Foundations and Footings

Foundations are a critical consideration in any wood frame seismic retrofit. All the earthquake forces that shake a house are ultimately transferred into the foundation through what is known as a load path. The load path is the engineering basis behind all seismic retrofit work and therefore it is absolutely that the load path be fully understood. In the illustration below, the load path is transferring earthquake forces through the retrofit components into the foundation. are being transferred into the foundation through the load path. Assume the earthquake is pushing against the floor you walk on as illustrated by the green arrow. The floor then pushes against the floor framing in the same direction, and tries to make it slide. This sliding movement is restrained by transfer this sliding force from the floor framing into the shear transfer ties. The shear transfer ties transfer this sliding force into the upper top plate, the upper top plate transfers this force into nails that attach the plywood to the top plate. These nails transfer the sliding force down through the plywood into the row of nails at the bottom of the plywood. The nails at the bottom of the plywood transfer the sliding force into nails that attach the plywood to the mudsill, the mudsill transfers the force into the bolts, and the bolts transfer the movement into the foundation. The foundation transfers the movement into the ground where it is finally dissipated. This movement chain from the floor to the foundation is the load path. If any component 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 that it is retrained from movement when pushed on by an earthquake.

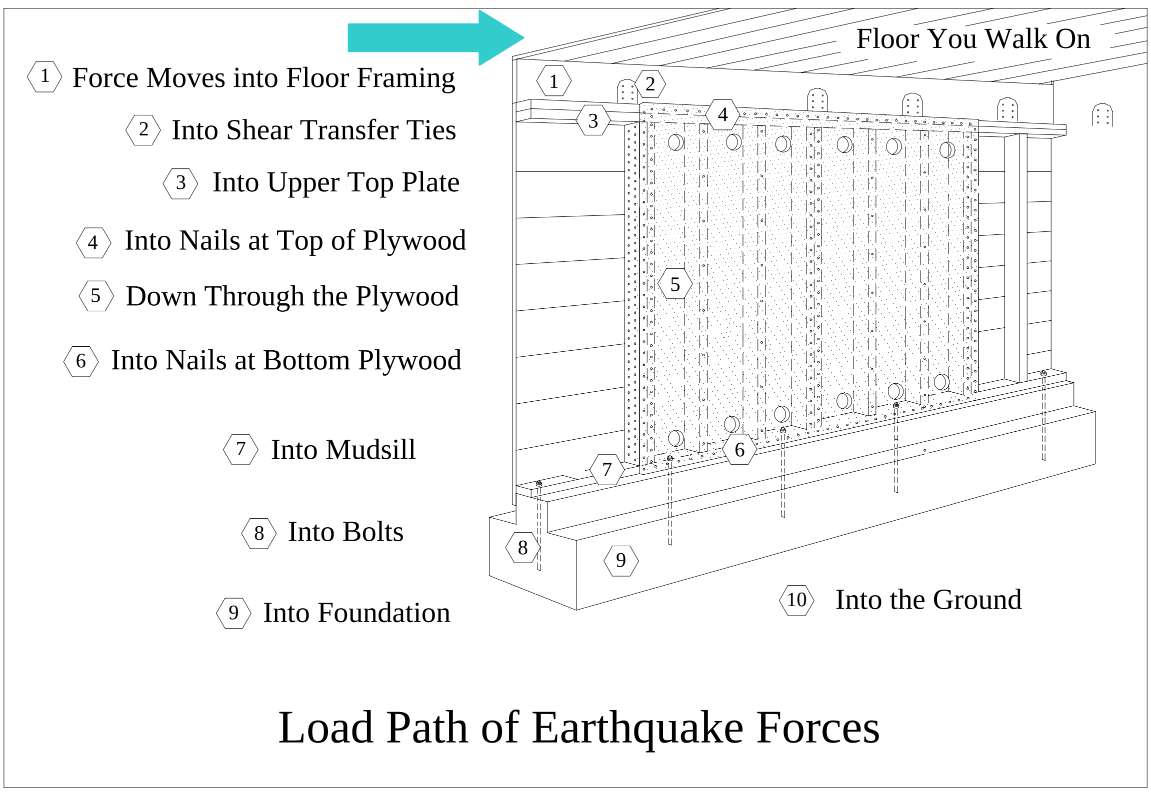

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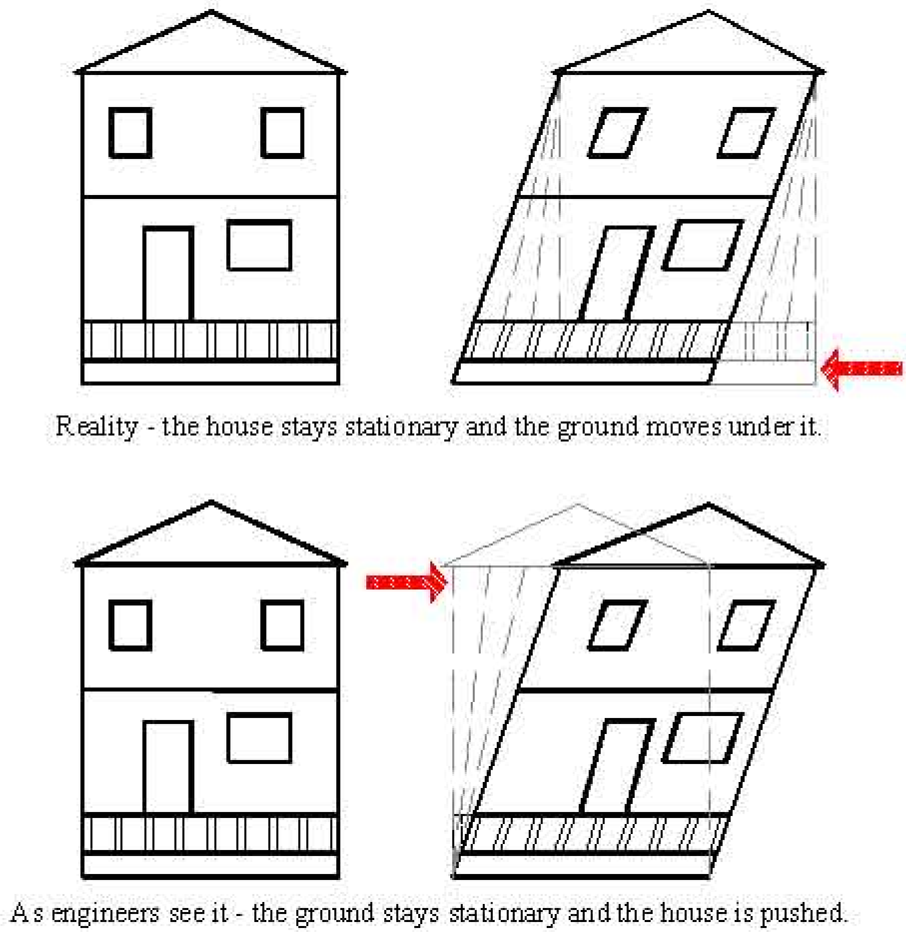
Figure 1



The Result is the Same

Figure 2

The reason we talk about earthquake forces pushing against a house is because it is much easier to conceptualize. An earthquake effects a house is 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. This forward reverse cycle can occur ?

