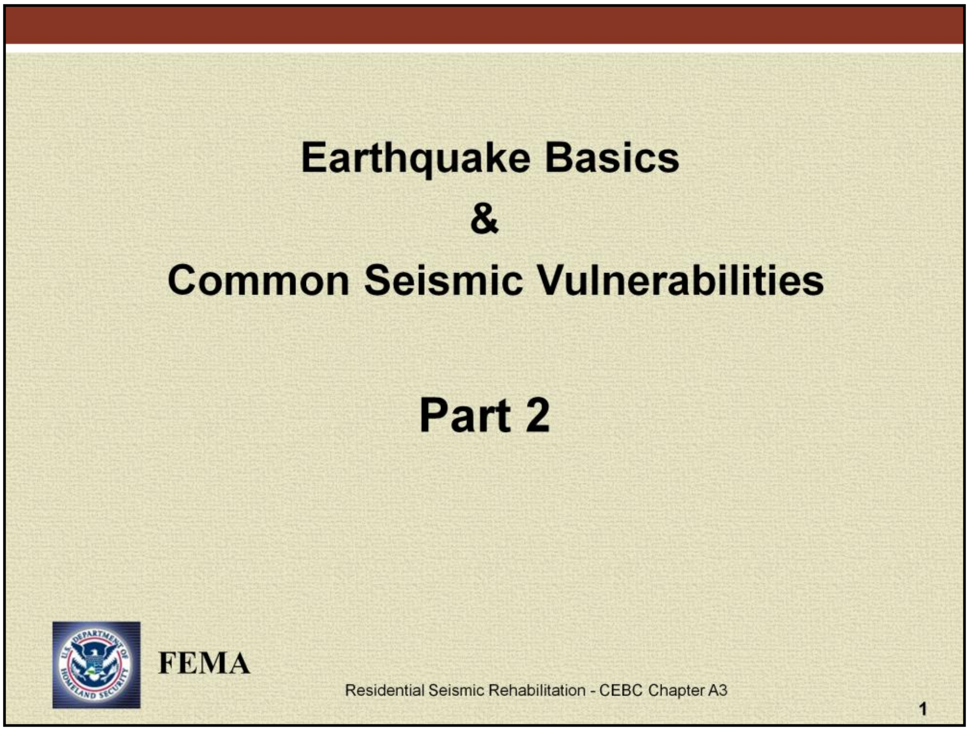
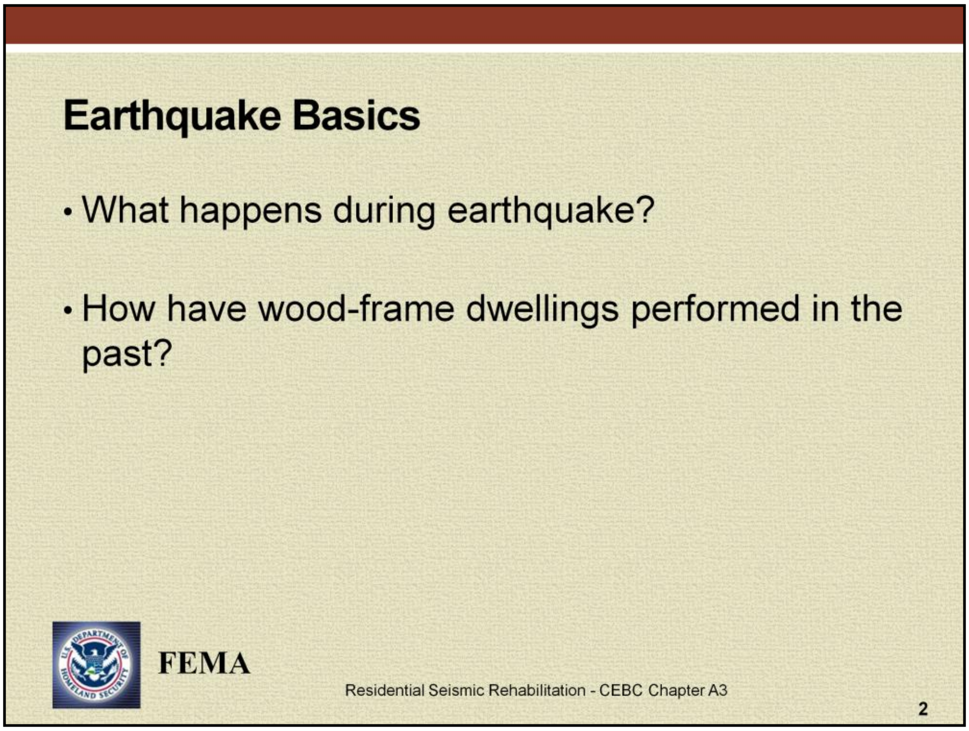


This section gives a basic introduction to earthquakes and the effects of earthquakes on dwellings. The information is geared toward non-technical audiences.

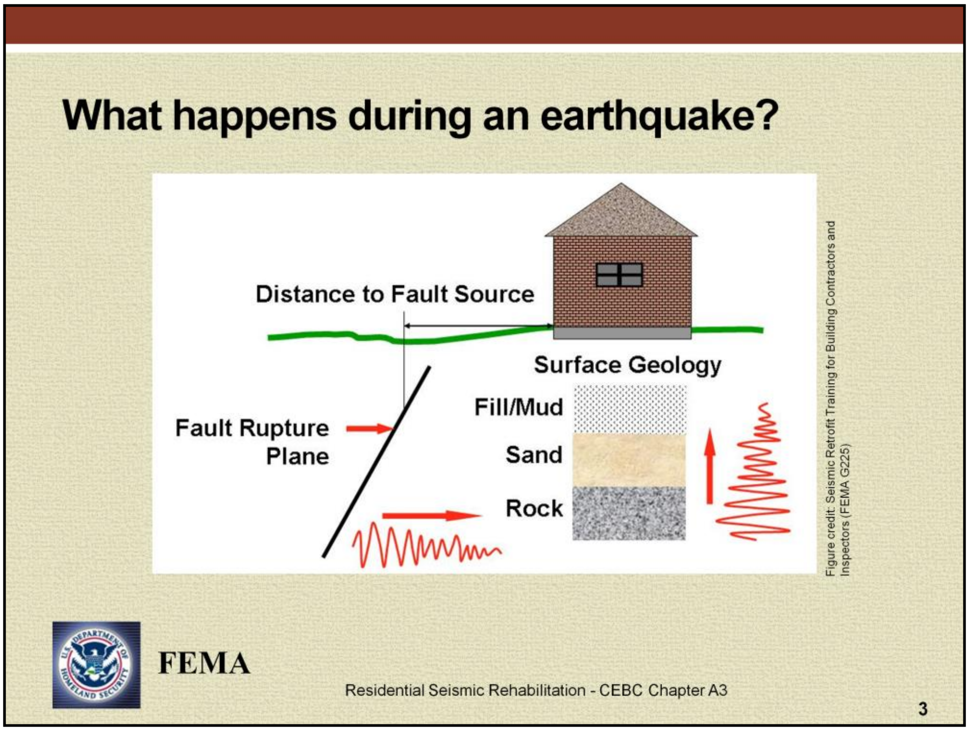
In addition, this section introduces seismic vulnerabilities commonly seen in dwellings. Based on past earthquake experience, these are vulnerabilities that have been repeatedly seen, and therefore considered most likely to occur. Dwellings should be evaluated and potentially rehabilitated for these vulnerabilities.



Part 2 will answer the following questions:

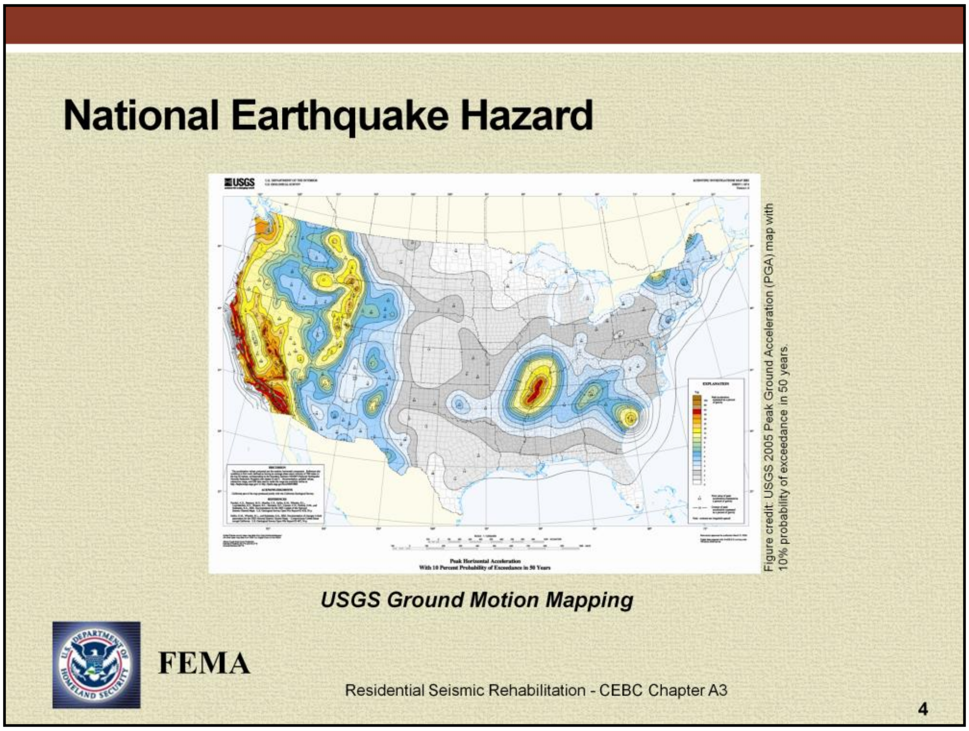
-What happens during an earthquake, and what are the effects of an earthquake on dwellings?

-How have wood-frame dwellings behaved in the past, during earthquakes?



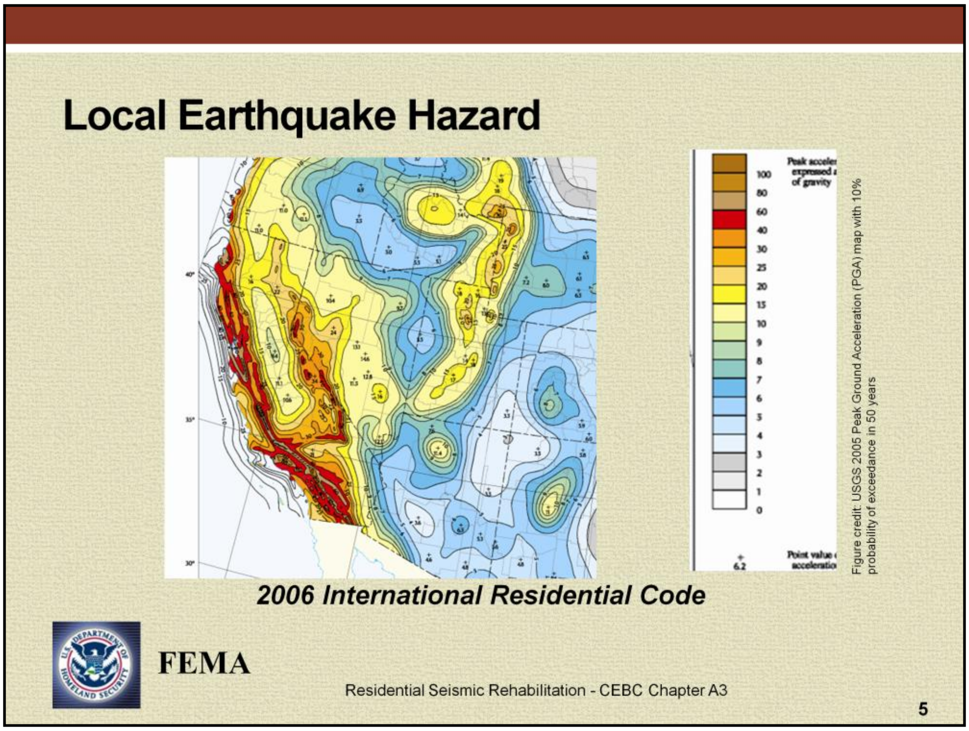
An earthquake starts with the rupture of a fault, which causes the ground to lurch and waves to move through the soils like ripples in a pond. The earthquake ground shaking at any particular building site can vary greatly, depending on factors that include: the distance to the fault, the length of the fault rupture, and the type of soils below the building. Earthquake design codes take into account these effects on ground shaking, using the best available estimates of the many factors.

Figure credit: Seismic Retrofit Training for Building Contractors and Inspectors (FEMA G225)



Earthquake hazard maps, such as this one developed by United States Geological Survey, USGS, illustrate regional levels of seismic hazard. Red areas are the location of highest seismic hazard; white are the lowest.

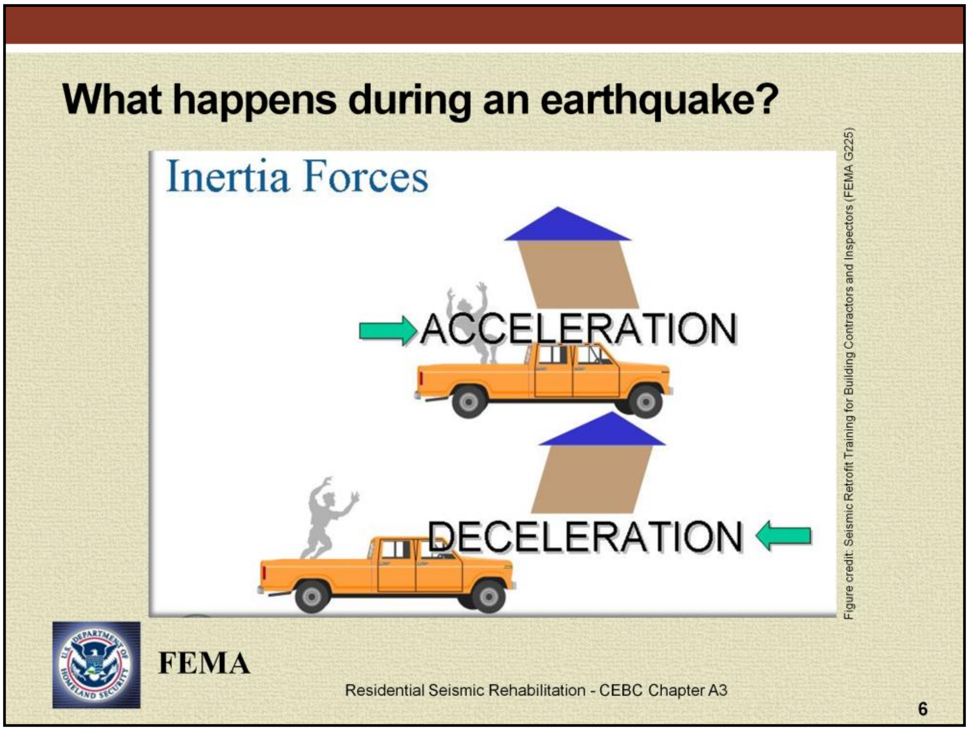
Figure credit: USGS 2005 Peak Ground Acceleration (PGA) map with 10% probability of exceedance in 50 years.



