The Brace and Bolt Benefit

New research shows earthquake retrofits can save thousands of dollars for owners of single-family wood-frame homes in California.

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Inadequate bracing and anchoring is a major cause of earthquake damage in older wood-frame houses that have a first floor above a crawlspace. Past quakes have cost owners of pre-1970s homes tens to hundreds of thousands of dollars in damage. Most homeowners do not have earthquake insurance or enough financial resources to cover such repairs.

In 2020, the project "**Quantifying the Performance of Retrofit of Cripple Walls and Sill Anchorage in Single-Family Wood-Frame Buildings**," hereafter referred to as the "PEER-CEA Project," was completed. This was a multi-year, multi-disciplinary project coordinated by the Pacific Earthquake Engineering Research (PEER) Center and funded by the California Earthquake Authority (CEA).

In California and many other states, understanding how older, wood-frame houses benefit from retrofitting is important because of high earthquake hazard and the vulnerable condition of the older housing stock.

For all housing styles and locations considered, bracing and bolting a house significantly reduced risk, offering important financial protection for homeowners.

To understand how retrofits reduce damage, project researchers tested crawlspace walls with and without brace and bolt retrofitting of the style designed in a previous CEA-FEMA project known as ATC-110.[1] State-of-the-art computer modeling was then used to estimate how retrofits can reduce losses in vulnerable pre-1970s housing styles common in California.

Workshops with experts generated realistic repair cost data and assured the usability of results in future insurance rate-setting and incentive program design, as well as by homeowners considering a retrofit. View the complete study methods and results at: www.peer.berkeley.edu/cw-woodframe.

The chance of a Magnitude 6.7 or greater earthquake somewhere in California within 30 years is over 99%.[2] Depending on factors like the number of stories, exterior siding type, and how near a house is to the earthquake fault, the study estimated potential savings of $10,000 to $200,000 or more after a major earthquake. That is as much as 20-40% of the replacement value of many California homes. As of July 2020, more than 10,000 retrofits have been completed through the CEA Brace and Bolt Program, at a typical cost of $3,000 to $7,000.[3]

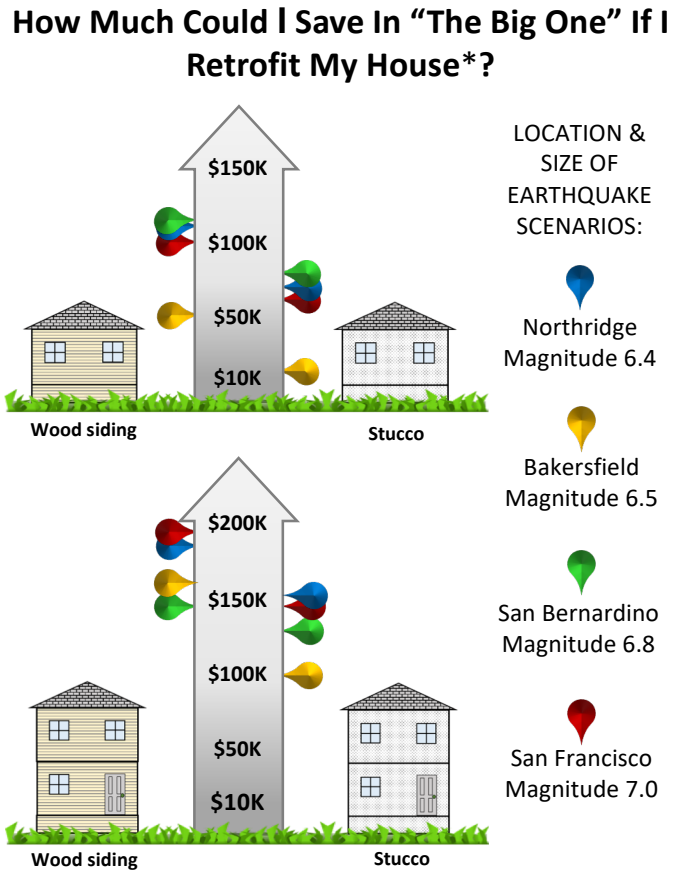


Figure 1. Estimated average savings for four generic house types in four scenario earthquakes.
* Note: Savings are average repair costs avoided in thousands of 2019 US dollars. Values assume a one-story 1,200 sq.ft. house (UPPER) and a two-story 2,400 sq.ft. house (LOWER), at a construction cost of $200 per sq.ft. Potential savings depend on the actual size, age, location, and configuration of the house, the quality, and types of construction materials, the intensity of earthquake shaking, and regional construction market conditions.

