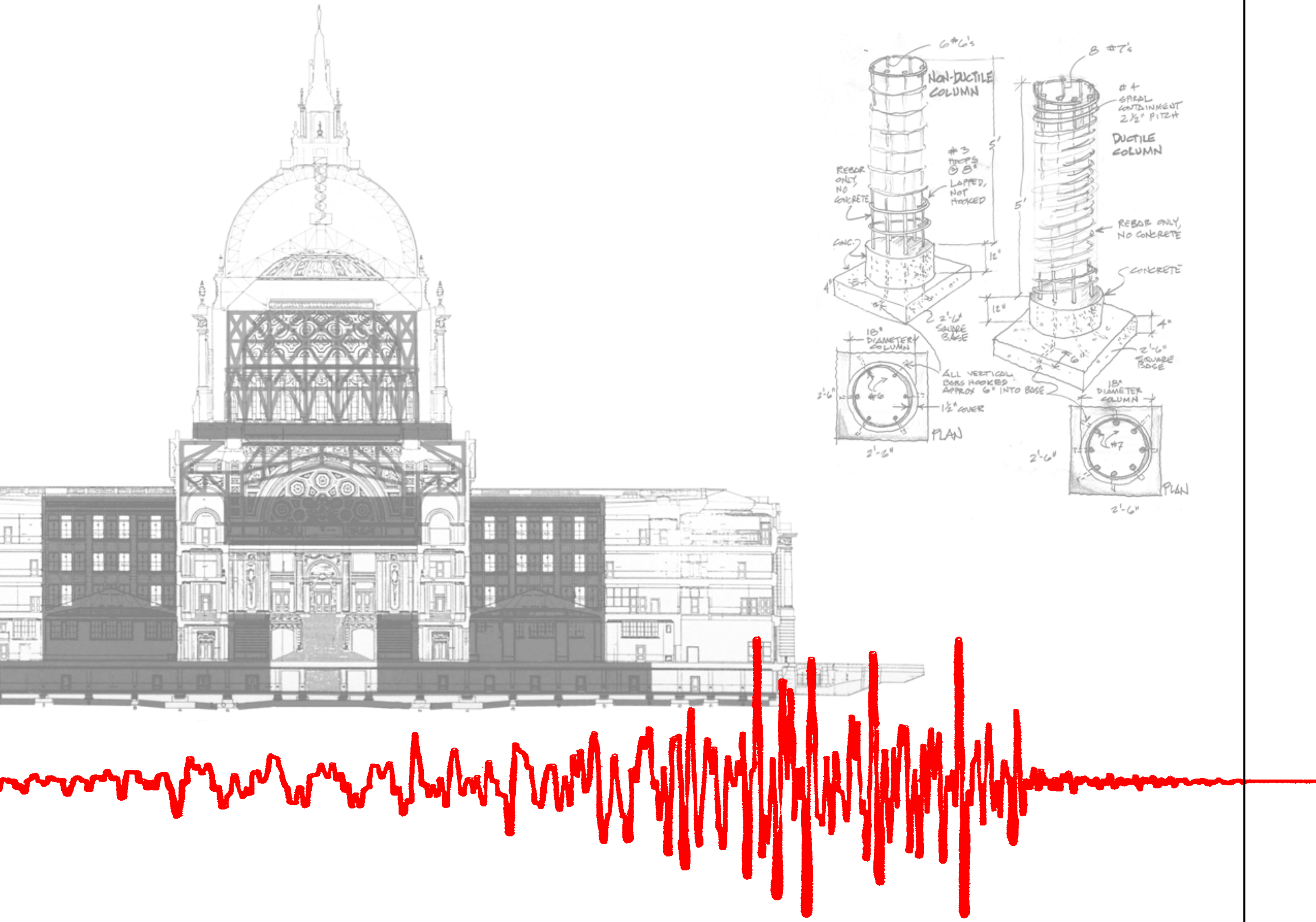



the San Francisco Department of Building Inspection presents

EARTHQUAKE ENGINEERING

by

Consortium of Universities for Research in Earthquake Engineering



DEPARTMENT OF BUILDING INSPECTION

City & County of San Francisco
1660 Mission Street, San Francisco, California 94103-2414

The Department of Building Inspection is pleased to support the educational activities of CUREE as part of the commemoration of the Great San Francisco Earthquake and Fire of 1906. This Centennial exhibit is closely aligned with the mission of the Department of Building Inspection:

> **To serve the City and County of San Francisco and the general public by ensuring that life and property within the City and County are safeguarded, and to provide a public forum for community involvement in that process.**

Under the direction and management of a seven-member citizen Building Inspection Commission, it is the mission of the Department of Building Inspection to oversee efficient, fair and safe enforcement of the City and County of San Francisco's Building, Housing, Plumbing, Electrical and Mechanical Codes, along with the Disability Access Regulations.

In the past year, the Department of Building Inspection issued over 61,000 permits, conducted over 131,000 inspections on construction valued at over $1.3 billion. Many of the 26,659 building permits issued included earthquake safety measures.

It is our hope that this exhibit will provide information and encouragement to San Franciscans to consider the earthquake safety of the buildings in which they live and work, and to be better prepared for future earthquakes of any magnitude.

March 26, 2006

the San Francisco Department of Building Inspection presents

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A free public exhibit held April, 2006
At the Yerba Buena Lane Plaza, Market Street, San Francisco

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CONSORTIUM OF UNIVERSITIES FOR
RESEARCH IN EARTHQUAKE ENGINEERING
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INTRODUCTION

A public exhibit on earthquake engineering in San Francisco during the centennial of the April 18, 1906 earthquake seems so appropriate it may not need any explanation of its rationale. However, there is a definite purpose: To give the general public some insights into the practice of earthquake engineering which, though they may not have recognized its features, is all around them.

