World Housing Encyclopedia

A Resource on Construction in Earthquake Regions

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HOUSING REPORT

Wood frame single family house

Report#	65
Last Updated	
Country	USA
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Important

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General Information

Building Type:	Wood frame single family house
Country:	USA
Author(s):	Chris Arnold
Last Updated:	
Regions Where Found:	Buildings of this construction type can be found in In the earthquake-prone regions of the Western USA wood frame housing accounts for about 98% of existing and new single family houses that are constructed. There is also a considerable market for prefabricated manufactured houses, generally of low cost, that use a factory-built version of standard wood frame construction. This type of housing construction is commonly found in rural, sub-urban and urban areas. There are many of these buildings in suburban areas too. Some wood frame single-family houses may still be found in a few urban areas: these are generally large houses that are now remodeled into a number of apartments or professional offices.
Summary:	Wood frame construction is typical for single family houses throughout the USA.. Historically, in the Eastern, Midwestern and Southern USA, brick masonry and stone were used for house construction, but this began to be superseded by wood frame around the turn of the nineteenth century. In the earthquake prone western regions of the USA stone and brick has been little used, and wood frame has been dominant throughout the development of these regions. The development of today#s wood frame construction began with the appearance of standardized sawn lumber and cheap machine made nails. By 1840 the typical wood frame house was built of milled lumber in standard sizes.(Reference 1) The standardized wood frame structure is now augmented by a wide range of compatible standardized components such as doors, windows, electrical and plumbing fixtures and the like, that are designed to be easily installed in the wood structure. Because wood frame walls are hollow, alternative levels of insulation can be installed enabling any climatic conditions to be accommodated and plumbing and electrical

	services are easily installed within walls, in the open spaces above ceilings, within the floor structure and in the space between the first (ground) floor and the ground below. Because of their light weight (compared to brick or stone), their relatively large number of walls, and the use of a multiplicity of nails for connections, woof frame houses have traditionally performed well in earthquakes. Deaths and serious injuries are very rare in these structures. Today#s wood frame construction is highly codified and regulated, with a good standard of inspection by suburban local building departments in earthquake-prone regions. In smaller towns and rural areas quality control may be lacking.
Length of time practiced:	76-100 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Single dwelling
Typical number of stories:	1-3
Terrain-Flat:	Typically
Terrain-Sloped:	Typically
Comments:	The standardized wood frame construction described here applies to houses built approximately from the 1940#s to today. Many de

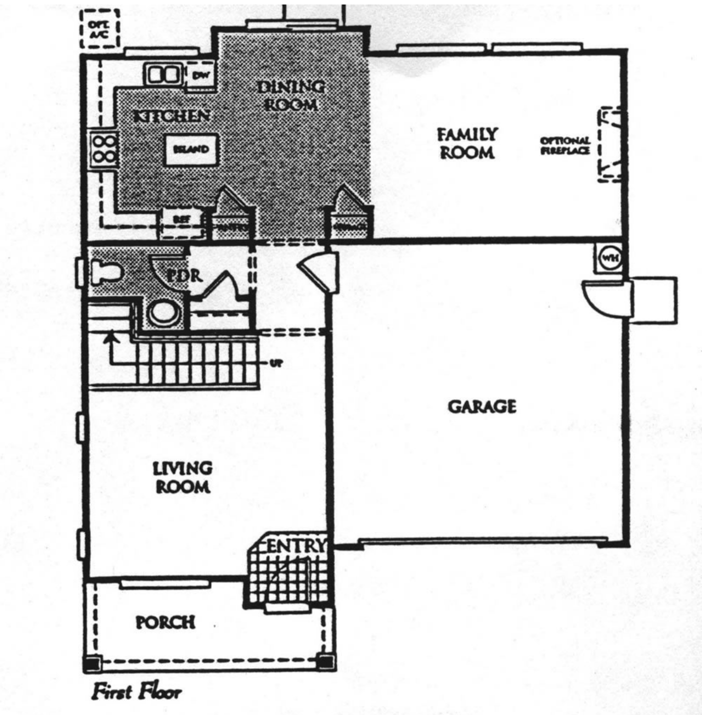
Features

Plan Shape	Rectangular, solidL-shapeU- or C-shape
Additional comments on plan shape	There is great variation in building configuration. Early small houses were generally rectangular or L-shaped or U- shaped. As house increased in size many variations of these basic forms were used. In addition, setbacks on the upper floors are common, and combinations of one and tow-story portions of the house. Sometimes portions of the house may be designed as post-and #beam structures, relying on sufficient shear walls to provide lateral resistance. In more recent merchant- built houses and architect designed houses two story interior spaces are common, often at the entrance or main living areas. Individual architect designed houses often have extreme configuration irregularities.
Typical plan length	

