Concrete condition therefore is not a serious concern, unless very low psi is demonstrated by tests, or a visual examination reveals the kind of deterioration shown below

Example 8

Nor are large cracks in a foundation usually a serious concern. Cracking is natural in un-reinforced foundations, where the foundation may contract many inches when drying. Settling of the soil over time can also cause cracking. Cracking due to moisture penetration is rarely a serious structural consideration in terms and earthquake but any problem that causes serious cracks in a foundation should most certainly be addressed.

Another condition often found in existing foundations, called rotation, is when the foundation leans outward. This occurs over time when the outside of the footing is softened with moister while the inside of the foundation remains dry; a common occurrence in wet weather. This phenomenon is not a serious concern in retrofit work, though it may be a concern in terms of the foundation providing vertical support. .

Foundation leaning out makes this look like the studs are leaning in.

When analyzing any foundation one must ask oneself "what would happen in the foundation were forced to slide." At worst a cracked foundation may move on the ground an insignificant amount until it strikes the abutting foundation. With a rotated foundation the cripple bracing will work the same as if the foundation had not rotated.

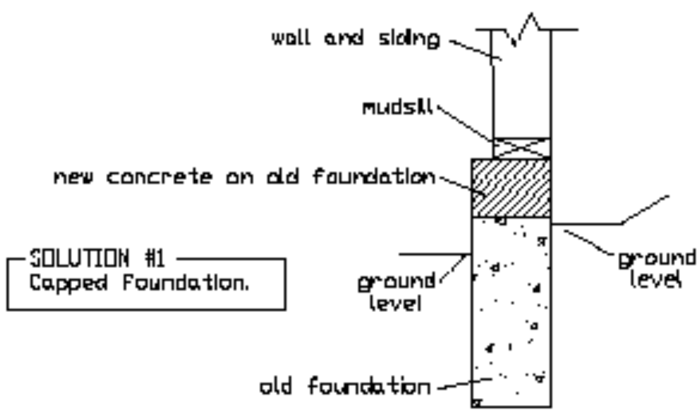
Foundation Size

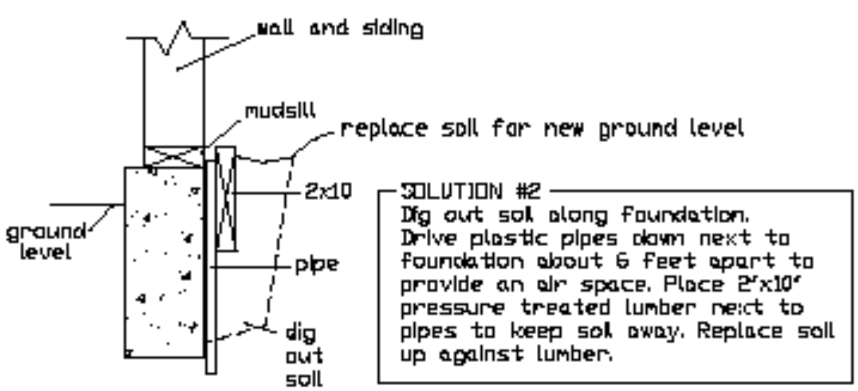
Foundations built after XXXX were required by the building code to be 12 inches wide, 12 inches deep, and embedded a minimum of 12 inches into undisturbed soil. Many older foundations are much smaller and are embedded into the ground only 2 to 6 inches, if at all, and almost never have reinforcing steel. The part of the foundation that is embedded in the earth is called the footing. Most retrofits are installed on older foundations with shallow footings, so it is important to understand their performance characteristics.

Movement of a floor is transferred into a footing through the load path until soil friction fully dissipates this force. This friction can be considerable. However, past earthquakes have shown that foundations with undersized non-code-compliant footings slide on the ground minimally if at all. This is why shallow footings are rarely a consideration in wood frame seismic retrofit work.

Capped Foundations

Foundations in the Bay Area are sometimes capped in order to increase the distance of the soil to the wooden walls. This is just as easily done with a shovel. In these cases it is important to use bolts that extend through the new foundation cap into the old foundation. This keeps the new foundation cap from sliding.





Foundation Bolting

Mudsills should be bolted to the foundation with epoxy bolts, wedge anchors, or Simpson StrongTie UFP10s, carefully following the manufacturer's recommendations. Epoxy bolts are the preferred method because the required distance from the bolt to the edge of the concrete is much less than for wedge anchors and they hold to the concrete better.

Example 9, Epoxy Bolt

Example 10, Wedge Anchor

Example 11, Expansion Wedge

Wedge anchor installation is a simple 3-part process:

1-Drilling the hole through the sill into the concrete.

2-Driving the bolt into the hole with a hammer.

3-Tightening the bolt so that the brass expansion sleeve expands and grabs the concrete. . Sometimes the quality of the concrete is such that the wedge anchors will not tighten in these cases epoxy bolts should be used.

Epoxy bolt installation is a much more labor-intensive 5-part process:

1-Drilling the hole through the block and sill into the concrete.
2-Blowing out the hole with compressed air.
3-Injecting epoxy into the hole.
4-Placing the bolt in the hole.
5-Coming back a few hours later and tightening the bolt.

It is important to use 3-inch square plate washers. Plate washers help keep the mudsill from splitting. (See diagram XXX) and protect the mudsill from cross grain bending. Cross grain bending will be discussed later in this book.

Installed bolt with plate washer

Below is a list of the relative strengths of the *bolt to concrete* connection in 2000psi concrete when the bolt is placed in the center of a 6-inch wide mudsill. The two bolting systems manufactured and tested by the Simpson StrongTie Company have bolt to concrete strength ratings as shown:

5/8” SET epoxy bolt	2953 pounds
½” SET epoxy bolt	2833 pounds
½” wedge-anchor	1650 pounds
5/8” ET epoxy bolt	1336 pounds
½” ET epoxy bolt	1053 pounds
5/8” wedge anchor	(No recognized value)

(SET and ET are two types of epoxy)

Neither the Simpson StrongTie Company, nor any other wedge anchor manufacturer, approves the use of the 5/8-inch wedge anchor in cripple wall retrofit applications. This is because when a 5/8-inch bolt is installed through the center of a mudsill, the distance from the bolt to the outside concrete edge is less than manufacturer's minimum requirement. 5/8-inch wedge anchors should not be used in cripple wall retrofits. The Simpson StrongTie Company graciously tested their ½ inch wedge anchor specifically for this book, using a concrete edge distance equal to that which would exist if the wedge anchor were installed in the center of a full-dimensioned mudsill. The conclusion of the test was that their ½ inch wedge anchors could resist 1650 pounds of force in the bolt to concrete connection. This test is not legitimate for ½ inch wedge anchors installed through the center of a 2 by 4 mudsill because of the increased bolt to concrete edge distance. i

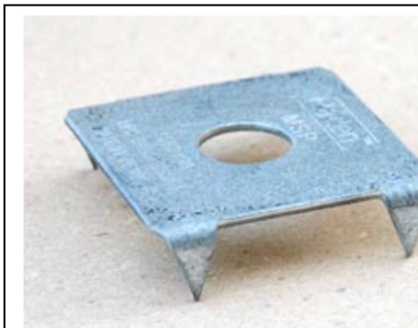
The Bolt to Wood Connection

The *bolt to wood* connection is the part of the foundation bolting system that fails in earthquakes and should be strengthened whenever possible. The relative strengths of bolt to wood connections according to tests done at Virginia Tech University are as follows:

½ bolt in 1 ½ thick Douglas fir.	1037 pounds
5/8 bolt in 1 ½ thick Douglas fir	1485 pounds.
½ bolt in 2-inch thick old growth redwood	1182 pounds
5/8 bolt in 2-thick old growth redwood	1555 pounds

The wood to bolt connection is stronger than the bolt to concrete connection in all cases except when Simpson StrongTie ET epoxy is used. For this reason ET epoxy should not be considered in retrofit applications. The strongest bolt to wood connections is in old growth redwood. Virtually all mudsills on old houses are made of old growth redwood and the reason why almost all the old growth redwood forest in California are gone.

