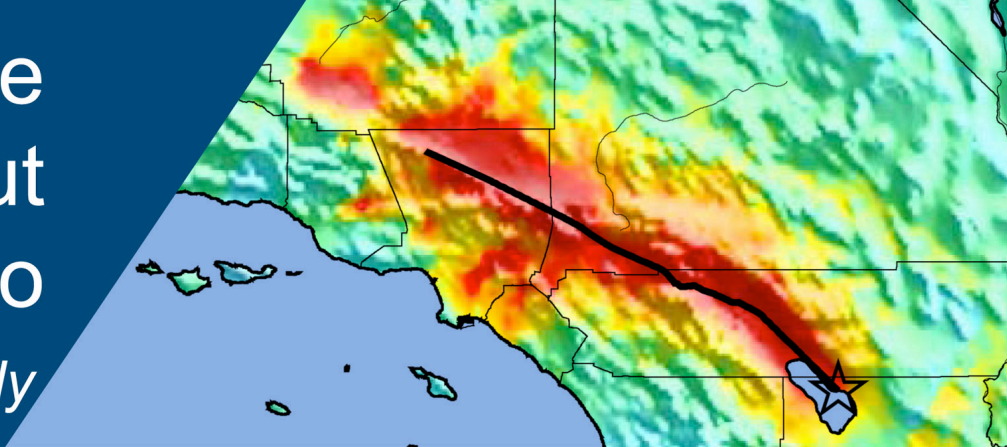


The ShakeOut Scenario

Supplemental Study



Woodframe Buildings

Prepared for
United States Geological Survey
Pasadena CA

and

California Geological Survey
Sacramento CA

Under contract to
SPA Risk LLC
Denver CO

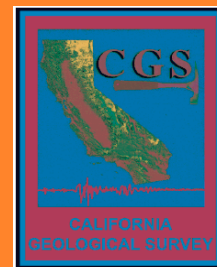
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May 2008



The ShakeOut Scenario:

U.S. Geological Survey Open File Report 2008-1150
California Geological Survey Preliminary Report 25 version 1.0

U.S. Geological Survey Circular 1324
California Geological Survey Special Report 207 version 1.0



Note: over the course of the ShakeOut Scenario, the project name evolved. Where a study mentions *the SoSAFE Scenario* or *San Andreas Fault Scenario*, it refers to what is now named the ShakeOut Scenario.

Damage to Wood-Framed Buildings

OVERVIEW AND SUMMARY OF MAIN POINTS

This chapter presents an overview of the behavior of wood-framed construction in earthquakes, and outlines the expected behavior of wood buildings in the San Andreas M7.8 earthquake scenario. Recommendations for post-earthquake inspection are given, measures to reduce earthquake damage to wood-framed structures are described, and areas for future research are outlined.

Wood-framed buildings are the most common form of construction in Southern California. Wood-framed construction is used for single-family dwellings, for apartments, as well as for retail and office buildings, and structures for education and government.

Past earthquakes have taught us much about the seismic response of wood-framed buildings. Wood buildings are light in weight and strong, and modern wood-framed buildings have performed well and provided a high level of life-safety in earthquakes. However, collapses of wood-framed buildings in the 1989 Loma Prieta Earthquake and the 1994 Northridge Earthquake focused the attention of the engineering community on a number of key weaknesses in wood frames. For example, apartment buildings with tuck-under parking can experience heavy damage and even collapse under intense shaking, and materials like stucco and gypsum wall-board provide poor resistance to cyclical earthquake motions. These dramatic failures have also spurred research including both testing and the development of sophisticated analytical models.



Figure 1. Dwelling in Oakland with Failed Cripple Wall, 1989 Loma Prieta Earthquake

Earthquakes such as the M7.8 San Andreas scenario will subject many thousands of wood-framed buildings to loads well beyond their elastic range, yet the nonlinear, inelastic behavior of wood-framed buildings is extremely difficult to model. The seismic behavior of wood-framed buildings is complex, but comprehensive tools for nonlinear static and

nonlinear dynamic analysis of realistic wood buildings are lacking. Before cracking of gypsum drywall and stucco finishes, typical wood-framed structures are very stiff. After these finishes crack, wood buildings rapidly degrade in stiffness, with dramatic shifts their dynamic properties. The strength of wood depends on the direction of its grain, defects in wood members such as splits and knots, and moisture content. Wood is subject to damage by fungus, water and fire. Modes of failure in wood structures include nail bending and slip, sliding and overturning of wall piers, shear failures in wall sheathing, various connection failures, and crushing of boundary members. Good earthquake performance of wood-framed buildings depends upon careful attention to component detailing (i.e., for members, walls, diaphragms and connections) and a good grasp of overall system behavior. Heavy, rigid elements such as masonry fireplaces and chimneys or masonry veneers require careful reinforcement and good connections to prevent damage to the light, flexible wood-framed structure under strong ground shaking.