This is a close up of California in the earthquake hazard map from the USGS. Seismic hazard is high in the area shown. This makes seismic rehabilitation of high importance throughout the area.

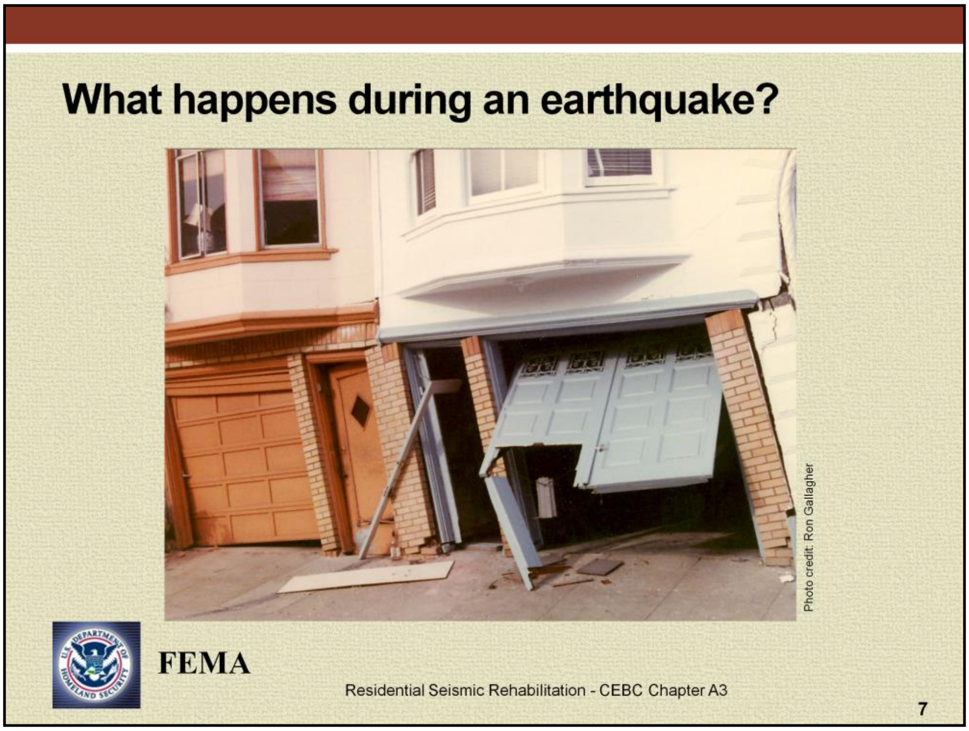
Because the ground motion from each earthquake is unique, a dwelling that has survived past earthquakes is NOT NECESSARILY OK for future earthquakes. The vulnerability of each existing dwelling should be evaluated.

Figure credit: USGS 2005 Peak Ground Acceleration (PGA) map with 10% probability of exceedance in 50 years



When earthquake waves reach the soils under a dwelling, they cause that dwelling to accelerate and decelerate in a series of sudden steps, similar to the sudden starting and stopping of a car. Just like the passenger in a car, the dwelling will lurch back and forth as a result.

Figure credit: Seismic Retrofit Training for Building Contractors and Inspectors (FEMA G225)

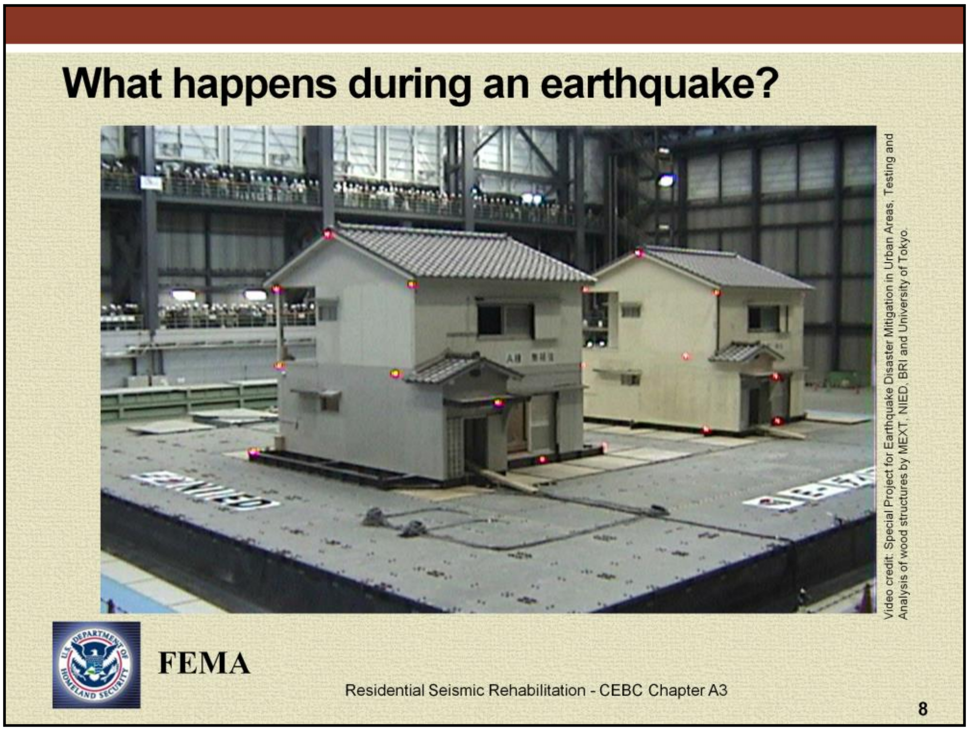


The lurching of the dwelling results in loads and deformations in the dwelling.

Loads and deformations result in:

-Damage to finishes
-Structural damage
-Possible partial or full collapse

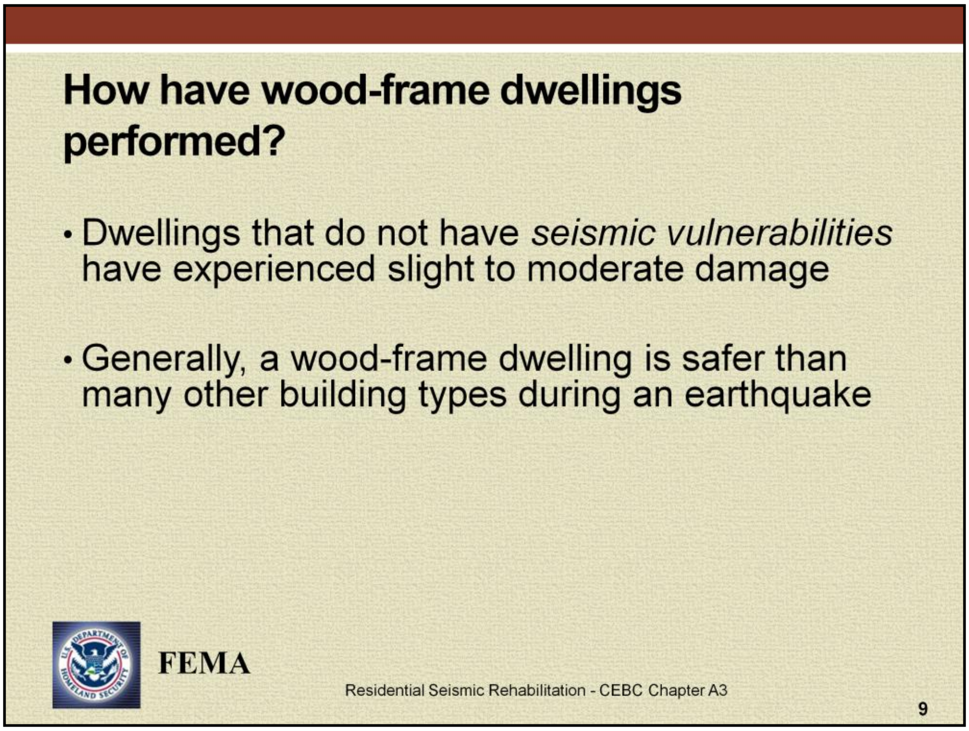
Photo credit: Ron Gallagher



This video is of a two full-scale houses being tested on a Japanese earthquake shake table. A shake table simulates the ground shaking that occurs during an earthquake.

The video illustrates improved performance due to moderate seismic rehabilitation measures. The two buildings shown represent common Japanese residential construction. Both buildings were occupied as residences prior to being purchased and transported to the shake table facility. One of the buildings was not modified, while the other has a moderate level of seismic rehabilitation. The buildings were subjected to seismic ground motions based on the 1995 Kobe Earthquake. The building with moderate seismic rehabilitation stands up through the ground motion, while the other does not. As is seen in this video, the goal of this training is to provide information on moderate seismic rehabilitation measures that can greatly improve building performance.

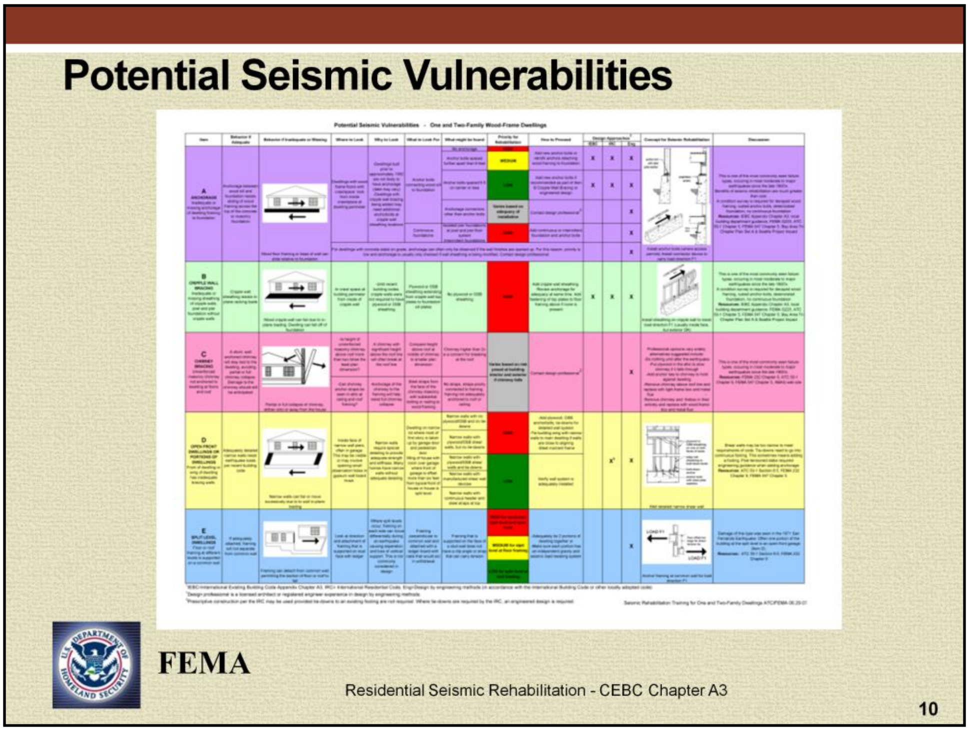
Video credit: Special Project for Earthquake Disaster Mitigation in Urban Areas, Testing and Analysis of wood structures by MEXT, NIED, BRI and University of Tokyo.



In terms of threat to life, performance during past earthquakes has shown that one- or two-family wood-frame dwellings are generally safer than other building types.

In earthquakes to date, slight to moderate damage has been seen in areas of strong ground shaking. In particular, wall finishes and sheathing have been widely damaged.

It should be anticipated that all buildings will require repair, including those that have had seismic rehabilitation and those buildings without vulnerable characteristics!



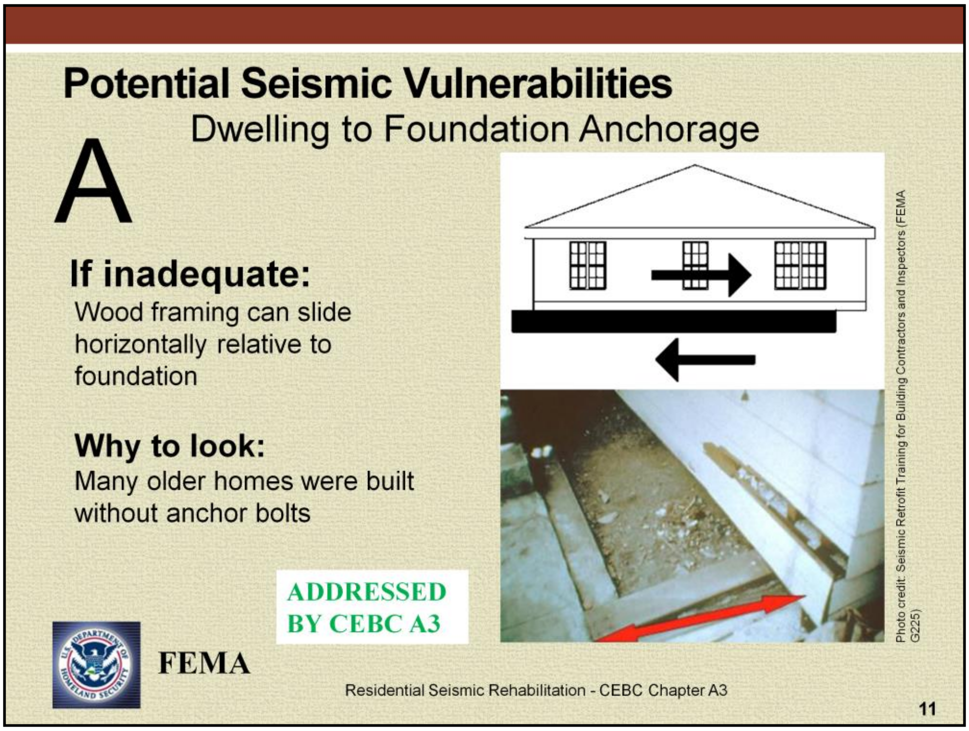
The rest of Part 2 will introduce 11 potential seismic vulnerabilities in wood-frame dwellings, noted as A to K . The audience can follow with the 11x17 picture card or these notes.