Steel reinforcing in residential foundations did not become common until the late 1950s and did not become a building code requirement in the Bay Area until the California Building Code was adopted in July of 2000. For homes built before July of 2000, there is no way to know for sure if it has reinforcing steel without metal detector testing. test. A pachometer is a metal detector that is used to find steel in concrete. Sometimes you may see rebar exposed somewhere along the foundation, in which case you can assume the entire foundation is reinforced with rebar.

Foundations built after XXXX were required by the building code to be embedded a minimum of 12 inches into undisturbed earth. On the other hand, older foundations built approximately 1950 and before are often embedded into the ground only 2 to 6 inches, if at all, and rarely 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 unique characteristics.

Old Foundation, 6 inches tall, 4 inches embedment, 10 inches wide.

Figure 3

Sliding motion exerted on a foundation by an earthquake is resisted by the friction between the sides and bottom of the footing where it touches the soil. This friction can be considerable. Past earthquakes have shown that foundations with undersized and shallow footings slide very minimally on the ground, if at all. Shallow footings are therefore rarely a consideration in wood frame seismic retrofit work. If the foundation happens to slide, the house will move right along with it.

Existing foundations are also quite effective in resisting breakage that may be caused when the sliding force is pushes against the bolts which in turn push against the foundation. This is confirmed by table A-!-D of the Uniform Code of Building Conservation (UCBC) and tests done by the Structural Engineers Association of Southern California. The UCBC specifies that all existing foundations can be assumed to be 1500psi concrete unless tests prove otherwise.

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1500 psi for plain concrete footings

1997 UNIFORM CODE FOR BUILDING CONSERVATION

TABLE A-1-D—ALLOWABLE VALUES FOR EXISTING MATERIALS

EXISTING MATERIALS OR CONFIGURATIONS OF MATERIALS[1]	ALLOWABLE VALUES × 14.594 for N/m
3. Existing footings, wood framing, structural steel and reinforced steel	
3.1 Plain concrete footings	f_c = 1,500 psi (10.34 MPa) unless otherwise shown by tests[4]
3.2 Douglas fir wood	Allowable stress same as D.F. No. 1[4]
3.3 Reinforcing steel	f = 18,000 lbs. per square inch (124.1 N/mm^2) maximum[4]
3.4 Structural steel	f = 20,000 lbs. per square inch (137.9 N/mm^2) maximum[4]

[1]Material must be sound and in good condition.

Figure 4

Psi means one cubic inch of existing concrete will fail when put under 1500 pounds of mechanical pressure. Newer concrete used in foundations is normally 3000 psi.

In 1994 The Structural Engineer's Association of Southern California conducted tests to see how well low strength concrete would perform when foundation bolts and retrofit foundation plates were connected the wood mudsill to the foundation. In these tests a jack was used to push against the mudsill so that the mudsill in turn pushed the bolts. This mimicked the later force that would be generated by an earthquake. In this scenario either the bolt would cause the foundation to crack or the mudsill would split. When the bolts pushed against this low quality concrete, it did not break apart, rather the wood mudsills invariable failed.. The final conclusion of these fairly extensive tests was as follows:

CONCLUSION (COMPARING PHASEI VERSUS PHASE II)

"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 (f'c approximately 1500psi). The predominant failure mechanism in these anchorage connections was the wood sill plate (mudsill) in both the good and weak concrete foundations." The experimenters who conducted these tests also discovered this existing concrete to be low quality 1500 psi concrete, identical to the UCBC specification.

In these tests the failure was always in the wood at the wood to bolt connection and not in the bolt to concrete connection. Footnote one of the UCBC specifies that the existing concrete be “sound and in good condition” (this means it is solid when you hit it with a hammer or jab it with a screwdriver). If the foundation is in “sound and good condition” it does not matter if the footing is shallow or if it does not have reinforcing.

Overturning Forces

In addition to resisting sliding motion, shear wall must also resist forces that try and tip them over. Imagine trying to slide a chest along the floor. If the chest is short and you push on the top of it, it will slide along its length. If the chest is tall and you push on the top of the chest it will not only slide on the floor but also try and tip over. This tendency to tip over is called overturning. When the chest tries to tip over, one end lifts up and the one end presses into the floor. The end that lifts up is subject to a force reasonably called “uplift.” The force that pushes the other end down into the floor is called compression. All shear walls, no matter how tall, are subject to these two forces.

In a manner similar to our short chest of drawers, short shear walls tend only to slide rather than tip over. On the other hand, tall shear tend to slide as well as overturn. In all cases, to protect the home they support, shear walls must resist sliding and overturning. If a shear wall overturns, even just an inch or two, it can cause severe damage by pulling the nails out of the mudsill.

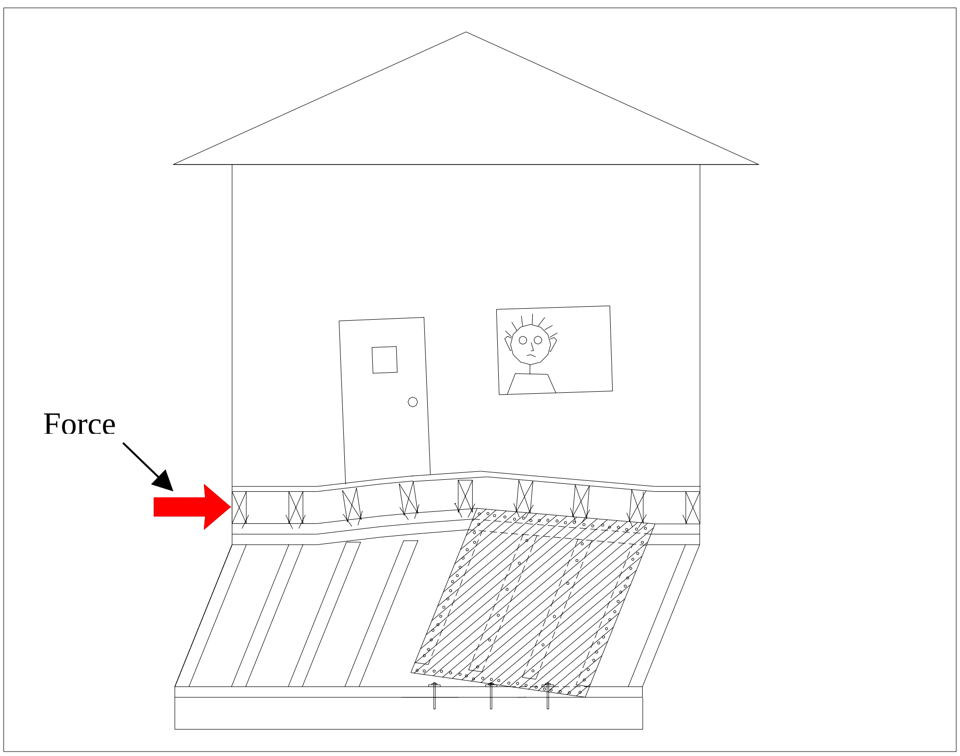


Figure 5

This shows a shear wall tipping over and pulling up from the mudsill. This destroys the ability of the shear wall to resist sliding forces because now the plywood has been separated from the bols.

Here is a closer view of a shear wall overturning. This drawing is exaggerated for illustration purposes. The shear wall is damaged as the lower edge of the plywood lifts up and away from the mudsill so that the plywood can no longer transfer shear forces into the bolts.