PROJECT OVERVIEW

Objectives

The purpose of the PEER-CEA Project was to provide state-of-the-art scientific information about the benefits of improving the crawlspace walls and foundation anchoring in wood-frame housing types common in California. CEA sponsored this three-year study to better understand and help improve the resilience of California's housing stock. The focus was on studying repair cost savings from retrofits of the type that qualify for CEA's Earthquake Brace and Bolt Program.

This brochure summarizes the methods and findings of the PEER-CEA Project. Further details are available in technical reports available at: www.peer.berkeley.edu/cw-woodframe.

Figure 2. The unbraced crawlspace walls of this wood-frame house racked and collapsed, breaking utility connections and leading to a red tag designation in the 2014 South Napa, CA earthquake. – Photo credit: Petros Keshishian

Research Strategy

The project team tested crawlspace walls with and without plywood sheathing (bracing) and improved foundation anchors (bolting) in labs at UC Berkeley and UC San Diego. Researchers considered factors such as the type of exterior finish (wood or stucco), interior wall material (gypsum board or plaster), crawlspace wall height (two to six feet), and number of stories.

Advanced computer modeling by researchers at Stanford University and UCLA estimated how retrofits can reduce losses in common housing styles built before the mid-1970s, which have been vulnerable to damage in past earthquakes. A wide range of potential earthquake shaking levels in four different locations in the state were considered (see Figure 6 map, page 3).

Workshops with catastrophe modeling professionals and insurance claims adjustors were held to estimate realistic repair costs and to understand the repair cost benefits of brace and bolt improvements.

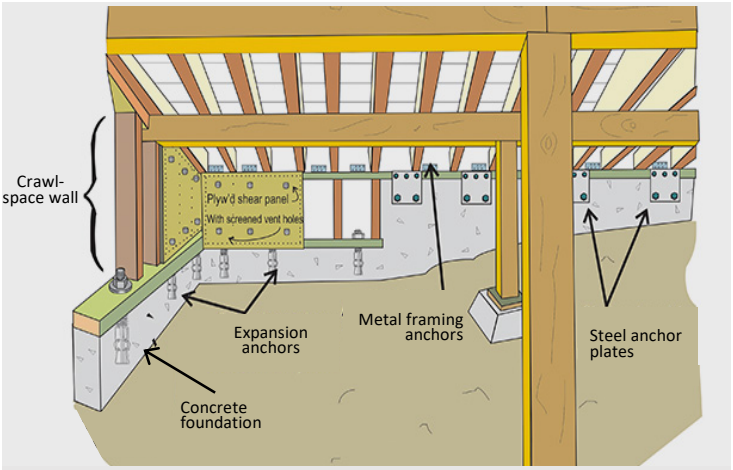
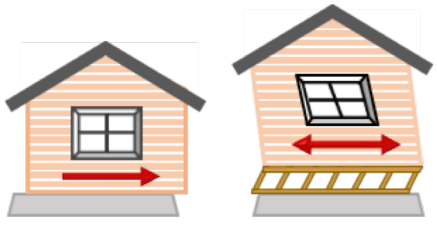


Figure 3. A typical crawlspace retrofit adds plywood to the inner side of the cripple walls (bracing) as well as more anchors, plates or bolts to secure the frame to the foundation.[4]



Sliding
House slides off foundation

Racking
Crawlspace deforms and collapses

Figure 4. Drawings show common causes of damage in homes with crawlspaces.[5]

KEY FINDINGS

Large Benefits Compared to Cost

Bracing the crawlspace walls of older (pre-1945) wood-frame houses with plywood and improving anchorage to the foundation (pre-1970) are relatively inexpensive upgrades that can reduce earthquake damage by tens of thousands of dollars in a major quake, according to the research study. In a typical older home, savings in a major quake averaged about $75,000 for a single-story house and $150,000 for a two-story house, based on an earthquake with about a 10% chance of occurring in the next 30 years.