For each of these seismic vulnerabilities, the vulnerabilities card provides information on

- What to look for
- Rehabilitation priority
- Rehabilitation concept
- Resources for rehabilitation design

CEBC Chapter A3 provides prescriptive rehabilitation measures for some of the described vulnerabilities. Evaluation and rehabilitation design by an engineer or architect is required for other described vulnerabilities.

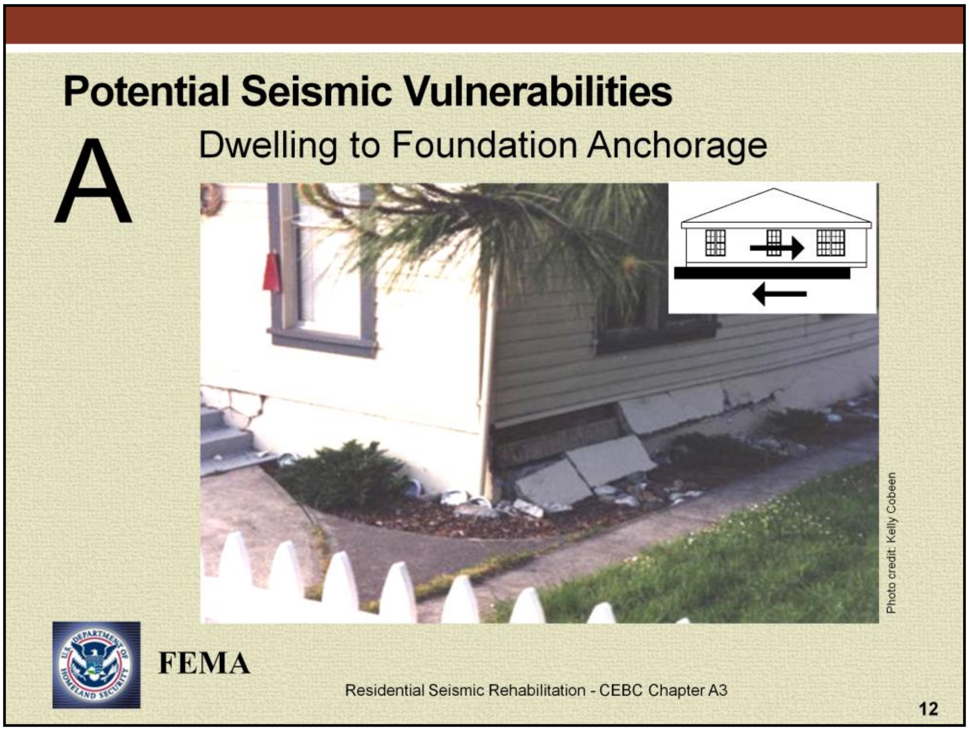
While these items address common seismic vulnerabilities, other vulnerabilities might sometimes be identified, particularly in complex and unusual building configurations.



Dwellings that slide off of their foundations due to lack of anchorage to the foundation have been very commonly seen in moderate to major earthquakes. Many older buildings were constructed without anchor bolts, or have too few or inadequately installed bolts. On the west coast anchor bolts became common in approximately the 1950's. This date may vary locally and regionally.

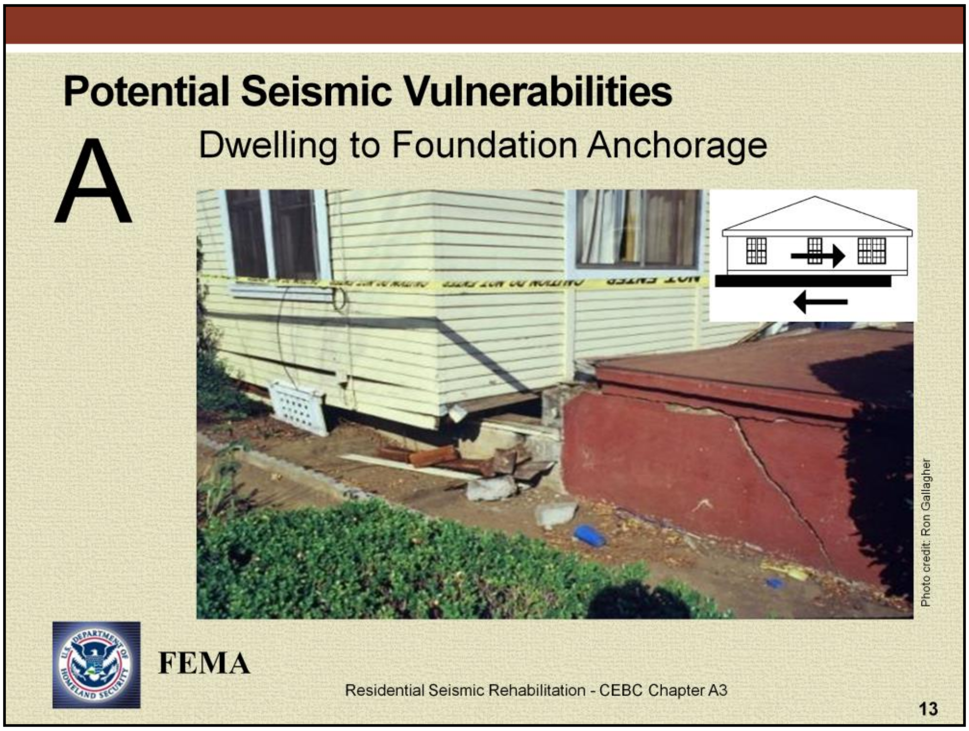
Rehabilitation of anchorage is a high priority because it provides a very large earthquake bracing improvement at a very small cost. Rehabilitation of this vulnerability is addressed by CEBC Chapter A3.

Photo credit: Seismic Retrofit Training for Building Contractors and Inspectors (FEMA G225)



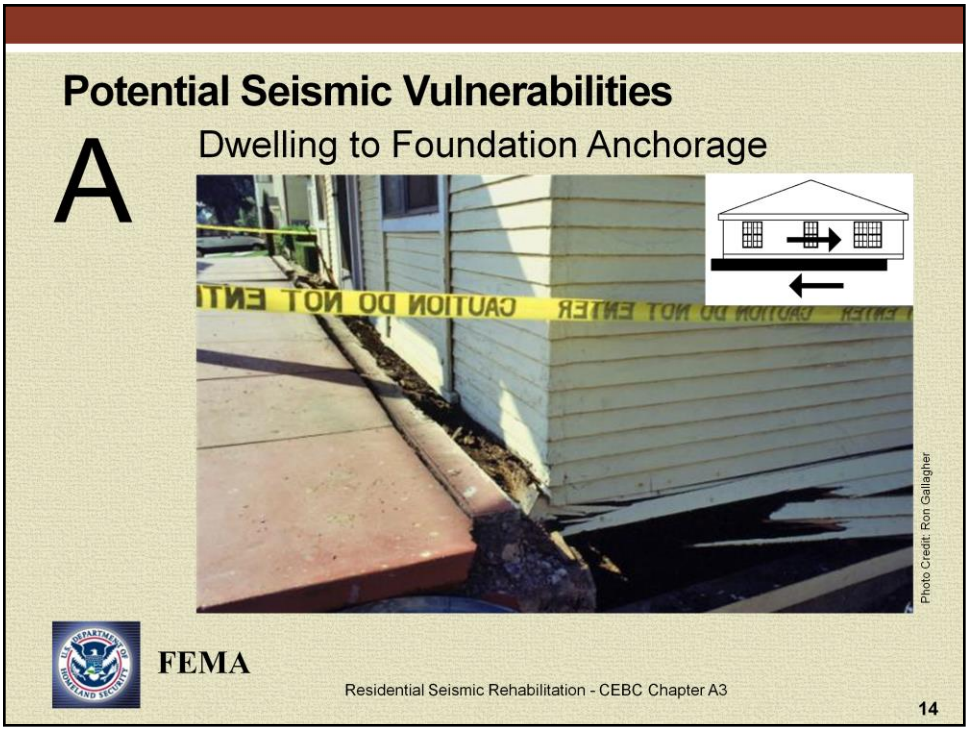
House slid on its foundation – Cape Mendocino Earthquake

Photo credit: Kelly Cobeen



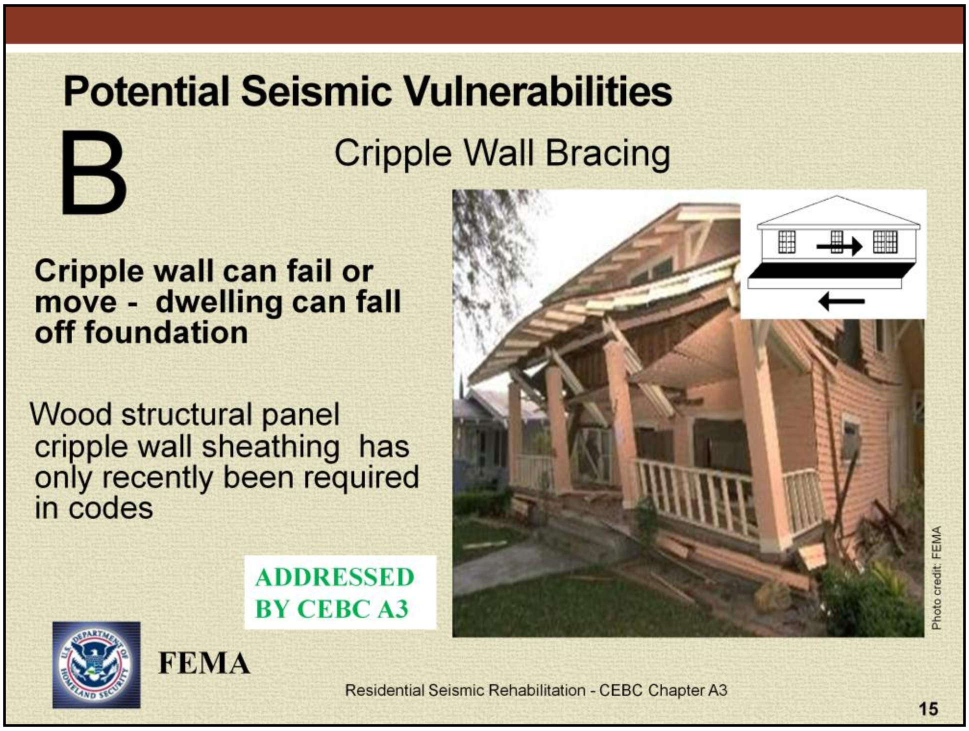
House slid on its foundation

Photo credit: Ron Gallagher



House slid on its foundation

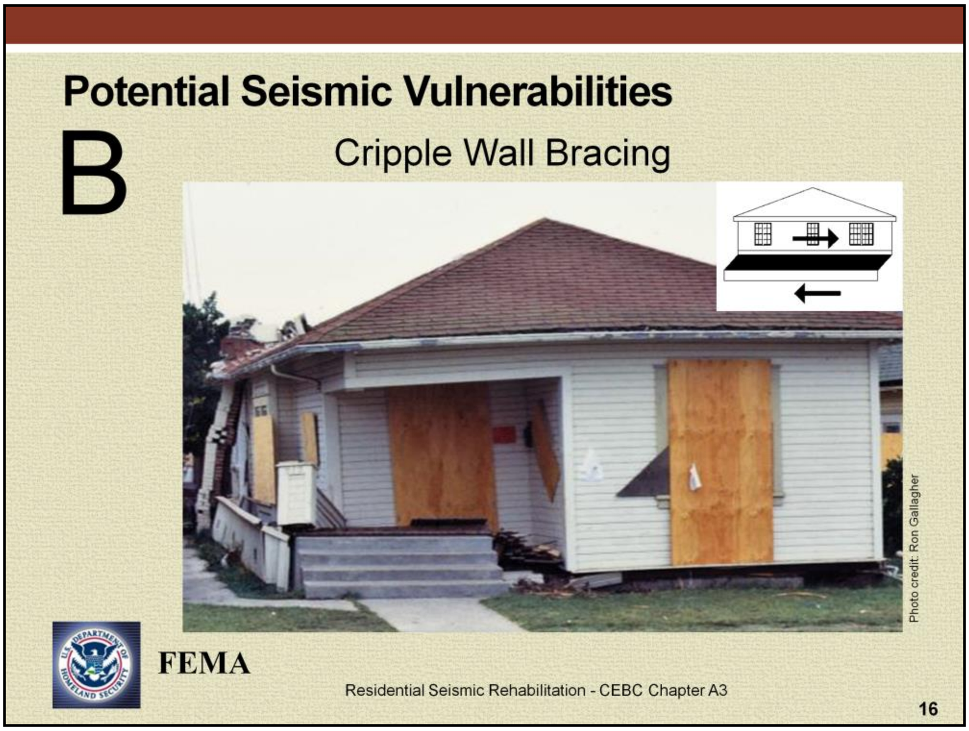
Photo Credit: Ron Gallagher



A cripple wall is a partial height wall that extends from the foundation to the first framed floor. Cripple walls generally enclose crawlspaces, but are also found in partial basements. Cripple wall failures have been very commonly seen in moderate to major earthquakes. Building codes for new dwellings now require use of plywood or OSB sheathing for cripple wall bracing in areas of high seismic hazard; however this requirement is very recent and many existing buildings are braced with other materials that do not perform as well in earthquakes.