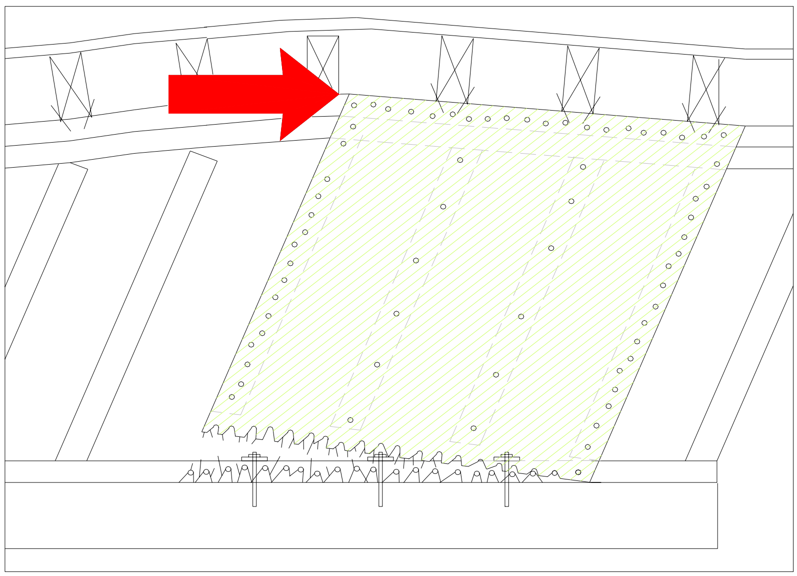


Figure 6

The photo below demonstrates how, just like with the chest, the tendency to overturn is much greater in tall narrow shear walls.

Figure 7

The overturing of narrow walls on either side of a garage door opening as shown in Figure 7 is quite common. This occurs more readily when a living area is above the garage because the added weight moving back and forth creates stronger overturning forces.

Figure 8

This collapse was caused by overturning of tall narrow shear walls on either side of the garage.

Resisting Overturning

The hold-down hardware, also called tie downs, shown at the ends of the shear wall in the figure below are designed to resist overturning forces. The hold down hardware is attached to the end wall framing at each end of the shear wall. When the ends of the shear wall try to lift up and overturn, the hold downs prevent this by keeping the end wall framing held firmly to the foundation. Each hold-down is connected to the foundation with a threaded rod set deep in the concrete and secured with epoxy.

Hold down threaded rod installed with epoxy as deep into the foundation as possible.

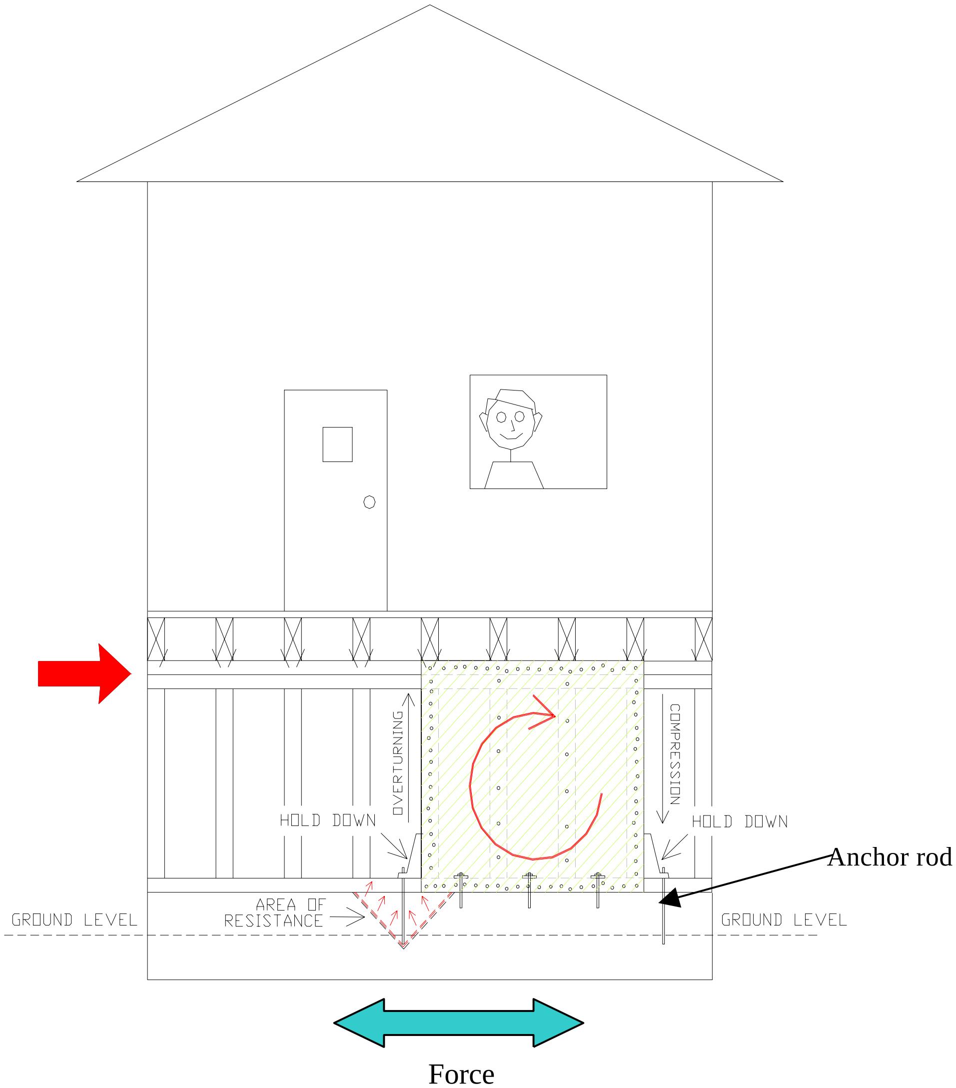
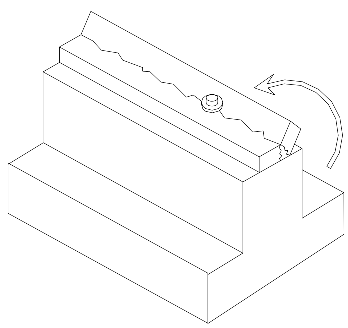


Figure 9

This is similar to the load path we discussed earlier. The earthquake forces pushes sideways on the top of the shear wall. The nails on each end of the plywood pull up on the end wall framing.. The end wall framing then pulls up on the hold down, which pulls up on the anchor rod, which pulls up on the concrete, which tries to pull the concrete out of the ground. If any link in this load path chain is weak or missing the shear wall can be damaged.

When the shear wall tries to resist the overturning shown by the red circular arrow in the middle of the shear wall, in order to resist this upward pulling force the plywood must be sufficiently nailed to the end wall framing This is accomplished by correct edge nailing. In the same way, the hold down hardware must resist this force by being securely attached to the end wall framing. This is done by installing it according to the manufacturer's instructions. The anchor rod that attaches the hold down to the foundation must also be securely fastened to the concrete to keep it from pulling out. This is accomplished with structural epoxy. Finally, the concrete itself must be strong enough not to break when pulled up on by the anchor rod. This is hard to control unless rebar is present. The weight of the concrete must also be sufficient to keep the foundation from lifting up out of the ground. 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* holdown acts at any given moment as the shear wall rocks back and forth.