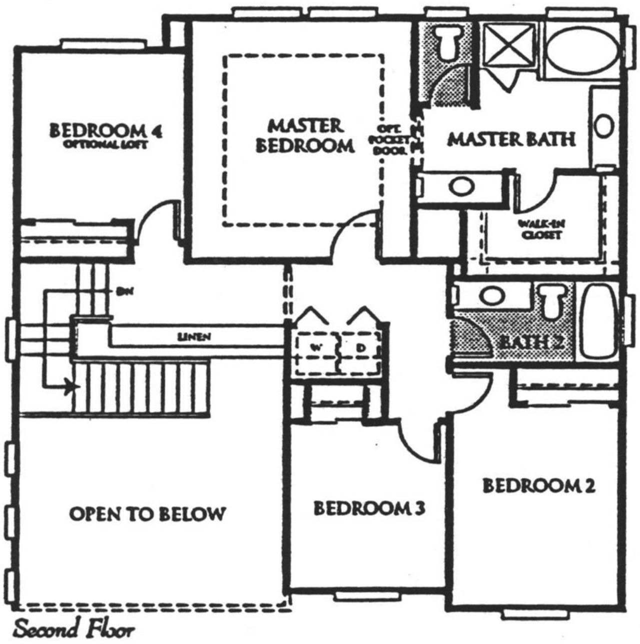
Typical plan length (meters)	15
Typical plan width (meters)	10
Typical story height (meters)	2.43
Type of Structural System	Wooden structure: Load-bearing Timber Frame: Stud wall frame with plywood/gypsum board sheathing
Additional comments on structural system	Gravity loads are accommodated by wood #studs#, commonly spaced at 16 inches (approx 400mm.) centers. The entire structural system is typically constructed from milled lumber which is 2 inches (approx. 50mm.) in thickness. Wood studs are 2 inches by 4 inches in section (approx 50mm X 100mm). If deemed necessary, the stud spacing may be reduced to 12 inches (approx 300 mm.) and the stud width increased to 6 inches (150 mm.). Floor and roof framing members are 2 inches in thickness and may be from 6 to 14 inches (150mm to 350mm) in depth. Construction lumber is supplied by merchants in standard dimensions of multiples of 2 inches: thus heavier beams are commonly 4 or 6 inches in width and 6 to 12 inches in depth. 2 inch wide members are connected by nails: larger members are connected by bolting. In the last two decades the use of metal nailed connectors has become common. (the finished dimensions of construction lumber are less than the nominal dimensions, which refer to the rough, unplaned material. A 2X4 is commonly 1.1/2 inches wide by 3.1/2 inches deep (approx. 40mm.X 90mm.) Lateral resistance is provided by a shear wall system consisting of plywood or manufactured wood panels (#particle board#) nailed to the vertical wood studs, creating shear walls. In lower seismic zones shear resistance may be provided by gypsum sheathing nailed to the studs. The vertical studs are connected to the foundation by bolting, and to the plywood or particle board panel diaphragms by nailing. A direct load path from roof to foundation is provided. The thickness and types of shear panels and the size and spacing of nails are specified in the building code. Older houses, before the common use of plywood, employed horizontal or diagonal sheathing nailed to the studs, or wood diagonal bracing nailed to the studs. When the structure is complete, waterproof building paper is attached to the exterior sheathing and the exterior finish material is applied. This is commonly cement plaster (#stucco#), wood or vinyl planks, or