The capacity of a 1/2-inch bolt can be increased to 1330 pounds by installing a Mudsill Plate. This hardware is only available from KC Metals. The original tests were done in Los Angeles by Harlen Metal Products, which went out of business a number of years ago. KC metals did not renew Harlen's costly ICBO approvals, but still produces the hardware. Half-inch bolts with mudsill plates are almost as strong as 5/8 epoxies bolts without mudsill plates and are far cheaper to install, both in terms of labor and material. The ½ inch wedge anchor with a Mudsill Plate is probably the best choice in retrofit applications.



Mudsill Plate

Plate washers required in new construction should also be used in retrofit applications. The 1992 SEAOSC tests showed that plate washers greatly reduced mudsill splitting in the manner illustrated below.

Code Requirements

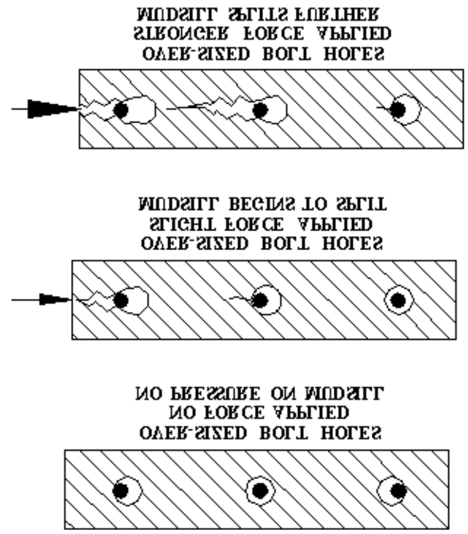
The building code for new construction specifies that a 1/2-inch bolt must be placed every 6 feet and at each end of a mudsill. In cripple wall retrofit designs bolts only need to be placed at shear wall locations. This is because earthquake forces are resisted by the stiffest element in a wall, and unless the walls are covered with stucco, the stiffest elements are the shear walls. It is logical that earthquake forces are only transferred to the bolts attached to them. If the walls are covered with stucco the brittle stucco cracks before the shear walls need to resist the earthquake.

The building code also specifies that if mudsills are less than 2 ½ inches thick (3 by nominal lumber), bolts can only be rated at half strength if used in shear walls that are designed to resist between 350 and 650 pounds of force per each linear foot. Meeting this code requirement and a base shear demand on homes with limited available foundation would require doubling the number of bolts at shear wall locations. An engineer with the national shear wall testing agency, *APA*, *The Engineered Wood Association,* told one of the authors of this book that this provision was placed in the code by a group of engineers in Southern California to resist cross grain bending on shear walls with 1 ½ thick mudsills. This was done as a precaution based on observed cross-grain bending damage after the Northridge earthquake. However, the APA tests have shown cross grain bending *is not a problem* so long as bolts are placed 2 feet apart at shear wall locations, overturning forces are resisted with hold downs, each bolt has a 3 inch square plate washer, and the plywood is properly nailed. Damage in Northridge was probably a result of poor designs where shear walls were built without plate washers and adequate bolt spacing. Some designs perhaps relied on the code required 6 foot bolt spacing without regard to shear wall locations

A secondary purpose for the 3by-framing members is to provide a wider nailing surface. The code requires a 3/8-inch plywood edge to nail distance, which is far easier to achieve with 2 ½ framing members. It is impractical to replace all studs at panel edges with 3by material when working with an already framed cripple wall. A more practical approach is to double the existing 2 by 4s at all horizontal plywood seams. Tests performed by the APA proved that two 2 by 4s nailed together perform as well as 3by material. The plywood edge nailing damage in Northridge was probably a result of sloppy nailing rather than size of the framing material; this code requirement has undoubtedly reduced this problem.

Oversized Holes

The building code only allows holes in the mudsill to exceed the diameter of the bolt by 1/16 of an inch. If this is exceeded, the mudsill can split as shown in the photo at left. It is very common to find oversized holes because oversized holes allow builders to adjust the position of the mudsill on the foundation. The illustration on the right illustrates the damage caused by oversized holes. The most cost-effective way to address this problem is to add more bolts or UFP10s.



Rather than capping the foundation to increase the wood to soil clearance, a more economical solution is illustrated above or simply buy a shovel and clear the dirt away

Bolting Homes with Short or No Cripple Walls

Retrofit hardware, the Simpson UFP10, is bolted to the side of the foundation and lag bolted to the side of the mudsill when no cripple walls exist or the cripple walls are very short.

Installing lag bolt into mudsill

Complete installation

Retrofit Misconceptions

Under-floor retrofit bracing of homes with short cripple walls, or no cripple walls at all, are often retrofitted with hardware designed to resist hurricanes instead of earthquakes. Many contractors install this hardware based on the misconception that a house can jump up vertically off its foundation. This is not an observed cause of failure in previous earthquakes or a design consideration found in the building code. This is the case even with thrust faults like the Hayward Fault, which will have a strong vertical component. The most common types of hardware used in this way are the Simpson FJA and FSA hardware. Eight FJAs have the strength of just one 5/8 inch bolt. The FSA has no ability to resist earthquakes whatsoever. Nor do small twist straps.

A Simpson FJA

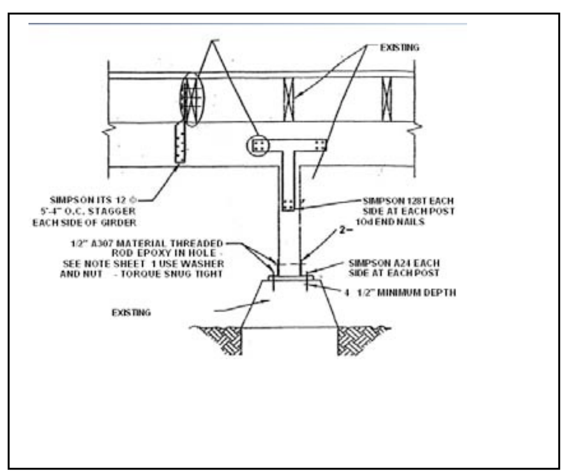
A Bent FSA

Twist Straps

All of these examples represent a misapplication of hardware and should be avoided due to their low capacity when compared to the labor involved to install them. Under-floor retrofit bracing of homes with short cripple walls, or no cripple walls at all, should always be retrofitted with laboratory tested Simpson UFP10s, or similar hardware specifically designed for such applications, if at all possible.

Laboratory tested hardware for under-floor retrofits with short cripple walls or no cripple walls at all only recently became readily available in the Bay Area. Before this time, low clearance homes were retrofitted using angle irons and/or shop fabricated steel plates. The installations of this hardware are common even today.

The American Wood Council, the agency that publishes all data used by building codes and engineers throughout the country, has been funding research in the field of wood frame engineering for over 65 years, does not consider angle irons to be a viable retrofit strategy. This is because the floor joists, when shaken by an earthquake, are subjected to cross grain bending, a condition where wood breaks very easily. Cross grain bending will be discussed in a later chapter. The black steel plate on the right is also an untested method. Notice the damage caused to the mudsill by the very large lag bolt.



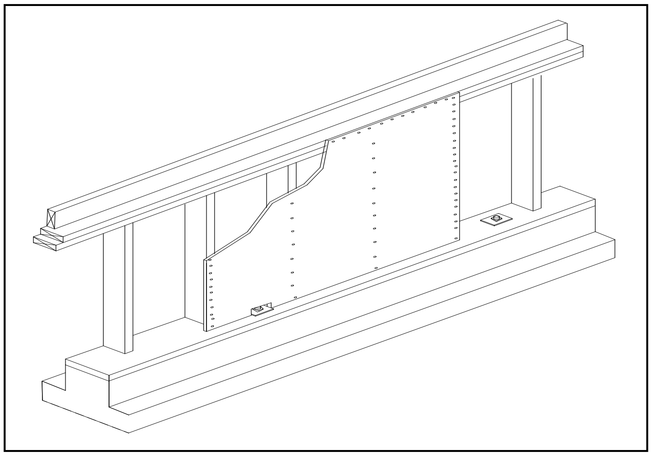
There is also a common misconception regarding the need to strengthen the post connections found under most houses. It is believed that earthquake forces will separate the post from the lower concrete pier block and from the beam above. It is further believed that if either of these connections fails, the posts will tip over and cause the floor to lose vertical support. In actuality, if the perimeter edges of the floor do not move because they are firmly attached to the foundation, the rest of the floor supported by these posts will move very little if at all.

