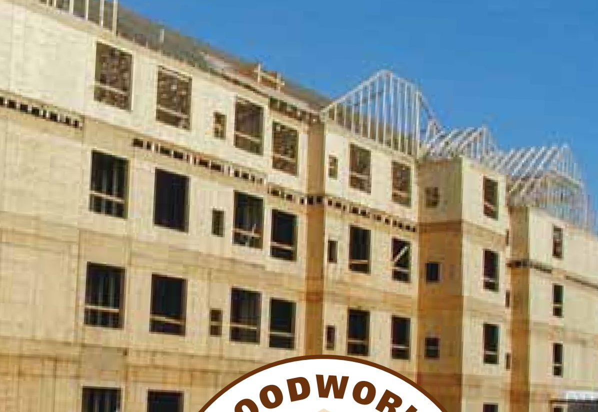


Designing for Earthquakes

Wood Design & Building Series

Years of research and building code development have proven that wood-frame construction can be configured to meet or exceed the most demanding earthquake design requirements. The key is understanding the effects of lateral loads on wood framing systems, and how construction detailing and fasteners affect the ultimate performance of a structure.

There are over three million earthquakes each year, but most are too small to be felt. They can occur anywhere; however, the likelihood of earthquakes strong enough to threaten buildings is especially high in certain areas. In North America, where wood-frame construction is common, loss of life due to earthquakes has been relatively low compared to other regions. As design and building professionals look increasingly to wood-frame construction for office, retail, school and other non-residential applications, it is reassuring to know that the same basic technology that has provided residential construction the ability to survive earthquakes can be applied to larger buildings.

Earthquake Effects on Buildings

It is well known that the west coast of the United States has a high likelihood of earthquakes. In fact, more than 40 of the 50 states are at some risk from damage caused by seismic forces.

The type of seismic ground motion at a building site depends on a number of factors, including:

- Distance of the building from the earthquake's epicenter
- Magnitude of the earthquake
- Depth of the earthquake's focus, and
- Soil conditions at the building site

Earthquakes affect buildings differently depending on the type of ground motions and characteristics of the building structure. If the ground motion is strong enough, it will move a building's foundation. However, inertia tends to keep the upper stories in their original position, causing the building to distort (*Figure 1*). Since inertial forces are greater when objects are heavier, earthquake forces are greater in heavier buildings. Higher ground accelerations also create more stress in a structure.

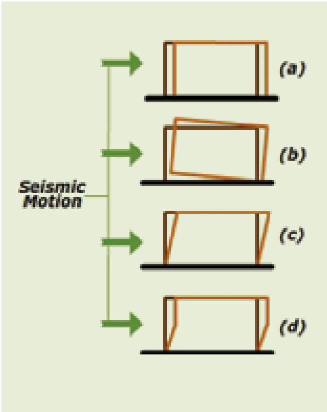


Figure 1

Earn one AIA/CES LU (HSW) by reading this document and taking a short online quiz. For details and learning objectives, visit the Online Training Library at *woodworks.org*. WoodWorks is an approved AIA provider.

Code Requirements

Building codes address the probability and severity of earthquakes by providing design requirements specific to regional risks. With the exception of post-disaster buildings that are required to remain in service after an earthquake, codes accept that some structural damage can be tolerated as long as the possibility of collapse is minimized. This is in recognition that, when designing for a highly infrequent event, it is not economical to prevent structural damage to all buildings.

Building codes establish the minimum lateral forces for which buildings must be designed to provide life safety for the occupants. To do this, they provide an equation in which the cyclic seismic forces are represented by a single static force, called the "base shear," applied at the base of a building. Variables in the equation enable the designer to adjust the design force for varying site seismicity, soil conditions, structural and nonstructural systems and materials (building ductility), building height, and occupancies. (For example, a hospital would need to perform better in an earthquake than a warehouse.)

Current codes, such as the *International Building Code (IBC)*, define site seismicity by means of seismic contour lines, proximity, construction type and building occupancy, and provide numerical values for the acceleration used for design.

The correct design of critical elements such as frames, shear walls, diaphragms and their connections to each other is of utmost importance as earthquake forces "search out" the weak links between structural members. Where there is serious damage or collapse, research shows it is often initiated by connection failure.

In addition, the following best practices should be applied:

- The configuration of the building (its size and shape) should be as simple and regular as planning and aesthetic requirements permit. Experience has shown that irregular building shapes and certain architectural design elements contribute to poor seismic performance.
- A high level of quality control is required to ensure that the building is constructed according to the design requirements.
- An adequate level of inspection and maintenance is required to ensure that the building retains its integrity over time.