	aluminum planks (in lower cost houses). In addition, brick masonry or stone is sometimes applied to the exterior as a non-load-bearing veneer.
Gravity load-bearing & lateral load-resisting systems	
Typical wall densities in direction 1	10-15%
Typical wall densities in direction 2	10-15%
Additional comments on typical wall densities	There is wide variation in wall density.
Wall Openings	There is great variation in openings in this type of construction. Early houses (1940s and 1950s) had relatively small openings, due to limitations in available window sizes . Architectural trends in the 1960s, together with the development of aluminum windows, resulted in large #picture windows#, #window walls# and the use of large sliding glass doors (#patio doors#.) Energy conservation requirements in the 1970s caused a reduction in window openings, but economic improvement and the development of standardized double glazed windows resulted in increasing openings. The mild climate in the western USA also encouraged large glazed areas and #indoor-outdoor living#. In general, openings are large and irregular: large skylight areas are now common, which may diminish the integrity of the roof diaphragm.
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	Modifications are not widespread occurrence in this building type. Possible patterns of modification are demolishing interior walls and extensions to buildings.
Type of Foundation	Shallow Foundation: Reinforced concrete strip footing
Additional comments on foundation	Other: Wood post and pier Houses constructed on soft of unstable soil sometimes use a foundation composed of a number of short concrete piles.
Type of Floor System	Other floor system
	Close spaced beams that support wood planks,

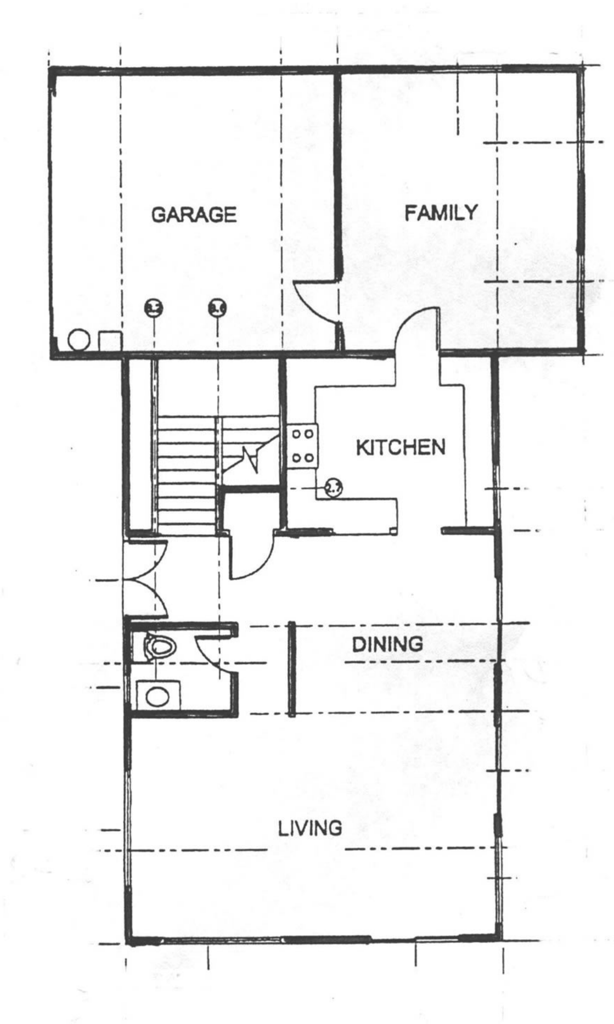
Additional comments on floor system	plywood, or manufactured wood panel sub-floor or roof structure. Although plywood diaphragms are nominally flexible, in wood frame construction the lightness of the entire structure is such that the diaphragms are assumed to maintain structural integrity in a design earthquake.
Type of Roof System	Roof system, other
Additional comments on roof system	Close spaced beams that support wood planks, plywood, or manufactured wood panel sub-floor or roof structure. Although plywood diaphragms are nominally flexible, in wood frame construction the lightness of the entire structure is such that the diaphragms are assumed to maintain structural integrity in a design earthquake.
Additional comments section 2	When separated from adjacent buildings, the typical distance from a neighboring building is 3-6 meters.