If the perimeter edges of the floor happen to move enough to cause these posts to tip over, the house will have already slid off its foundation and suffered catastrophic damage. This makes elaborate connections like this one unnecessary and emphasizes the need to attach the floor to the perimeter foundation. The building code only requires “a mechanical connection” on these post connections. A few nails are a “mechanical connection” and their presence needs to be verified.

The photos below provide a good exercise in tracing a load path. If you look at the floor and imagine it moving towards you in an earthquake, you will see that the large wooden beam will push down on the lower end of that beam and into the foundation where this force will be stopped. This ineffective retrofit strategy has the potential of driving the beam up through the floor.

Retrofit Shear Wall Mudsill Connections

The most problematic challenge in building retrofit shear walls arises from the fact that mudsills are almost always wider than the vertical studs and horizontal top plates. Usually the mudsill is a 6 inches wide and the studs and top plates are 4 inches wide. This means plywood cannot be nailed to the cripple wall because the framing is not on a smooth place. Framing modifications must be made to create a 4 inch wide plane on the mudsill.

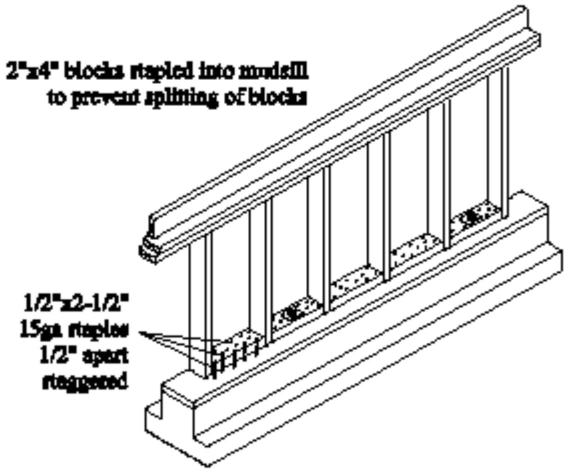


The mudsill is wider than the 2 by 4 upright studs and top plate. This makes it impossible to nail the plywood to the bolted mudsill without framing modifications.

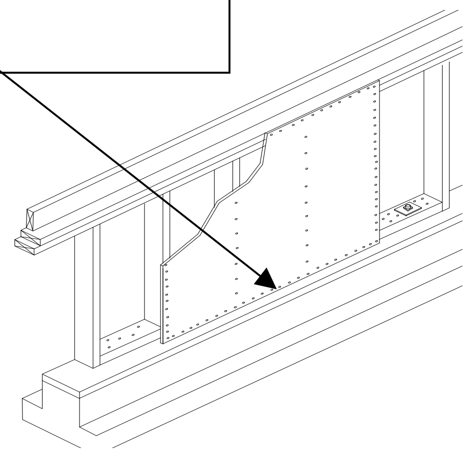
Stapled Blocking Method

When a mudsill is deeply embedded in concrete, stapling blocks onto the exposed mudsill surface is often the best option. If possible, use galvanized or stainless steel staples to resist corrosion from moisture. Always use stainless steel in pressure treated wood.

Mudsill embedded in Concrete



Staple plywood to prevent blocks splitting



Blocks are virtually impossible to split with staples. This block has 114 staples with a capacity of nearly 8000 pounds.

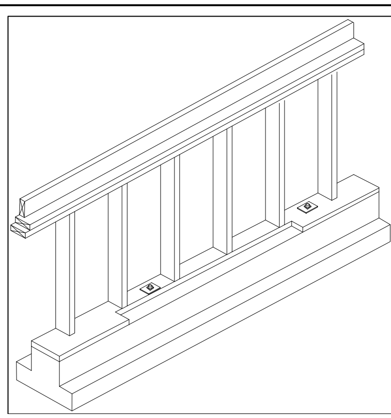
Nailed Blocking Method

Similar to the stapled blocking method is the nailed blocking method. This method uses nails instead of staples. It is the method recommended by all wood frame retrofit guidelines throughout the nation. The primary weaknesses of this method is the tendency for the blocks to split, and like the nailed blocking method, it has never been tested for effectiveness. In addition, after the plywood is installed it is not possible to determine if the nails are the correct length and diameter or even present at all.

This would not have happened if staples had been used.

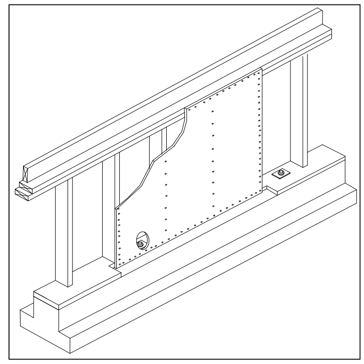
Flush-Cut Method

The third method we will consider is the flush-cut method. In this method the mudsill is cut flush with the studs and top plates, if required. This method is very cost effective because no new framing material and minimal labor is required.



This illustration shows the mudsill cut flush with the rest of the 2 by 4 wall framing.

Photo of a flush cut mudsill.

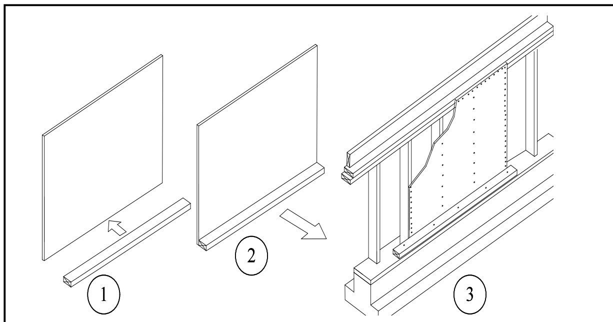


A flush cut old growth redwood mudsill versus wood from a modern tree farm. .

Plywood nailed to a flush cut bolted mudsill.

When this method is used there is very little concern that the incredibly dense old growth redwood will split when the plywood is nailed to it. It is the author's experience that nails can be installed 1 inch apart staggered in old growth redwood and old growth Douglas fir without splitting the framing. In addition, future evaluations of the retrofit never need be concerned that that blocks are split, improperly nailed, or missing.

Reverse Block Method
Another method for connecting the plywood to the mudsill is called the reverse block method and is illustrated below. This can only used when the mudsill extends at least 2 inches beyond the face of the studs.



Constructing a reverse blocking mudsill connection

Carpenter nailing reverse block

The reverse blocking method is almost as cost-effective as the flush cut method because of its simplicity, minimal material usage, and labor.

The reversing blocking and flush-cut methods are the two that most closely resemble tested configurations found in APA Research Report 154.

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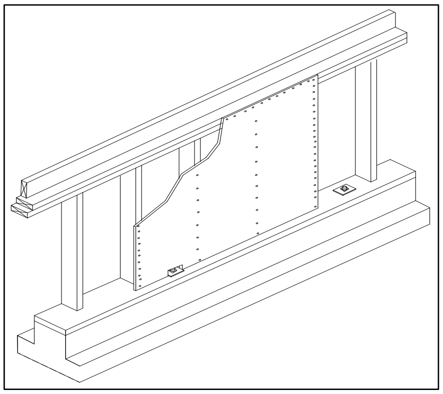
Shear Wall Repairs

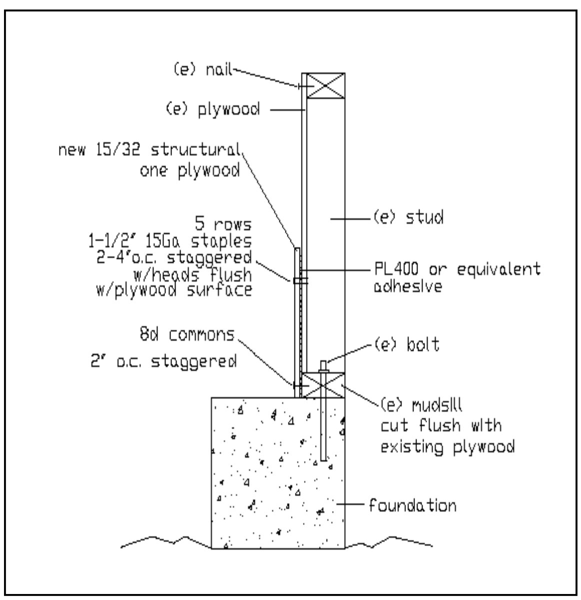
Sometimes existing shear walls have no blocking of any type or any other attachment to the mudsill.