Earthquake engineering is the application of engineering to the earthquake problem. It is a sub-category of civil engineering, which includes the kinds of engineering needed to design and construct the physical features that we live and work in everyday: buildings, bridges, airports, highways, water supply systems, and so on. This exhibit provides some examples that explain the work of earthquake engineers and points out a few earthquake problems and solutions.

Structural engineering is a primary part of earthquake engineering. Structural engineers design the construction that holds up a building or other structure to resist gravity and—in an earthquake-prone region—must deal with the more challenging problem of earthquakes. In California, the professional title “Structural Engineer” is regulated, and only civil engineers with the necessary qualifications can use that term. Geotechnical engineers specialize in the engineering aspects of the localized ground, considering both the gravity and earthquake forces of the way a building or other structure and its foundation are supported.

Students who would like to become structural or geotechnical engineers should take a full set of mathematics and science courses in high school. In college, by the freshman or sophomore year, a student should have a major in civil engineering (often called today a Department of Civil and Environmental Engineering). Getting a master’s degree in addition to an undergraduate degree is usually recommended. Our website has information and links to universities on earthquake engineering and civil engineering programs.

Seismology is the other primary discipline earthquake engineers rely on in their design work. Seismology deals with the causes of earthquakes—the breakage of rock along faults—and the way ground motion travels through the ground to shake a particular site. Students who would like to become seismologists should take a full load of math and science in high school, and then major in what is called a Department of Geology or Department of Earth Sciences in college. Graduate school leading to a master’s or PhD degree is also usually recommended.

Acknowledgment of the funding and energetic staff work of the San Francisco Department of Building Inspection is important to note here, in particular the leadership of Chief Building Inspector Laurence Kornfield and Technical Services Building Inspector Kirk Means. Our thanks for exhibit materials by Taylor Devices, EPS, Forell-Elsesser, the NIED E-Defense facility in Japan, and funding by the Federal Emergency Management Agency in a previous CUREE project on woodframe construction. CUREE staff members Reed Helgens, Associate Executive Director, and Darryl Wong, Media Manager, skillfully did whatever it took to accomplish the various tasks involved in putting on such an exhibit. CUREE President and structural engineer Professor Andrew Whittaker of the University at Buffalo helped provide engineering guidance.

Further Information: For those unable to attend the exhibit in the Yerba Buena Lane plaza on Market Street. This Exhibit Guide is designed to provide additional information on the exhibits you will be viewing. This publication and further information can also be accessed at the CUREE website: www.curee.org.

Bob Reitherman, *Executive Director*
Consortium of Universities for Research in Earthquake Engineering (CUREE)

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EXHIBITS

E-Defense Shake Table

The Biggest Shake Table in the World

A shake table is a **dynamic** earthquake simulator that can “re-play” the record of earthquake motions from a past earthquake or vibrate to represent expected future ground motions.

The largest such facility, able to carry a structure weighing **1200 metric tons**, is located in Miki City, Japan and is known as E-Defense. The shaking platform is 15 by 20 meters (about 50 by 65 feet) in plan. A building five-stories tall will fit on the platform.

E-Defense Shake Table near Kobe, Japan, ready to test a full-scale house.

As with the abrupt starting and stopping of a car, **acceleration** is a measure of the severity of the movement. The E-Defense shake table can reproduce the maximum usually recorded in earthquakes, about **1 g**.

The E-Defense shake table can shake an entire building model the way an earthquake does—in **3 dimensions**. During an earthquake, the ground shakes with some vertical motion while also shaking horizontally in various directions. Size and power are useful in a shake table to allow for larger, more realistic structural models to be tested, however, a sophisticated shake table must be able to accurately reproduce particular earthquake motions. Like a high-quality **hi-fi** system playing the music off a CD or electronic file with fidelity or accuracy, a high-quality shake table accurately plays back an earthquake ground motion without “noise” or distortion.

Actuators under the shake platform provide this 3-D, accurate, and powerful earthquake simulation. The computer-controlled brute force that powers the actuators is hydraulic; it comes via pipes to each actuator from a large supply of pumped-up oil pressure. In autos (e.g. brakes) and airplanes (e.g. ailerons on the wings), **hydraulic** systems provide similar but much smaller control forces.

dynamic: rapidly changing, moving

1200 metric tons: about the weight of 600 autos

acceleration: change in speed or direction

1 g: a drag racer reaching 200 mph in 6 seconds exerts 1.4 g’s.

3 dimensions: 2 horizontal axes, X and Y, and vertical axis, Z

hi-fi: high-fidelity

actuators: pistons

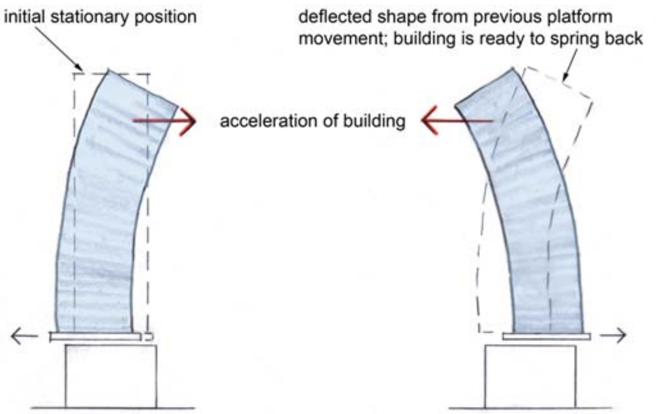
hydraulic: force exerted by fluid under pressure

Credits: Model of the E-Defense shake table courtesy of NIED, National Research Institute for Earth Science and Disaster Prevention, Hyogo Earthquake Engineering Research Center, E-Defense Facility, Dr. Masayoshi Nakashima, Director; **For more information:** www.bosai.go.jp/hyogo/

Model of Building Being Shaken by an Earthquake

It Takes Two to Tango

A small building model on a shake table illustrates **dynamic response**. The earthquake motion of the ground (or shake table) only partially determines how severely the building (or model) shakes. Equally significant is how much the structure tunes into the rate of ground shaking. “It takes two to tango.” The rate of ground shaking varies erratically in an earthquake, but is usually most intense at a **frequency** of around 2 cycles per second. Stiffening a building with more earthquake bracing gives it a higher frequency; increasing its mass gives it a lower frequency. Each building has a built-in or natural tendency to sway back and forth at a particular rate—its **natural frequency**.