Figure 2. Apartment with Soft/Weak Story Collapsed in 1994 Northridge Earthquake

Seismic building codes require explicit design by a Professional Engineer (Civil or Structural) for the earthquake force-resisting system for all buildings, but regular wood dwellings up to three stories in height may be built using prescriptive conventional light-frame construction rules (e.g., 1997 Uniform Building Code Section 2320, or 2006 International Building Code Section 2308). These buildings are “deemed to comply” with earthquake provisions without formal design. Larger structures and buildings not meeting the restrictions for conventional light-frame construction must be engineered. Until engineered design is required for dwellings, dwellings built under conventional light framing rules must be regarded as more vulnerable than engineered construction.

The San Andreas M7.8 scenario will produce intense ground shaking of long duration over a wide region. Since the 1964 Great Alaskan Earthquake, we have not seen wood framed buildings exposed to intense ground shaking lasting minutes. Because materials like gypsum wallboard (drywall) and stucco crack and lose both strength and stiffness with cycles of loading beyond their elastic strength, older wood-framed buildings that rely on these materials to resist earthquake motions may experience more damage than expected. More recent wood-framed buildings, especially engineered wood-frames using plywood shear

walls, should perform well, even under the conditions produced by the San Andreas event considered.

Wood-framed dwellings, town-homes and apartments provide the principal form of housing in Southern California, so damage to wood-framed housing will increase demands for shelter for the populations affected by large earthquakes like the one under consideration here. According to the 2000 Census, in Riverside, single-family dwellings account for about 70% of the housing units, while apartments and town-homes account for about 26%, and the balance from mobile homes. In San Bernardino, 61% of the housing units are single-family dwellings, and 24% of the units are in apartments and town-homes. Both counties saw substantial residential construction in the 1960's, 70's, 80's at a time when wood-frames relied heavily upon gypsum wallboard and stucco as sheathing for shear walls, leaving them more vulnerable than older structures that sheathed wall in gypsum lath and plaster, or newer structures using plywood.

Past earthquakes have demonstrated the value of a number of loss reduction measures, including:

- Bolting older homes (pre-1940) to their foundations and adding plywood sheathing to weak cripple walls where these exist.
- Connecting gravity posts to concrete foundation pads and floor beams in older homes and apartments with crawl spaces (see Figure 3).
- Strengthening older apartments with a soft/weak first story caused by tuck-under parking.

In most cases, these retrofit measures may be shown to be cost-effective [Porter et al., Earthquake Spectra, 2006]. The first step in implementing such measures is to conduct surveys to identify the buildings with the specific weaknesses. Older buildings with crawl spaces and apartment buildings with tuck-under parking may be readily identified by visual surveys.

The sections below provide greater detail for each of the points summarized above.



Figure 3. Post Beneath Apartment not Secured to Foundation Pad or Floor Beam

DAMAGE TO WOOD BUILDINGS IN PAST EARTHQUAKES

Perhaps the first systematic observations of earthquake damage wood-frames were made following the 1886 Charleston, South Carolina Earthquake (M7.3). The resistance of wood-framed construction to damage in the 1906 San Francisco Earthquake was overshadowed by the devastating losses to wood buildings in the fire that followed. High levels of damage to dwellings in the 1925 Santa Barbara and 1933 Long Beach Earthquakes prompted the development of seismic design codes and a requirement to bolt wood-framed walls to reinforced concrete or masonry foundations. Collapses of wood-framed buildings in the 1989 Loma Prieta and 1994 Northridge Earthquakes focused the attention of the engineering community on a number of key weaknesses in wood frames – for example, soft / weak story conditions created by tuck-under parking, and the seismic vulnerability of stucco and gypsum wall-board construction.

A more detailed chronology of earthquake damage to wood frames is attached.

SEISMIC RESPONSE OF WOOD-FRAMED BUILDINGS

Wood-framed buildings are by far the most prevalent type of construction used for homes and apartment buildings, especially in Southern California. Wood-framed construction is also used for retail, office, school and government occupancies. Wood construction provides high strength with relatively low weight, and the high strength-to-weight ratio makes wood a good choice for earthquake-resistant construction.

By understanding how wood structures resist earthquake ground motions, we can understand failures. Earthquakes generate complex, time-varying ground motions in three dimensions. Vertical ground motions generate forces that add or subtract to gravity, and safety margins inherent in the gravity load-carrying system helps prevent damage. When the ground moves horizontally, it accelerates the building, generating forces in each element of the building in proportion to its mass. The lateral force induced by earthquake ground motions is termed “shear.” The roof and floors act as deep beams (“diaphragms”) to collect these forces and deliver them to the wood-framed walls, where the wall sheathing – typically gypsum board, stucco or plywood – acts in shear to transfer the forces to the foundation. Overall, the building acts as a stiff box-like structure. The strength of the building depends upon the strength of the sheathing and connections, acting in a continuous load path. Roof and floor diaphragms must connect properly to walls, and the base of the walls need a strong positive connection to the foundation. Connections use nails, lag screws, bolts and specialized hardware. The resisting walls are called “shear walls.” Sheathing must be nailed to the framing, and forces must be transferred from the edge of one sheet to the next. Where forces are high, this requires closely spaced nailing to a wood member (“blocking”) along all edges of the sheathing. The structure must resist the horizontal forces and the overturning moments produced by the forces. Where overturning moments can produce uplift of tend of the wall, the uplift is resisted by special brackets or straps called “hold-downs.”