That means that if an earthquake of that size happens near you, the savings in post-earthquake repairs could be eight to fourteen times more than a typical retrofit costs ($3,000 to $7,000).

Houses With Wood Siding Benefit the Most

Retrofitting houses that have wood siding produced the greatest benefit. Post-earthquake repair costs were reduced on average by 75% in the wood-sided buildings modeled. Retrofitting stucco houses, which may already stand up better to earthquake shaking, still reduced losses on average by 65%. Two-story houses get the largest dollar benefit.

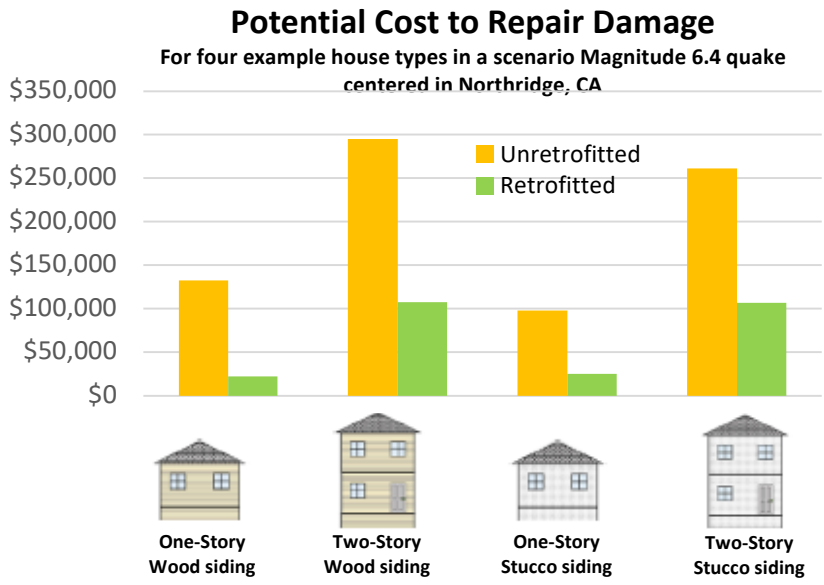


Figure 5. Damage costs in a major quake can be significantly reduced when crawlspace walls are bolted and braced.