Platform moves to left. Mass of building tries to stay in original position -- that’s inertia -- but the base is forcibly moved, causing the building to feel acceleration. This makes the building bend over toward the right.

Platform moves to right. This throws the building back to the left -- just as the building is about to spring back that direction anyway. The two motions reinforce each other -- that’s resonance -- and increases the building acceleration.

There is more **resonance** when the frequency of the ground motion and the inherent frequency of the building closely coincide—as in this demonstration model. More resonance means greater earthquake forces that the structure must resist. These factors are taken into account in building codes such as in the **UBC** or **IBC** and local versions such as the San Francisco City Building Code.

Structural engineers and **geotechnical engineers** make calculations based on both the structure and the earthquake and compute the necessary earthquake resistance for that combination. If earthquakes with frequencies matching a building’s natural frequency occur in a region, high **accelerations** in the building result. If there is more acceleration, there is more force, and the building design must then be stronger.

dynamic response: movement in response to vibrations

frequency: number of back-and-forth cycles per second; called Hertz (Hz)

natural frequency: inherent tendency to vibrate at a given rate

resonance: boosting of response because of similarity of building and ground motion frequency

UBC: Uniform Building Code

IBC: International Building Code

structural engineers design the structure of the building

geotechnical engineers analyze the soil and its earthquake properties

accelerations: changes in direction or speed

Credits: Accelerograph instrumentation and software by Kinemetrics Inc. **For further information:** http://webshaker.ucsd.edu/, UC San Diego “web shaker” shake table; http://cive.seas.wustl.edu/wusceel/ucist/, the University Consortium on Instructional Shake Tables. Information on engineering professions: American Society of Civil Engineers (www.asce.org) and structural engineers associations (http://seaint.org/)

The “Soft Story” and Its Remedies

The Problem of Fewer Walls at Ground Level

architect: licensed designers of buildings; the career starts with a college degree in architecture

lateral: horizontal

structural engineer (SE): requires a civil engineering degree, passing state exams, and work experience

shear walls: walls that resist lateral forces

braced frames: diagonal bracing

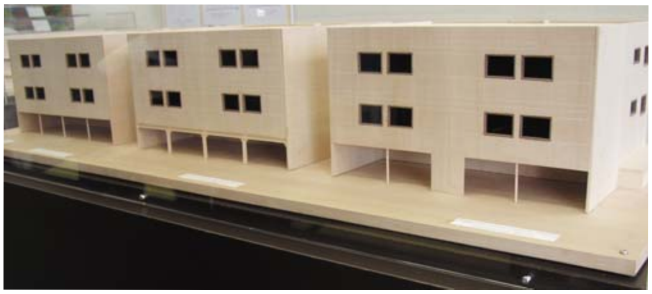
moment-resisting: ability to resist rotation and keep a joint rigid; a column-beam frame with such joints is a “moment frame;” round steel pipe columns are not usually part of a moment-resisting frame

An **architect** often has practical reasons for having fewer walls at the ground level of a building. A building may have larger public spaces at this entry level, such as lobbies, large meeting rooms, or open-plan retail space. In urban locations, residential buildings sometimes have fewer walls at the ground level to allow for parking underneath the building.

When a multi-story building is shaken in an earthquake, the bottom story must carry the sideways force of the moving story above, and that upper story carries the **lateral** force from above and so on. The horizontal forces (as well as vertical gravity forces) thus build up toward the base. When a lower level of a structure is weaker than the stories above it is called a soft story—this is an earthquake vulnerability.

When the **structural engineer** is faced with this building layout in new designs, there are ways to pack more strength in the ground story columns or walls to eliminate the soft story condition. In existing buildings, it is more difficult but still feasible to add lateral bracing to counteract the openness of a ground story. Retrofit options include (with associated foundation work):

- **shear walls** that are parallel to the open side or sides;
- diagonal bracing, such as X-braces. Usually made of steel, these **braced frames** are often seen in storefront retrofit situations;
- steel or reinforced concrete frames that resist lateral forces, which can be arranged around openings; these column-beam frames have **moment-resisting** joints.
- an innovative garage door bracing scheme is now being investigated by the San Francisco Department of Building Inspection



Models of Woodframe Apartment Buildings with Tuck-under Parking.
[SHOWN LEFT]: no added seismic bracing; [CENTER]: steel moment-resisting frames added;
[SHOWN RIGHT]: shear wall added

Credits: Models by University of Southern California architecture students under the direction of Prof. G. G. Schierle, in the CUREE-Caltech Woodframe Project, funded by the Federal Emergency Management Agency through a grant administered by the California Office of Emergency Services. **For Further Information:** www.curee.org/projects/woodframe/; www.seaint.org/; www.sfgov.org/site/dbi

Collapse of the Northridge Meadows Apartment Building

The Northridge Earthquake

The January 17, 1994 Northridge Earthquake in the Los Angeles area caused the greatest property loss to date resulting from an earthquake in America. Fortunately, because of generally adequate earthquake-resistant construction and a long history of enforcement of **building code** regulations in the region, life loss was low—less than 60. However, sixteen fatalities occurred all at once in the same place—the Northridge Meadows Apartment Building—indicating the potential for life loss when a structure collapses.

The **soft story** configuration of the building was its key weakness: To allow for parking underneath the building in many locations, there were fewer structural walls at the ground level. Engineering and construction measures to counteract that weakness were not present, and when the earthquake occurred at 4:31 AM that day, extensive ground story collapse occurred. The details of the collapsed building are shown in the display model.