Plywood not attached to mudsill

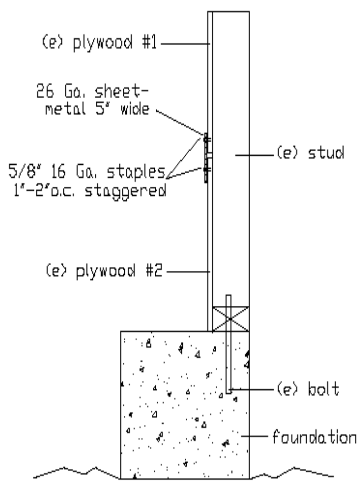
No blocking

The method used to address no blocking or split blocking is illustrated below.

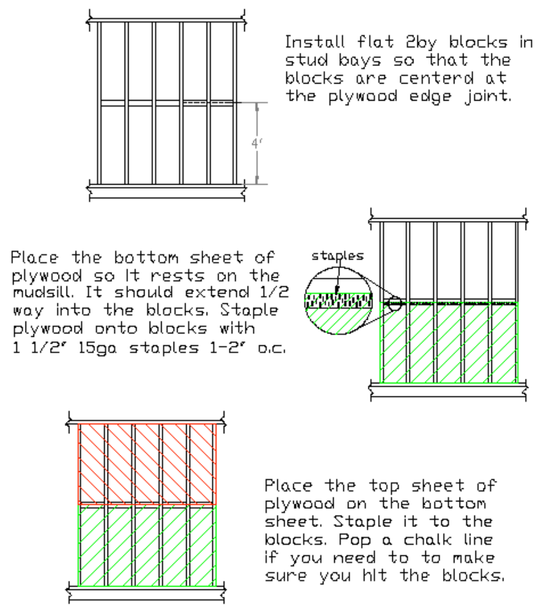


No blocking at seam

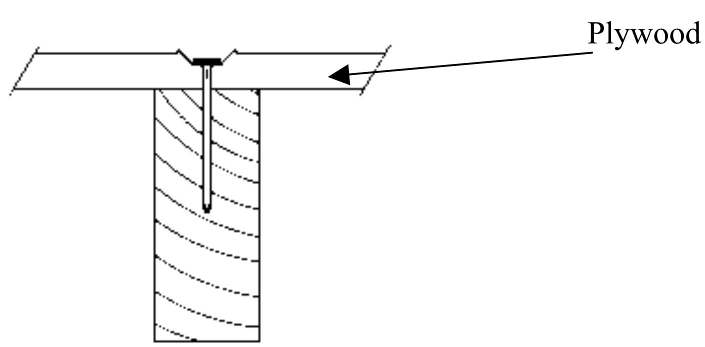
Another problem seen in existing shear walls occurs when the upper sheet of plywood cannot transfer earthquake forces into the lower piece of plywood because they are not connected. This is corrected using the sheet metal blocking system described in American Plywood Association technical bulletin number #N370C.



Below is an illustration of how new retrofit shear can be built or even repaired if sheet metal is not available. The upper piece of plywood must be stapled to the block on the horizontal seem as does the lower piece. Staples are used to prevent splitting of the short flat blocks, which need to be attached to the plywood. When used as a repair the upper piece of plywood is removed and blocks are placed behind the lower piece of plywood such that a row of staples can be installed. These staples hold the block in place so that the upper piece of plywood can be stapled into the blocking.



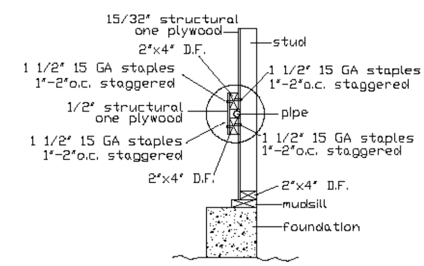
In many existing retrofits and even new shear walls on new houses the nails in the plywood have been driven deep into the plywood. The building code requires that plywood nail heads be installed flush with the plywood to prevent pre-mature failure.

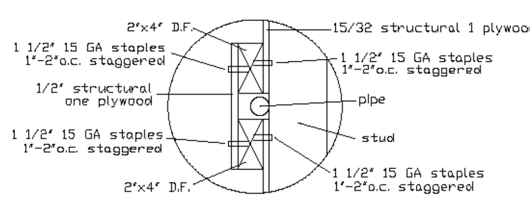


If the nails are spaced close together re-nailing the plywood may cause the wall framing to split. I recommend repairing the shear wall according to Technical Note TT-012 American Plywood Association available on the internet. This option will allow you to repair the plywood to framing connection rather than remove and replace it.

In old homes it is common to find pipes or other obstructions running along the sides of the cripple walls. This weakens the shear wall. The metal strap below does nothing to provide continuity between the plywood above the pipe and the plywood below.

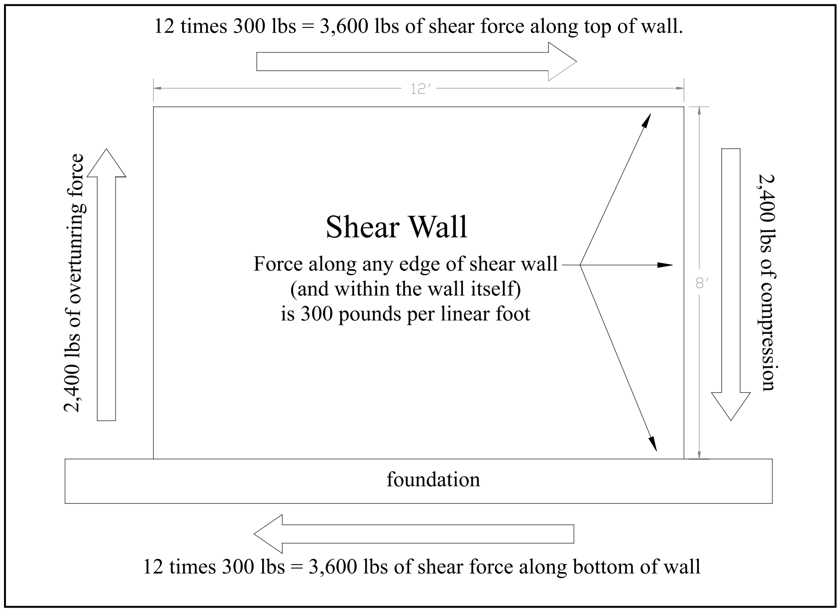
In these cases it is best to use the technique illustrated below. Existing bisected shear walls can also be repaired in the same way except the 2 by 4s are stapled into the plywood with 2 ½ inch staples.