Earthquake damage occurs when the “demands” generated by earthquake ground motions exceed the “capacity” of the structure.

Earthquake demands depend not only upon the ground motion, but the dynamic interaction of the ground motion and the structural response. The building’s dynamic characteristics depend upon its seismic mass (i.e., the weight of the structure above the foundation), stiffness and strength, as well as its capacity to absorb and dissipate energy

through damping (like the shock absorber on a car) and damage. As damage occurs, the dynamic characteristics of wood framed buildings change dramatically. Before cracking of gypsum drywall and stucco finishes, typical wood-framed structures are very stiff. After these finishes crack, wood buildings rapidly degrade in stiffness, causing dramatic shifts in the building's fundamental period of vibration – the time required to complete one cycle of oscillation. A typical undamaged 1-story dwelling may have a fundamental period of vibration of 0.15 seconds or 0.2 seconds, but after heavy damage, its period may lengthen to 0.5 seconds or more. This shift in period greatly affects the part of the earthquake ground motion to which the building responds. For the San Andreas M7.8 scenario, in the area of strong shaking close to the fault, initial high levels of strong shaking may “tune in” to stiff, undamaged structures, causing cracking, nail slip and other damage that degrades the stiffness and strength. The damaged structure would now have a longer period that may tend to “tune in” and amplify the subsequent intense, rolling ground motions that may last for a minute or more, with the result that the building may experience much more damage than would occur in a smaller magnitude earthquake of similar initial intensity.

The “capacity” or resistance of any particular wood-framed building depends upon the strength and ductility (toughness) of the elements of its structural system.



Figure 4. Shattered Chimney – 1992 Big Bear Earthquake

The strength of a wood member like a 2x4 depends on the direction of its grain, defects in wood members such as splits and knots, and moisture content. Wood is subject to damage by

fungus, water and fire. Modes of failure in wood structures include nail bending and slip, sliding and overturning of wall piers, shear failures in wall sheathing, various connection failures, and crushing of boundary members. Good earthquake performance of wood-framed buildings depends upon careful attention to component detailing (i.e., for members, walls, diaphragms and connections) and a good grasp of overall system behavior. Heavy, rigid elements such as masonry fireplaces and chimneys (see Figure 4) or masonry veneers require careful reinforcement and good connections to prevent damage to the light, flexible wood-framed structure under strong ground shaking.

EVOLUTION OF WOOD-FRAME CONSTRUCTION

The vulnerability of the wood-frame structures varies with the year and location of construction. With the exception of the City of Los Angeles, most of the affected building jurisdictions utilize the seismic provisions of the Uniform Building Code. The evolution of wood-frame construction under the UBC code is illustrated in the attached timeline. Seismic building codes have progressively incorporated many of the “lessons learned” from these earthquakes, and design and construction practice have evolved significantly through time – although some changes resulted in increased damageability [cf: B. Schmid et al.]. In particular, low-rise wood-framed construction came to rely upon stucco and gypsum wallboard for high shear resistance in the 1960’s, 70’s and 80’s until allowable shear values were cut in half in the 1988 Uniform Building Code. More recent engineered wood-framed construction utilizes plywood or oriented strand board sheathing for the shear walls, with hold-down systems to prevent shear wall overturning, with steel straps to serve as collectors and prevent damage around openings in walls and floors.

Figure 5 illustrates the evolution of wood-framed construction.