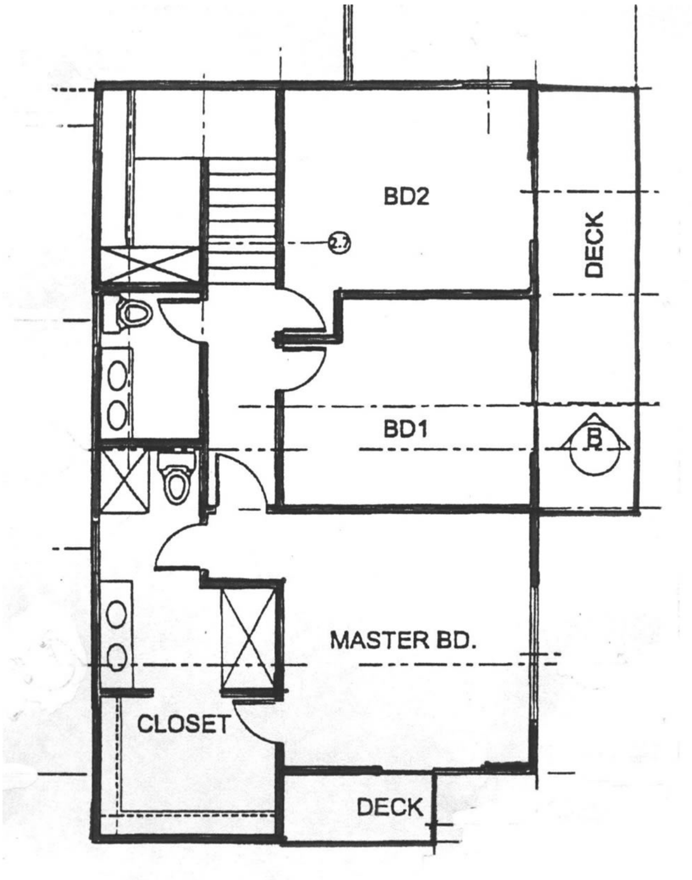
Plan of a Typical Building



Second floor plan of a typical building



Example 2: First floor plan



Example 2: Second floor plan

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame		These are described in Section 2
Foundations		These are described in Section 2
Floors		These are described in Section 2
Roof		These are described in Section 2
Other		

Design Process

Who is involved with the design process?	EngineerArchitectOther
Roles of those involved in the design process	Single family houses are not required to be architect or engineer designed. Developer built housing is generally designed by draftspersons, who though not licensed architects, specialize in residential design. In California, an increasing number of larger developers are now using architectural firms that specialize in residential design. Since developers' houses are now often of considerable size and complexity, it is common to employ engineers. Houses designed for individual owners are more likely to be architect and engineer designed. It has been estimated that approximately 2% of houses in the United States are designed by architects.
Expertise of those involved in the design process	

Construction Process

Who typically builds this construction type?	Other
Roles of those involved in the building process	Commonly built by developers, or by a contractor for an individual owner.
Expertise of those involved in building process	Basic framing is constructed by carpenters: sometimes this is subcontracted by the general contractor to a firm that specializes in wood frame construction. Installation of other components and specialized construction (such as installing windows or applying final finishes, exterior and interior, etc) is performed by specialized subcontractors to the general contractors. Each will be skilled in their specialty: a house may typically by employ over a dozen subcontractors.
Construction process and phasing	Typically built by a developer /builder (on speculation) or by a builder contracted by the owner. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size.
Construction issues	

Building Codes and Standards

Is this construction type address by	Yes

codes/standards?	
Applicable codes or standards	Wood frame construction has been regulated for several decades in California. The current code (such as the Uniform Building Code, used in California) defines wood frame construction in Section 23, and Earthquake requirements in Section 1630 (Reference 3). Structures that are one or two stories in height can use prescriptive code requirements that define the size and quality of all materials and will size framing members relative to spans and loads without the need for structural analysis. Three story structures require structural analysis, and any structure of irregular configuration or with other non-typical characteristics may require analysis at the discretion of the building official.
Process for building code enforcement	Complete plans and specifications must be submitted to the local building department for checking and approval. Building inspectors will inspect the structure at key points in the construction process. These are at such times as just prior to pouring foundation concrete, and at the completion of structural framing.

Building Permits and Development Control Rules

Are building permits required?	Yes
Is this typically informal construction?	No
Is this construction typically authorized as per development control rules?	Yes
Additional comments on building permits and development control rules	

Building Maintenance and Condition

Typical problems associated with this type of construction	
Who typically maintains buildings of this type?	Owner(s)