It is important to note that ordinary foundation bolts do not help keep the shear wall ends from lifting up off the foundation. There are a number of reasons for this. First, the sills can rip up over nuts and washers on anchor bolts (especially when the washers are small round cut washers rather than plate washers). Second, the shear wall pulls up against the bolts and the mudsill must now resist "cross-grain bending." Cross-grain bending is the very weakest property of wood. You can demonstrate this to your self by grasping the edges of a wood shingle and twist your wrists upward. Cross grain bending will cause the shingle to break lengthwise. Bolts do resist cross grain bending somewhat, especially when bolts with large plate washers are place close together at shear wall locations with large plate washers.



Cross Grain Bending

American Plywood Association Shear Wall Test with Cross Grain Bending Failure

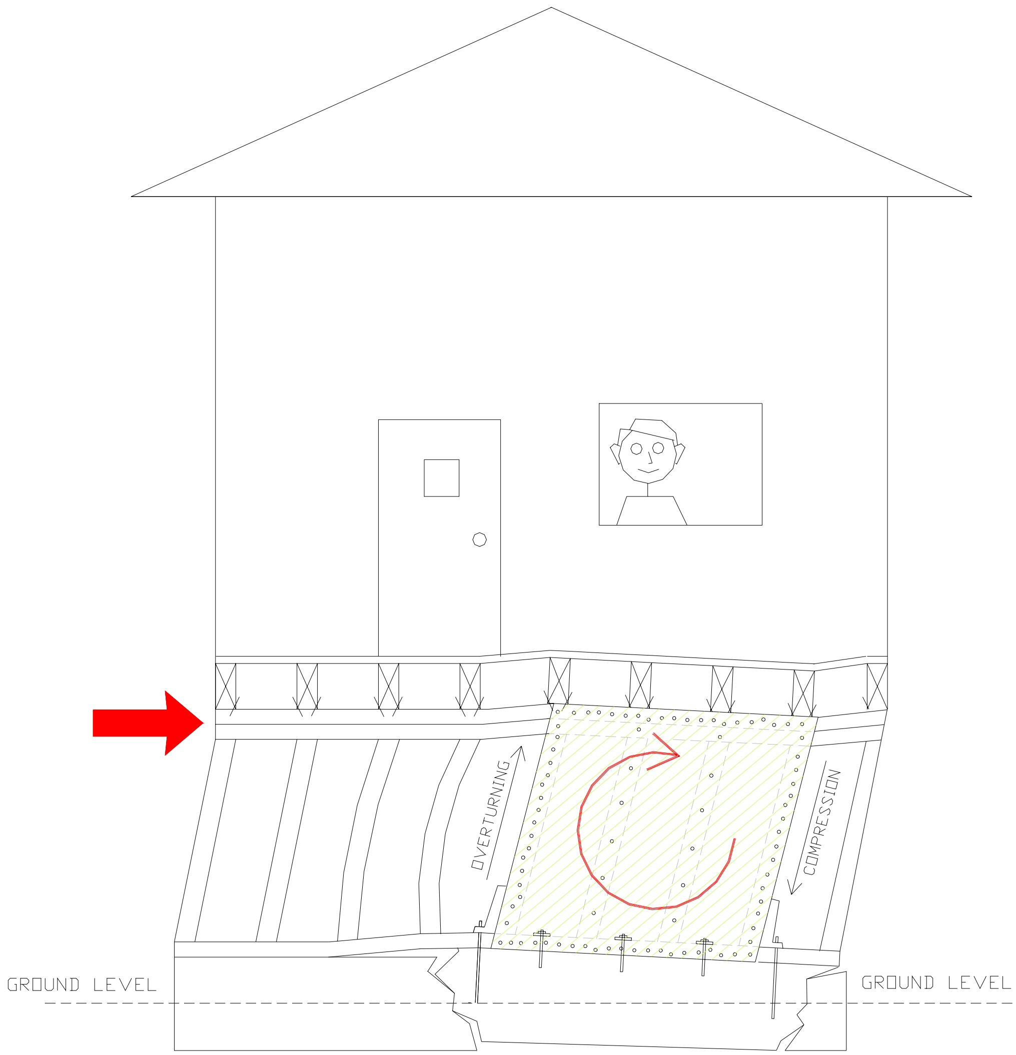


Figure 10

Sometimes the overturning forces are so great that an un-reinforced concrete foundation breaks, or an improperly reinforced foundation deforms. This can lead to significant damage to the structure.

Overturning Considerations in Foundations and Footings

Foundations under retrofit shear walls often need extra attention in order to resist overturning forces. Many old foundations have minimum embedment in the soil, are short and narrow, and do not have reinforcing steel. Many of them are also cracked. Without reinforcing steel these foundations readily break at hold-down locations as the anchor rod pulls up on the concrete. We want to make sure that the uplift force measured in pounds exerted vertically as it pulls up on the hold down, is resisted by the same amount of downward force provided by the house and 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 down anchor rods to. This can be done by pouring heavy blocks of concrete beneath the hold downs. 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. Remember the plywood to end wall framing, the hold down to end wall framing, the hold down anchor rod, and the anchor rod to concrete must all be able to resist 4000 pounds of force.

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.

Installing the concrete under the hold downs

In order to gain this extra weight it is necessary to anchor the hold downs to new concrete placed under the existing footing, centered under the hold down anchor. After calculating the required amount of weight, dig a hole under the hold down so that it can be filled with the proper amount of concrete. One cubic yard (3’x3’x3’) of concrete weighs 4000 pounds and on tall narrow walls you often need at least a full cubic yard of concrete under each hold down. Thus if the hold down is pulling up on the foundation with 4000 pounds of force it will be resisted by 4000 pounds of concrete weight. Once you have the hole dug, drill through the concrete at the hold down location so that it extends through the old foundation and into the hole. Install the all-thread anchor-rod through the old foundation until it extends into the hole to within about 8 inches from the bottom.

The existing unreinforced concrete foundation shown here is only 8 inches tall and 10 inches wide. This is clearly insufficient to resist the overturning forces that a new 8 foot tall by 10 foot long shear wall will exert on the foundation. In this case the front cripple wall was being braced by a shear wall this size. 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.