RIGHT: E-Defense **shake table** test in Japan of housing with large ground floor openings, with (right) and without (left) special bracing

BELOW: Model of collapsed Northridge Meadows Apartment Building; **tuck-under** parking at ground level

building code: laws, usually locally enforced, that require building permits and set construction standards

soft story: a story with less horizontal strength than the level above

shake table: engineering testing apparatus; platform moves to simulate an earthquake

tuck-under: located underneath the building

Credits: Model by Graphic Blade, in the CUREE-Caltech Woodframe Project, funded by FEMA through a grant administered by the California OES; E-Defense photo courtesy of NIED/E-Defense. **For Further Information:** www.curee.org/projects/woodframe/, CUREE, (see Case Studies report and "Shake Table Test of Multistory Apt. Bldg."); EERI, www.eeri.org, (see "Soft Story Fact Sheet")

Hillside Houses

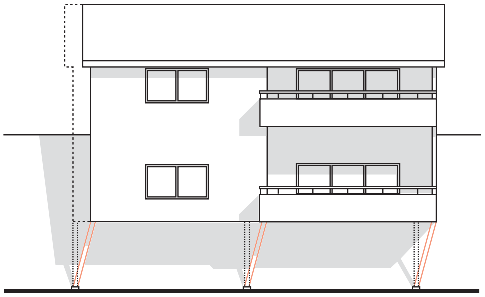
The Special Problems Posed by Hillside Houses

When a house is built on a hillside, there are two basic ways to deal with the slope:

- Cut into the hill to make a level surface;
- Extend a floor out over the slope and support it from beneath. With this second option, **seismic bracing** underneath the floor structure is necessary.

LEFT: A hillside house model illustrating steel diagonal bracing connected to floor **beams** across the open front ground level

RIGHT: Model of a similar hillside house without this bracing, with illustration of a dangerous amount of **drift** during earthquake.



In typical house construction, the horizontal resistance to shaking of vertical wood structural members (**columns**) is insignificant. With a house of this layout, a common seismic bracing solution is to use diagonal braces. Properly engineered, earthquake forces can be resisted by these **braced frames**. Another retrofit option is solid walls extending under the building down to a foundation. These walls require adequate sheathing (e.g. plywood or oriented strand board), in addition to proper nailing and use of steel connection hardware at top and bottom.

seismic bracing: earthquake bracing

beams: horizontal structural framing; girder

drift: amount the structure leans over

columns: posts

braced frames: diagonally-braced rectangles formed by columns and beams

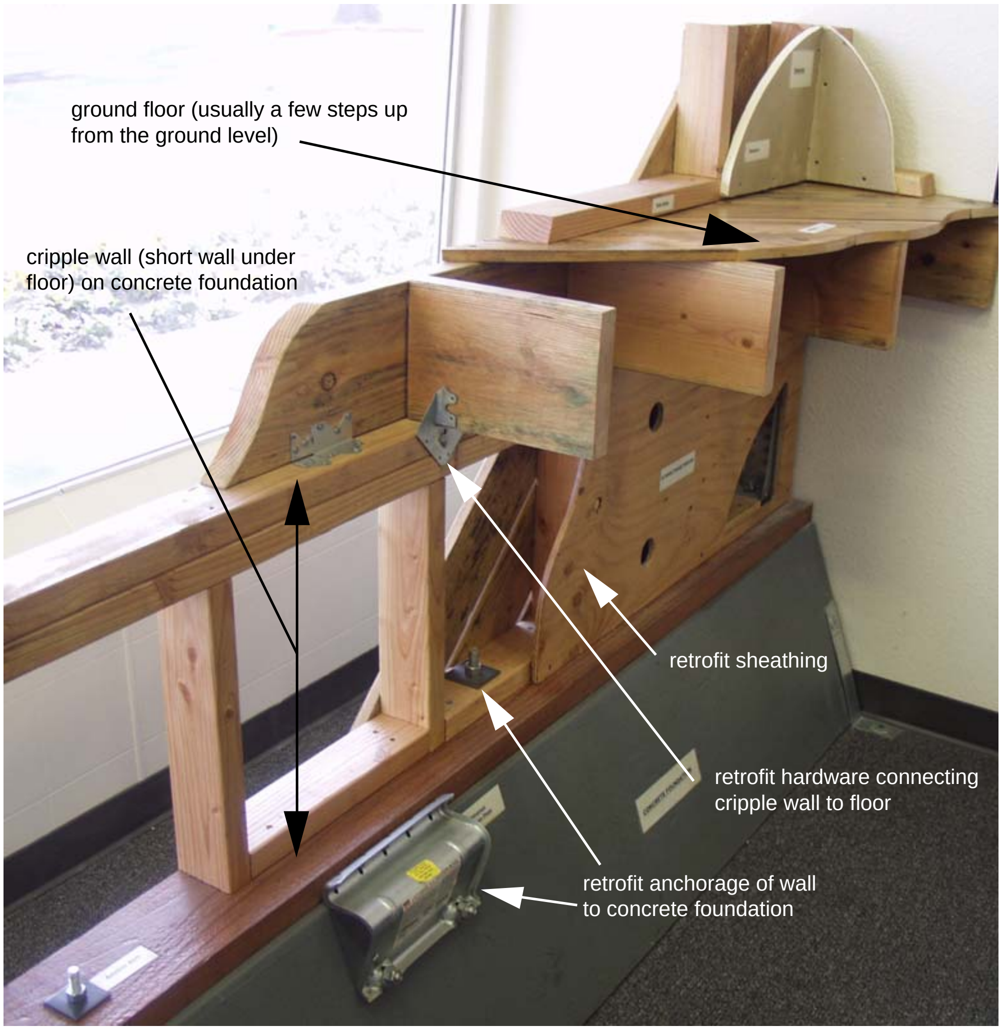
Credits: Models by University of Southern California architecture students under the direction of Prof. G. G. Schierle, in the CUREE-Caltech Woodframe Project, which was funded by the Federal Emergency Management Agency through a grant administered by the California Office of Emergency Services. **For Further Information:** www.curee.org/projects/woodframe/ ; www.seaint.org/

Unbraced Cripple Walls

An Earthquake Weakness in Some Older Homes

When there are a few steps to get up to the front porch of a house, the first or ground floor is often supported on **cripple walls**.