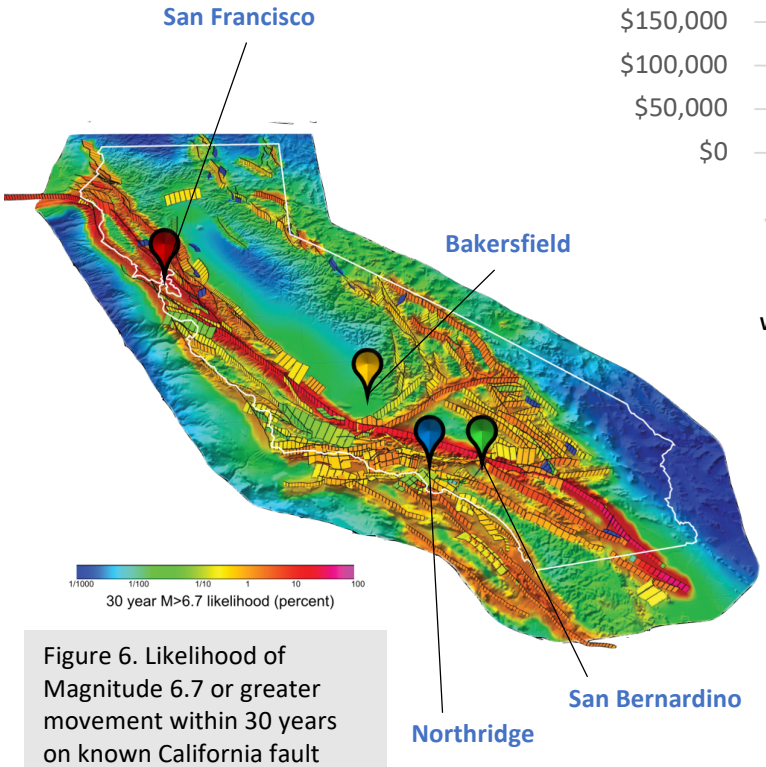


Figure 6. Likelihood of Magnitude 6.7 or greater movement within 30 years on known California fault segments, overlain with simulated earthquake locations modeled in the project.[6]

Significant Benefit in Many Parts of the State

For all locations studied, bracing and bolting a house offers important financial protection for homeowners. Depending on age, siding type and number of stories, expected savings in earthquake-related repair costs ranged from $500 to $9,000 *per year* in San Francisco, $100 to $4,000 *per year* in Bakersfield, $700 to $10,000 *per year* in Northridge, and $1,000 to $11,000 *per year* in San Bernardino.

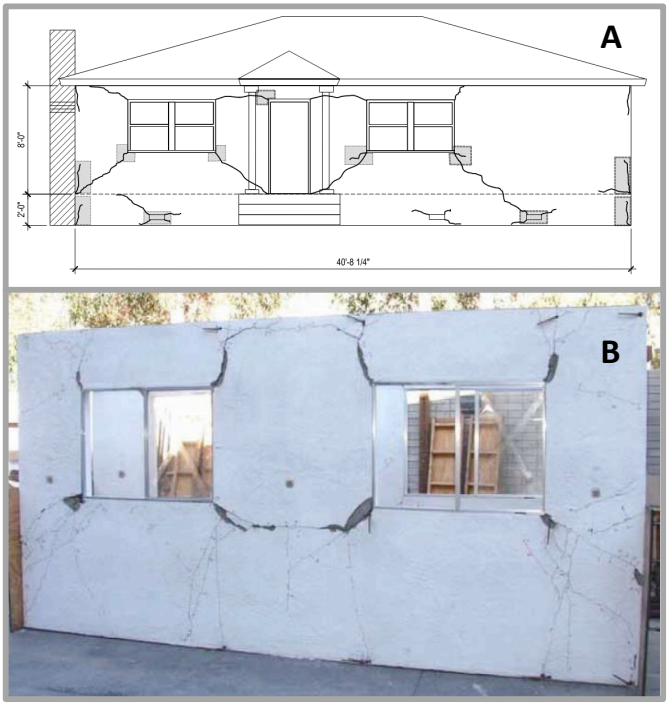
UNDERSTANDING HOUSING DAMAGE AND ITS COSTS

No one can perfectly predict what will happen in future earthquakes, nor can one go back in time to see what would have happened if houses had been built differently. The PEER-CEA Project used past studies to inform which types of houses to study, combined that with the best possible information about California earthquake risk, to create realistic estimates of what could happen.

Past Quakes and Previous Studies Show How Damage Happens

The project team gathered data from hundreds of sources on the performance of wood-frame houses in major earthquakes in recent decades as well as previous testing experiments. Past earthquakes show that wood-frame houses are generally strong and safe in earthquakes, but some older houses have structural vulnerabilities in their crawlspaces that put them at risk of damage in moderate to major earthquakes.

Older houses supported by short wood-framed walls ("crawlspaces") can collapse when the unbraced crawlspace walls rack sideways in an earthquake. Also, houses that are not well-anchored can slide off their concrete foundations as the ground shakes. Houses built before 1970, and especially before 1945, are more likely to have these vulnerabilities.



Learning From Experts About the Costs to Repair Damage

After an earthquake, insurance claims adjusters evaluate insured houses and estimate how much it will cost to repair the damage.