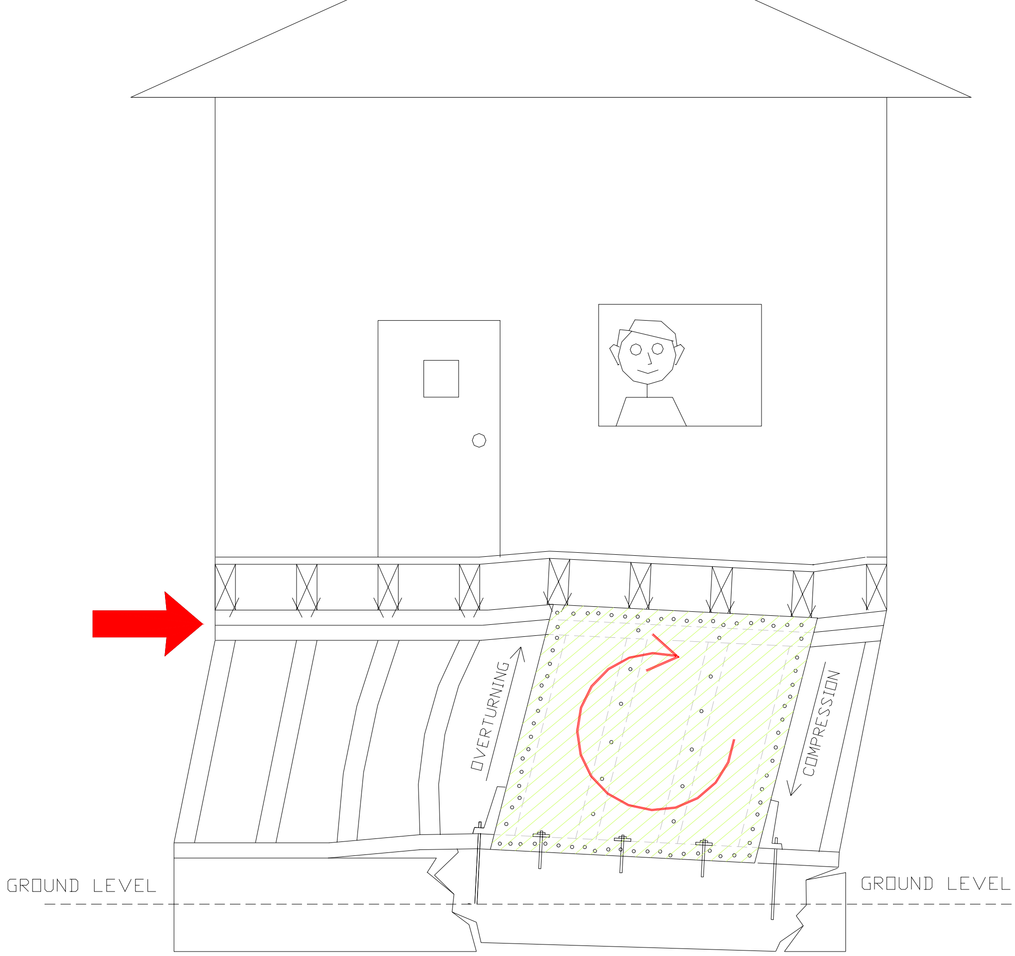
Figure 11

Hold Down

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.

Figure 12

We now have a complete overturning load path where the weakest element has been reinforced with concrete.



In foundations where rebar exists, the hold downs will try and pick up a very long and heavier segment of foundation because the foundation is connected together with steel, This is always the case unless a hold down is located near the end of a foundation, such as by a garage door opening,

It is often the case that homeowners cannot afford the additional foundation work. Here it is very important to inform the owner of the limitations his retrofit will have without the foundation work. (WHICH ARE?) If the homeowner chooses not to do this foundation work it is it important to provide for longer embedment of the anchor rods that will connect the hold downs to the foundation. In this way the hold downs will try and pick up as much of the foundation as possible, the deeper the embedment, the more concrete the anchor rod will try to pick up.

Efflorescence

Figure 14
Typical Foundation with Efflorescence

Foundations often have deteriorated concrete surfaces. The deterioration is most often caused, not by a faulty old mix, but by periodic wet-dry-wet-dry exposure to moisture over many years. The mechanism is this: the base of the wall gets wet, and some of the water penetrates the concrete, carrying dissolved salts picked up from the soil, or the concrete Does concrete have naturally occurring salts on the outside?. When the water evaporates and comes to the surface, the salts are left behind and form salt crystals on the surface of the concrete.

Figure 15 Masonry Blocks with Efflorescent Crystals

As the crystals grow, they exert enough pressure on the surface of the concrete to cause the surface of the concrete to deteriorate. The crystals leave salt deposits on the side of the concrete which have a white powdery appearance (efflorescence).

If efflorescence has formed, you can brush or rub away the white powder and get to sound concrete. It is rare for efflorescence to reach more that about ½” into the concrete, though there are instances where it has worked away one third of the thickness of the wall or more. Nevertheless, one will always find sound concrete once the crystals are scarped away. If this is what is taking place it means the concrete under the house is getting we, the FIRST step is to get moisture under control [correct the yard drainage, repair gutters and downspouts, fix leaky plumbing, stop landscape irrigation next to the house, etc.]. As with rotated foundations, water is the usual suspect. It does little good to correct a damaged foundation without FIRST correcting the cause: get the water near the house under control, then fix the structure.

If the damage has an objectionable appearance, it may be repaired with a skim coat of Portland cement stucco that is applied to a well prepared [wire-brushed and wetted] concrete surface, with care to assure a good bond. Efflorescence has no structural significance and will not undermine a retrofit in any way.

Rotated Foundations

A rotated foundation describes a foundation that is leaning outward into the yard. This is caused by poor drainage. The mechanism behind rotated foundations is this: .Most foundations are at least 7 inches wide at the top. The wall framing of the cripple wall sits on of the outer 4 inches of this top surface so that more downward pressure is being exerted on the outer top surface of the foundation than on the inner top surface. When the soil becomes saturated with water this softens the soil under the foundation. Most of the saturation occurs in the soil under the outside of the foundation relative to the dryer soil under the inside of the foundation. This is because on the outside water tends to collect from eave run off and other sources. For this reason the soil under the outside of the foundation is softer than the soil under the inside of the foundation.   This causes the foundation to rotate outward because of the downward pressure being exerted on the softer soil. This rotation usually takes several years to notice and many older homes with poor drainage can be seen with this problem.

Rotated foundations rarely rotate enough to cause a home to lose vertical support. Though when sever it may create some unevenness in the floor. In addition, rotation does not effect the ability of a foundation to resist the lateral forces of an earthquake transferred to it by a retrofit. Therefore the cost versus benefit ratio achieved by replacing a rotated foundation rarely makes sense as part of a seismic retrofit.

Figure 16

The foundation segment on the left has rotated outward and caused this crack. If this foundation would have been reinforced with steel rebar, such that the rebar wrapped around these foundations segments, this would not have happened.