These walls are usually built similarly to the exterior walls above. However, above the floor of the house there are many interior walls as well as the walls around the outside that provide support. Underneath, there are fewer walls—only the exterior cripple walls. This creates an earthquake weakness. In an earthquake, the cripple walls can tilt, dropping the house. Reinforcing the cripple wall will reduce the risk of collapse.



cripple walls: short walls (about a yard/meter tall) underneath a building's ground floor

sheathing: sheets (plywood shown) attached to studs (typically 2 x 4's) of the wall

anchorage: bolts embedded in the concrete foundation,to connect it to the wood structure above

Credits: Model by Paul Johnson, North Road Builders, in the CUREE-Caltech Woodframe Project, which was funded by the Federal Emergency Management Agency through a grant administered by the California Office of Emergency Services.
For Further Information: www.curee.org/projects/woodframe/; and www.seaint.org

Woodframe Walls

Special Details to Resist Earthquake Forces

woodframe: framed with light repetitive wood structural members

joists: horizontally-spanning framing; beams

sheathing: typically oriented strand board or OSB (shown here), or plywood

nailing includes size of nail as well as spacing around panel edges and on intermediate studs

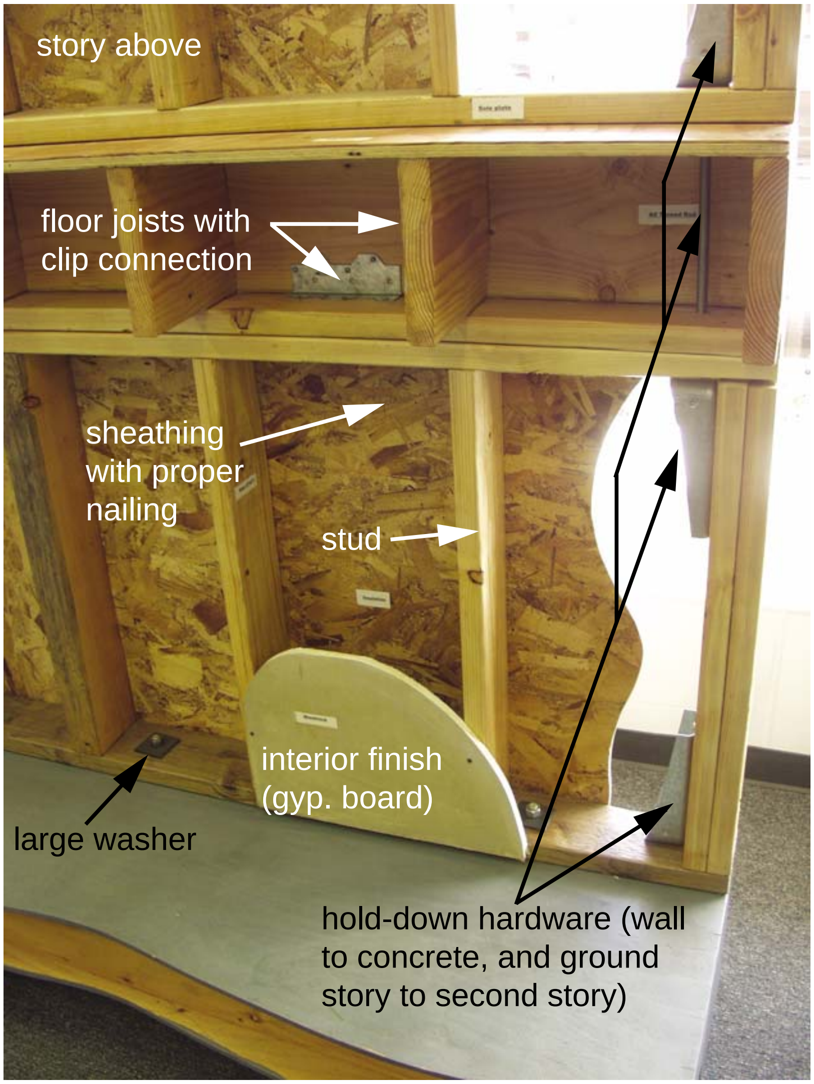
stud: typically a 2 x 4 (actual size 1 1/2 in x 3 1/2 in)

gyp. board: gypsum board, drywall

large washer: square washer, bigger than the usual round one

hold-down: holds the wall down; picture the earthquake force shoving the wall sideways toward left, tending to tip up the right-hand side

While all the pieces of a building have to work together to resist an earthquake, perhaps the most important seismic feature of a **woodframe** building is its walls. Although woodframe walls are quickly and relatively easily framed, there is a right way—and many wrong ways—for them to be built. The full-scale model (with ground story height reduced to a manageable size) illustrates some of the key earthquake-resistant features that may be necessary in a particular wall.