Additional comments on maintenance and building condition	

Construction Economics

Unit construction cost	Construction cost varies widely, depending on the geographic region and the quality and complexity of the building. In California, construction costs vary from about 60 US$/ft# to 200 US$/ft# (approx. 540 US$/m# to 1800 US$/m#). Houses are generally sold by developers on an all-inclusive basis: house and land, with some basic appliances, ready for the owner to move in. The house shown in Figure 3 is currently offered for sale at US$ 693,000. This house in constructed in the San Francisco Bay area, in a region with greatly inflated prices. In other parts of the Bay Area (further from the urban centers) the price might be half. In other parts of the country a comparable house might be one third the price or less. The difference is due to higher wage s and living costs in the western United States compared to many other states. The hypothetical house shown in Example 2, Section 2.3, is estimated to cost US$ 334,670 (in 2001 prices), or 127 US$/ft# in Los Angeles. These prices are for construction only and do not include land and marketing. They are median price estimates (Reference 2). Approximate regional variations are: Alaska: 146 US$/ft# Phoenix, Arizona 102 US$/ft#. Seattle, Washington 111 US$/ft# San Francisco 136 US$/ft#.
Labor requirements	Depending on size and complexity, a wood frame house takes from 4 months to a year to construct, exclusive of time required to obtain financing and necessary building and planning permits.
Additional comments section 3	

Concrete slab-on-grade, complete with wood sills installed ready to receive stud walls

Some wall framing is now installed

Carpenters installing a stud wall which has been constructed on the concrete slab

House is framed, sheathed with particle board and windows are installed

Socio-Economic Issues

Patterns of occupancy	Typically one family will occupy a house. Sometimes the house owner may rent out rooms to others, and in very low economic groups two or more families may share the house.
Number of inhabitants in a typical building of this construction type during the day	<5
Number of inhabitants in a typical building of this	

a typical building of this construction type during the evening/night	<5
Additional comments on number of inhabitants	Typically, in a house with pre-school children the day occupancy might be two or three. In a house with school age children, where both parents work, the day occupancy might often be zero. In a house with three or more children, the night time population might be five or more. At the upper income levels it is unusual for another relative beside the parents to live in the house. At the lower income levels extended families (grand parents, aunts, uncles) are fairly common.
Economic level of inhabitants	Very low-income class (very poor)Low-income class (poor)Middle-income classHigh-income class (rich)
Additional comments on economic level of inhabitants	The basic construction will apply to all houses: as the economic level rises the house will become larger, better finished and with superior equipment. Ratio of housing unit price to annual income: 1:1 or better
Typical Source of Financing	Owner financedSmall lending institutions/microfinance institutionsCommercial banks/mortgagesGovernment-owned housing
Additional comments on financing	The majority of houses are financed by banks or other lending institutions. Few houses are government financed , but some may obtain bank loans that are assisted by specific federal government programs, such as for veterans of the armed forces.
Type of Ownership	Own outrightOwn with debt (mortgage or other)
Additional comments on ownership	Very few houses are owned outright.
Is earthquake insurance for this construction type typically available?	Yes
What does earthquake insurance typically cover/cost	After the Northridge earthquake of 1994.private agencies withdrew from the business of residential earthquake insurance. Subsequently, the state California Earthquake Authority was set up, which provides "mini" earthquake insurance policies, not covering pools, patios, fences, driveways or detached garages. The deductible is 15%: the policies cover no more than US$ 5000 worth of home contents and provide a minimum of US$ 1500 in living expenses. The cost of these policies varies throughout the state depending on the earthquake

cover/cost	risk and the age and construction of the home. The cost is highest in San Francisco, where the policy for a US$ 300,000 wood frame house built before 1960 would cost US$ 1,710 per year. In Sacramento, the same policy would cost US$ 600. More recently, some private insurance companies have offered more favorable rates, with premium deductions if mitigation measures, such as bracing cripple walls, have been undertaken (Reference 4).
Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?	No
Additional comments on premium discounts	In earthquake-prone country, in which earthquake codes are in effect, it is assumed that the house is reasonably earthquake resistant, and so no premium discounts are offered for superior construction.
Additional comments section 4	

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter
1971	San Fernando Valley
1983	Coalinga
1989	Loma Prieta California

Past Earthquakes

	The Northridge (Los Angeles) earthquake of 1994 is estimated to have experienced a magnitude of M L = 6.4 on the Richter Scale. This was regarded as a moderately strong tremor but the specific