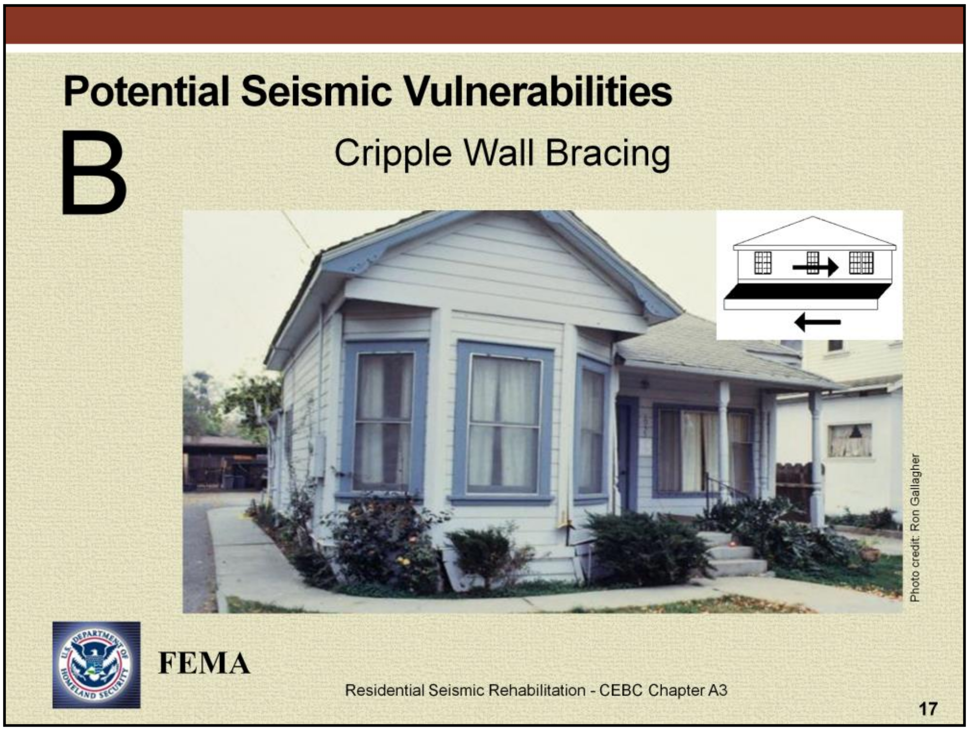
Rehabilitation of cripple walls is a high priority because it provides a very large earthquake bracing improvement at a small cost. Rehabilitation of this vulnerability is addressed by CEBC Chapter A3.

Photo credit: FEMA



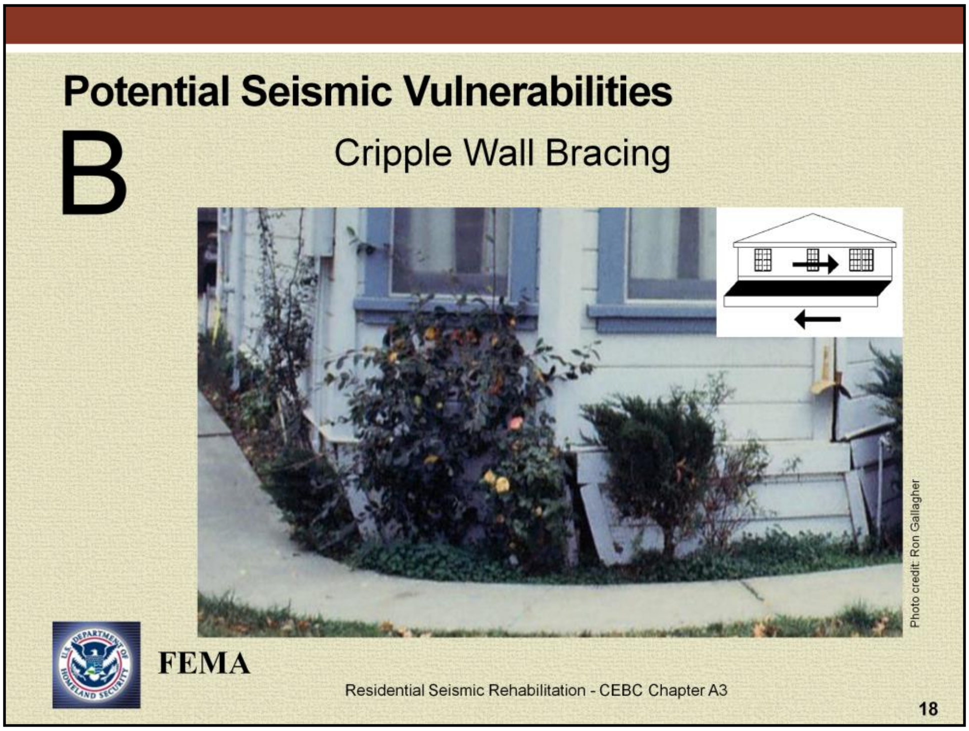
This dwelling fell off of its cripple walls and shifted to the right. The cripple walls are still vertical at the left side of the photo. The gap between the porch steps the porch wall shows how far horizontally the dwelling moved.

Photo credit: Ron Gallagher



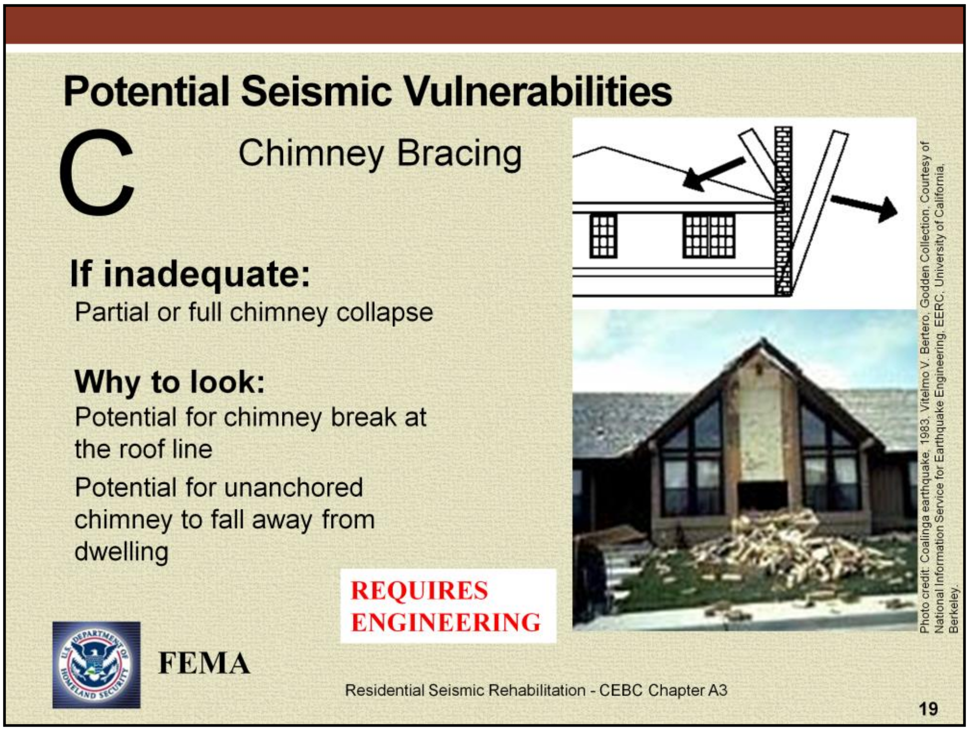
This dwelling has shifted significantly left on its cripple walls, as can be seen by the gaps and lean of the cripple wall fascia boards. This dwelling is near collapse, but has not yet collapsed.

Photo credit: Ron Gallagher



Close up from previous photo. Note lean of cripple walls.

Photo credit: Ron Gallagher

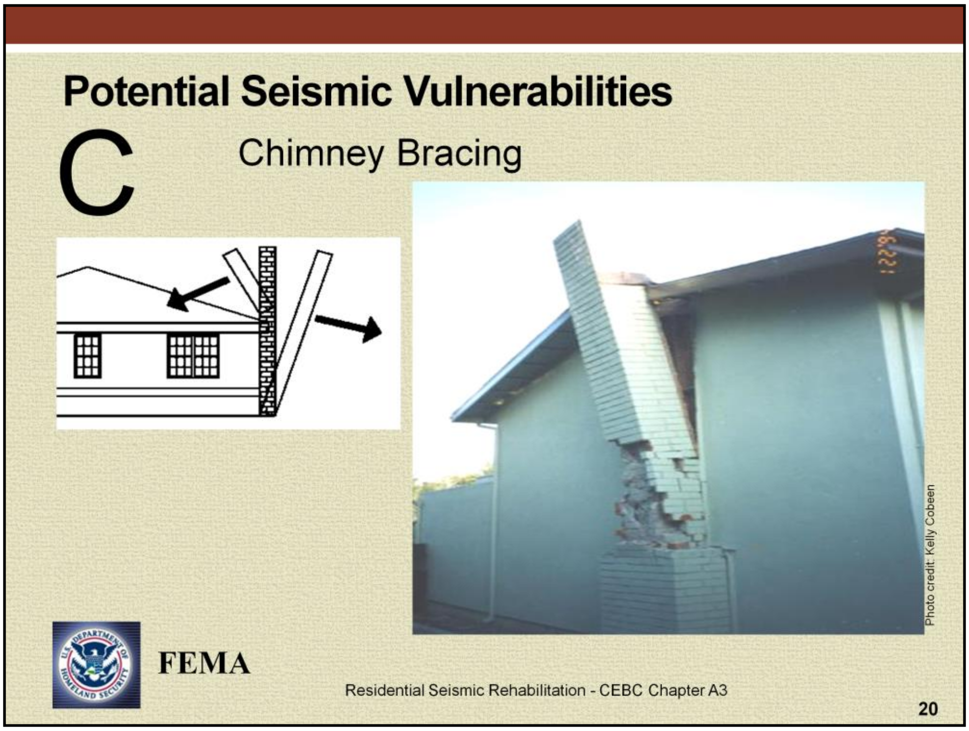


Damage to masonry chimneys is the most common damage seen in moderate to major earthquakes. Chimney construction is significantly stiffer that wood dwellings, and unreinforced masonry chimneys are brittle. Chimneys often fracture at the roof line, but may also fracture further down or completely collapse as seen in the photo.

When chimneys fracture, portions of the chimney can fall either towards or away from the dwelling, causing a local falling hazard. The severity of the hazard can vary significantly depending on the size and anchorage of the chimney and how surrounding areas are used.

The priority for chimney rehabilitation varies greatly depending on the risk posed by chimney damage. Rehabilitation of chimney bracing requires an engineered design.

Photo credit: Coalinga earthquake, 1983, Vitelmo V. Bertero, Godden Collection, Courtesy of National Information Service for Earthquake Engineering, EERC, University of California, Berkeley.



This brick chimney, damaged in the Northridge earthquake, is leaning significantly, and may collapse further on its own or with an earthquake aftershock.

Photo credit: Kelly Cobeen

Potential Seismic Vulnerabilities

C

Chimney Bracing

Photo credit: Ron Gallagher

FEMA

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This chimney collapse broke through the porch roof, showing the significant hazard that can occur.

Photo credit: Ron Gallagher

Potential Seismic Vulnerabilities

C

Chimney Bracing

Photo credit: Ron Gallagher

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This chimney collapse also collapsed the porch roof, again showing the significant hazard that can occur.

Photo credit: Ron Gallagher

Potential Seismic Vulnerabilities

D

Open Front Dwellings or Portions

If inadequate:
Narrow walls can fail or move excessively

Why to look:
Until recent building codes it was not common to give attention to design and detailing of narrow walls

REQUIRES ENGINEERING

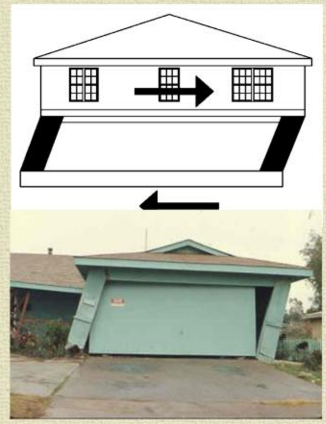

Photo credit: William Holmes

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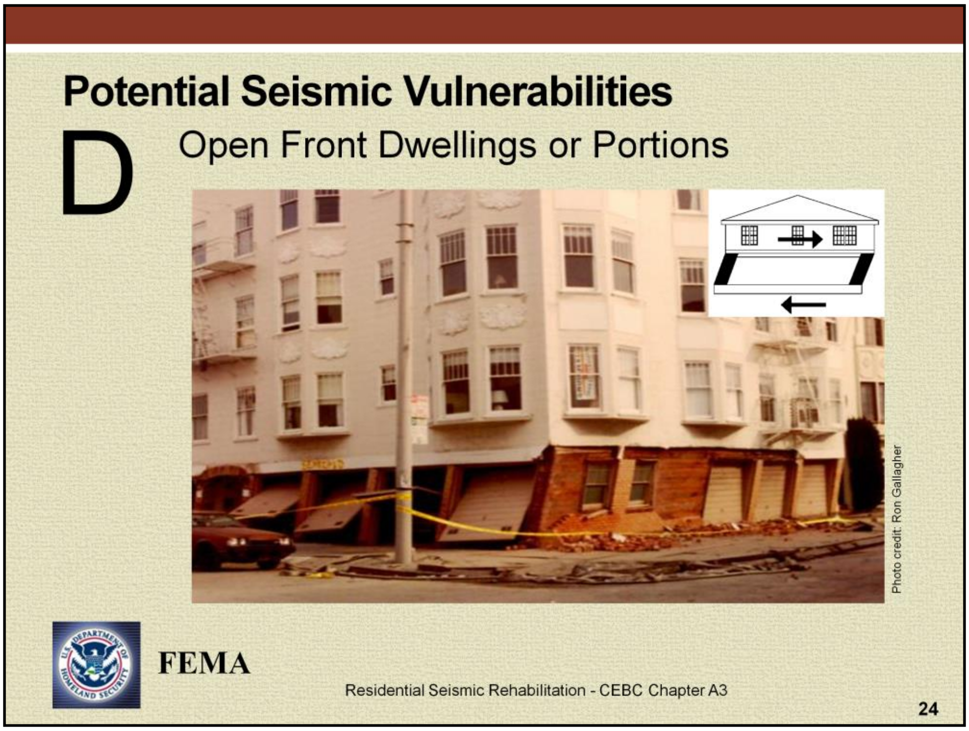
It is fairly common to see dwellings or portions of dwellings with little or no bracing wall at the front, as in the photo above. Where little or no bracing occurs, the dwelling front can move excessively or fail, due to in-plane loading during earthquakes.