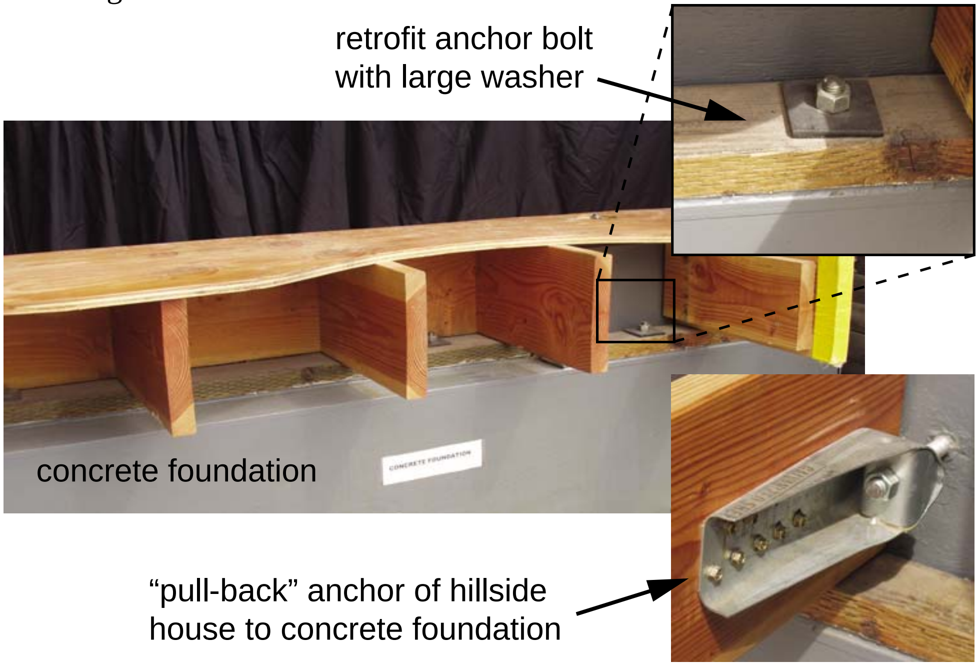
Credit: Model by Paul Johnson, North Road Builders, in the CUREE-Caltech Woodframe Project, funded by FEMA through a grant administered by California OES. **For Further Information:** CUREE, www.curee.org/projects/woodframe/; APA, the Engineered Wood Assoc., www.apawood.org; San Francisco Building Inspection Department, www.sfgov.org/site/dbi

Anchorage of Woodframe Buildings

Retrofit Connections to Concrete Foundations

Engineers calculate the **base shear** when doing an earthquake design. The base shear quantifies the total horizontal force of an earthquake at the base of a structure. The horizontal forces build up from the top of a building or structure on down: The top story must resist only its own earthquake force, but the story underneath must carry that upper story horizontal force as well as its own, and so on to the foundation.

Actually, the loads must not only be resisted to the foundation—they must be transferred via strong connections into the concrete foundation and from there into the ground.



The need to anchor the woodframe structure of a house or other building to its concrete foundation was only commonly recognized after the 1933 Long Beach Earthquake in Southern California. If there are no **anchor bolts** connecting the bottom of the woodframe structure, the sill, to the concrete foundation, this is a serious earthquake vulnerability. Even if there are anchor bolts, it can be prudent to install the higher amount of anchorage now known to be necessary for good earthquake performance. Fortunately, this retrofit is one of the easiest to be installed.

base shear: total sum of the horizontal forces from the top of a structure to its base

anchor bolts: in new construction, bolts are usually 1/2 in or 5/8 inch in diameter, and have hooks on their ends to anchor them when the concrete is poured; retrofit anchor bolts are installed into holes drilled into existing concrete

Credits: Model by Paul Johnson, North Road Builders, in the CUREE-Caltech Woodframe Project, funded by FEMA through a grant administered by California OES. **For Further Information:** www.curee.org/projects/woodframe/, CUREE, (see Anchorage of Woodframe Buildings); California Earthquake Authority, www.earthquakeauthority.com, for earthquake insurance premium discounts for anchorage and other retrofits.

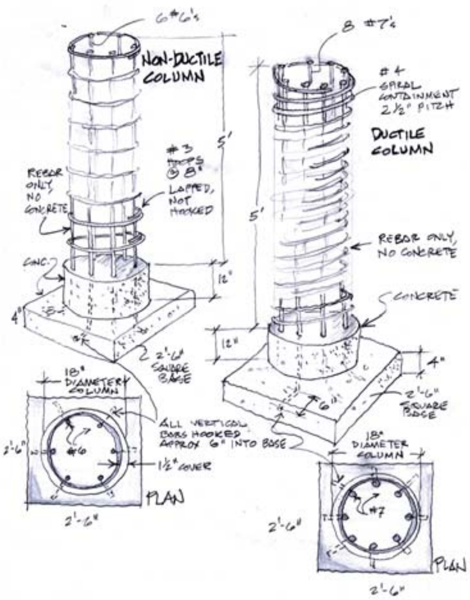
Earthquake Resistant Concrete

Modern Ductile vs. Older Non-ductile Construction

Concrete, like stone, is strong in **compression**.

Reinforcing steel bars called **rebar** are embedded in concrete to make a stronger combined material—reinforced concrete. Reinforced concrete can withstand the tendency to crack and pull apart when subjected to **tension** or **shear**.

an earthquake damaged non-ductile reinforced concrete column (1971 San Fernando Earthquake)



Modern earthquake-resistant reinforced concrete has more steel in it as compared to older non-ductile construction, especially in the **columns**.

The **transverse** or horizontal rebar in a ductile column is prominent. Spirals or hoops in a ductile column are very closely spaced to resist shear and confine the concrete. This **ductility** prevents the column from breaking apart in an earthquake and limits damage to controlled cracking.

Other ductile detailing ensures tough anchorage of the ends of bars and continuity of the rebar through joints of **beams** and columns.

concrete: Portland cement + sand + gravel, + water

compression: squeezing force

rebar: reinforcing steel bar

tension: stretching force

shear: sliding force

#4, #6, etc.: a #4 bar of reinforcing steel is 4/8 inch in diameter, a #6 bar is 6/8 inch in diameter, etc.

columns: posts, pillars;

transverse: crosswise

ductility: the physical property of being capable of sustaining deformation without fracture

beams: horizontal framing

Credits: Photo by Karl Steinbrugge, National Information Service for Earthquake Engineering, University of California at Berkeley. **For Further Information:** *Design of Concrete Buildings for Earthquake and Wind Forces*, Portland Cement Association, www.cement.org

Dampers

Putting Some "Give" in the Structure

The shock absorbers in an automobile allow it to have a smoother ride when going over bumps. Similarly, **damper** devices can be installed in structures to give them a smoother ride when going through an earthquake.