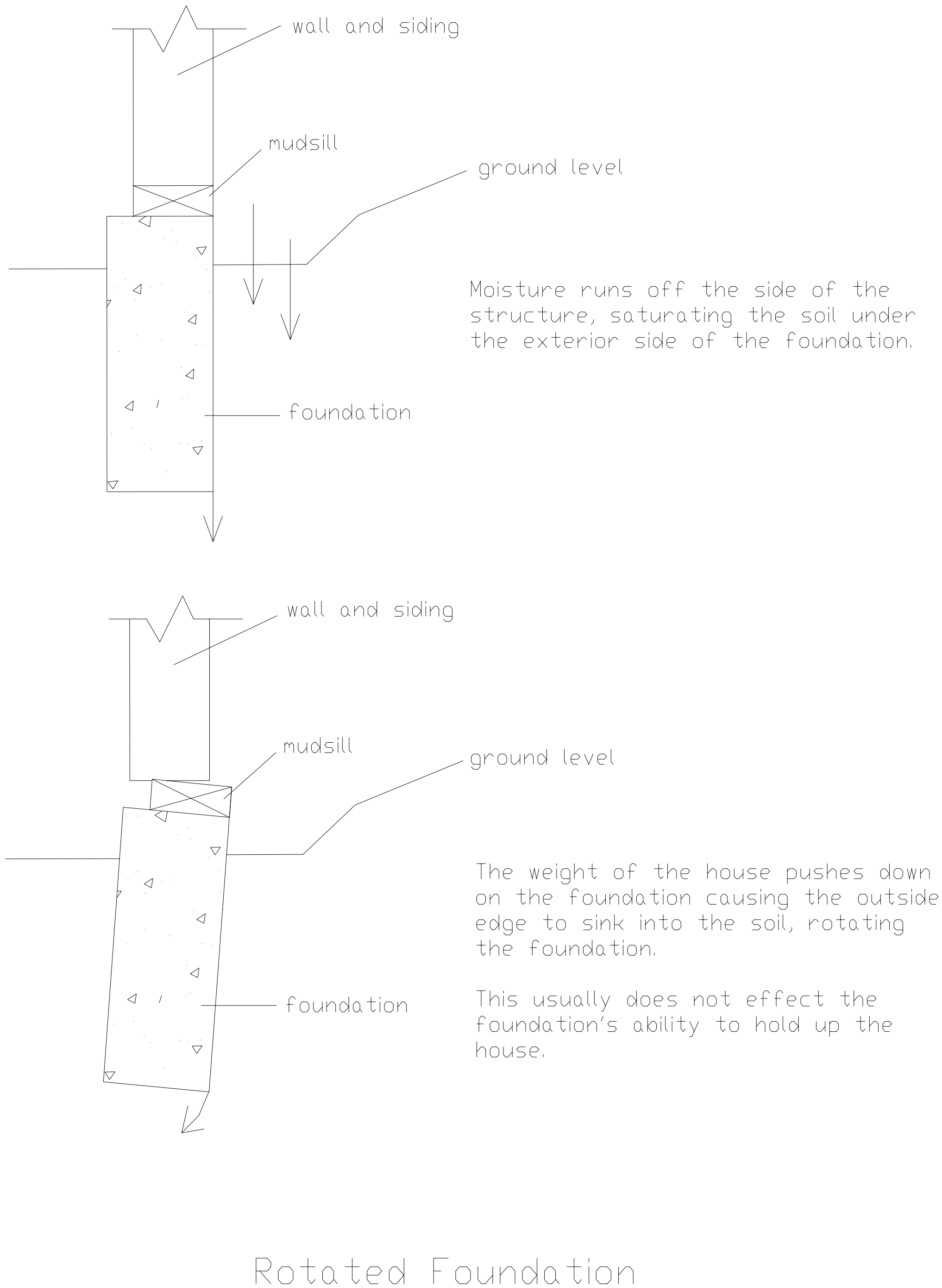

wall and siding
mudsill
ground level
Moisture runs off the side of the structure, saturating the soil under the exterior side of the foundation.
foundation
wall and siding
mudsill
ground level
The weight of the house pushes down on the foundation causing the outside edge to sink into the soil, rotating the foundation.
This usually does not effect the foundation's ability to hold up the house.
foundation
Rotated Foundation

Figure 15

Foundation Capping

Foundation capping refers to the addition of new concrete on the top and one or two sides of an existing foundation and is a common practice in the San Francisco Bay Area. Brick foundations are saddled rather than capped and this means the brick is stabilized by encapsulated it with concrete on the top and two sides. Capping is recommended to homeowner's for various reasons; including lack of rebar in the existing foundation, cracking, rotation of the foundation, and to bring the wood framing on top of the foundation away from the surrounding soil. California Building Code Section 2306.8, requires a minimum clearance of six inches wood that is not resistant to decay.

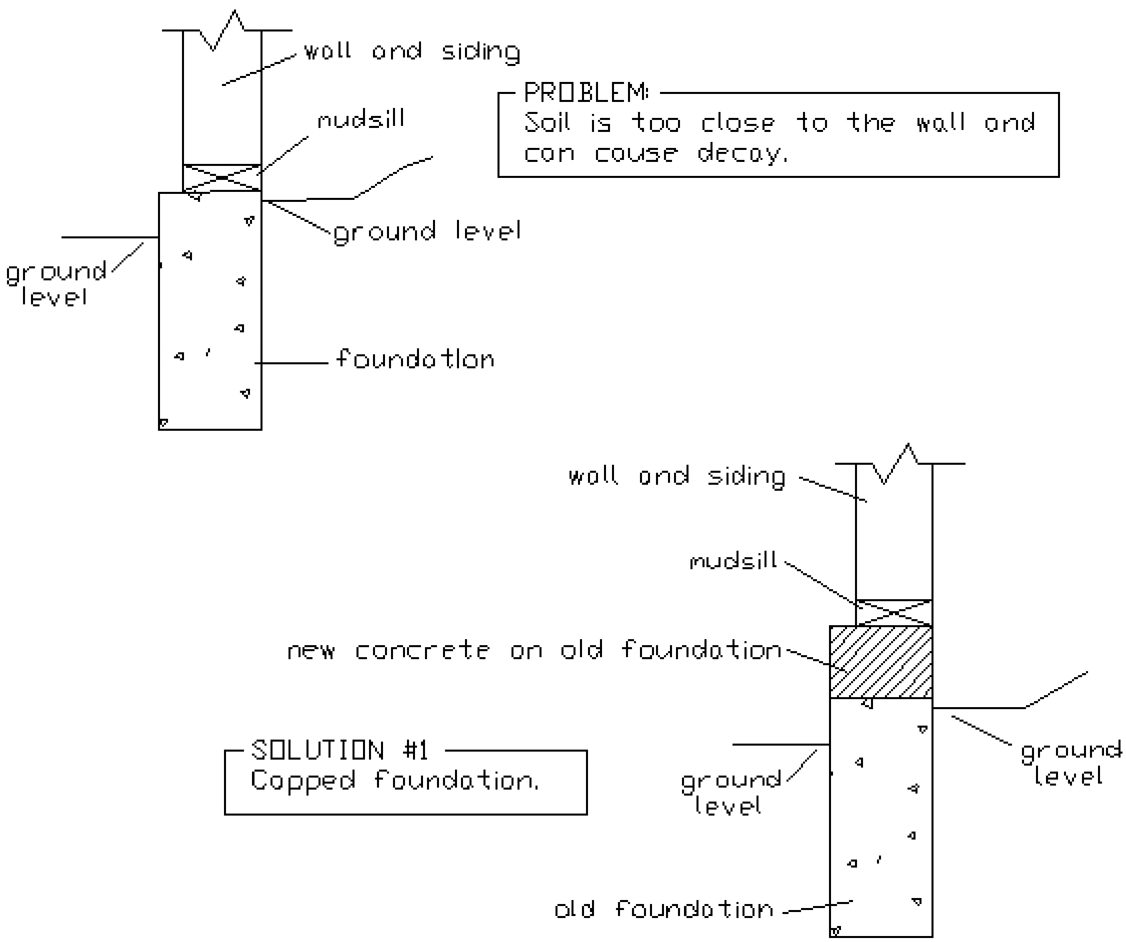


Figure 17

Foundation caps should be installed with horizontal reinforcing steel, vertical steel dowels made of either rebar or threaded rods should used to pin the cap to the old foundation. This is done to prevent the cap from sliding on top of the old foundation in an earthquake. Threaded rods are the preferred method because when the house is retrofitted they can be used as bolts. When examining an existing cap it is impossible to tell if steel reinforcing was installed unless it is seen protruding out of the new concrete or with a pachometer test. A pachometer is a metal detector that senses whether or not steel is in the concrete. Unfortunately, pachometers can only verify whether or not steel is in the concrete; not its size and spacing. In this respect it is very limited because even if it senses reinforcing steel, there is no way to know if it was installed vertically, horizontally, or in both directions. Vertical reinforcing should be visible protruding up through the mudsill and is by far the more important of the two. Steel reinforcing in caps is not required by the building code, and contractors have little incentive to install it when the goal can be achieved without it.