If built under recent building codes the narrow walls would be anticipated to have special detailing to increase strength and stillness, or special manufactured wall segments might be installed. This special attention to narrow front walls has only become required in recent building codes, so many older dwellings have vulnerable front walls (this condition is called open front or soft-story).

Rehabilitation of open-front dwellings is a high priority, particularly where the open front occurs in a lower story with one or more stories above. Rehabilitation of an open-front dwelling generally requires an engineered design, although some prescriptive design guidance is available.

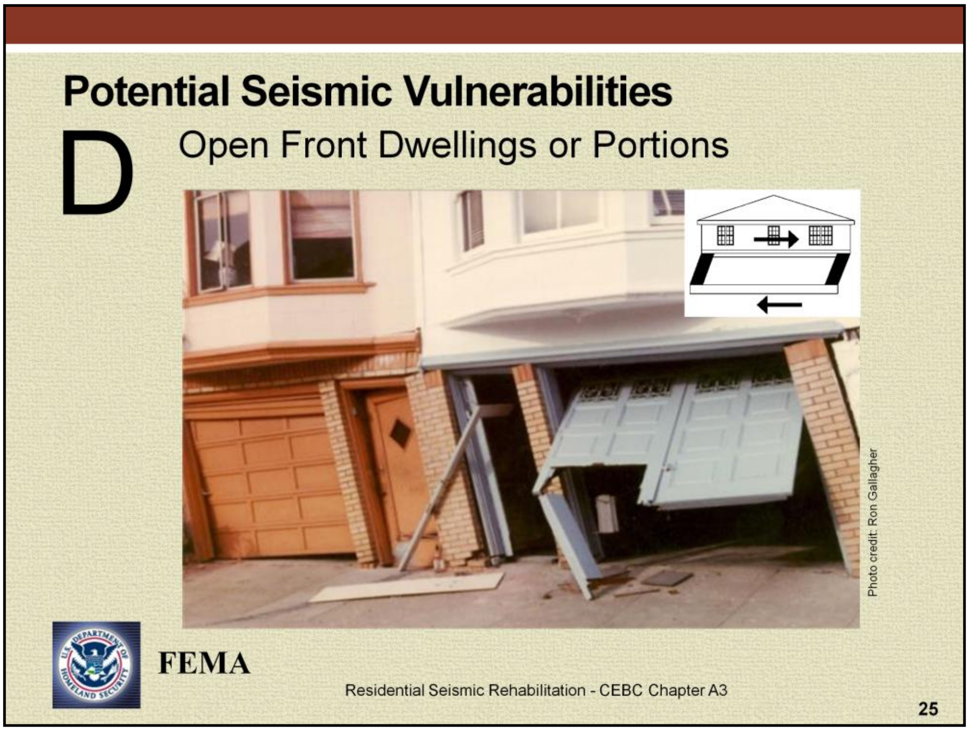
Photo credit: William Holmes



This open-front apartment building was well on its way to collapse in the 1989 Loma Prieta Earthquake. With so many garage doors, little wall was available for bracing.

Note that this is a large multi-family building, shown because it illustrates the type of behavior being discussed. The failure seen in this multi-family building is likely more critical than for a one- to four-family dwelling.

Photo credit: Ron Gallagher



Open front collapses and near collapses have also occurred in single-family dwellings. This home was damaged in the Loma Prieta Earthquake.

Photo credit: Ron Gallagher

Potential Seismic Vulnerabilities

D
Open Front Dwellings or Portions

Photo credit: Ron Gallagher

FEMA

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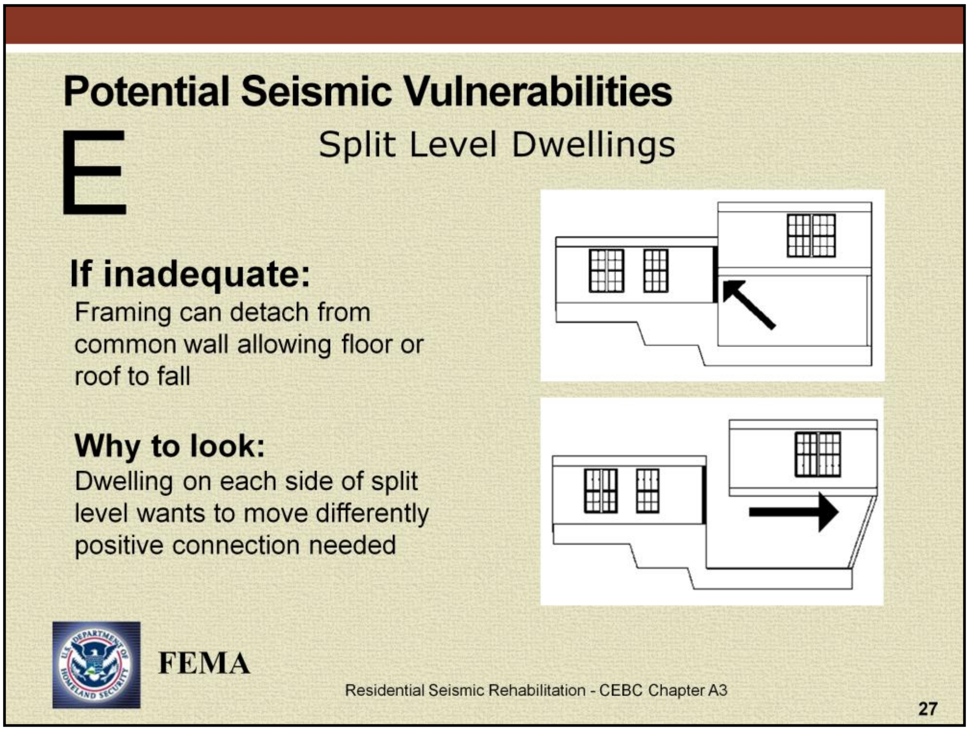
Open front collapses and near collapses have also occurred in single-family dwellings. Loma Prieta Earthquake.

Photo credit: Ron Gallagher

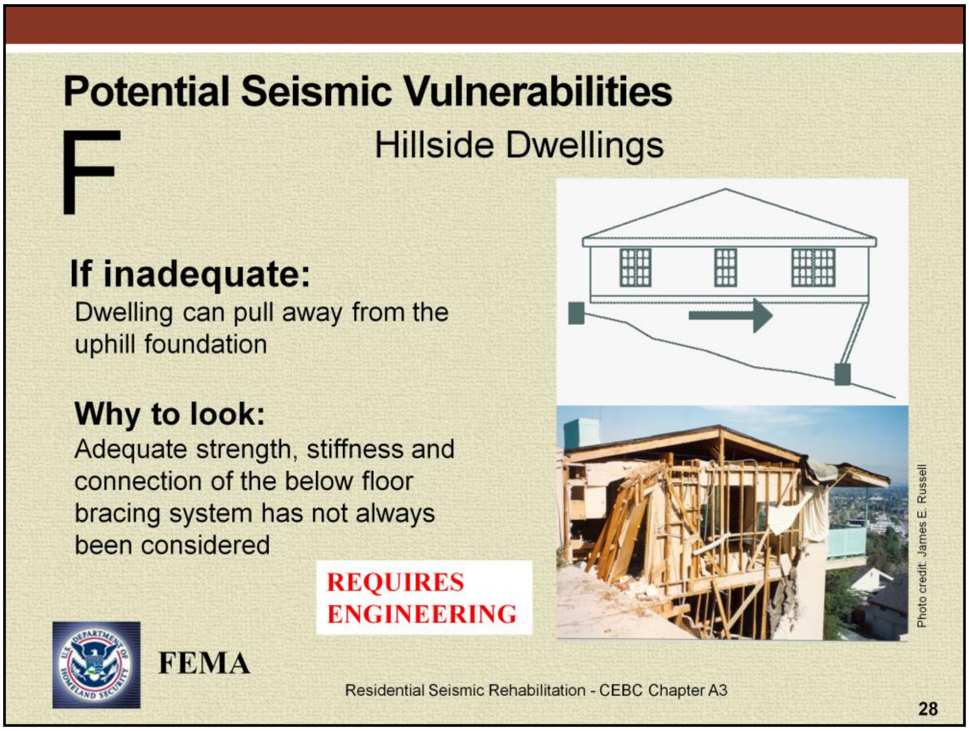


A dwelling is considered split level when the floor level varies between portions of the dwelling enough that direct ties between floor members are not possible. Significant damage occurred to split level homes in the 1971 San Fernando Earthquake, including partial collapse. Many of the damaged dwellings had a combination of an open front dwelling wing and split-level construction.

This vulnerability occurs because the portions of the dwelling on each side of the split move differentially under earthquake loading. If the portions are able to separate from each other,

collapse is possible.

The priority for split-level rehabilitation varies based on the dwelling configuration. Rehabilitation of split-level dwellings requires engineered design.

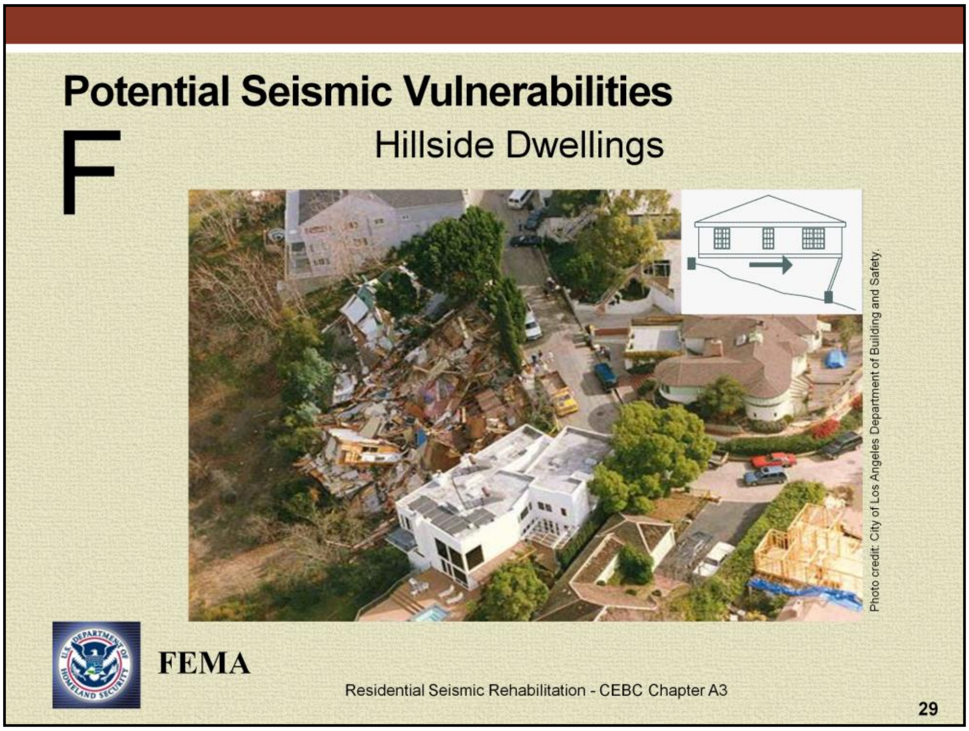


Hillside dwellings were found to be vulnerable in the 1994 Northridge Earthquake where a handful of complete collapses occurred. The failures occur when the dwelling is pulled away from the uphill foundation.

It is important to look for this vulnerability because most hillside dwellings have not been designed or evaluated with this type of behavior in mind.

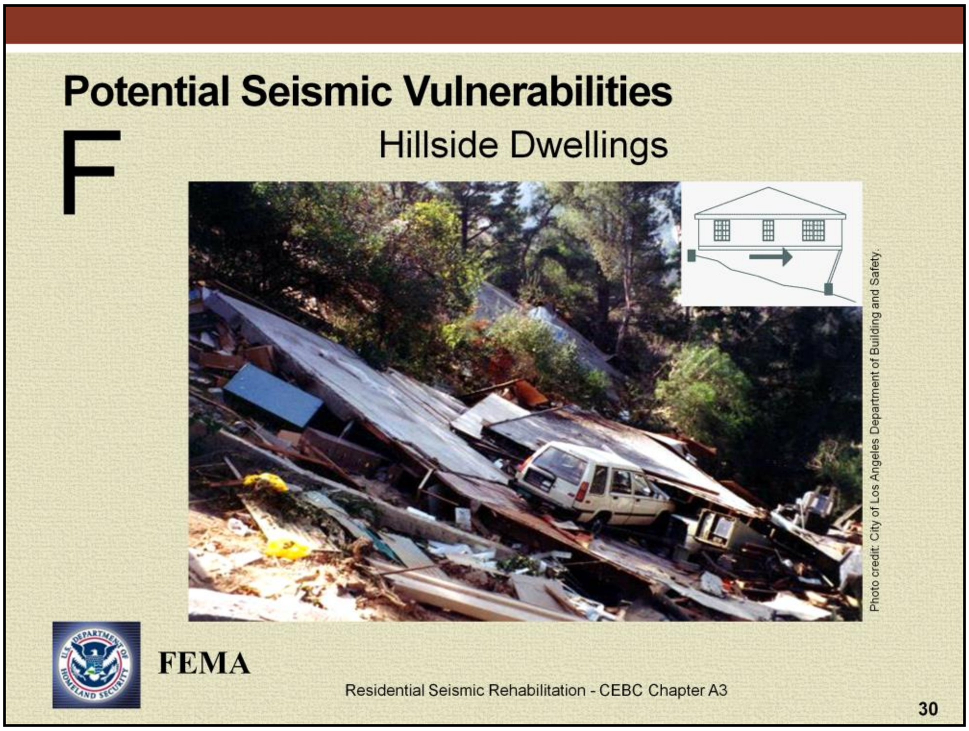
Seismic rehabilitation of hillside dwellings is a high priority. Rehabilitation measures for hillside dwellings require an engineered design because the existing building configurations vary widely, and prescriptive rehabilitation measures have not yet been developed.