Imagine a vertical steel rod embedded rigidly in a block of concrete. (Also note there is nothing but thin air around it). You pull it to the side and let it go, and it vibrates energetically, and for a long time. Now, imagine the same rod embedded in the same block, but submerged in mud. You pull it to the side and let it go, and as it begins to vibrate back and forth its motion is damped out as it tries to move through the thick mud. More damping means less vibration.

Seismic damper installed where the western portion (suspension spans) of the San Francisco-Oakland Bay Bridge meets Yerba Buena Island

If a structure had 100% of **critical damping** you could pull it to the side, let go, and it would only slowly spring back to the original position and go no farther—vibration would be damped out and stop right there. In practice, structures can't attain that extreme amount of damping. However, **seismic forces** can be reduced by a factor of 3 or more if the structure has added dampers and high damping (like 20%) rather than the usual 1 to 5%. Reducing forces by a factor of 3 is like making the structure 3 times stronger.

Dampers need to be very large and strong to handle the huge forces generated as a massive bridge or building begins to move in an earthquake. They also must be precisely calibrated. They must avoid letting the structure move too much and too fast. On the other hand, if a damper allows too little movement and at too slow a rate, it defeats the purpose of putting some give in the structure.

damper: a device that adds damping to the structure

viscous fluid dampers have a piston with small holes in the ends that force oil to flow through at a controlled rate as the piston moves

a friction damper makes two surfaces rub against each other to retard movement

critical damping: the theoretical amount of damping that will return the structure to its initial position with no further vibration

seismic forces: inertial forces in the structure generated by its acceleration (as it is shaken by the earthquake) times its mass; for example, an acceleration of 1/4 g means this horizontal force will be 1/4 of the weight of a building or bridge

Credit: Photo here and full-size damper on display courtesy of Taylor Devices Inc. **For further information:** www.taylordevices.com, see "Seismic Dampers and Seismic Protection;" www.eeri.org, the Earthquake Engineering Research Institute, see monograph publication on Seismic Design With Supplemental Energy Dissipation Devices by Robert Hanson and T. T. Soong. Support stand by Don Rich Studios, Oakland, CA.

Seismic Isolation

Insulating a Structure From an Earthquake's Severity

Inertia makes matter stay where it is, or continue moving in a straight line, unless acted on by forces; if forcibly moved, the object experiences inertia force

restoring force: force to bring the isolated structure back to its initial position after it slides sideways

The basic principle of earthquake forces in structures is that the ground shakes and forcibly moves the base of the structure, whose **inertia** makes it try to remain where it was. Tremendous forces result.

The basic idea of seismic isolation is to separate the base of the structure from the ground's shaking—let the building or other structure more or less remain in space where it originally was as the ground lurches beneath it, insulating it from the earthquake severity.

A basic challenge with seismic isolation: how to provide a **restoring force** to keep the structure constantly returning to its initial position vis-a-vis the ground as the earthquake keeps shaking. If a building were just mounted on ball bearings, by the end of an earthquake it might end up across the street – a bit of a traffic hazard not to mention a bother to the other property owner who unexpectedly finds a building in their front yard.

An innovative seismic isolation approach is called the friction pendulum (a term trademarked by Earthquake Protection Systems). It uses large carefully shaped metal dishes to support the weight of a structure on a bearing point that can slide over the dish. As the structure starts to move sideways in an earthquake, it slides its way across the isolator—and up the side of the isolator because of the dish shape—letting the continuous force of gravity bring it back to the center point. The contact of the weight of the structure and the dish have precise friction properties to absorb energy and translate the jolting motion of an earthquake into simple pendulum type motions of the structure. These devices have been used on a number of large structures around the world and in the San Francisco Bay Area, including the International Terminal at San Francisco International Airport and the retrofitting of the Benicia-Martinez Bridge.

Concave Disk **Slider** **Housing Plate**

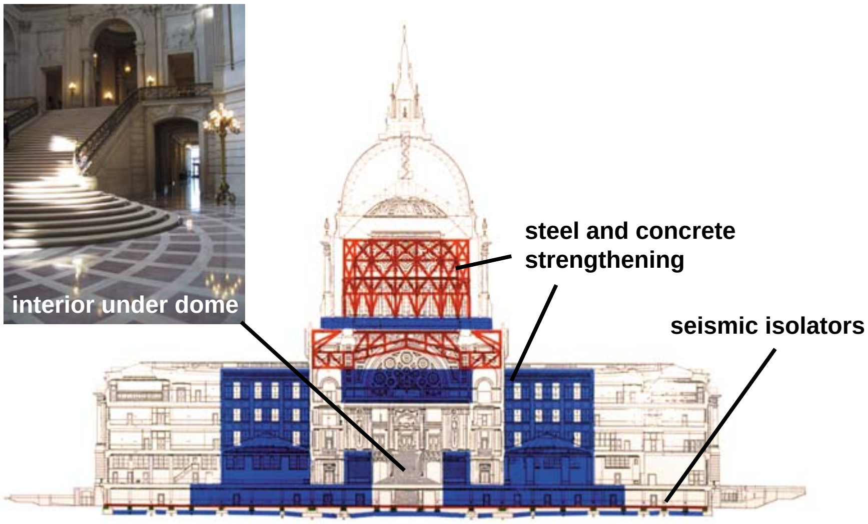
SHOWN ABOVE: Components of a friction pendulum seismic isolator for a large offshore structure.
The housing plate will be turned upside-down and installed on top of the slider.