A first of its kind, day-long workshop was held with experienced claims adjustors who were asked to estimate the cost to repair many types of damage that can happen to houses with crawlspaces in large earthquakes. For example:

- Cracks to inside and outside walls
- Tilted or crooked walls, door or window frames
- Broken fixtures, tile, and counters
- Damage to floors, roofs, garage doors, or porches

Adjustors were given detailed information about houses with different features and then estimated costs to repair each building at three levels of damage: slight, serious, or unrepairable (total loss).

Among the many insights from the workshop:

- The quality of finishes such as plumbing fixtures, lighting, and tile are important and can cause repair costs to go up significantly.
- Improved standards for cost estimation may help insurers price insurance more accurately and justify discounts for retrofit work done.
- The project team's computer modeling results were consistent with claims adjuster estimates.

Figure 7. Claims adjusters were given diagrams, photos, and descriptions of house types and asked to estimate the cost of repair for slight, serious, or total damage.[7]

INNOVATIVE HOUSING RESILIENCE RESEARCH

The PEER-CEA Project has produced the most comprehensive information to date on the effectiveness of brace and bolt earthquake retrofitting of older wood-frame houses, significantly advancing our understanding using state-of-the-art testing and modeling techniques.

Component Testing

Researchers at UC San Diego and UC Berkeley conducted laboratory tests of over 30 full scale models, simulating earthquake forces and recording the strength and responses of different parts of a house. Test specimens were built to match different combinations of building materials and construction techniques commonly in use in California before the mid-1970s.

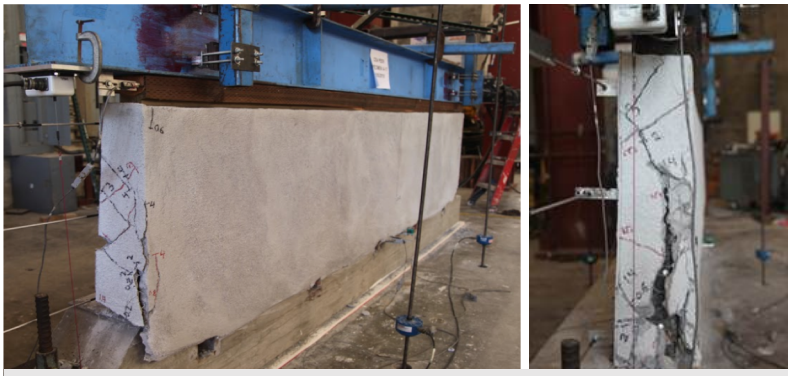


Figure 8. Laboratory tests for assessing the strength and flexibility of a stucco-covered crawlspace wall.

Computer Simulation and Loss Modeling

The results of the laboratory experiments, combined with information on damage and repair costs, were used in creating sophisticated computer models to predict what happens to retrofitted and unretrofitted wood-frame houses, under a range of earthquake scenarios in four representative cities in California. The computer models analyzed over 3.8 million damage simulations, representing over one hundred combinations of building heights, siding types, and exterior and interior wall materials in nearly 100,000 dynamic structural simulations. The results were used to estimate the benefits of retrofitting houses of different types, in terms of the reduced cost of repairs.