Photo credit: James E. Russell



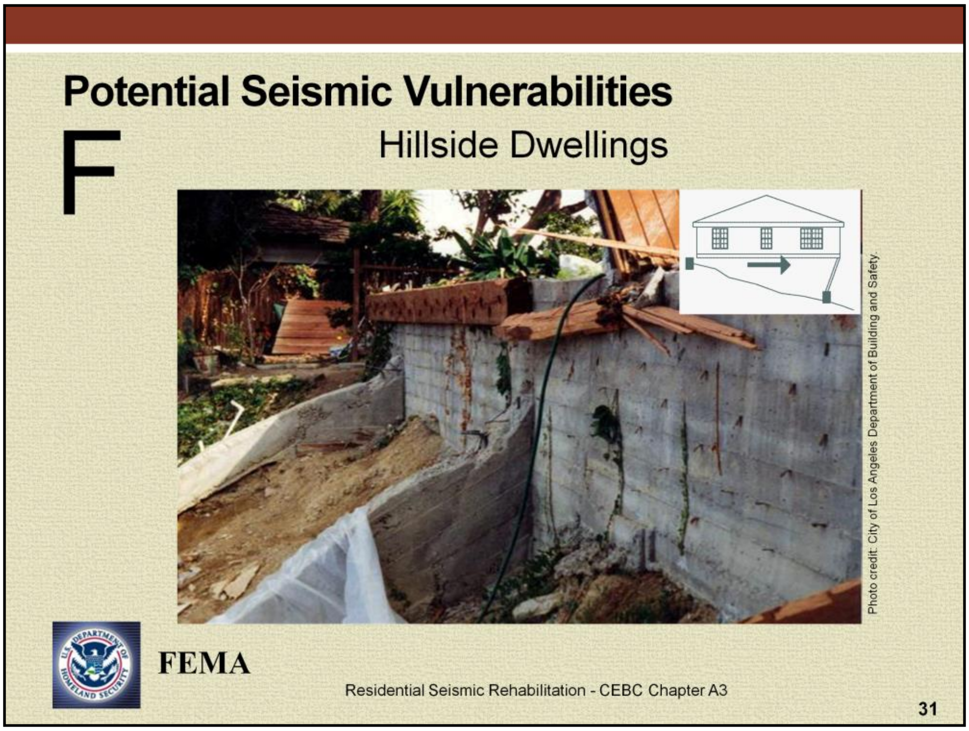
This is an aerial view of a hillside dwelling that collapsed during the 1994 Northridge Earthquake. The dwelling is in the very center of this photograph, but there is no recognizable roof structure, while walls and roofs are recognizable in dwellings on either side.

Photo credit: City of Los Angeles Department of Building and Safety.



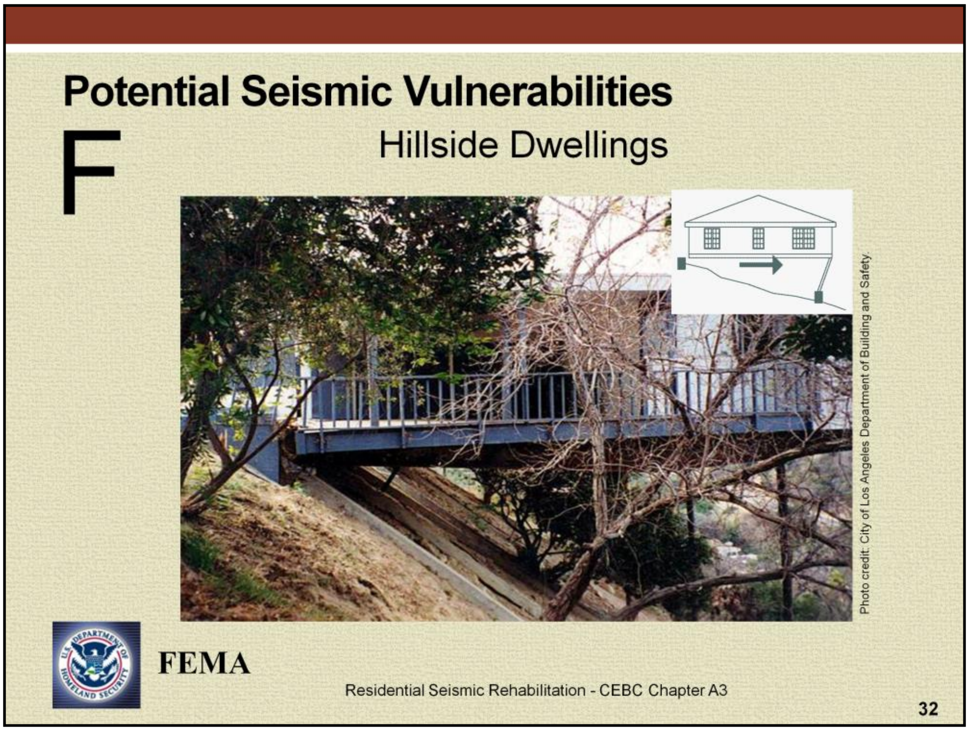
This is one portion of the collapsed dwelling.

Photo credit: City of Los Angeles Department of Building and Safety.



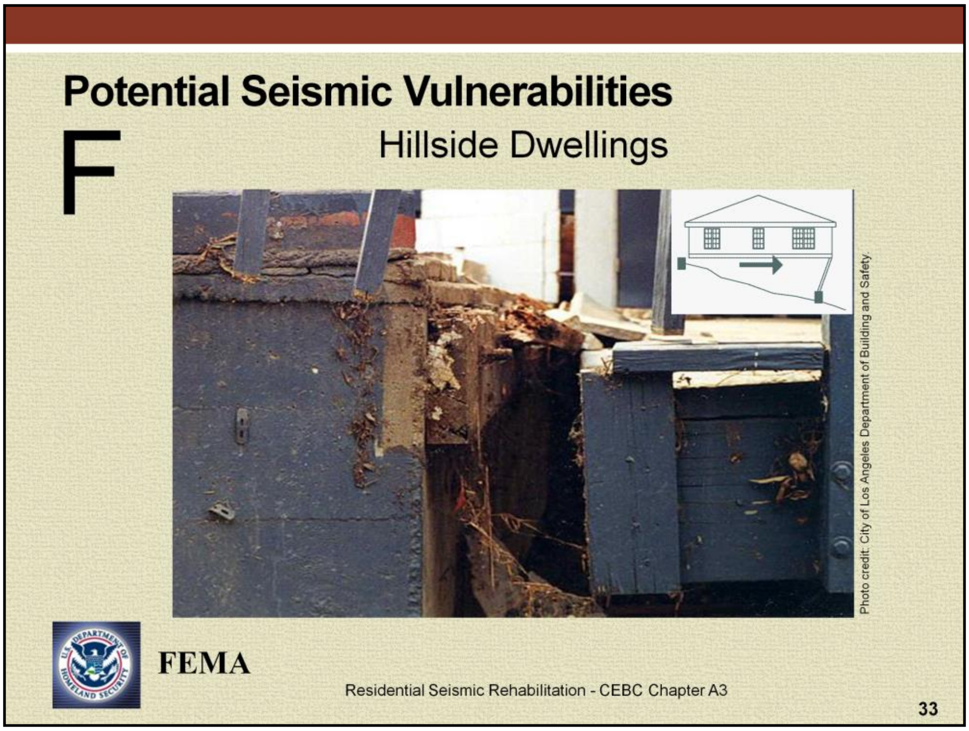
This is a close up of the failed dwelling anchorage at the uphill foundation. A partially complete ledger for floor joists can be seen; the floor joists have pulled away completely. Failure at this connection is likely responsible for the collapse.

Photo credit: City of Los Angeles Department of Building and Safety.



This photo shows a hillside dwelling near collapse during the 1994 Northridge Earthquake. The dwelling has started to pull away from the uphill foundation. If the earthquake had continued longer, collapse could have occurred. Notice the lack of any bracing walls or frames between the occupied floor and grade (grade beams are still visible). Notice the gap at the right side of the floor where it meets the uphill foundation.

Photo credit: City of Los Angeles Department of Building and Safety.



This photo shows a hillside dwelling near collapse during the 1994 Northridge Earthquake. This is a close up of where the floor meets the uphill foundation. The dwelling has started to pull away from the uphill foundation. If the earthquake had continued longer, collapse could have occurred.

Photo credit: City of Los Angeles Department of Building and Safety.

Potential Seismic Vulnerabilities

F Hillside Dwellings

FEMA

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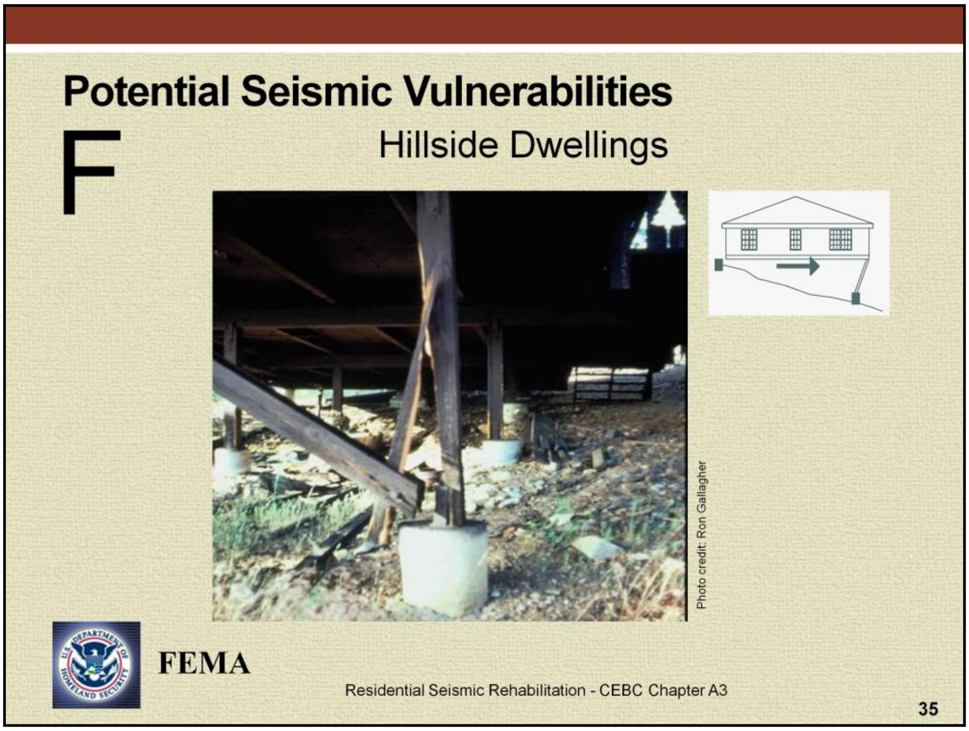
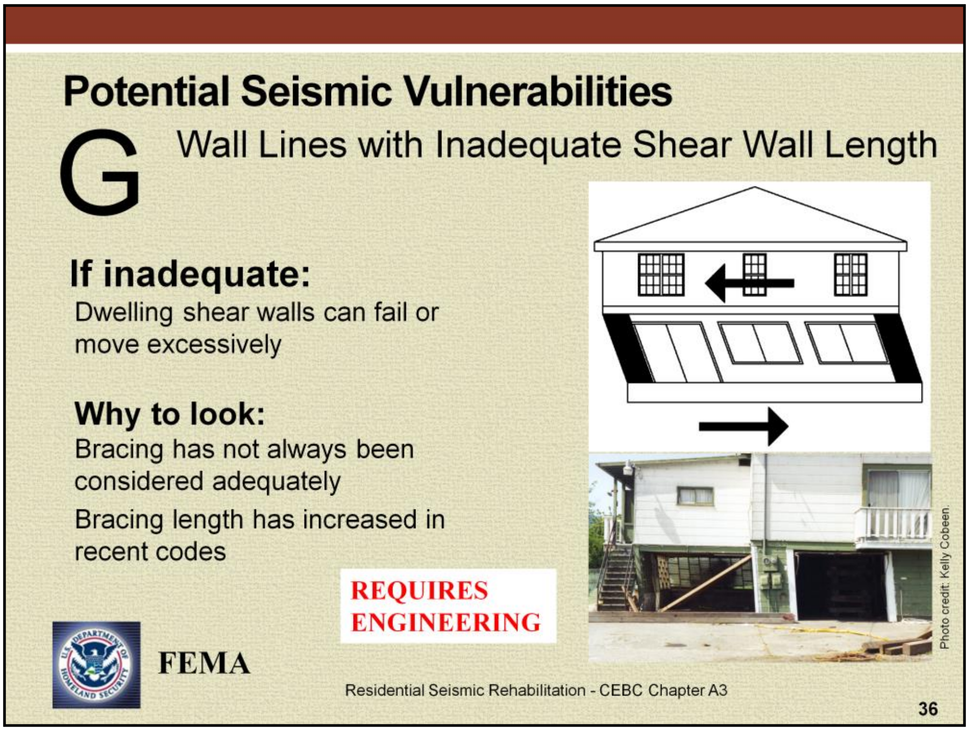
This dwelling, elevated above the hillside on posts and beams, also has a vulnerable configuration. Below the main floor a bracing system is provided at the front of the dwelling, and in one direction only. A close look shows that the bracing system was not adequate. In this case failure did not occur, but could have if the earthquake continued.

Photo credit: Ron Gallagher



This photo shows a close up of the failed bracing system.

Photo credit: Ron Gallagher



Dwellings with inadequate bracing may deform excessively (due to in-pane load) and cause failure, similar to the open front configurations discussed in Item D.