Credit: Photo and full-size isolator display by Earthquake Protection Systems (EPS), http://www.earthquakeprotection.co

San Francisco City Hall

A Seismic Retrofit Project On A Monumental Scale

The monumental San Francisco City Hall, built too soon after the 1906 earthquake and fire to benefit from modern earthquake engineering, revealed its earthquake weaknesses when it was damaged in the 1989 **Loma Prieta Earthquake**. The source of the 1989 earthquake was about 120 kilometers (70 miles) south of San Francisco. Much closer and stronger earthquakes are possible on the San Andreas and Hayward Faults. Thus, without retrofitting, San Francisco City Hall would eventually be much more badly damaged.



The longer the life of a building and its **exposure period**, the more likely it is to experience the occasional damaging earthquake. If a building is historic today, it will arguably be even more historic 50 years or a century from now, and thus it will be preserved for a very long time. However, extensive strengthening that removes authentic material and detracts from the appearance would be a sure and immediate loss of historic character. A solution was needed to give great earthquake protection to the building and yet not compromise its architecture.

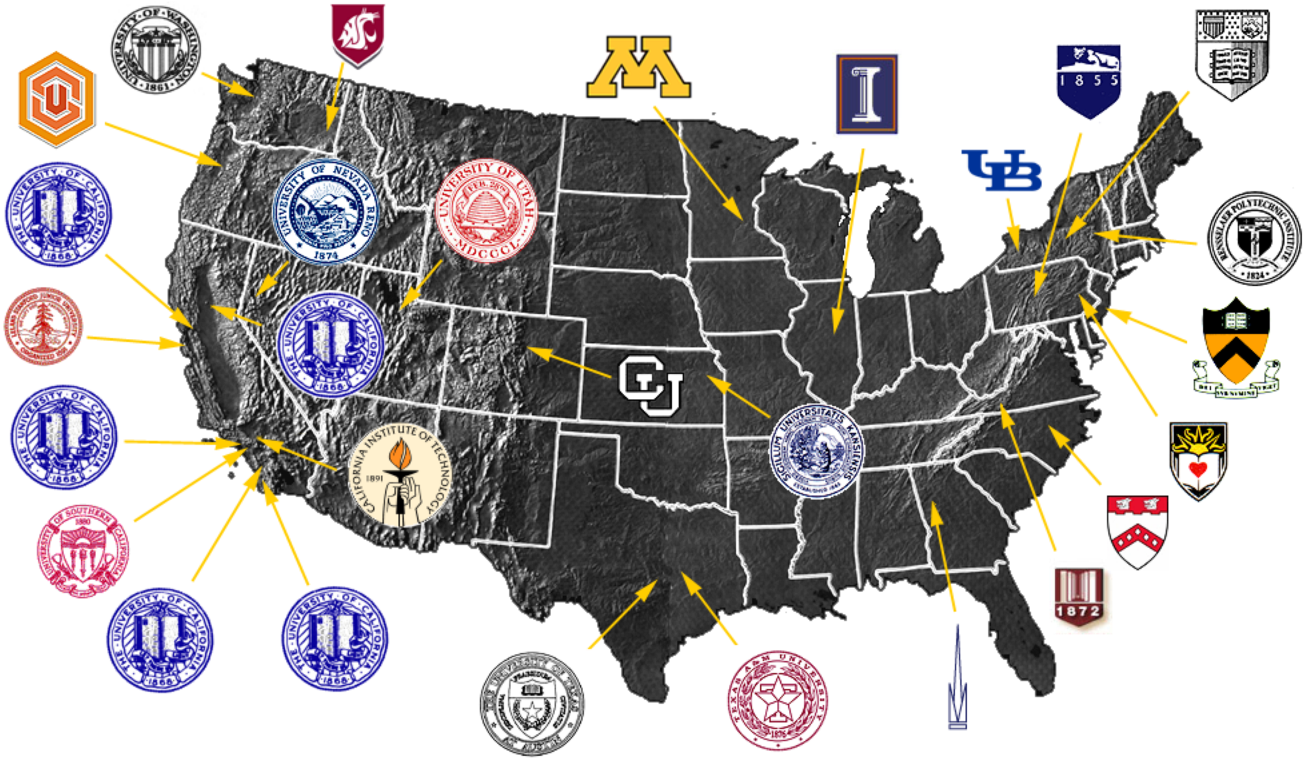
The answer was (1) installation of **seismic isolation bearings** just above the foundation to greatly reduce the severity of shaking the building can experience, and (2) steel and concrete strengthening hidden within the building. The bearings, invented in New Zealand in the 1970s, are strong sandwiches of steel and rubber plates that squish back and forth to absorb energy and to make the structure too “soft” to respond to jittery earthquake motions.

Loma Prieta Earthquake: October 17, 1989, magnitude 7.1

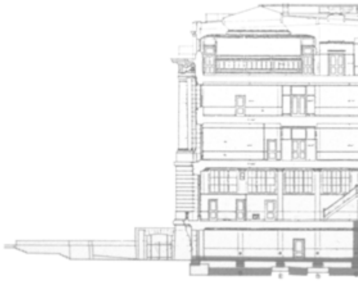
exposure period: number of years the building will be exposed to a risk; for earthquake shaking that on average happens once a century, during a 50-year timespan there is 40% chance it will happen; in 100 years there is over a 60% chance; in 200 years there is almost a 90% probability

seismic isolation bearings: devices that are vertically stiff to carry the structure’s weight, but horizontally very flexible

Credits: Cross section diagram by Forel-Elsesser Engineers, San Francisco, lead engineers on the retrofit project. Design/blueprint of the original 1915 building by Bakewell and Brown, Architects. Seismic isolator sample by DIS, Inc.



The Consortium of Universities for Research in Earthquake Engineering (CUREE) is a non-profit organization, established in 1988, devoted to the advancement of earthquake engineering research, education and implementation.



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