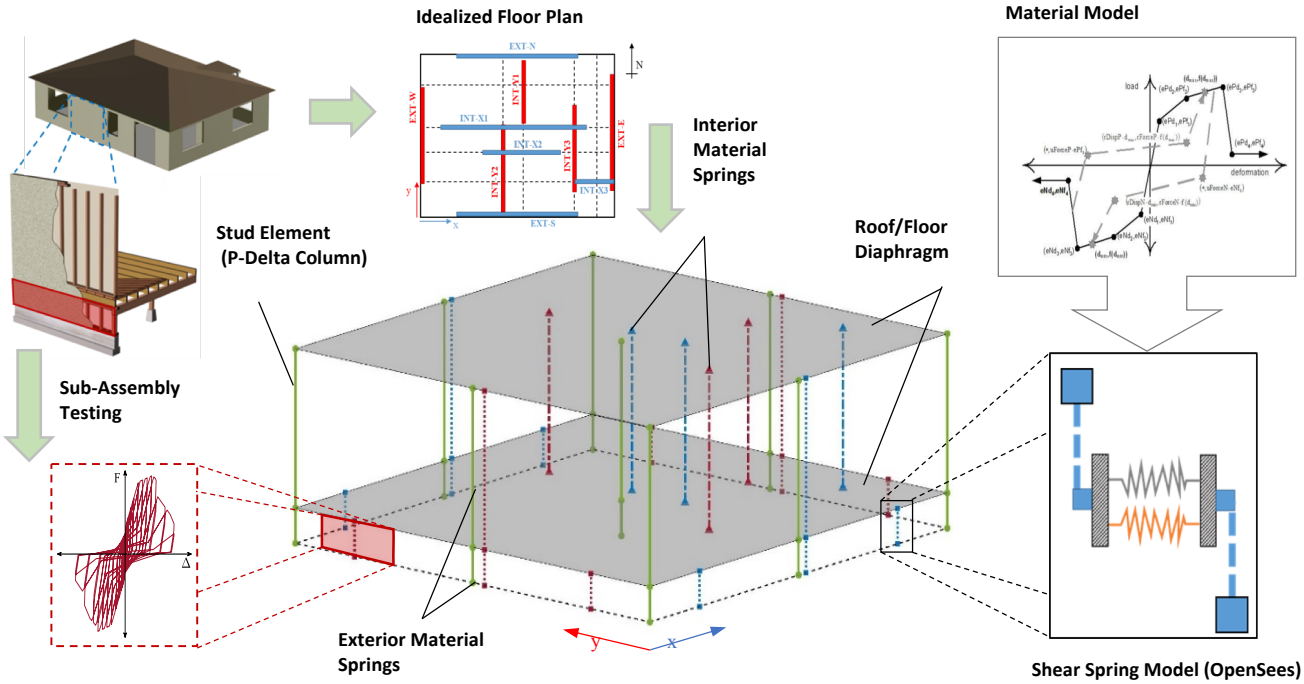


Figure 9. Schematic diagram showing a variety of computer modeling techniques integrated in the PEER-CEA project to estimate how earthquake forces damage wood-frame homes.[8]

A BETTER FUTURE FOR CALIFORNIA HOUSING

Crawlspace Retrofits Can Make California More Resilient

Brace and bolt retrofits of the type studied in the PEER-CEA project can help homeowners avoid costly damage, protecting what is likely their most important asset. These benefits can make our families and communities safer and more resilient.

Understanding how older, wood-frame California homes benefit from retrofitting is important because of the state's high earthquake hazard and the vulnerable condition of our older housing stock. Research from the PEER-CEA project shows that stronger crawlspace walls and improved foundation anchoring can effectively reduce risk. Homeowners can use information from this study to better understand their risk and the benefits of retrofitting for themselves.

References

[1] https://www.atcouncil.org/atc-110-cea-2, Accessed August 15, 2020.
[2] Field, et al., 2015. UCERF3 U.S. Geological Survey Report 2015–3009.
[3] Retrofit costs from: https://www.earthquakebracebolt.com/HomeownerRegistration, Accessed March 15, 2020.
[4] Image from: https://www.seismicsafety.com/los-angeles/, Accessed March 15, 2020.
[5] Adapted from: http://www.earthquakesafety.com/earthquake-retrofitting.html, Accessed March 15, 2020.
[6] Background map image and probability information from Field et al., 2015.
[7] (A) Adapted from CUREE Publication #EDA-02, 2010, B) CUREE Publication #EDA-07, 2003.
[8] Diagram includes images from CUREE #EDA-2, 2010, and other sources to conceptually show steps in the modeling process.

Find Out More

For further details and the complete set of technical reports, see the PEER-CEA Project website: www.peer.berkeley.edu/cw-woodframe.

Earthquakes are inevitable in California, but disasters do not have to be.

Figure 10. A two-story house with wood siding (LEFT) was heavily damaged and unusable after the 2014 South Napa, CA earthquake while a similar retrofitted one (RIGHT) remained occupied. – Photo credit: CEA

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