The provision of adequate bracing wall length, strength and stiffness has not always been considered in dwelling design and construction, even when building codes have provided guidance. It is appropriate to check that adequate bracing is provided.

The priority for rehabilitation of dwellings with inadequate shear wall length varies based on the existing dwelling configuration. Rehabilitation generally requires an engineered design, although some prescriptive design guidance is available.

Photo credit: Kelly Cobeen.

Potential Seismic Vulnerabilities

H

Post Attachment at Top & Bottom

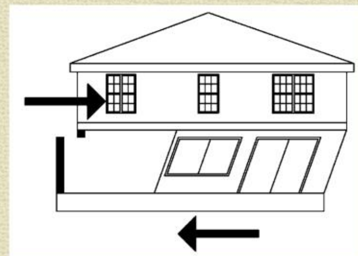
If inadequate:

Beam can pull away from top of post

Post can pull away from foundation

Why to look:

This is easy and inexpensive to retrofit



FEMA

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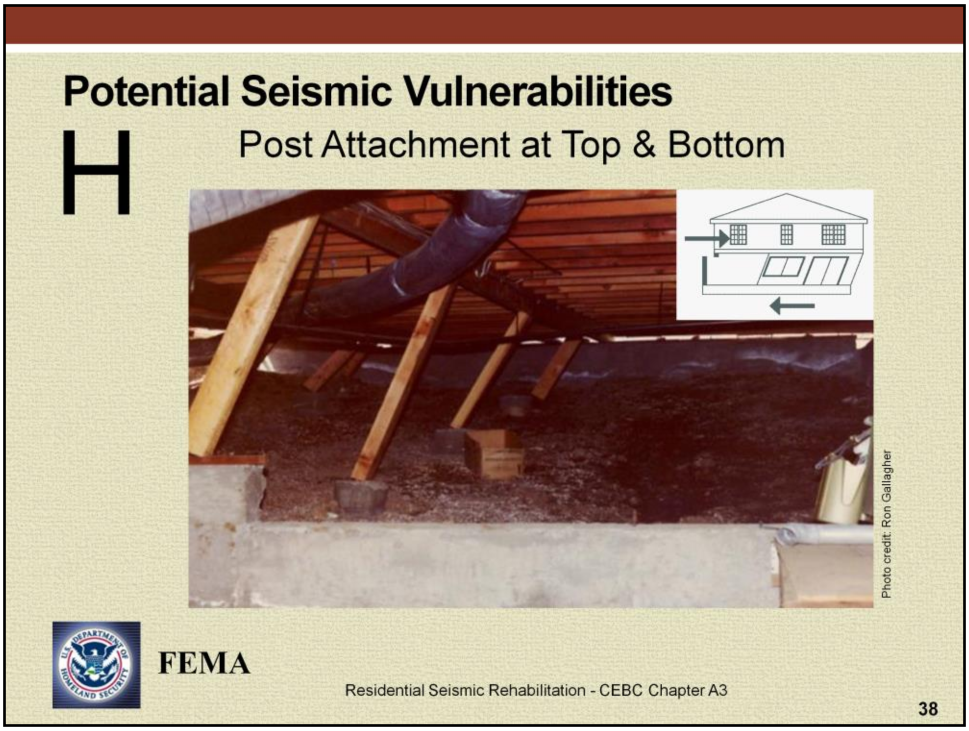
Even when a wood-frame dwelling has adequate earthquake bracing, movement will still occur during an earthquake, and may be up to several inches over the height of a story. It is important that posts which provide gravity support are adequately anchored top and bottom so that they move with the dwelling rather than becoming separated. As shown in the figure above, a post that does not move with the dwelling could leave floor framing unsupported and cause partial collapse.

Seismic rehabilitation priority varies based on hazard posed. Rehabilitation is easy and inexpensive, and no design is required.

Providing post anchorage does not make up for poor foundation anchorage or cripple wall bracing. Rehabilitation of vulnerabilities A & B should be given higher priority than vulnerability H.



This photo shows posts that have shifted significantly, but are still able to carry gravity loads. Seismic rehabilitation of anchorage and cripple wall bracing (Items A & B) should be given first priority. Post attachment should be addressed after vulnerabilities A & B are addressed.

Photo credit: Ron Gallagher

Potential Seismic Vulnerabilities

H

Post Attachment at Top & Bottom

FEMA

Residential Seismic Rehabilitation - CEBC Chapter A3

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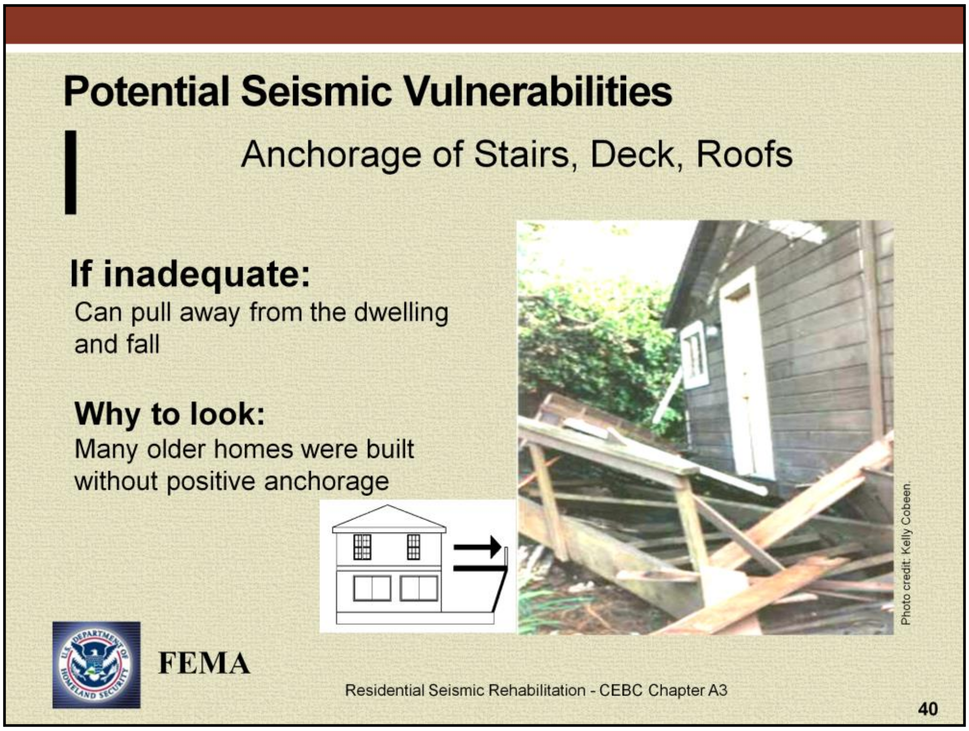
This photo shows posts that have shifted significantly, but are still able to carry gravity loads. Seismic rehabilitation of anchorage and cripple wall bracing (Items A & B) should be given first priority. Post attachment should be addressed after vulnerabilities A & B are addressed.

Photo credit: Ron Gallagher

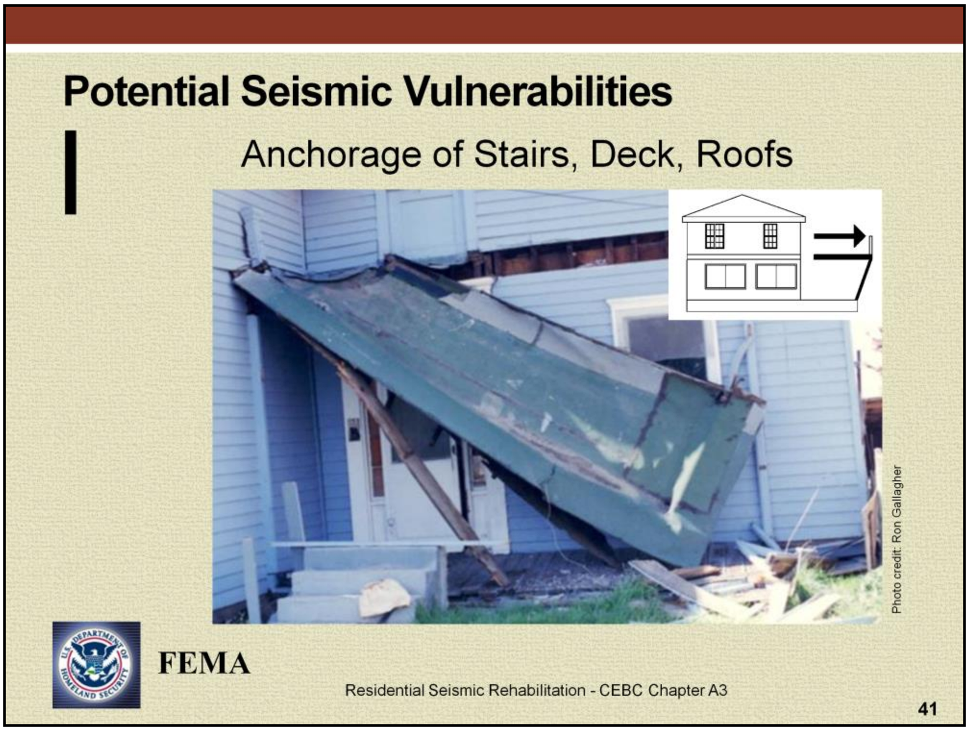


Decks, porches, stairs, porch roofs and other appendages attached to dwellings have often pulled away during earthquake loading, sometimes resulting in collapse.

Often these types of appendages are anchored with nails or screws attached only to exterior siding or ledger boards, rather than having a substantial tension connection to the main dwelling.

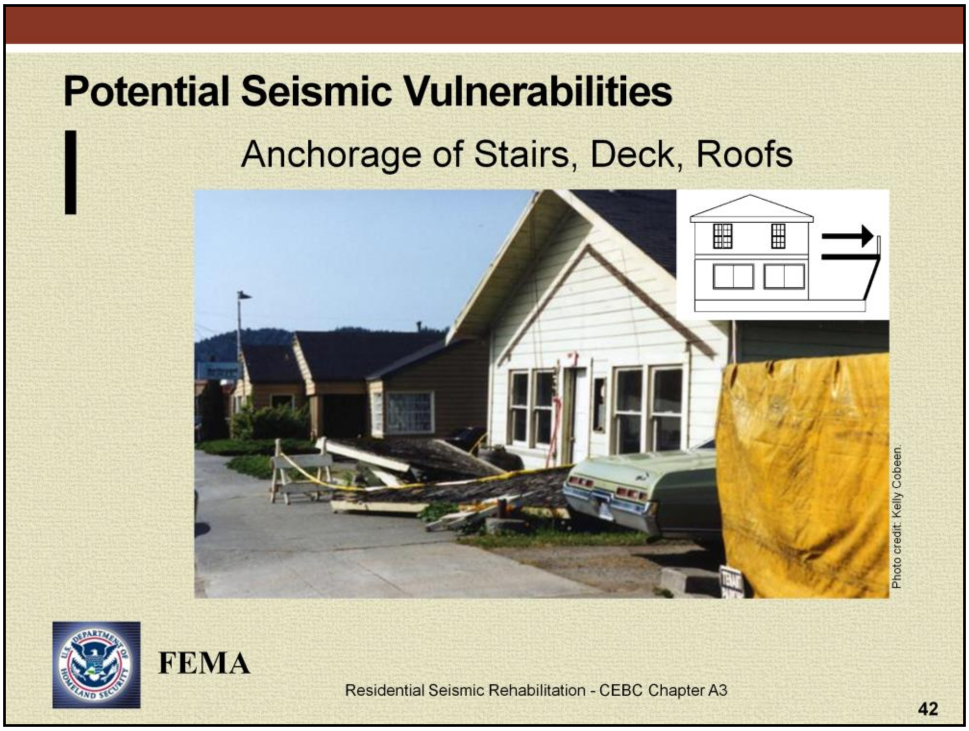
Priority for seismic rehabilitation is high to medium depending on the hazard posed.

Photo credit: Kelly Cobeen. Cape Mendocino – stairs fell off (in pile) roof over stairs fell off (area not painted on wall), cripple walls partially collapsed (under stairs)



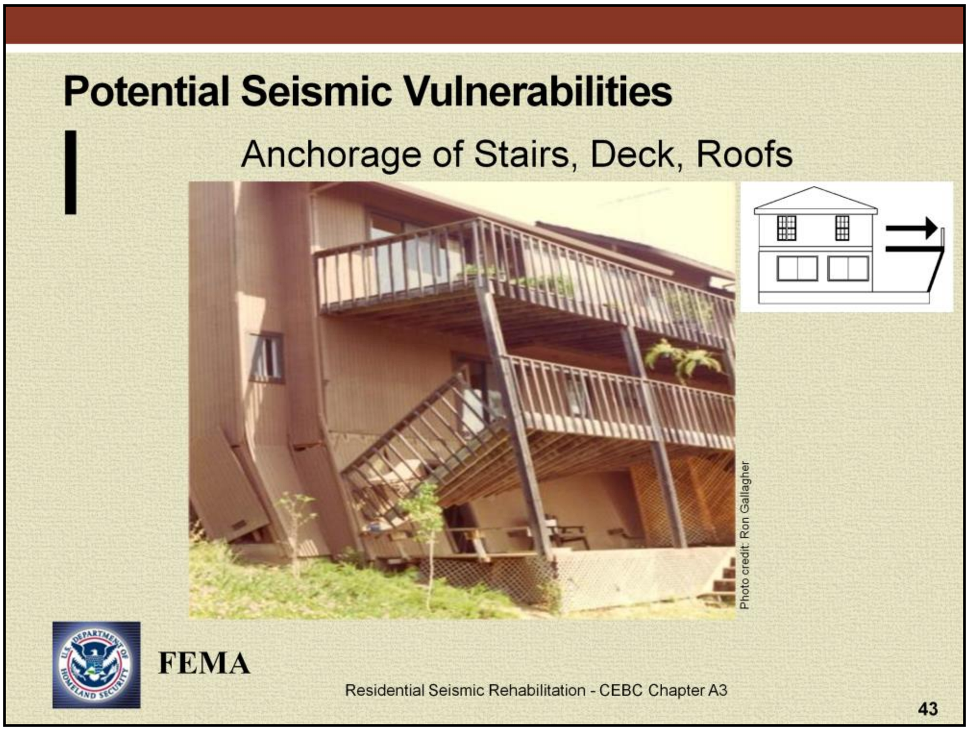
Collapse of roof without positive anchorage.