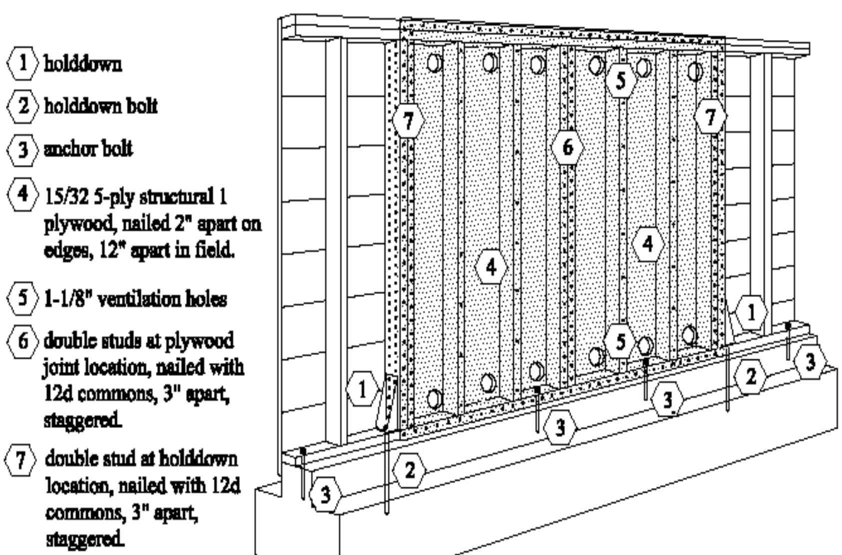


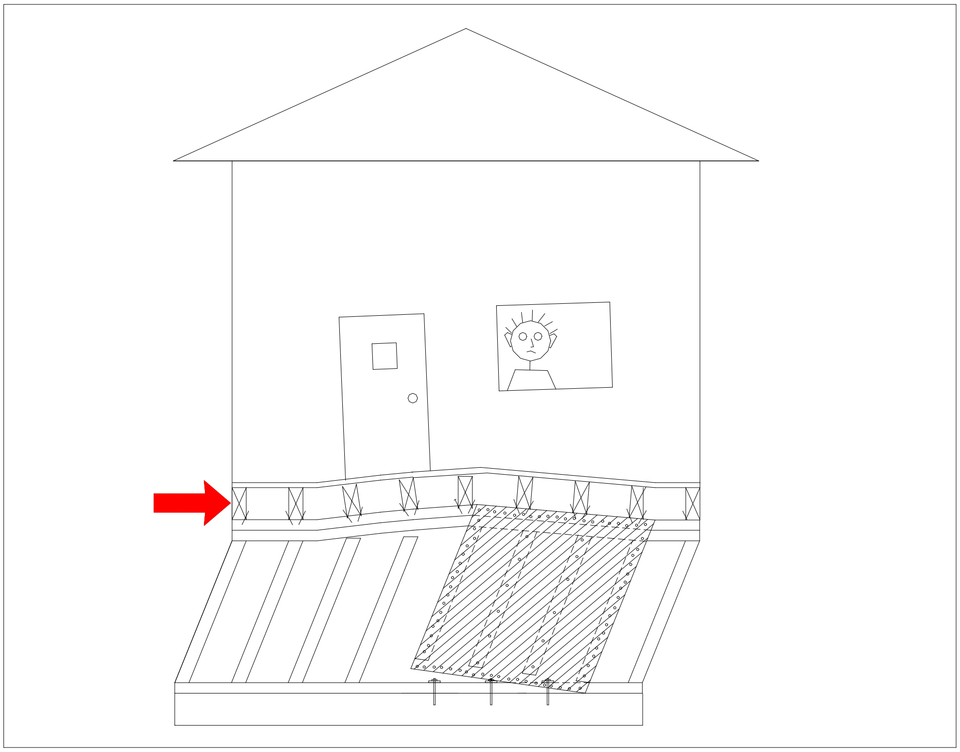
Overturning

In order to build an effective shear wall it is necessary to install the basic principles of how a shear wall works:



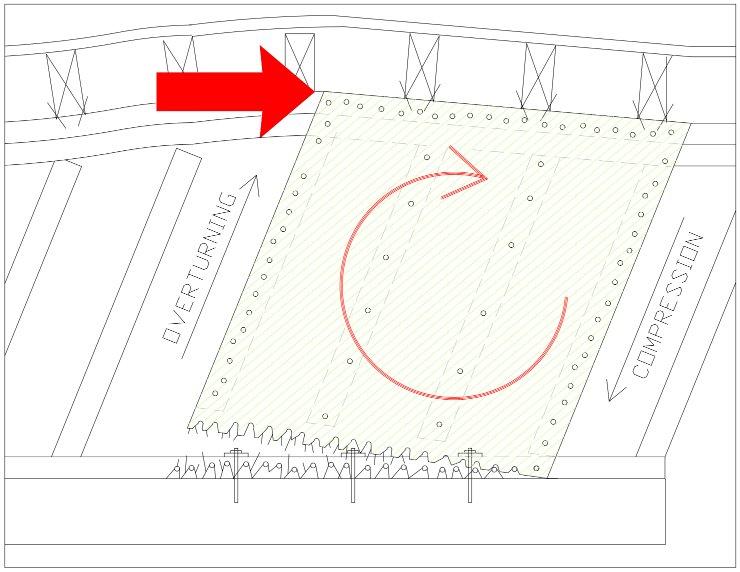
In this example the shear wall absorbs 300 pounds of lateral force for each linear foot of plywood. Thus the top and bottom are 12 feet long and thus must resist 3,600 pounds each; the 8 foot tall left and right sides, 2,400 pounds each. A shear wall is designed to resist this force on all sides of wall. Notice how the left side of the shear wall is being pulled up and the right side pushed down. Hardware that resists this lifting up or overturning force is called a hold down.





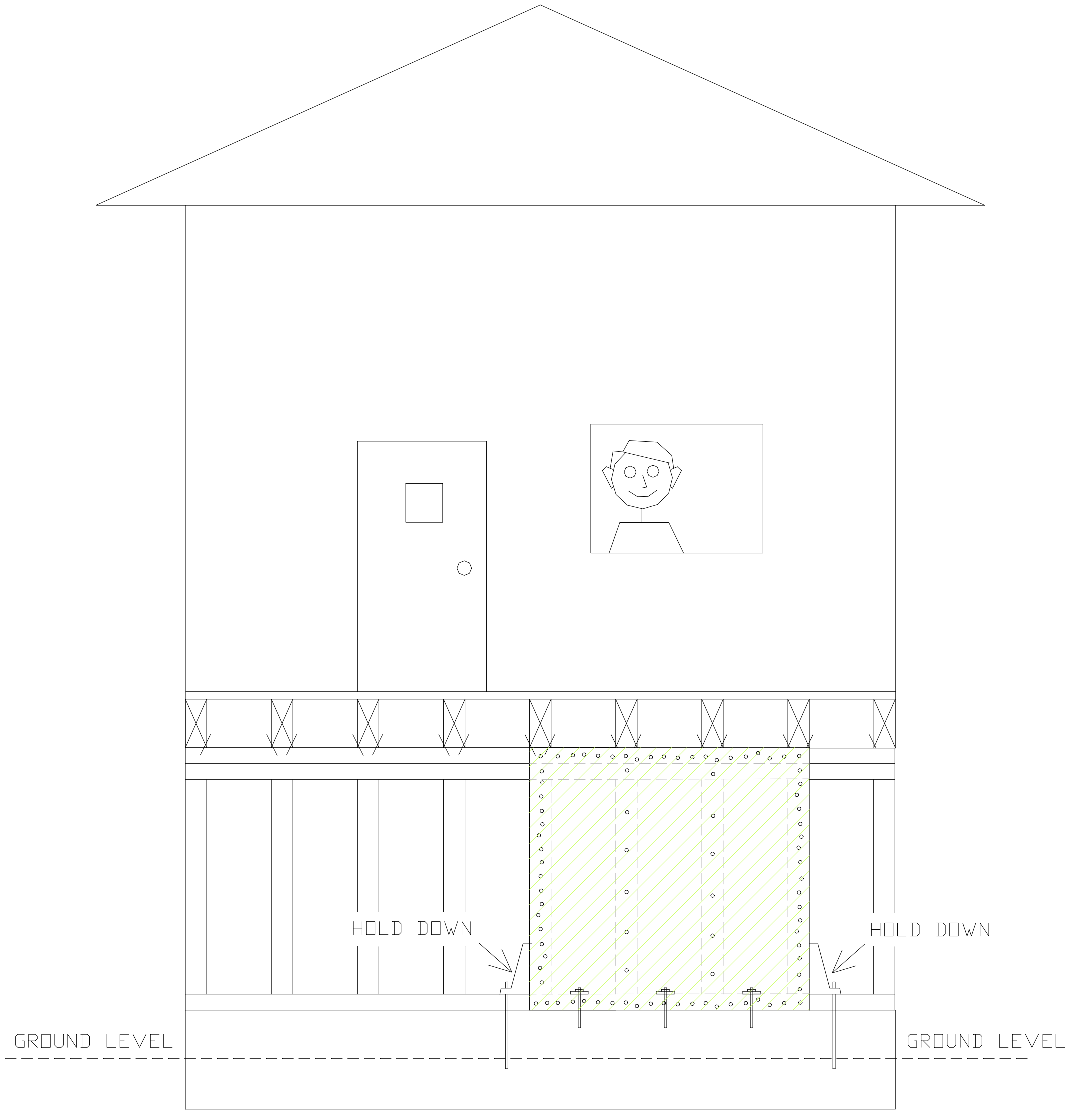
Here is an example of a shear wall overturning. This drawing is exaggerated in order to illustrate what happens. Most of the damage to the shear wall occurs where the plywood lifts up and away from the mudsill. The house will also sustain a significant amount of damage. Below is a close up illustrating tearing of the plywood at the mudsill. Once this happens the shear wall cannot longer transfer shear forces into the bolts.

All shear walls have an overturning component though this force is often minimal when shear walls are long relative to their height. The nails attaching the plywood to the mudsills can



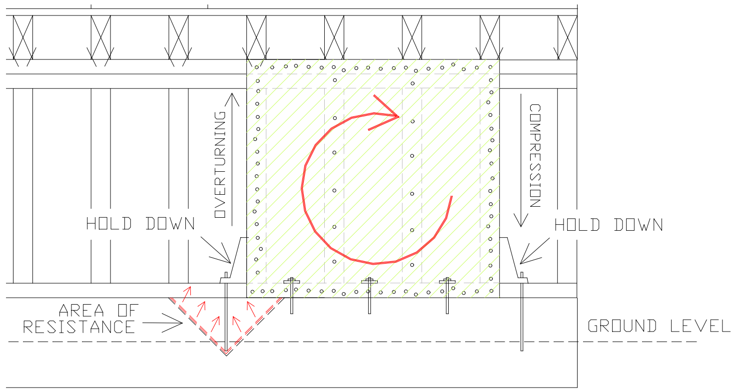
Overturning damage caused to shear walls at front of garage.

The building on the left used to be two stories. This collapse was caused by overturning of tall narrow shear walls that could not resist the earthquake forces generated by the heavy living area above a garage



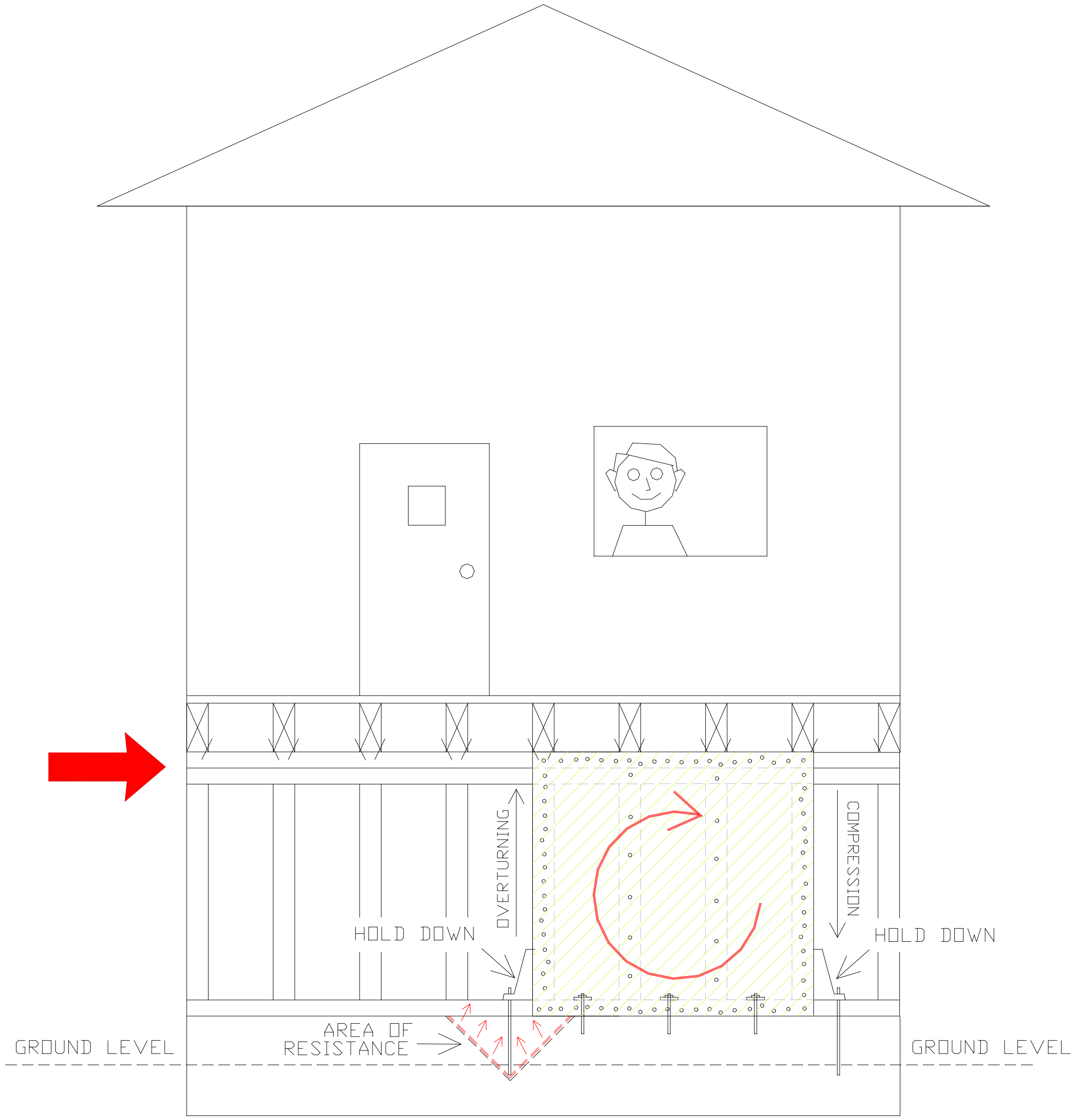
Shear Wall with Hold-downs to resist overturning

The hold-down hardware shown at the ends of the shear wall in the figure above is designed to resist overturning forces. The hold-down hardware is attached to the posts at each end of the shear wall and as the ends of the shear wall try to lift up and overturn, the hold-downs keep them held firmly to the foundation. Each hold-down is connected to the foundation with a foundation anchor rod set deep in the concrete, secured with epoxy.

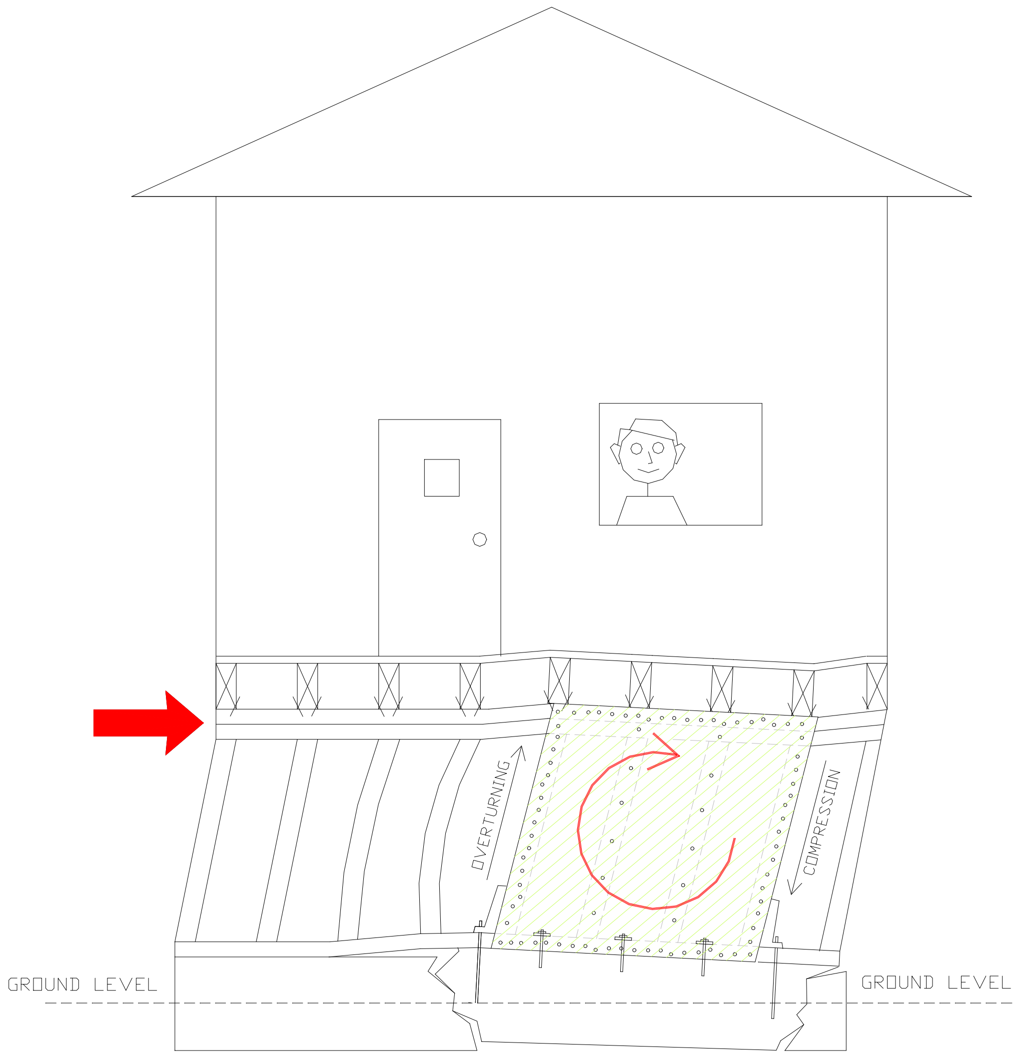


Hold down bolts will pull up on the concrete they are attached to. For this reason the bolts should be installed as deep as possible into the existing concrete and epoxied into place according to the manufacturer's instructions.

This is an installation of a hold down bolt being epoxied into the mudsill. It is important to make sure the hole is free of dust by brushing the hole out with the epoxy manufacture's bottle brush and blowing the dust out with compressed air. Ideally the hole is blown out and brushed 3 time



As it tries to overturn, the left end of this shear wall pulls up on the hold-down, which in turn pulls up on the foundation anchor rod. The concrete must be strong enough so that the foundation anchor rod does not break out of the foundation. In addition, the foundation must have enough strength and weight so that it does not lift up or deform. Large hold-downs can resist upwards of 15,000 pounds of force, but can only be effective if attached to a foundation that also weighs 15,000 pounds (or can mobilize 15,000 pounds of building weight). Note that only *one* hold-down acts at any given moment as the shear wall rocks back and forth.



Sometimes the overturning forces are so great that an un-reinforced concrete foundation breaks, or an improperly reinforced foundation deforms. This can lead to a lot of movement of the floor that results in significant damage to the structure.

Long anchor rods for holdowns need full embedment in concrete

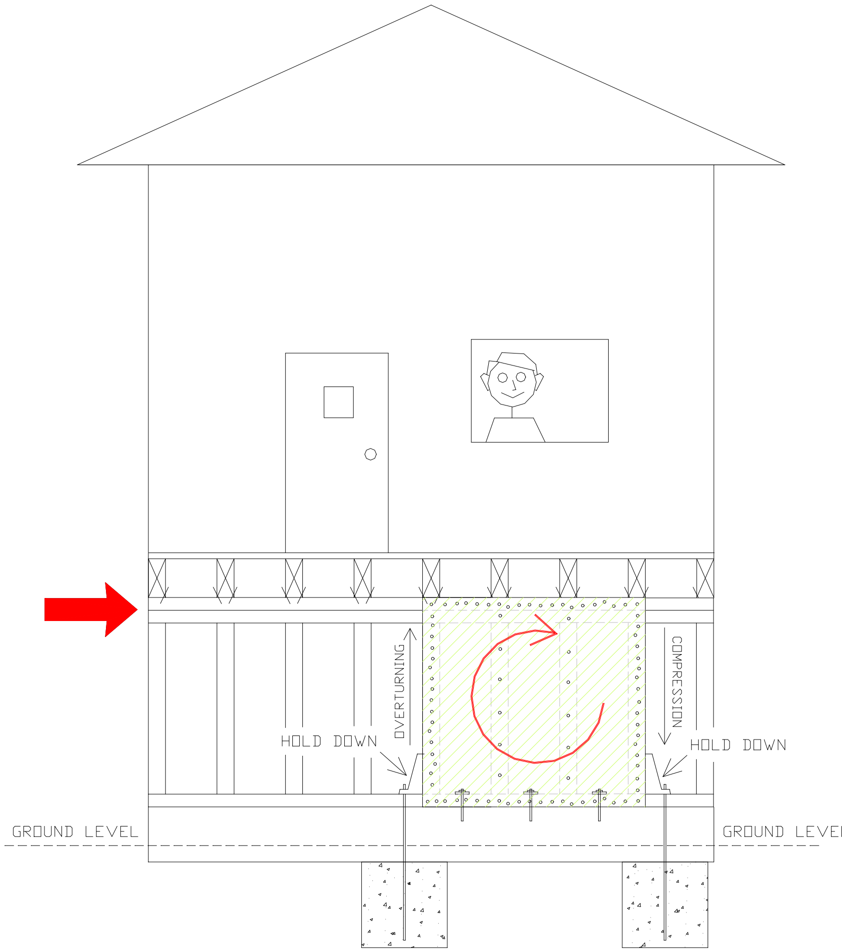
Foundations under retrofit shear walls often need extra attention in order for them to resist large overturning forces. Many old foundations are shallow and narrow and most do not have reinforcing steel. Many of them are also cracked. Without reinforcing steel these foundations can snap at the hold-down locations. Ideally we want to make sure that the uplift force on the hold-down is resisted by the same amount of downward force provided by the foundation weight. The best solution to prevent overturning in shear walls with un-reinforced concrete foundations is to provide additional weight to anchor the hold-downs. This can be done by pouring heavy blocks of concrete beneath the holdowns. One cubic yard of concrete weighs 4000 pounds; on tall narrow walls you often need a full cubic yard of concrete under each hold-down.

After calculating the required weight, dig a hole centered under the hold-down location that is large enough to hold the amount of concrete you will need. Once you dig the hole under the old foundation, drill through the existing concrete at the holdown location next to the end studs so that you can extend the hold-down anchor rod through the hole to be embedded in new concrete. Install the all-thread anchor rod through the old foundation until it extends to 4 inches above ground level at the bottom of the hole. Put a nut on the end of the anchor rod then fill the hole with concrete. If your shear wall is 8 feet tall and carries a force of 500 pounds per foot then you will have 4000 pounds of uplift and since concrete weighs 4,000 pounds a cubic yard, you have effectively resisted the overturning force.

The existing un-reinforced concrete foundation shown here is only 8 inches deep and 12 inches wide. This is clearly insufficient to resist the overturning forces that a new 8 foot tall by 8 foot long shear wall will exert on the foundation. A one-cubic yard hole has been dug out under both ends of the shear wall so that these holes can hold 4000 pounds of concrete.

Here is the same view after the concrete has been poured and the plywood installed. An all-thread anchor rod with a nut at its lower end has been cast into each block of concrete to anchor the holdowns to the new concrete.

Concrete poured under holdowns and foundation to prevent overturning



Some engineers have concerns that the added concrete weight will cause settlement of the ground beneath. Concrete weighs about 145 pounds per cubic foot while soil weighs about 115 to 120 pcf. Digging out soil and replacing it with concrete results in a net increase of about 30 pounds per cubic foot, or about an 800 lb. increase for a cubic yard. But when you dig down three feet (assuming a cube) you get a significant increase in the allowable bearing capacity of the soil. So in almost all cases, you're better off with respect to settlement by adding the concrete. It is extremely rare for the additional concrete to cause settling problems unless the house was built on un-compacted fill, in which case it would already be settling.

Lastly, if you have used the base shear formula and information provided here to calculate how much uplift you will have and what size hold-down to use, it's a very simple step to determine how much concrete it will take to resist that uplift. Its not so simple if you want to count soil adhesion and/or weight of adjacent building components, which can lessen by a substantial amount the quantity of required concrete and related excavation--but in the end it will probably be a toss-up between engineering costs vs. concrete/excavating costs. If you're curious, you might ask for a half hour of a structural engineer's time and get his opinion on these matters. Digging a hole for more concrete than you actually need is an unpleasant task, especially if it is not necessary.

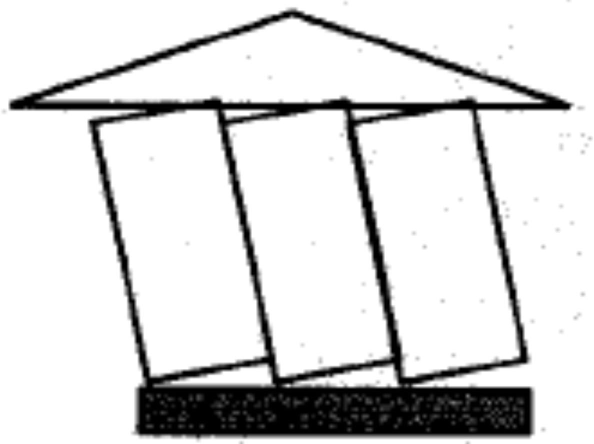
Foundations with steel reinforcing are much stronger than plain concrete foundations but surprisingly, the building code used in California only began requiring reinforcement ("rebar") in residential foundations in 1997, and then only in Seismic Zones 3 and 4. The Bay Area is in seismic zone 4. All concrete cracks as it cures so rebar is placed in foundations to hold the concrete together after it cracks. Unfortunately, in an older foundation there is no way to know for sure if it has rebar without using a special metal detecting device.

Cracks leave un-reinforced foundations very prone to breaking near the hold-downs due to the large uplift and compression forces that shear walls can exert at those locations. Cracks may be microscopic and are not always obvious to the naked eye. Fortunately, after about 1960 it was a common construction practice to install rebar in foundations, but it is still possible that a retrofit shear wall can exert sufficient forces on a reinforced foundation to damage it.

In reinforced foundations, because the concrete is connected together with steel, the hold-downs will try to pick up longer segments of foundation. Foundations reinforced with steel are much less likely to break, even though the foundation may not have sufficient weight to resist the overturning forces.

Homeowners often cannot afford the work involved in pouring additional concrete to anchor hold-downs, but still insist that something done. Here it is very important to inform the owner of the limitations his retrofit will have without this concrete work. Simply nailing up plywood on the walls should keep the studs from collapsing onto each other, but once overturning forces tear the plywood out of the sill the wall will no longer be able to resist shear forces . If the concrete is good and the footing deep the shear wall assembly should remain intact and keep the house from collapsing.. Best of all is to install concrete under the holdowns to resist any significant overturning. These options should be explained to the homeowner. If the homeowner still chooses not to do this foundation work it is it important to install the holdown anchor rods as deep into the existing foundation as possible. This way the hold-downs will try to pick up as much of the foundation as possible; the deeper the holdown anchor rod embedment, the more concrete the holdown anchor rod will try to pick up.

Force



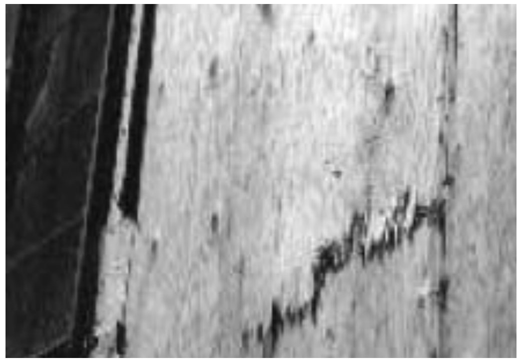
unzip if this force is not resisted by hold downs.

Hold downs should be installed on the ends of shear panels to resist this force. .

Hold downs do not do anything if the are not on the ends of shear walls.

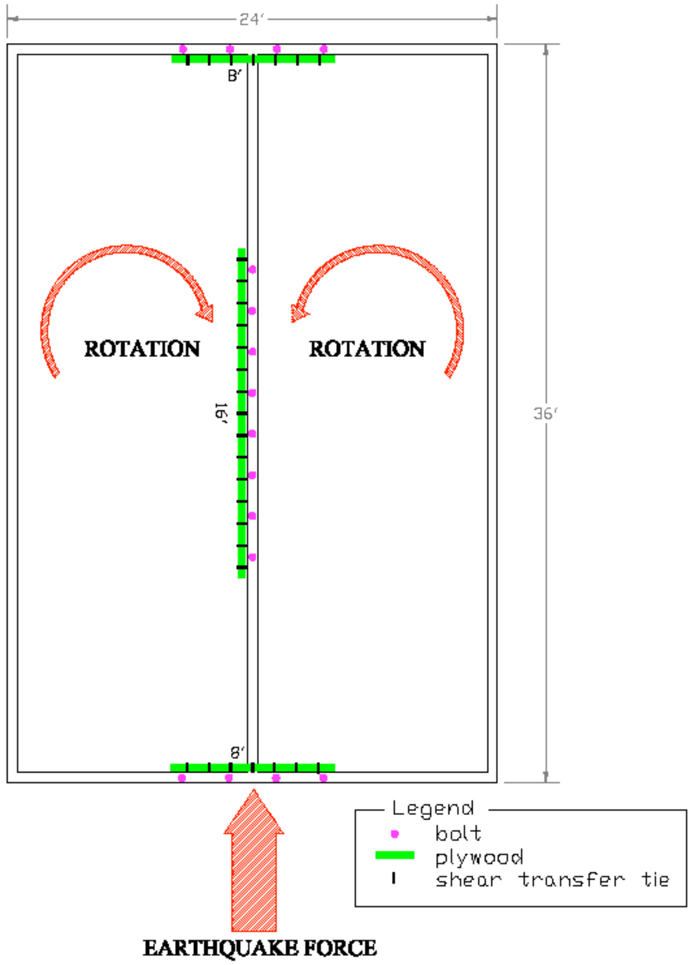
Sometimes existing shear walls are made of 3 ply plywood which is not the optimal grade of plywood. In fact, immediately after the Northridge earthquake, the city of Los Angeles downgraded this plywood to about 1/3 of its previously rated strength. This is another reason ½ inch structural 1

5-ply plywood should be used. Critical shear walls on an existing retrofit should be rebuilt with this stronger plywood.

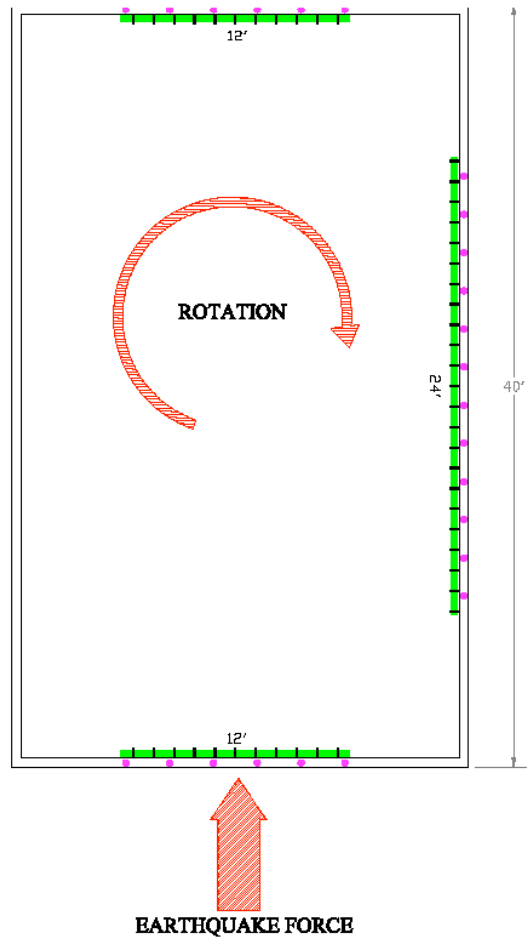


It is often necessary to use the principle of rotation in seismic retrofit work. For example, when the cripple walls on the left and right sides of the house have numerous obstructions and are difficult to access.

In these cases the most cost effective solution is to install all earthquake-resisting elements along the center foundation. The justification for this method can be found in Section 2315.1 of the International Building Code. This code citation has been edited for brevity: "*Where the principle of rotation is used in the design, the distance from the accessible cripple wall where shear walls can be built, to the cripple walls that disallow the construction of shear walls, the distance shall not exceed 25 feet or two thirds the length of the house, whichever is shorter.* In plain terms, this means you can protect a home against earthquake forces pushing against the front and back by bracing the cripple walls on the center foundation.


24'
8'
ROTATION
ROTATION
16'
36'
8'
Legend
bolt
plywood
shear transfer tie
EARTHQUAKE FORCE

If one side of the house has obstructions that prevent access to this cripple wall, and it does not possess a center foundation, a house can be retrofitted by bracing the cripple walls on the opposing side only. This approach uses the code citation mentioned above.



Houses with a living area above a garage have a serious problem because a shear wall cannot be built under the edge of the floor above the garage door opening without obstructing access to the garage. The posts and short segments of wall on either sides of the garage door opening will tend to tip over in an earthquake. The Building Code requires that in order to be effective these walls be 4 feet wide.

The principle of rotation can also be used in this case. It is often difficult to meet the code requirement that the distance from the opening to the back wall of the garage not exceed 2/3 the width of the garage door opening.