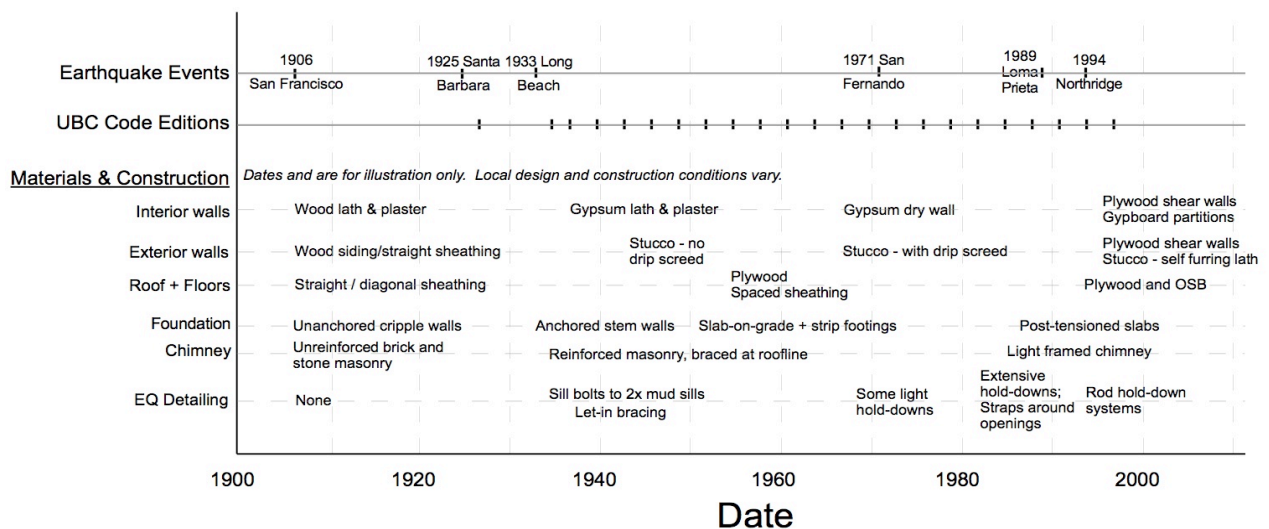


Figure 5. Seismic Evolution of Wood-Framed Construction

Following the Northridge earthquake, a number of significant changes were made in the Uniform Building Code and other local codes, with the intent of reducing the damage observed in wood frames in the Northridge earthquake. For example, the earthquake shear forces permitted in stucco and gypsum board wall sheathing were further reduced, and these materials were not permitted for use in resisting earthquake shear forces in the lower stories of multistory construction. The code revisions promoted an increased reliance on plywood-sheathed shear panels, and the height-to-length proportions were limited to avoid problems

observed with narrow panels. Hence, post-Northridge wood-framed construction may perform better than the models derived from Northridge earthquake damage statistics.

Unfortunately, the majority of wood-framed buildings in the San Bernardino, Riverside, Imperial and Ventura Counties were constructed in the period of highest vulnerability, from about 1960 – 1984 (see the chart above). High levels of damage are expected to the wood framed buildings constructed in this period, with significant impacts on all the regional response and recovery resources.

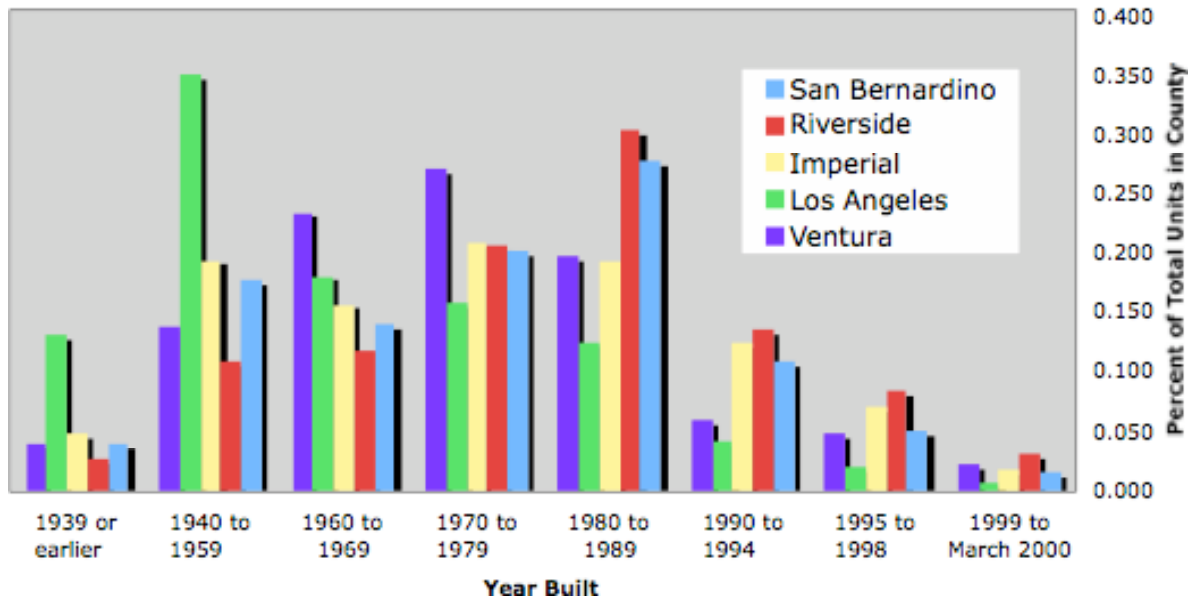


Figure 6. Year of construction for housing units in the 5 most affected counties.

CONVENTIONAL LIGHT-FRAME CONSTRUCTION

Given the complexity of wood as a structural system and the high level of detailing required to prevent component and system failures observed in past earthquakes, it seems surprising that current building codes do not require formal design of all wood buildings by a Professional Engineer.