The 2006 IBC brought changes in both format and content of seismic design requirements. For wood-frame buildings, there was an expanded and updated reference to *Minimum Design Loads for Buildings and Other Structures, ASCE 7-05* for earthquake loads and the addition of *2005 Special Design Provisions for Wind and Seismic* and *2005 National Design Specification® for Wood Construction (NDS)®* for the design of wood-frame lateral force resisting systems.

A combination hotel and residential structure in Napa, CA, the Westin Verasa Napa Residences was designed to withstand seismic forces.

Why Wood-frame Buildings Can Withstand Seismic Forces

Wood-frame construction has several characteristics that enhance earthquake performance:

DUCTILITY

Ductility is the ability of a structure to yield and deform without fracturing. Wood-frame structures, which have numerous nailed joints, are inherently more ductile than those with rigid connections. This makes them more flexible and allows them to dissipate energy when subjected to the sudden loads of an earthquake. The fact that wood structures have numerous load paths also helps to avoid collapse should some connections fail.

STRENGTH AND STIFFNESS

The lateral forces of an earthquake tend to distort (rack) buildings. Shear walls are critical for providing racking resistance, and walls and diaphragms (roofs and floors) constructed with plywood or oriented strand board (OSB) structural sheathing over lumber framing are very effective. In locations where there is a high likelihood of strong earthquakes, the stiffness and resistance of structural elements is bolstered by using thicker structural panels (on both sides if necessary) and increasing the number and size of nails. There are also new wall-system-developments that have even greater lateral capacity, such as Midply systems (see *Sources*).

WEIGHT

Wood-frame construction is lighter than other types of construction. (Concrete walls are about seven times heavier than typical wood-frame walls.) Since forces in an earthquake are proportional to the weight of a structure, light weight wood-frame buildings that are properly designed and constructed

REDUNDANCY

Wood-frame construction provides numerous load paths through shear walls and diaphragms, which typically have hundreds of structural elements and thousands of nail connections. This means that overloading can be transferred to alternate load paths. Alternatively, structures supported by heavy frames constructed from non-wood materials have relatively few structural members and connections. The failure of one load path due to design or construction flaw can lead to overloading of adjacent members or joints.

CONNECTIVITY

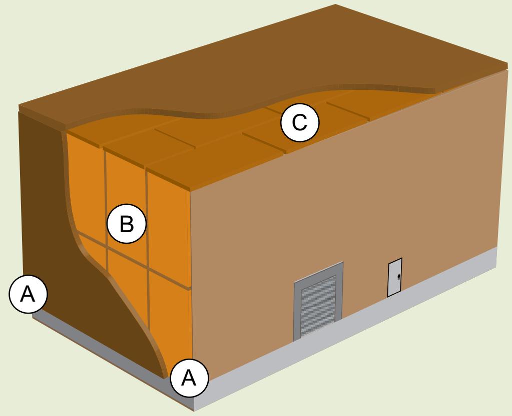
The connection of structural elements to the foundation is essential. Wood-frame construction is easy to secure to the foundation using standard connections and tie-downs manufactured for high-load designs.

DESIGN REQUIREMENTS

Engineered systems are designed to resist calculated earthquake loads. A lateral load path is established and each element is designed to resist the calculated earthquake force. Roofs and floors can be designed as diaphragms and some of the walls are designed to function as shear walls (*Figure 2*). Diaphragms and shear walls are used to transfer loads and to keep the building from distorting or twisting. Engineered designs require adequate sizing of lumber framing elements and connections between all of the elements in the load path.

Connections are especially important as this is where the majority of failures occur. Therefore, nails and framing anchors are typically required to connect the diaphragms to shear walls. Hold-down connections are used to hold down the corners of the shear walls and additional anchor bolts are required to connect shear walls to the foundation.

Hundreds of structural elements and thousands of nail connections provide alternate load paths.



A – Hold-down connectors at the bottom corners of each shear wall prevent overturning of the shear wall segments under seismic forces; B – Shear walls on all sides of the building transfer forces to the foundation; C – Diaphragms on the roof and floors transfer lateral forces.