Damage patterns observed in past earthquakes for this construction type	characteristics of the earthquake showed it to be one of the worst in recorded history in the United States. A random sample of 340 single-family houses within a 10 mile radius of the epicenter provided the following analysis of damage: COMPONENT DAMAGE in % of sample NONE LOW MODERATE HIGH Foundation 90 8 1 1 Walls and roof 98 2 0 0 Exterior finish 50 46 3 1 Interior finish 50 46 4 0 Source: Adapted from report by NAHB (reference 3) The damage scale used was as follows: NONE No visible damage LOW Component stressed but functional MODERATE Severe stress evident, permanent deflection or near failure in any structural component HIGH Partial or complete failure of any structural component About 90% of the surveyed homes were built prior to 1970, using simple prescriptive requirements. Most of the homes were one-story. Structural damage was very infrequent and primarily located in the foundation system. Less than 2% of homes suffered moderate to high levels of damage and most occurrences were associated with localized site conditions including liquefaction, fissuring and hillside slope failures. In general, the three main types of damage are: #Damage to exterior walls, particularly from unbraced cripple walls and where stucco (cement plaster) is used without wood sheathing. #Damage (typically overturning) to water heaters #Damage to interior gypsum faced walls
Additional comments on earthquake damage patterns	

Structural and Architectural Features for Seismic Resistance

The main reference publication used in developing the statements used in this table is FEMA 310 “Handbook for the Seismic Evaluation of Buildings-A Pre-standard”, Federal Emergency Management Agency, Washington, D.C., 1998.

The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.

Structural/Architectural Feature	Statement	Seismic Resistance
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to	TRUE

	transfer inertial forces from the building to the foundation.	
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	TRUE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	TRUE
Roof Construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	TRUE
Floor Construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	TRUE
Foundation Performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	TRUE
Wall and Frame Structures-Redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	TRUE
Wall Proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	FALSE

Foundation-Wall Connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	TRUE
Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	TRUE
Wall Openings		FALSE
Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	TRUE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	FALSE
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	TRUE

Building Irregularities

Additional comments on structural and architectural features for seismic resistance	The entries in the table assume a well-designed building constructed in accordance with current codes.
Vertical irregularities typically found in this construction type	Other
Horizontal irregularities typically found in this	Other

construction type	
Seismic deficiency in walls	
Earthquake-resilient features in walls	
Seismic deficiency in frames	
Earthquake-resilient features in frame	
Seismic deficiency in roof and floors	
Earthquake resilient features in roof and floors	
Seismic deficiency in foundation	
Earthquake-resilient features in foundation	

Seismic Vulnerability Rating

For information about how seismic vulnerability ratings were selected see the Seismic Vulnerability Guidelines

	High vulnerability		Medium vulnerability		Low vulnerability	
	A	B	C	D	E	F
Seismic vulnerability class				|-	o	-|

Cripple wall failure, large house, Morgan Hill earthquake, California, 1994

Cripple wall failure detail, older house, Coalinga earthquake, California, 1983

The porch in front of this house has collapsed due to inadequate bracing, Whittier earthquake (Los Angeles), California, 1987

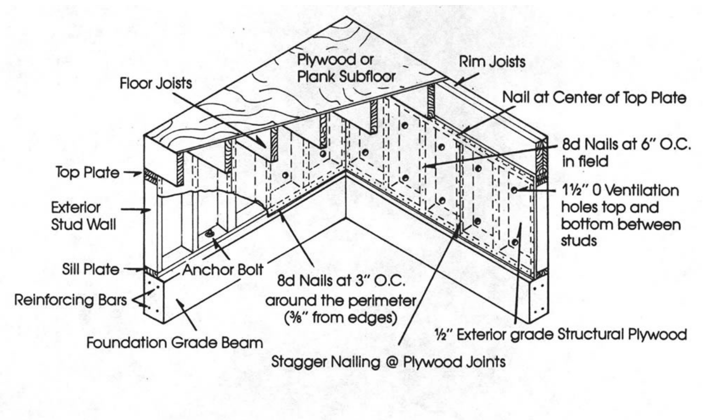
Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic Strengthening
unbraced cripple wall	Unbraced cripple walls are the most common deficiencies in wood frame houses. The figure shows the typical way in which an unbraced cripple wall is strengthened. It is not necessary to brace the entire wall: all corners should be braced together with some intermediate portions of wall, depending on the length of the walls. The work can be done at very low cost by a home owner who has moderate carpentry skills. If the work is performed by a contractor it may cost from $3,000 to $10,000 depending on the size and complexity of the work. See Figure 21.

Additional comments on seismic strengthening provisions	
Has seismic strengthening described in the above table been performed?	
Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?	
Was the construction inspected in the same manner as new construction?	
Who performed the construction: a contractor or owner/user? Was an architect or engineer involved?	
What has been the performance of retrofitted buildings of	

this type in subsequent earthquakes?	
Additional comments section 6	



Typical unbraced cripple wall strengthening

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