Seismic building codes require explicit design for the earthquake force-resisting system for other buildings, but since 1970 regular wood structures (including most dwellings) up to three stories in height may be built using prescriptive “conventional light-frame construction” rules (e.g., 1997 Uniform Building Code Section 2320, or 2006 International Building Code Section 2308). In this case, no formal earthquake structural design by an Architect, Professional Engineer (Civil) or Structural Engineer is required. Therefore, the actual lateral force-resisting capacity of wood-framed dwelling vary substantially – much more than the capacity of structures designed by formal capacity calculations.

These buildings are “deemed to comply” with earthquake provisions without formal design. Larger structures, irregular buildings and buildings not meeting the restrictions for conventional light-frame construction must be engineered. Conventional light-frame construction rules also omit important seismic detailing requirements, such as plywood sheathing, 3x sill plates, and connection hardware such as shear clips, collectors, and straps around floor and wall openings. Since most dwellings may be designed under conventional

light-frame construction rules, dwellings must be viewed as potentially more damageable than engineered wood-frame construction.

SEISMIC WEAKNESSES OF WOOD FRAMES

The weaknesses of wood-framed construction and rehabilitation techniques relevant to these weaknesses are detailed in Chapters 5 through 7 of FEMA 547. The major weaknesses involve:

Older Buildings

- Weak and brittle shear wall sheathing materials permitted under previous codes (e.g., gypsum wall board and stucco);
- Unbraced cripple walls and lack of foundation anchorage in older buildings;
- Limited shear strength in straight sheathing, diagonal sheathing and spaced-sheathing diaphragms;
- Unreinforced brick and stone masonry chimneys further described below); and,
- Fragile or poorly attached masonry veneers.

Multi-story Construction

- Soft- and weak-story conditions created by tuck-under parking designs, unless mitigated by steel moment frames or other special measures.
- Unknown performance of recent 4- and 5-story wood-framed apartment construction. These buildings are taller than those subjected to strong ground motion past earthquakes, and questions remain concerning the effectiveness of the hold-down systems used for the tall, narrow shear walls that often occur in these buildings.

Foundation Damage

- Hillside homes – these are susceptible to landslide, and are subject to torsion when not properly braced.
- Foundation problems from
 - cut-and-fill lots;
 - sloped or stepped foundations; and,
 - liquefaction, landslide, lateral spreading.

We discuss some of these weaknesses further below.

SEISMIC DAMAGE TO CHIMNEYS

Chimneys are a common feature of residential wood-framed construction, and damage to chimneys has been noted in every large historical earthquake. Older chimneys are particularly prone to earthquake damage (see Figure 4), in part due to changes that have occurred over time in the design and construction provisions of building codes, as well as inspection and enforcement practices.

PRIMARY ENGINEERING CONSIDERATIONS

Dynamic interaction occurs between the chimney and the dwelling structure. A masonry chimney will act as a propped vertical cantilever under lateral seismic forces. The cross section of the cantilever changes from large base (fireplace) to the flue. In newer construction, the chimney is typically supported on a thickened portion of the foundation slab-on-grade, with some degree of rotational fixity at the base. A steel strap tie to the roof (and floor) diaphragm serves as lateral restraint. An engineering model may consider the chimney mass, strength and stiffness, the foundation support stiffness, the lateral (roof) support strength and stiffness, and the wood-framed structure's period. Post-earthquake data collection efforts should consider:

- Intensity of ground shaking
- The type of chimney
 - unreinforced stone masonry
 - unreinforced brick masonry
 - reinforced brick or stone masonry
 - light framed chimney
- Chimney connection to roof (and floor) diaphragms
 - tied well
 - not tied or poorly tied
- Type of dwelling
 - 1-story
 - multi-story
 - relative seismic mass of the chimney compared to the wood-framed structure

CHIMNEY DAMAGE IN THE 1994 NORTHRIDGE EARTHQUAKE

URS performed detailed engineering inspections of more than 200 residences in 1994, following the Northridge earthquake. The surveys noted the type of chimney, date of construction, and damage state. 191 of the dwellings out of 225 had chimneys. URS noted:

- Older (pre-1940) chimneys occurred in areas mostly outside of the San Fernando Valley, and were subject to lower ground motions. Nevertheless, high damage and collapse occurred in some cases for peak ground acceleration (PGA) from 0.2g to 0.5g. Above 0.45g, all of these chimneys had some damage, but some chimneys were only cracked at 0.4g to 0.5g.
- Newer (post-1940) masonry and concrete chimneys fared better than older masonry and concrete chimneys, with collapses occurring from 0.25g up to 1.25g (the highest mean ground motion predicted at the inspected sites).
- New, framed chimneys were notably better in seismic performance, with only minor damage for ground motions up to 0.75g.