Figure 18

Side view of a foundation cap.

If a retrofit shear wall is built on top of this capped foundation, the cap and old foundation should be pinned together with threaded metal rods. This not only prevents the cap from sliding on the old foundation but on top of the old foundation, but also provides bolts for a future retrofit. Notice how the mudsill is now completely embedded in concrete. This is commonly found in capped foundations. The Nailed Blocking Method discussed earlier is the only method that can be used to provide a surface to nail plywood to.

Capping a foundation is a complex operation that requires a great deal of skill. The floor is supported in the crawl space with cribbing so that when the lower portion of the cripple walls are cut off, the floor is now supported independently of the cripple walls and foundation. . The cripple wall studs can now be cut off to allow room for the new concrete. Forms are then built on top of the foundation which usually extends above the new pressure treated mudsill. After that the forms are filled with concrete, usually embedding the mudsill in concrete as shown in Figure X. Once the concrete cures, the cribbing is removed and the house settles back on top of the foundation cap.
.

Figure 19

End view of a foundation cap

The concrete underneath this cap appears to be in very good condition and the cap was probably unnecessary so long as the two segments of foundation were connected together with long reinforcing rods..

If a brick foundation is capped it is usually saddled. This means the brick is covered on the top, inside, and outside edges. From the outside it appears that the home has a concrete foundation and can be deceiving. To find out if it is saddled brick foundations dig out the soil next to the foundation and see if you find brick.
An alternative to distancing wood from the soil with a foundation cap, it is the much more cost-effective to remove the soil from the wood. This is done by creating an air gap between the house and the soil with plastic PVC pipe and ground contact pressure treated wood. First a narrow trench is dug on the side of the foundation, then short lengths of PVC pipe are pounded into the ground next to the foundation, and then a pressure treated board is installed lengthwise on the outside of the pipes. The pressure treated wood should extend up beyond soil lever an inch or two to keep dirt from falling into the air gap.

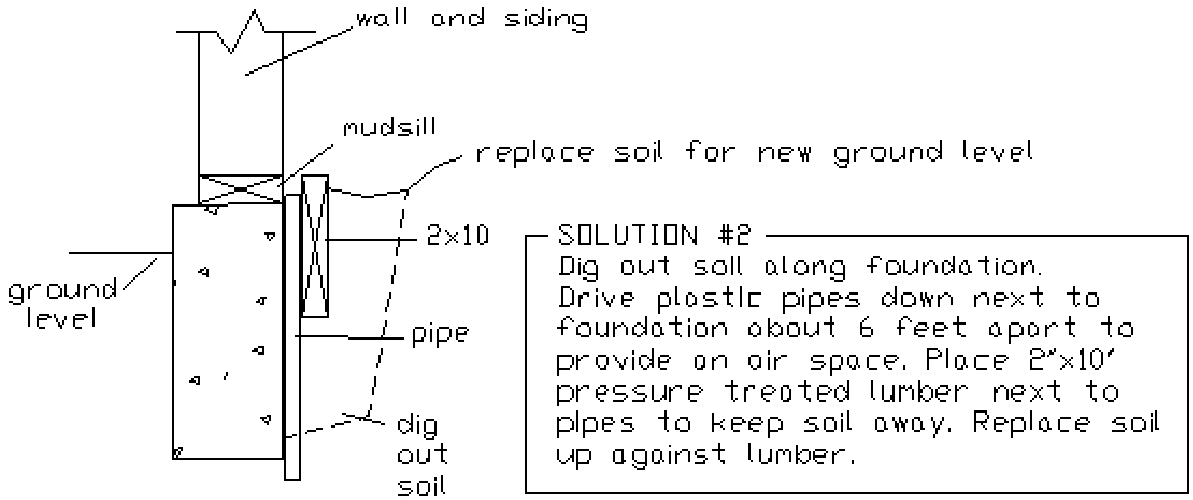


Figure 20

This is a much more cost-effectiveness way of increasing the wood to soil clearance. This technique is used extensively in Northern California.

Capping a foundation is a an expensive and intrusive approach to increasing soil to wood clearance. There are very few circumstances where this expense would be reasonable or necessary. A reasonable reason would be to stabilize a brick foundation. This approach is cheaper than a new foundation and saves on the expense of removing the brick.

The decision to modify an existing building should be based on the ease with which modifications can be made and the likely hazard if modifications are not made. For example, if a building has existed for 80 years without decay or pest damage, it is hard to justify expensive measures such as foundation capping to avoid possible future decay or pest damage; periodic monitoring would make more sense in this case. Whenever possible, clearing soil away from the wood framing is of the quickest, easiest, and cheapest solution to increasing soil to wood clearance. Where clearing the soil is not possible, it may be quite reasonable to do nothing at all if the building has shown no signs of significant decay. Older homes almost always have some minimal wood to soil clearance, but rarely does it meet the 6 inch modern building code requirements. In most cases this distance is sufficient to prevent rot and decay.

Where serious foundation fractures or deterioration have in fact occurred, and a seismic retrofit is being pursued, foundation replacement or capping is rarely the most cost-effective approach. Segments of new foundation should be poured parallel to the old foundation and all retrofit components built on these new foundations. This is far cheaper than replacement or capping the old foundation. Below is an illustration of what this would look like. Shear transfer ties are the same as framing anchors that attach the floor framing to the top plate.