Figure 2

Experience from Past Earthquakes

In California, there are over four million square feet of public schools and 80% of this area is wood-frame construction. An assessment of the damage to school buildings in the 1994 Northridge earthquake was summarized as follows:

> "Considering the sheer number of schools affected by the earthquake, it is reasonable to conclude that, for the most part, these facilities do very well. Most of the very widespread damage that caused school closure was either non-structural, or structural but repairable and not life threatening. This type of good performance is generally expected because much of the school construction is of low rise, wood-frame design, which is very resistant to damage regardless of the date of construction."[1]

In 2002, the California Department of Government Services completed a legislated inventory and earthquake worthiness assessment of schools. School buildings that were constructed of steel, concrete, reinforced masonry or mixed systems designed between 1933 and July 1, 1979 were required to be evaluated. Older wood-frame schools were exempted on the basis that "wood-frame buildings are known to perform well in earthquakes."[2]

1. *The January 17, 1994 Northridge, CA Earthquake An EQE Summary Report,* March 1994 www.lafire.com/famous_fires/940117_NorthridgeEarthquake/quake/03_EQE_commerical.htm
2. *Seismic Safety Inventory of California Public Schools,* California Department of Government Services, 2002 www.documents.dgs.ca.gov/Legi/Publications/2002Reports/Final AB300Report.pdf

Following is a brief summary of the way wood-frame buildings have performed in North American earthquakes:

San Leandro earthquake, 1971: The earthquake affected commercial buildings and many single-family homes as well as hospitals. Many masonry buildings with design faults collapsed or were severely damaged and had to be demolished. This shows that buildings that appear to be "solid" are subject to damage if their design and construction does not meet modern code requirements. Wood-frame houses performed well, especially from the standpoint of life safety.

Loma Prieta earthquake, 1989: The earthquake caused the collapse of a number of engineered structures including the double deck freeway in Oakland that resulted in the death of 49 motorists. Houses at the epicenter—most of which were wood-frame construction—were subjected to high peak ground accelerations and performed well unless they were located where ground fissures developed or had large openings in lower story walls.

Northridge earthquake, 1994: Though moderate in size (magnituded 6.7 on the Richter scale), the peak ground accelerations were among the highest ever recorded and significantly higher than those specified in building codes at the time. There were numerous building collapses, including many large structures. At a hearing before the U.S. House of Representatives by the Committee on Space, Science and Technology, one of the reasons given for the limited deaths and injuries was: "The earthquake occurred at 4:31 a.m., when the majority of people were sleeping in their wood-frame, single-family dwellings, generally considered to be the safest type of building in an earthquake."

Wood-frame construction has benefited from many research projects ranging from tests on the smallest nail to full-scale earthquake simulations. The extent and quality of this research has meant an increasing ability to understand how earthquakes affect wood structures and how to design them to perform even better.

Earthquakes cannot be prevented but sound design and construction based on research and building code development can reduce their effects. Wood-frame construction is proven to perform well against lateral loads and can be designed and constructed to meet or exceed the most demanding earthquake design requirements—while providing a wide range of other benefits.

SOURCES AND OTHER MATERIALS

American Wood Council / American Forest & Paper Association, www.awc.org

- *ANSI/AF&PA NDS-2005 – National Design Specification for Wood Construction (NDS)*
- *ANSI/AF&PA SDPWS-2005 – Special Design Provisions for Wind and Seismic Standard with Commentary*
- *Benchmarking Seismic Base Shear to Historical Practice*
- *Seismic Requirements for Wood Building Design: Recent Changes to ASCE-7 and IBC*
- *Wood Frame Construction Manual*

APA – The Engineered Wood Association, www.apawood.org

- *Design Concepts: Building in High Wind and Seismic Zones*
- *Diaphragms and Shear Walls*
- *EWS Data File: Lateral Load Connections for Low-slope Roof Diaphragms*
- *Introduction to Lateral Design*

FPInnovations – Forintek Division, www.fpinnovations.ca

- *Performance of Wood-frame Building Construction in Earthquakes*, Rainer, J. and E. Karacabeyli, FPInnovations – Forintek, Special Publication No. 40, 1999
- *Midply Shear Wall System: Performance in Dynamic Testing*, Varoglu, E. et al, Journal of Structural Engineering, Volume 133, Issue 7, pp. 1035-1042 (July 2007)
- *Ensuring Good Seismic Performance with Platform-frame Wood Housing*, Rainer, J. and E. Karacabeyli, National Research Council Canada, Construction Technology Update No. 45, Dec. 2000. http://irc.nrc-cnrc.gc.ca/pubs/ctus/45_e.html

Other

- *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds, Risk Management Series, Federal Emergency Management Agency*, www.fema.gov

Materials are also available via the WoodWorks Web site, in the section on *Key Issues/Seismic Protection*, www.woodworks.org

WoodWorks is an initiative of the Wood Products Council, which includes all of the major North American wood associations.

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