OBSERVED CHIMNEY FAILURE MODES

- The chimney shatters above the roof line (this is the most common failure mode, especially for unreinforced chimneys). As a result:
 - 1) the chimney falls away from dwelling, creating a falling hazard to anyone outside,
or

- 2) the chimney falls on the roof of the structure, with possible damage to the roof.
- The chimney separates from the structure, and often collapses. This may result failure of the roof tie strap or inadequate bolting of the strap, as observed for light framed chimneys (in the 1992 Big Bear Earthquake) as well as masonry chimneys (in the 1989 Loma Prieta Earthquake).
 - Masonry chimneys crack.
 - The fireplace is damaged (typically as masonry cracking, or with separation of the masonry from the walls and ceiling).
 - The roof is damaged and leaks (with possible water damage occurring later).
 - Additional damage occurs to the wood-framed structure from chimney inertial forces

CRIPPLE WALLS

Cripple walls are another common feature in older wood-frame residential construction, pre-dating slab-on-grade construction. Cripple walls are a short wall occurring between the concrete or masonry foundation and a framed first floor (see Figure 7). They allow a crawl space useful for routing utilities into the building. Seismic weaknesses occur when the bottom plate of the cripple wall is not bolted to the foundation, where the sheathing of the cripple wall is weak (e.g., with straight sheathing), and where posts supporting interior walls and columns are not seismically secured to foundations and floor beams (see Figure 3).

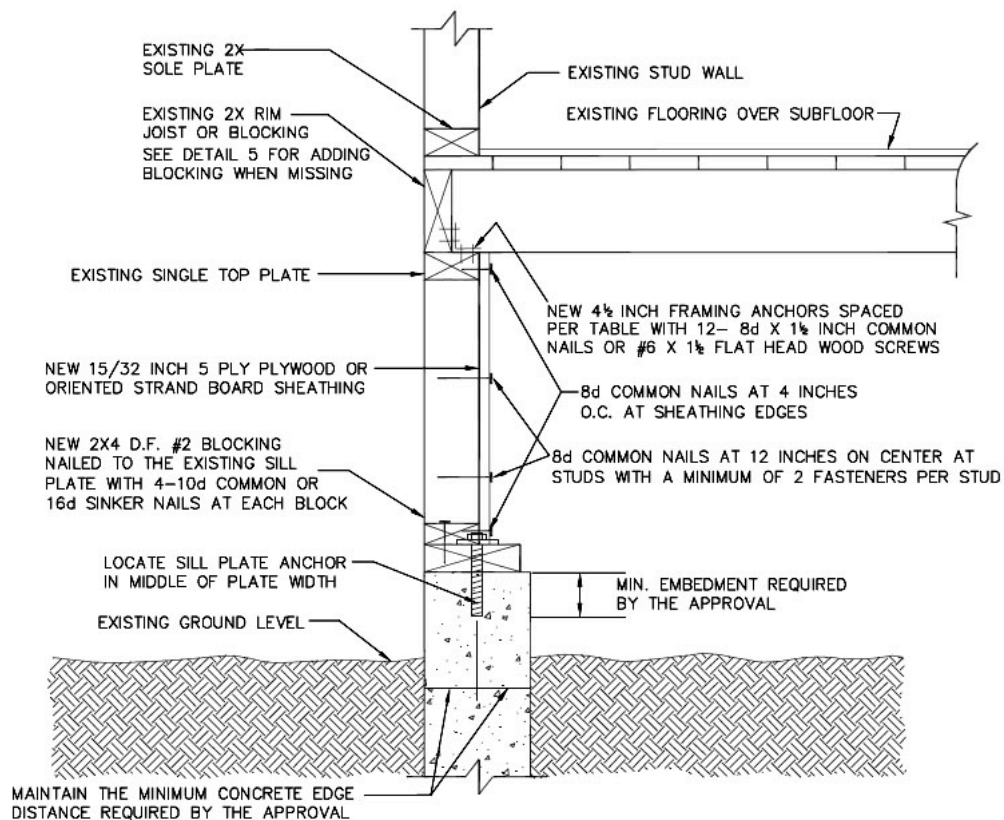


Figure 7. Excerpt from City of Los Angeles Recommended Rehabilitation Details: "Earthquake Hazard Reduction in Existing Wood Frame Residential Buildings with Weak Cripple Walls and Unbolted Sill Plates"

The seismic deficiencies associated with cripple wall construction are well known and documented in nearly all large historical earthquakes affecting wood-framed construction, yet to date no building jurisdictions have enacted mandatory rehabilitation ordinances. The City of Berkeley has a voluntary ordinance with tax incentives. Other jurisdictions like the City of Los Angeles Department of Building & Safety (LADBS) promote seismic rehabilitation of weak cripple walls by providing pre-approved retrofit details (see the excerpt in Figure 7. See also the discussion in FEMA 547.



Figure 8. Apartment Building with tuck-under parking in the San Fernando Valley, damaged in the 1994 Northridge Earthquake, temporarily braced to prevent collapse.

TUCK-UNDER PARKING

In wood-frame construction, the roof and floors collect and redistribute the earthquake forces to "shear walls" that act as stiff panels and deliver the forces to the building foundations. Typical wood-frame buildings act like a box, with the tops and bottoms corresponding to roofs, floors and foundation, and the shear walls acting like the sides of the box. Like a box, this provides stiff and strong configuration to resist earthquake and wind loads.