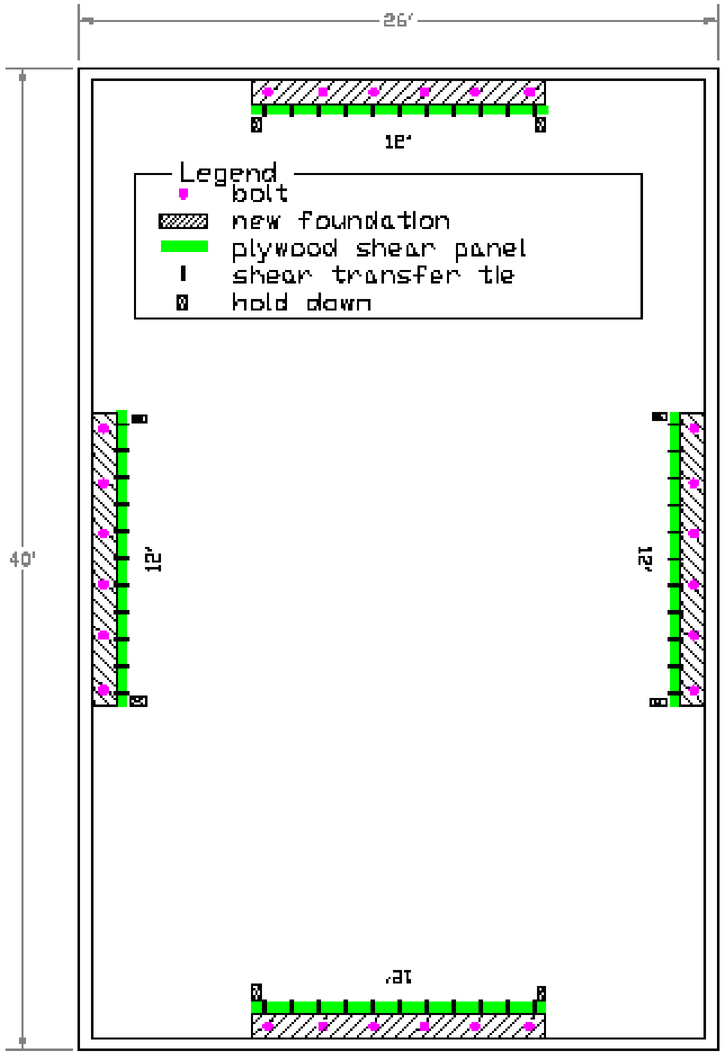
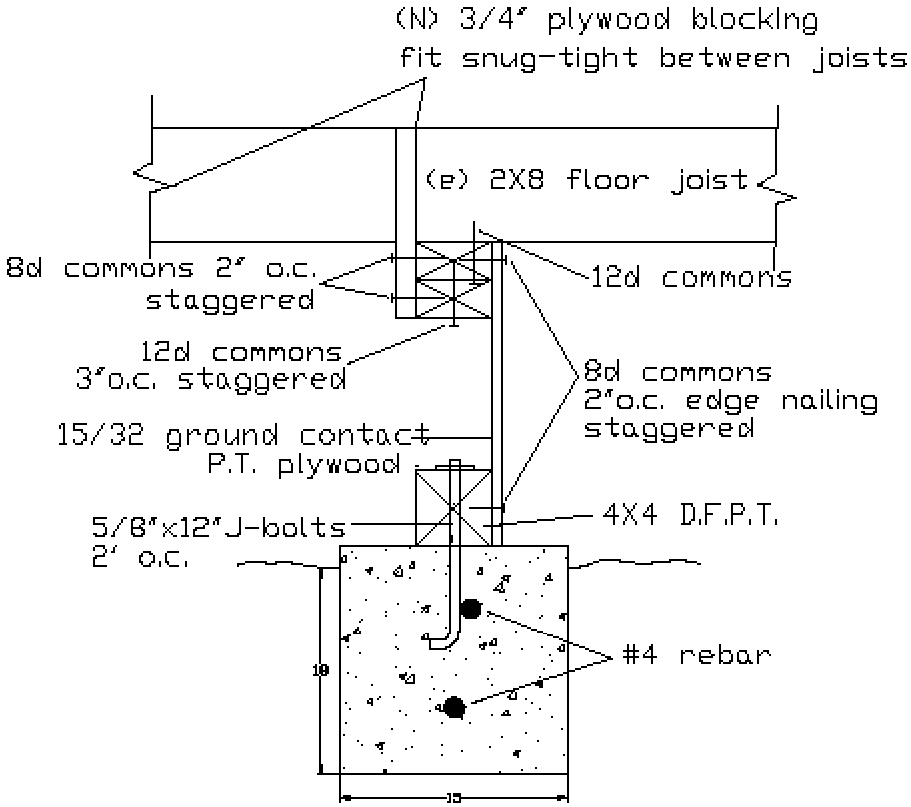


Figure 21

Along the longitudinal walls which are the longer walls on the sides of the house, the foundation is attached to the floor as shown below:

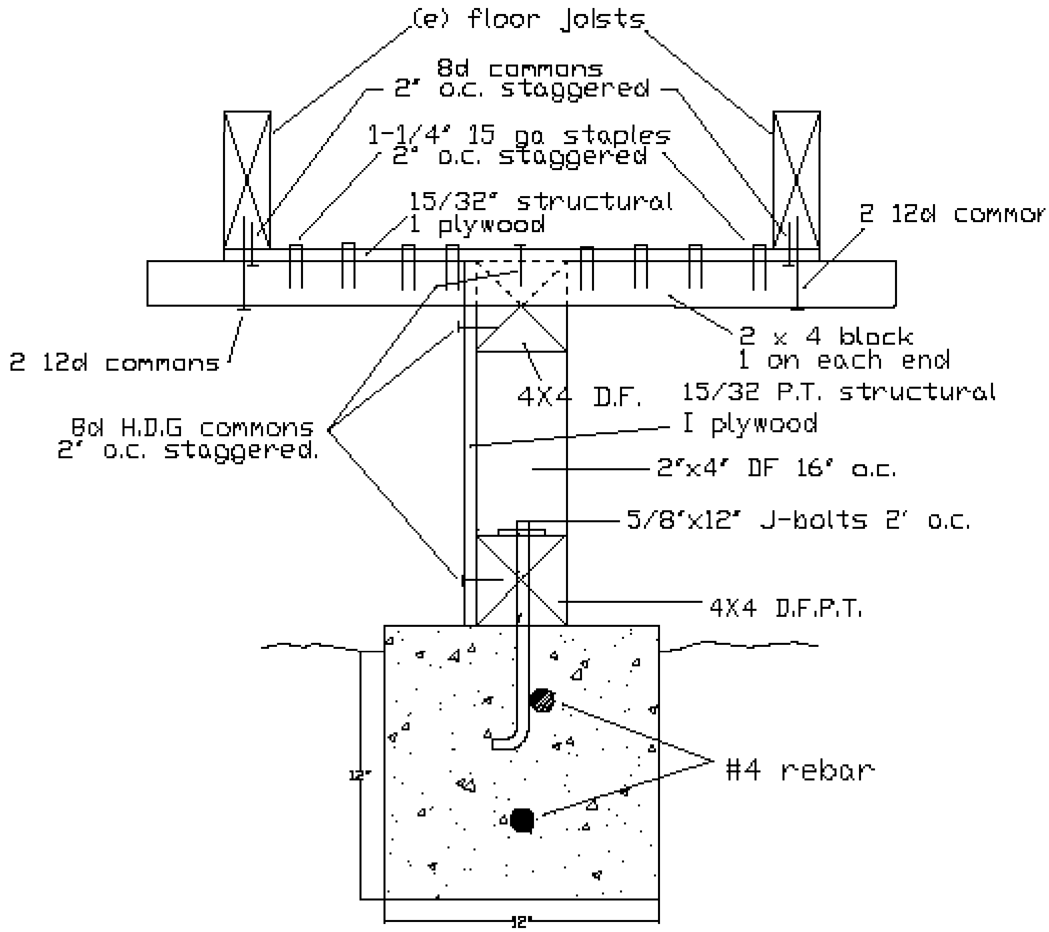


New Footing and Shear Wall
with plywood blocking
(Two Story Building)

Vertical studs installed per U.B.C.
3/4 inch blocks installed between each
joist bay above chear wall.

Figure 22

On the transverse walls, which are located at the front and back of the house, the foundation is attached to the floor as shown on the next page:.



New Footing and Shear Wall
to two joists

(One story building, transverse direction)

Figure 23

At this time there are no guidelines available that address design, sizing, and reinforcing of capped foundations. In the unlikely event foundation capping is deemed necessary, a design should be reviewed by a competent wood frame engineer.. In rare cases where serious damage to an existing foundation appears to be caused by soil conditions, it is may be desirable to consult with a soils engineer.