Photo credit: Ron Gallagher



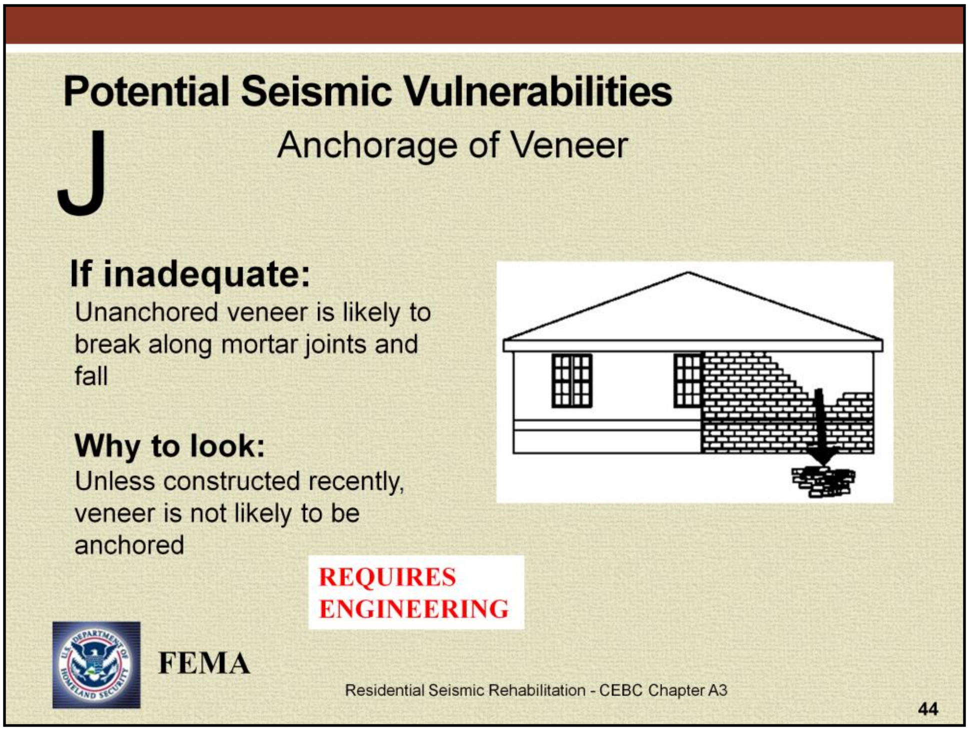
Collapse of roof over front door - without positive anchorage.

Photo credit: Kelly Cobeen.



Collapse of deck without positive anchorage. When house moved under earthquake loading, the deck did not move with it, allowing the deck to pull away from the house and partially collapse. This hillside house also has other extensive damage.

Photo credit: Ron Gallagher



Concrete and masonry (brick or stone) veneers are stiffer and more brittle than the wood-frame dwellings that they enclose. During earthquake loading it is common for cracking to occur along the mortar joints, allowing the veneer to break and fall. If the veneer is unanchored, large sections of veneer can fall with little resistance. Veneer anchors can reduce the falling hazard posed, but will not necessarily eliminate damage.

Veneer anchors have only recently become common practice in areas of moderate to high seismic hazard.

Priority for seismic rehabilitation of veneer anchorage varies based on the hazard posed by falling veneer. An engineered design for seismic rehabilitation is generally required.

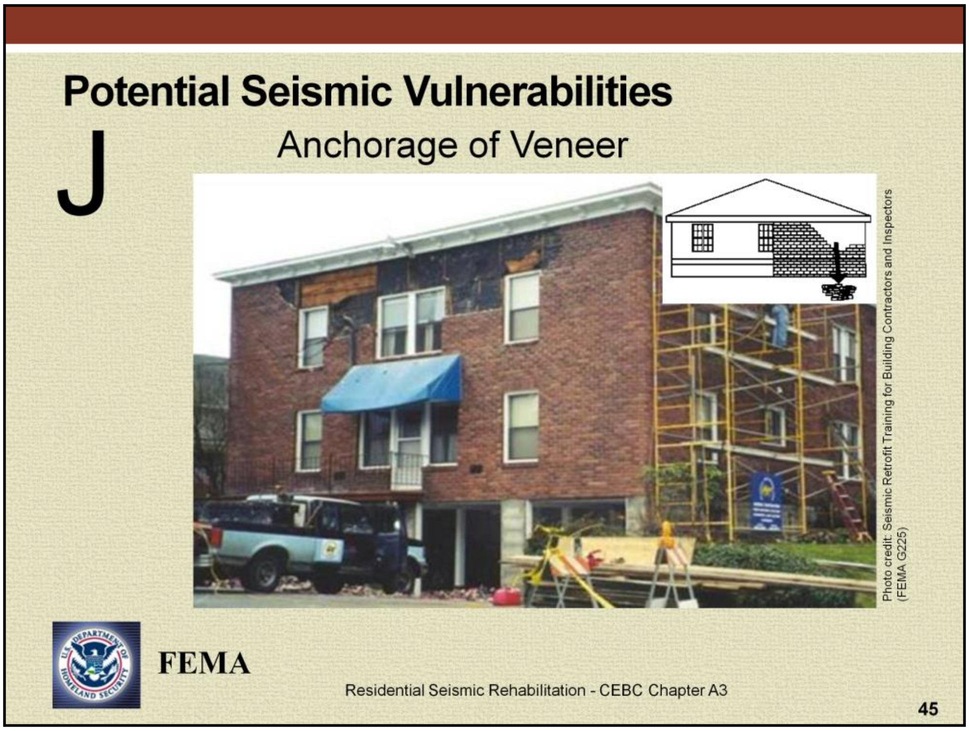


Photo of collapsed veneer over building entrance. The height of the veneer increases the falling hazard.

Photo credit: Seismic Retrofit Training for Building Contractors and Inspectors (FEMA G225)

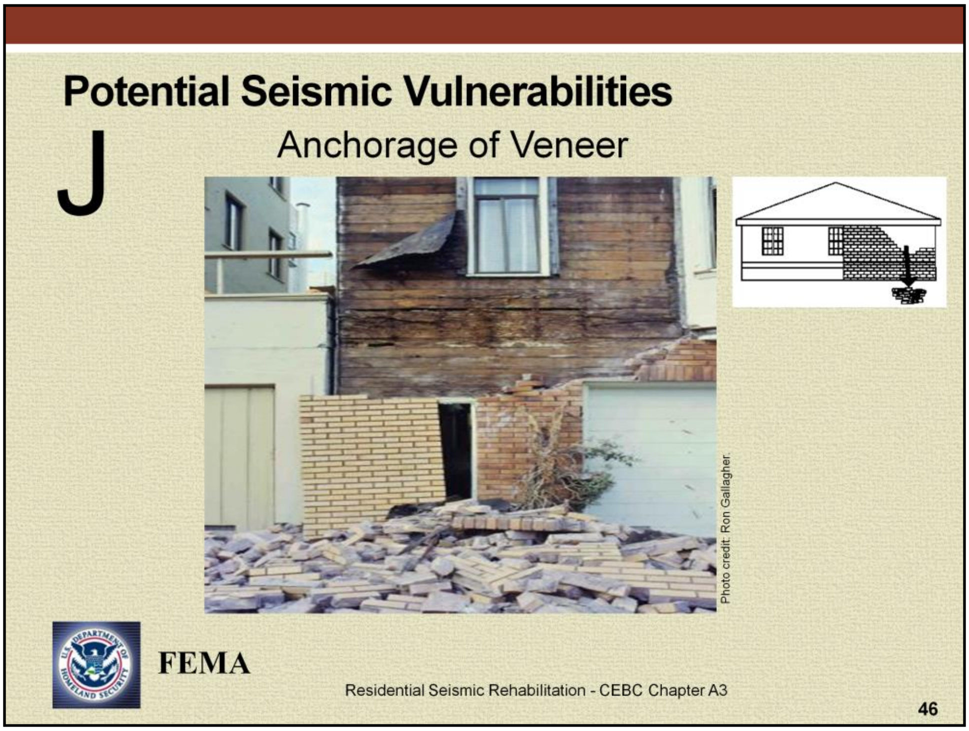
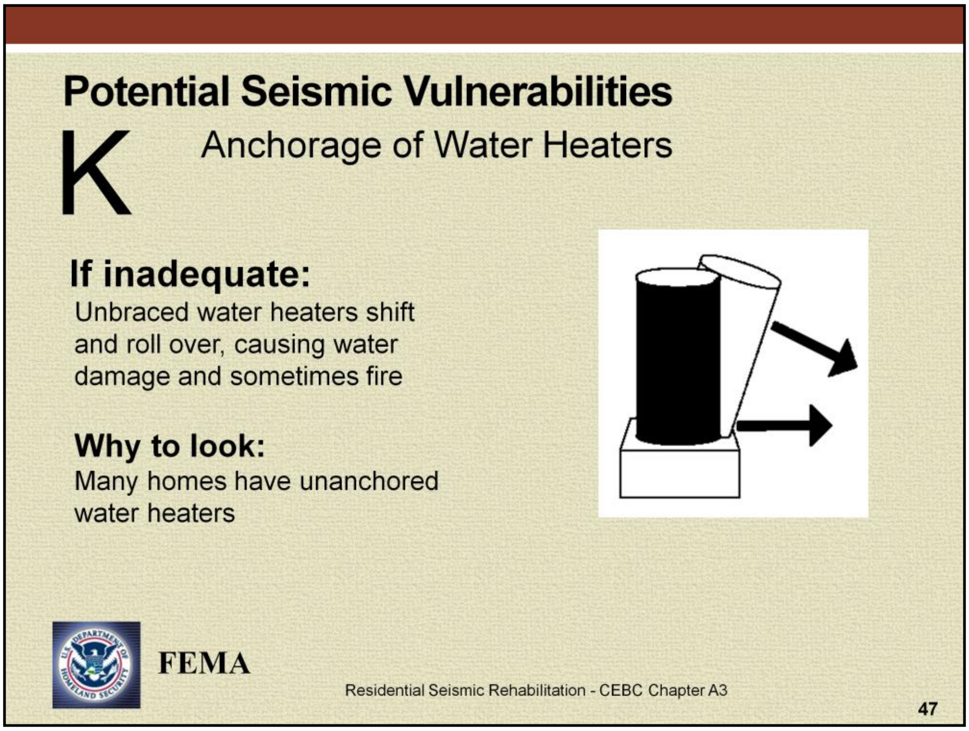


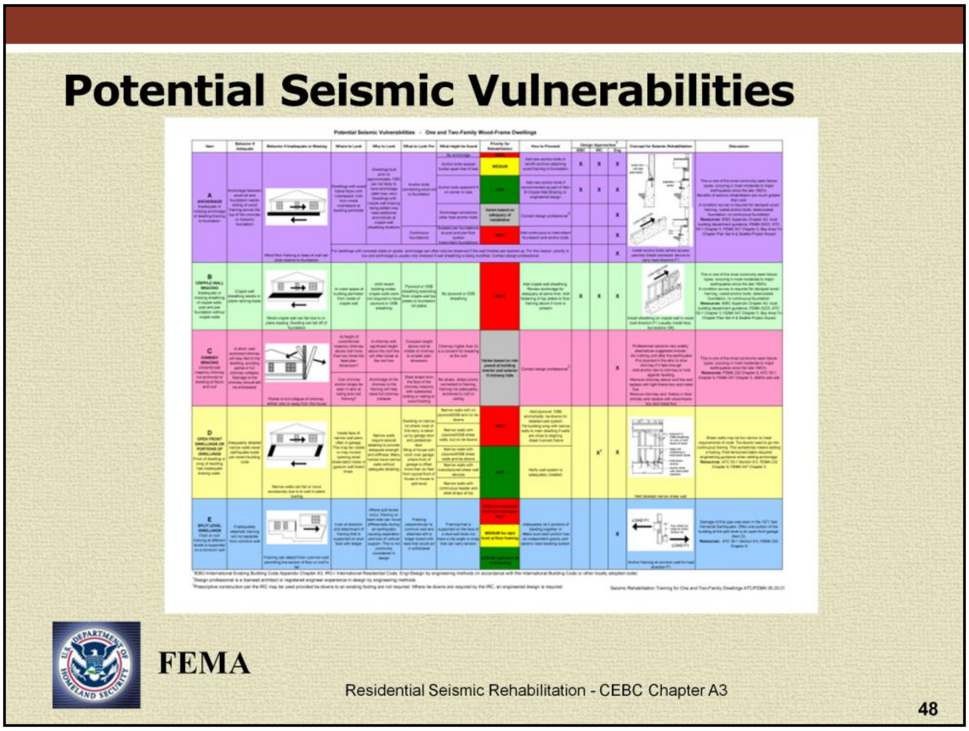
Photo of collapsed veneer over building entrance. Fallen veneer is in both small and large pieces.

Photo credit: Ron Gallagher.



Although required by recent building codes, many homes have unanchored water heaters. Water heaters that are not anchored very readily shift and roll during moderate and major earthquakes. Shifting and rolling often breaks the water heater, causing water leakage and water damage. On occasion gas lines to the water heater also break when the water heater shifts, causing a fire hazard.

High priority is given to bracing of water heaters. Prescriptive design guidelines and bracing kits are generally available. Unusual configurations will require engineered design.



Each of the 11 potential vulnerabilities A through K are addressed on the 11x17 picture card, along with information on how to evaluate and undertake seismic rehabilitation.

While these items address common seismic vulnerabilities, other vulnerabilities might sometimes be identified, particularly in complex and unusual building configurations.

Earthquake Basics & Common Seismic Vulnerabilities

Part 2 Quiz

FEMA

Residential Seismic Rehabilitation - CEBC Chapter A3

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You have completed part 2 of the educational module.
Contractor’s please return to the contractor dashboard to take a short quiz.