During the 1960s and early 1970s, tens of thousands of wood-framed, multi-unit residential buildings were constructed with tuck-under parking. However, such designs introduce large open area on the ground level where walls along the garage fronts are discontinued, leaving only slender columns to carry the gravity loads. The designs interrupt the "load path," like cutting out one of the side of the box at its base. As a result, the structural system is weaker, and prone to large distortions and twisting motions, multiplying damage.

These buildings were generally constructed prior to the 1980's. UBC revisions in 1976 and 1988 increased seismic load requirements and design with tuck-under parking has been discouraged (though not entirely eliminated). Newer apartment construction with a tuck-

under condition may have steel moment frames along the open face, or other structural systems to prevent a soft/weak story condition.

To date, no building jurisdictions have enacted mandatory rehabilitation ordinances for tuck-under parking. Some cities have begun programs to inventory weak-story buildings. See also the discussion in of tuck-under parking and associated rehabilitation techniques in FEMA 547.

SURFACE FAULT RUPTURE

Note that some single-family homes are exempted from the restrictions of the Alquist-Priolo Act, and may be built across faults deemed active by the State.

“A single-family wood-frame or steel-frame dwelling not exceeding two stories when that dwelling is not part of a development of four or more dwellings.”

ANALYSIS AND DESIGN OF WOOD FRAMES

The nonlinear, inelastic behavior of wood-framed buildings is extremely difficult to model. Wood as a material is light and strong, but its strength depends on the direction of wood grain, defects in wood members, and moisture content. Wood is subject to damage by fungus, water and fire. Modes of failure include nail bending and slip, sliding and overturning of wall piers, shear failures in wall sheathing, various connection failures, and crushing of boundary members. The roof and floor diaphragms of a wood building have rigidities that are similar to the rigidities of the wall elements that interconnect them. Whereas in the computer-based seismic analysis of steel or concrete buildings, we can assume that the roof and floors act as rigid diaphragms, such simplifying assumptions are not justified for most wood-framed buildings.

Given this complexity, most engineers rely upon elastic models and simplifying assumptions. For example, roof and floor diaphragms are assumed to be flexible, so that loads may be distributed in proportion to tributary floor area. Design fees for Structural Engineers designing typical wood-framed buildings are low, and sophisticated tools for nonlinear static and nonlinear dynamic analysis of complete wood buildings are lacking.

Good seismic performance of wood-framed construction relies heavily on good detailing of members and connections. Damage often occurs where seismic loads are transferred from diaphragm to shear wall, or from shear wall to foundation. Window and door openings often leave only narrow piers between them to resist seismic loads, with the result that these piers are subject to high shear and overturning forces. Modern wood-frames rely on sophisticated hold-down systems to resist overturning and shear transfer hardware (by Simpson Strong-Tie and others) to deliver the required performance.

SURFACE FAULT RUPTURE

Note that some single-family residences are exempted from the restrictions of the Alquist-Priolo Act, and so may be built across faults deemed active by the State. The Act exempts any “single-family wood-frame or steel-frame dwelling not exceeding two stories when that dwelling is not part of a development of four or more dwellings.”

WOOD-FRAME DAMAGE RELATIONSHIPS

Figure 9 shows typical damage relationships for wood-frame construction, as published by J.H. Wiggins (1986), ATC-13, NIBS' HAZUS software, and Wesson et al [Earthquake Spectra, 2004].

DAMAGE VARIABILITY

From statistics of residential damage in past earthquakes [from studies by K. Steinbrugge, as well as the Northridge study by Wesson et al, etc.], it is clear that variations of ground shaking and variation in wood-frame building vulnerability produce high variability in the observed damage. Figure 10 plots the coefficient of variation of the Damage Factor (DF) as a function of mean Damage Factor for wood-framed construction, as found in large damage surveys by various researchers. The Damage Factor is defined as repair cost divided by the replacement value of the structure. Coefficient of variation is defined as the standard of deviation (sigma) divided by the mean. The plot shows that for 10% damage (DF=10%), the standard deviation of damage is about 15%, so mean damage \pm one standard deviation would range from near zero to about 25 or 30 percent. For dwellings subjected to ground motions with peak horizontal accelerations of about 0.75g, damage states may range from "no damage" to rare cases of "complete damage."

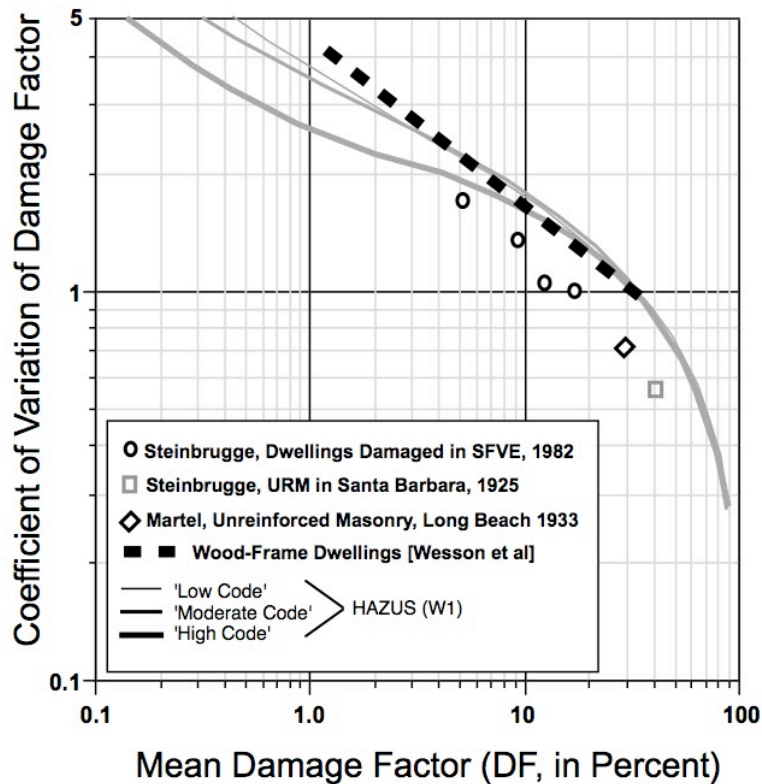


Figure 10. Uncertainty in Wood-Frame Earthquake Damage

COMMUNITIES IN HARM'S WAY

Based on the ground motion intensity shown in the simulations for the M7.8 San Andreas scenario, the geologic conditions, and age of the built environment, the following

communities are expected to experience significant damage to wood-framed construction. This list represents an initial “guess,” and is by no means rigorous or complete.

Table 1. Communities with expected heavy or moderate damage to wood-frame construction in M7.8 San Andreas scenario

Residential Communities with Expected Heavy Damage	Residential Communities with Expected Moderate Damage
Bombay Beach	Palm Springs
Mecca	Sun City Palm Desert
Thermal	Cathedral City
Coachella	Rancho Mirage
Indio	Banning
Bermuda Dunes	Beaumont
Indian Wells	Cherry Valley
Thousand Palms	Calimesa
North Rancho Mirage	Morongo Valley
Desert Hot Springs)	Rialto
North Palm Springs	Colton
Yucaipa	Loma Linda
Redlands	Grand Terrace
Highland	Highgrove
Muscoy	Crestline
San Bernardino	Hesperia
South Hesperia	Lancaster
Wrightwood	Acton
Palmdale	
Devore	
Valyermo	
Lakeview	

POST EARTHQUAKE INSPECTION

Following earthquakes like the San Andreas scenario in question, local building jurisdictions and others will need to conduct inspections and safety postings. ATC-20 (www.atcouncil.org) describes a typical procedure for such inspections.

Table 2, taken from the HAZUS MR-3 Technical Manual, presents descriptions of damage states for wood-framed construction.

Additional considerations:

- Finishes to wood-framed construction (e.g., stucco and drywall) are often more susceptible to damage than other structural elements such as plywood shear walls. For this reason, they serve as good indicators of overall damage. See CUREE Publications No. EDA-02 through EDA-07.
- Damage to wood-framed construction varies dramatically from one site to another.

Even neighboring structures may show dramatically different damage levels. There are many reasons for this, but this variability should be expected. Thorough inspections should be done in areas strongly shaken, since brief surveys can easily miss instances of highly damage.

- In the southern part of Riverside County and Imperial County, initial damage reconnaissance may need to be done from the air – due to the many small communities, widely scattered. Communications will be limited – perhaps to cellular phones, radio, CB, and satellite phones. Outside access by roads may be limited in the vicinity of Salton Sea and in other areas subject to liquefaction, landslide and surface fault rupture
- We note that a high percentage of the residents in Riverside, San Bernardino, and Imperial County are employed in the construction industries. As such, they may be able to effect their own repairs in many cases.

OPPORTUNITIES TO REDUCE THE DAMAGE

Local building jurisdictions can take steps to prevent the earthquake damage that can occur to weak forms of wood-framed construction. The following steps may be considered:

- Require seismic evaluation of apartments with tuck-under parking constructed prior to 1980, using the procedures in ASCE 31-03 or equivalent. Require seismic retrofit to remedy all soft/weak story conditions found.
- Require seismic evaluation of residences with cripple walls constructed prior to 1950, using the procedures in ASCE 31-03 or equivalent. Require seismic retrofit to remedy all soft/weak story conditions, unanchored foundations, or unsecured posts found.
- Reinforce the ‘quality chain’ – require good design, thorough plan check and inspection, etc.
- Insist on engineered design for all new wood-frames, rather than permitting construction under conventional light-frame rules.
- Require inspection of older homes at time of sale or refinancing, with disclosure of known seismic weaknesses.
- Require the addition of plywood sheathing for roofs with spaced sheathing at the time of re-roofing.

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