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Controlling Disaster: Earthquake-Hazard Reduction for Historic Buildings

By Rachel Cox

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Earthquake preparedness is a subject that tends to evoke either great emotion or great indifference. Those who have felt the earth shake hope fervently never to repeat the experience, while those who have never experienced a quake prefer to believe they never will. What's more, the topic seems to lead down confusing technical byways—from geological probabilities to engineering equations—that may appear too forbidding to enter.

Yet there are numerous reasons why owners of older buildings, especially, ought to concern themselves with the subject. The earthquakes that have rattled California have left behind graphic images of the frightening effects of even moderately strong earth shaking. The Loma Prieta quake that interrupted the 1989 World Series in San Francisco left 62 dead and caused $6 billion in property damage. Lessons learned and precautions taken as a result of this and other earthquakes proved very effective when the 6.7 magnitude Northridge Earthquake struck in 1994. It was the most destructive earthquake in the United States since the 1906 San Francisco Earthquake, killing more than 50 people, injuring thousands, and causing some $40 billion in damage. Were it not for the seismic strengthening and risk reduction programs that had been implemented, the devastation would have been significantly greater. Further north, the 6.8 magnitude Nisqually Earthquake that shook Seattle, Wash., in 2001 caused extensive damage, but investments in retrofitting paid off here as well, while those buildings without seismic upgrades suffered greater damage.

Fortunately, preparing for the next earthquake need not be enormously complicated or terribly expensive. