

This guide is intended to help you evaluate your home to determine if it has been retrofitted properly and also to help you evaluate proposals from contractors. Every house is different and no house matches exactly what you will see here. You should consult a professional before retrofitting your home.

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Homeowner's Guide to Seismic Retrofitting

Many homes on the West Coast were built at a time when the floor of the house was elevated off of the foundation with something called cripple walls. Most of these homes were also built before the building code was either established or had provisions for making newly constructed homes earthquake resistant. Older homes with these cripple walls need to be retrofitted to avoid collapse in a major earthquake.¹ Yet surprisingly, not even now, not even in California, do we have building codes and special contractor licensing for seismic retrofit work. Although your city may issue permits for retrofit work, the city has no code by which to evaluate the work. This puts the onus on the homeowner, but if you take the time to understand the basic principles of seismic retrofitting you can make sure your retrofit is done properly.

Most homes need to be strengthened in three areas:

1. The cripple walls need to be braced with plywood.
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.

The following illustrations explain what these areas are and why they are important. If any one of these three areas is not earthquake resistant, your house can fall off of its foundation.

1. Bracing the Cripple Walls with Plywood

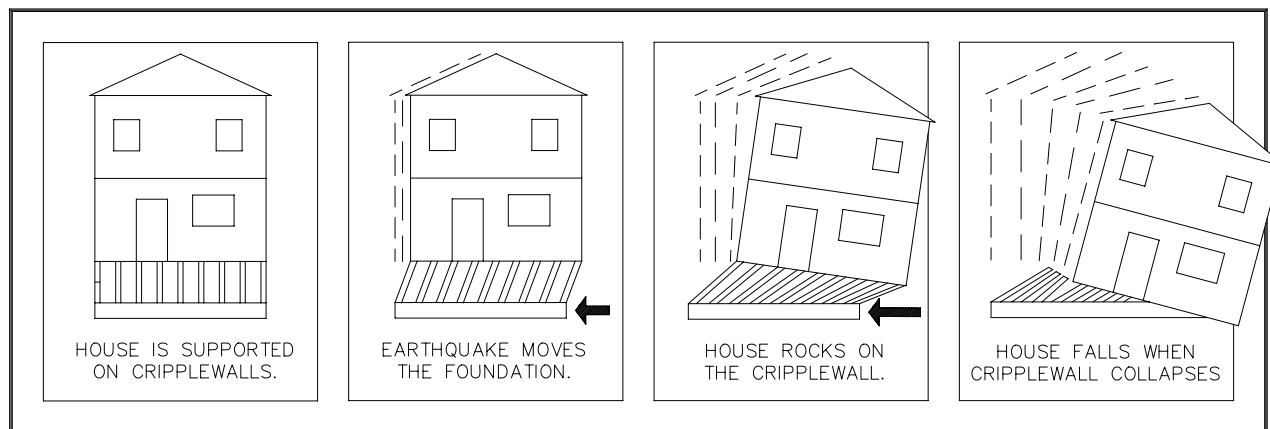


Figure 1: Failure of house due to lack of cripple-wall bracing

Figure 1 shows what can happen to a house if it is not properly retrofitted with plywood on the cripple walls. History has shown that unbraced cripple walls are the first thing to fail in an earthquake and their failure usually makes the home uninhabitable.

2. Bolting the Braced Cripple Walls to the Foundation

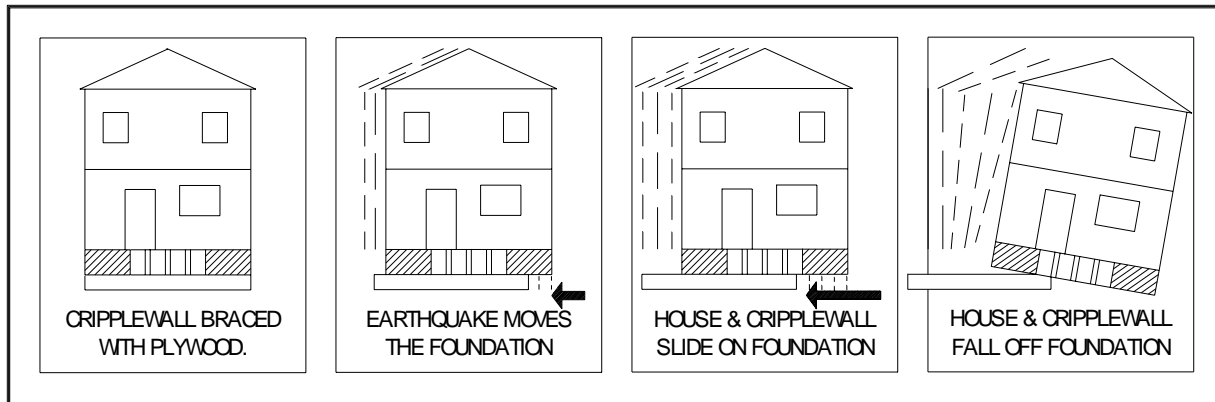


Figure 2: Failure of house due to lack of foundation bolts

The plywood-braced cripple walls should be bolted to the foundation to keep them from sliding off of the foundation.² Notice in Figure 2 that plywood is only on part of the cripple wall. It is not necessary to put plywood on the entire cripple wall. Knowing how much plywood to install involves the use of an engineering formula known as the *base shear formula*. This formula is explained at the end of this paper.

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

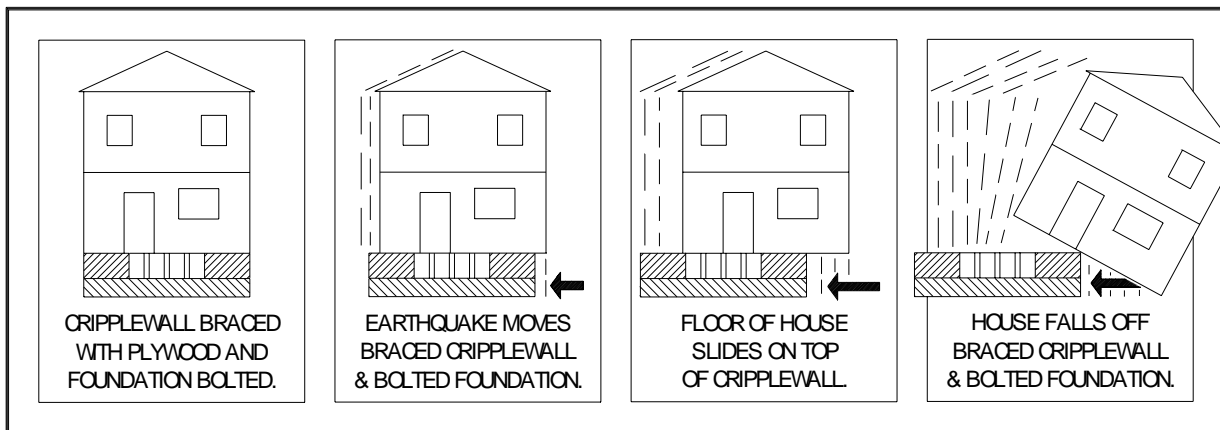
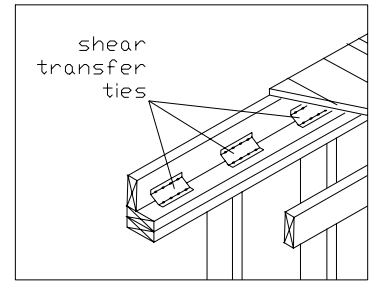
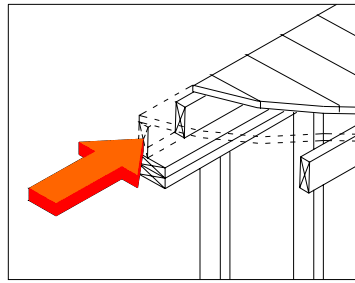
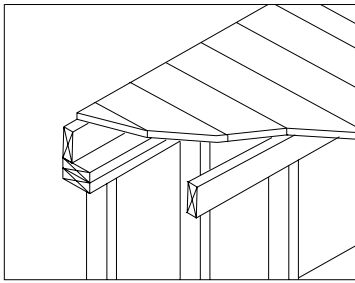


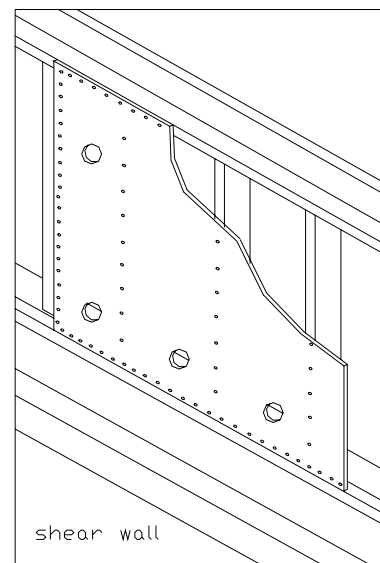
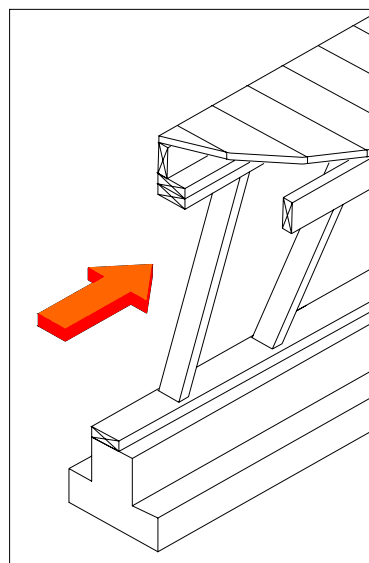
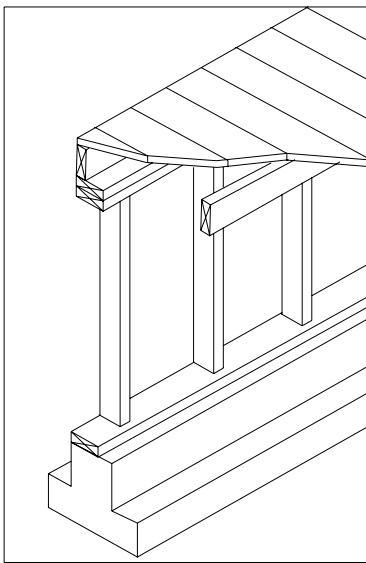
Figure 3: Failure due to no connection of floor to cripple wall

Attaching the floor of the house to the braced cripple walls is the last component in any effective retrofit. In Figure 3 the cripple wall is braced with plywood to prevent collapse and bolted to the foundation, but the floor is not attached to the braced cripple wall. This connection is strengthened with something called *shear transfer ties*.

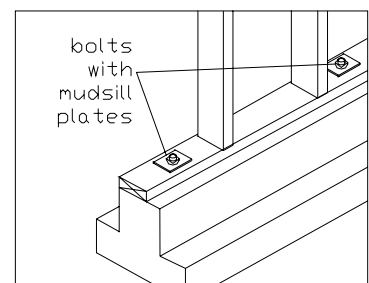
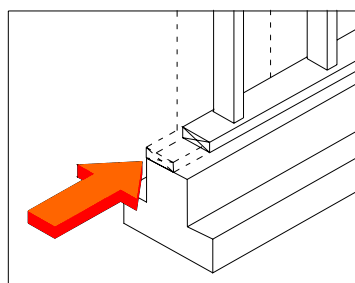
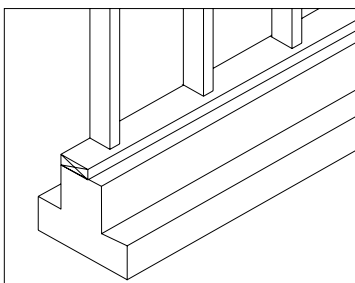
The following cross-sectionals give you another view of how the house can move in the three areas during an earthquake and where the bracing will be applied to curb the movement.



Movement prevented by shear transfer ties.



Movement prevented by shear panels.



Movement prevented by bolts.

Under your House

Diagram 1 shows what a cripple wall looks like from underneath the house where the actual retrofit work takes place. As a homeowner in the Bay Area you should be able to look under your house and identify the components shown in Diagram 1.

- 1 – the foundation
- 2 – the mudsill
- 3 – the 2x4 cripple wall stud
- 4 – the topplates
- 5 – the floor joist
- 6 – the floor you walk on

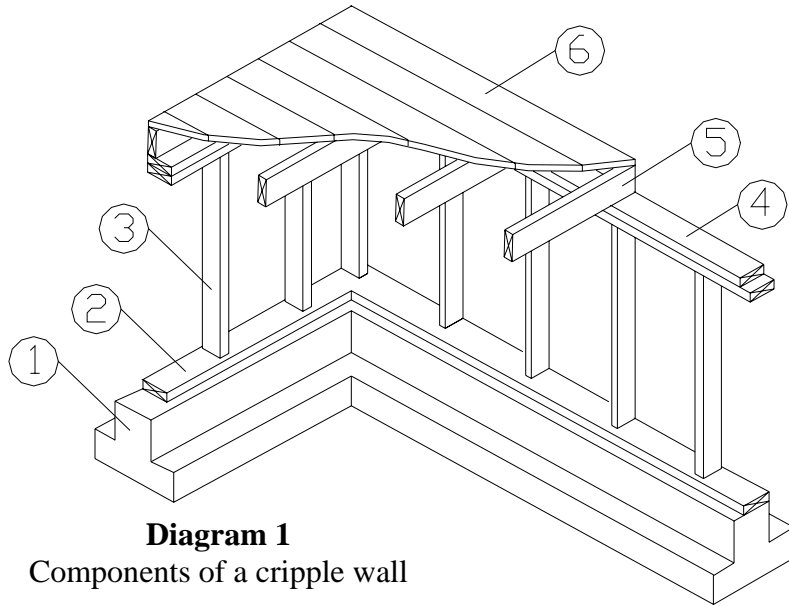


Diagram 2 below shows the same cripple wall after it has been retrofitted. The plywood shear wall keeps the 2x4 studs of the cripple wall from falling over in an earthquake, the bolts keep the mudsill from sliding off the foundation, and the shear transfer ties keep the floor joists from sliding off the top of the cripple wall. When you crawl under your house you should see something that looks like Diagram 2. Most retrofitted homes are missing at least one of these components.

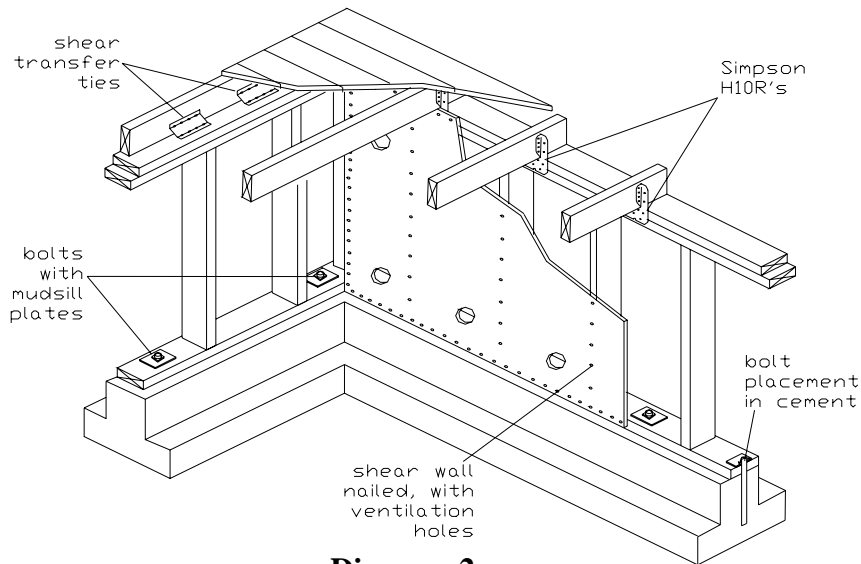


Diagram 2
Retrofitted cripple wall

Different Ways to Build Retrofit Shear Walls

Retrofit plywood shear walls can be built in four different ways:

1. Nailed Blocking Method

This method nails 2x4 blocks between the studs into the mudsill. The plywood is then nailed to these blocks. This is the most common method used to attach the plywood to the mudsill. The 2x4 blocks are placed between the upright 2x4 studs and nailed onto the mudsill.

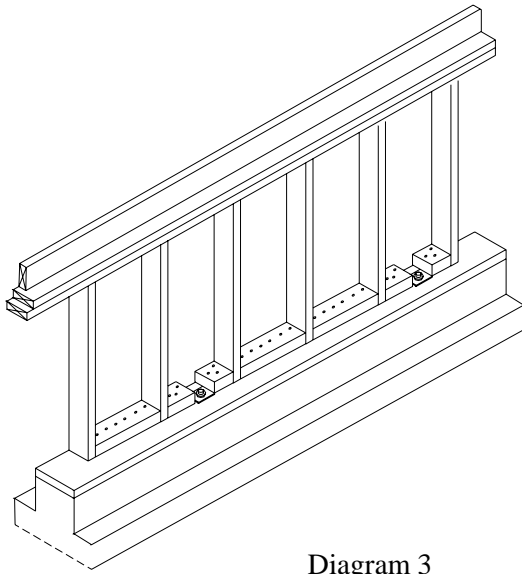


Diagram 3

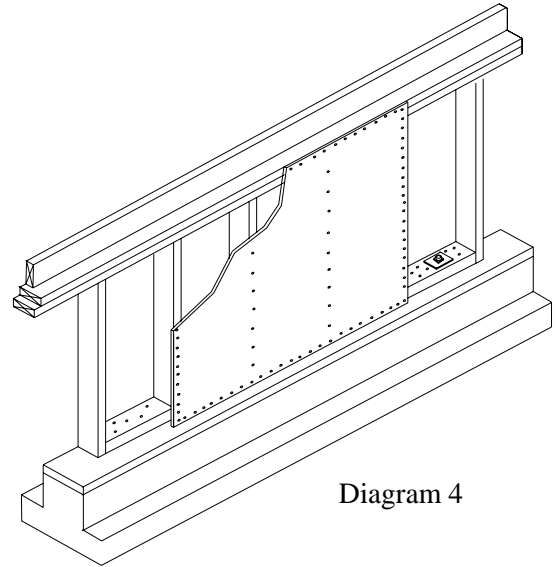


Diagram 4

The plywood is then nailed into the 2x4 blocks at the bottom of the panel. The point of concern when using the nailed blocking method is that the blocks can split.

2"x4" blocks stapled into mudsill to prevent splitting of the blocks.

1/2"x2-1/2" 15ga staples, 1" min. penetration into mudsill

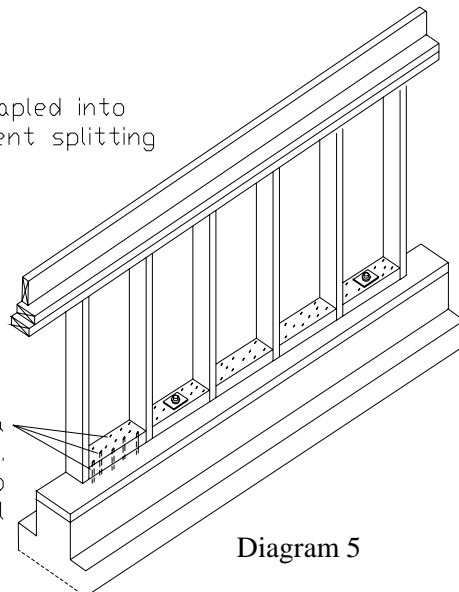


Diagram 5

2. Stapled Blocking Method

This method is identical to the nailed blocking method except staples are used as shown in Diagram 5. The American Plywood Association recommends the use of staples. A report published by the American Plywood Association states: "Staples provide a method for developing high design shear values while still using 2 inch nominal framing. The small diameter of the staple legs is not as apt to cause splitting- of the framing as are large diameter nails."



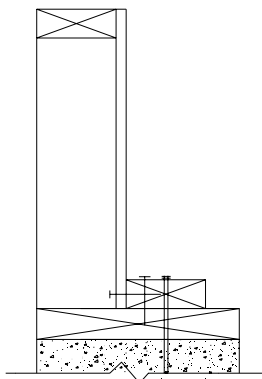
The photo above shows a block behind a shear wall that split with only four nails installed.



This photo shows a 14-inch block with **114** 2-1/2 inch staples. Notice no splitting of the block.

3. Reverse Blocking Method

Diagram 6 shows a shear wall made with reverse blocking. The reverse blocking method is quite effective in homes that have wide mudsills. The 2x4 reverse block is nailed to the plywood before the plywood and 2x4 are installed on the cripple wall.



from the side

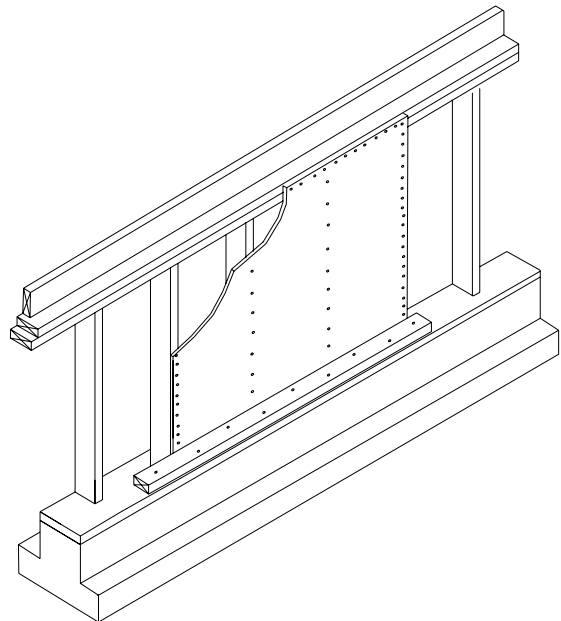


Diagram 6

4. Flush Cut Method

With this method the mudsill is cut flush with the 2x4 upright studs with a special saw. The lower edge of the plywood is then nailed directly into the redwood mudsill as shown in Diagram 7. This method of building a retrofit shear wall is the method that most resembles the shear walls that have been tested in laboratories by the American Plywood Association.

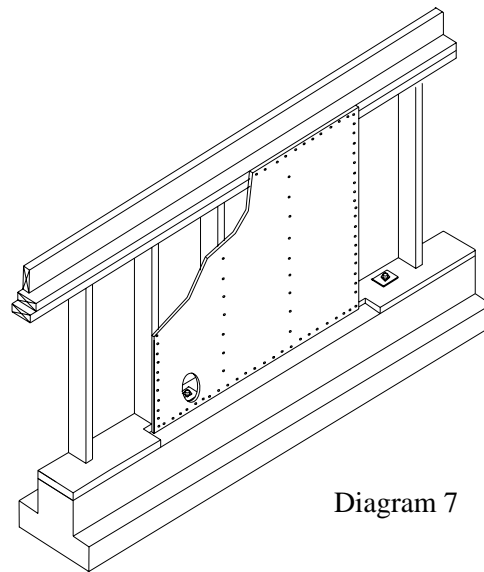
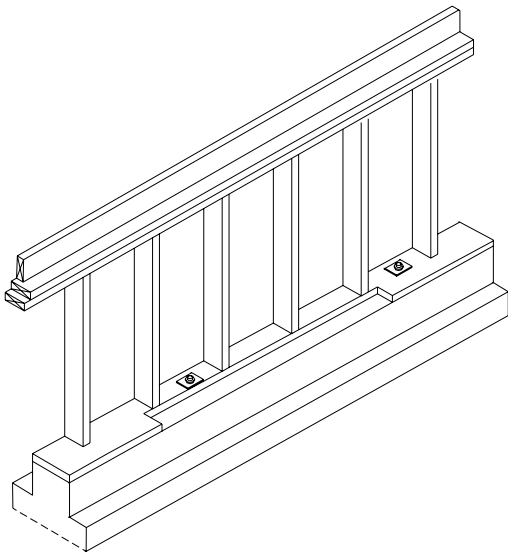


Diagram 7

The International Code Council asked the American Plywood Association, the world authority on plywood construction and testing, to evaluate these four methods for creating shear walls. The following letter is the American Plywood Association's response.

A P A

The Engineered Wood Association

To: The International Code Council

Dear Council Members,

Based on my professional opinion, I would judge the retrofit strategies in the following order, from most preferred to least preferred.

- 1.) Flush-cut mudsill method
- 2.) Reverse block method
- 3.) Stapled blocking method
- 4.) Nailed blocking method

I have chosen to order the retrofit strategies based on several reasons. In the past 8 years, there has been an unprecedented amount of cyclic testing on shear walls by APA and other organizations. The results from these various programs would be more similar to either the flush-cut mudsill or the reverse block method; hence I have a great deal of confidence in either of these methods. I believe the flush cut method would be more practical for most retrofits, but the reverse block method would be an acceptable alternative.

In my experience of personally working with small blocks of wood in the laboratory as well as small building projects of my own, I believe that multiple nails through the face of the small blocks greatly increase the splitting potential of the small wood blocks. Obviously if the blocks split for either the nailed or stapled blocking method, the structural integrity of the retrofit will be compromised. Nails tend to split wood worse than staples. Therefore, I believe the stapled block method is preferred over the nailed blocking method.

In summary, on paper, all of the retrofit strategies are acceptable. Since APA has not, and has no plans to conduct testing of these retrofit strategies, engineering judgment based on experience can be used to rank the different methods. I am of the opinion that my itemized list above is a reasonable ranking of the four methods.

I hope you find this information useful and if you have any questions, or would like to discuss this further, please don't hesitate to contact me.

Sincerely,

THOMAS D. SKAGGS, Ph.D., P.E. Senior
Engineer Technical Services Division

The Base Shear Formula

You will have to do a bit of arithmetic and use a very simple formula known as the base shear formula to determine exactly how many bolts, how much plywood, and how many shear transfer ties your house will need.

Geologists are able to calculate an “anticipated” amount of force that will be generated by a major earthquake in a specific geographical region. Knowing that “anticipated” force, retrofitting uses what is called the *base shear formula* to calculate the amount of shear force (earthquake force) that will hit the base of a specific house. If the three potential areas of failure are made strong enough to resist the forces determined by the base shear formula, the house is considered retrofitted and should survive a major earthquake. Elementary multiplication is all you need to know to understand this formula.

The base shear formula is:

$$V = 0.185 (W)$$

V represents the shear force that will be generated at the base of a building.

0.185 represents anticipated force of ground acceleration from a major earthquake. This number varies from region to region and is based upon proximity to known earthquake faults.

W represents the weight of the building. Single story homes weigh approximately 50 pounds per square foot. Two story homes weigh 80 pounds per square foot of the first floor.

Example: We have a one-story house with a first story that is 35 feet by 40 feet. The first story is thus 1,400 square feet ($35 \times 40 = 1,400$). If we multiply this times 50 pounds, we determine that the building weighs 70,000 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.

So, the base shear formula tells us the anticipated earthquake force equals 0.185 times the weight of the house being retrofitted.

For our example we would use the base shear formula as follows:

$$V = 0.185 \times \text{weight of house}$$

$$V = 0.185 \times (\text{area in square feet} \times \text{weight per square foot})$$

$$V = 0.185 \times 1,400 \text{ sq. ft.} \times 50 \text{ pounds per sq. ft}$$

$$V = 0.185 \times 70,000 \text{ pounds}$$

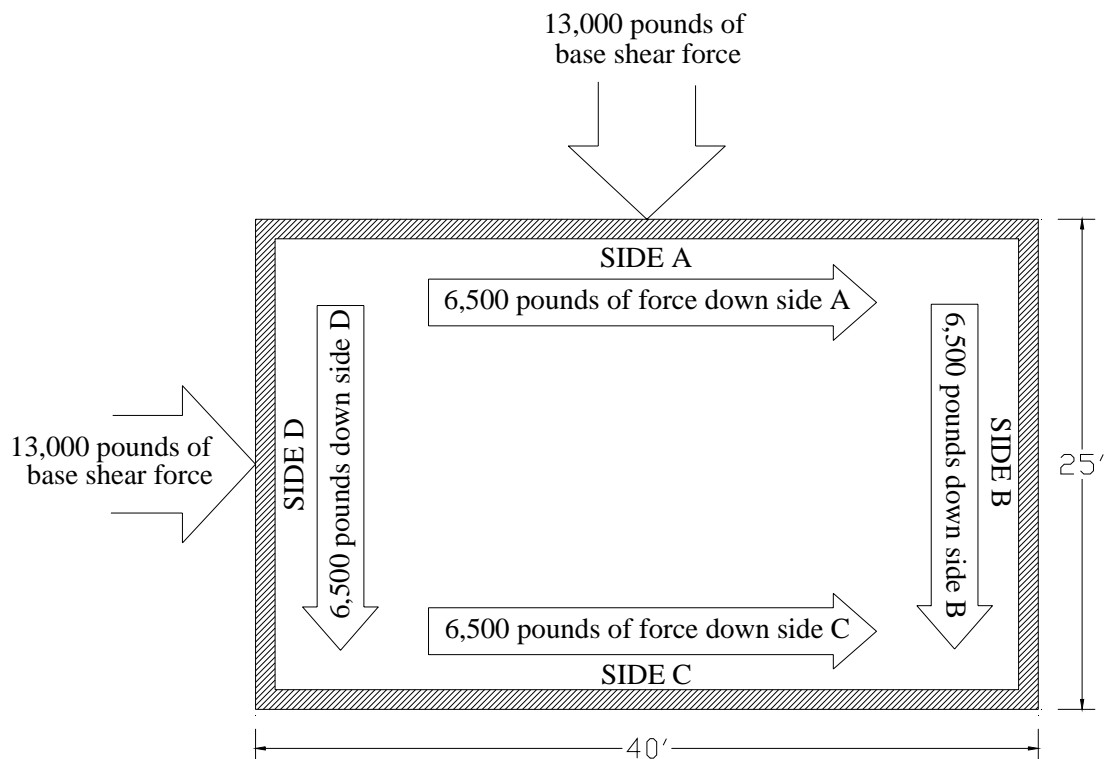
$$V = 12,950 \text{ pounds}$$

Therefore the amount of shear force that is anticipated to strike this Bay Area home at its base (foundation area) during a major earthquake is 12,950 pounds. For our purposes we will round 12,950 pounds to 13,000 pounds.

This means a properly designed retrofit for this house must resist a minimum of 13,000 pounds of force where it sits on the foundation, AND a minimum of 13,000 pounds against the cripple walls, AND a minimum of 13,000 pounds of force where the floor sits on top of the cripple wall.

This information allows us to calculate how much hardware and plywood is needed to protect these three weak areas. All bolts, nails, plywood, shear transfer ties, etc., are rated in terms of the amount of shear force they can resist. For example, a 1/2-inch bolt with a plate washer can resist 1,000 pounds of force. Each linear foot of high capacity plywood bracing can resist approximately 500 pounds of force. Good shear transfer ties can also resist around 500 pounds of force.

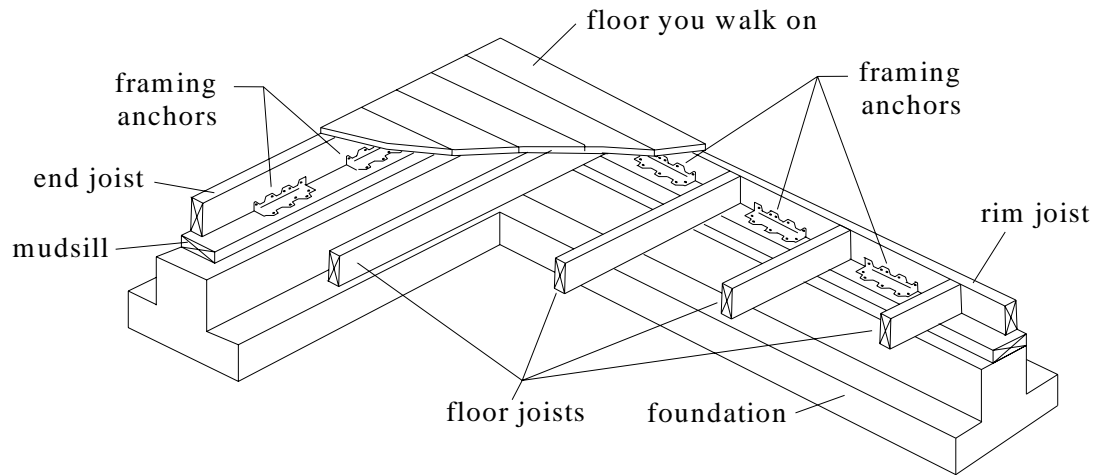
The house in our example will be attacked by 13,000 pounds of earthquake force in each direction. We know that a 1/2-inch bolt provides 1,000 pounds of earthquake resistance. To determine the number of 1/2-inch bolts we will need, we divide 13,000 by 1,000. The answer is 13. This means we need a total of 13 bolts to protect the house in the north-south direction and 13 bolts to protect it in the east-west direction. We will round this number up to 14 and install 7 bolts along each foundation wall.



Next we need to address the bracing of the cripple walls. A medium capacity plywood shear panel can resist 500 pounds of shear force per each linear foot. If we divide 13,000 by 500 we get 26. This means we need 26 linear feet of plywood in the east-west direction and 26 linear feet of plywood in the north-south direction, or 13 feet of plywood on each wall.

The same method is used to calculate the number of shear transfer ties needed to attach the floor framing to top of the cripple wall. Good shear transfer ties can resist 500 pounds of shear force. 13,000 divided by 500 equals 26. This means we need 26 shear transfer ties for each direction or 13 shear transfer ties along each foundation wall.

Below is a drawing of what it probably looks like under your house if you do not have a cripple wall. The mudsill needs to be attached to the foundation and the end and rim joists attached to the mudsill.



Here is an example of what can happen when the floor framing is not attached to the mudsill. The unbolted mudsill can also slide off if it not bolted to the foundation. This mudsill happened to be bolted.



The base shear formula and the other information in this guide should help you evaluate if your home has been properly retrofitted or not and also help you evaluate bids from retrofit contractors. Retrofits cost thousands of dollars and to make sure that your retrofit is a good one, the best thing you can do is to research the topic on the Internet, through books at the library, and by attending retrofitting seminars. You would not buy a new car without first making sure you knew exactly what you were getting, so please take the time to educate yourself so you can make your home a safer place to live in.

Endnotes:

1. After the mid 1940s we don't see many cripple walls. However, almost all homes built on hillsides have cripple walls.
2. Sometimes cement foundations are decayed and need to be replaced but these cases are actually rare. A study was done by the Structural Engineer's Association of Southern California in 1992 in which they discovered that unreinforced foundations do fine in earthquakes. However it is commonly known that brick and stone foundations found in some Victorian homes should be replaced.

For additional information about seismic retrofitting, go to www.bayarearetrofit.com.

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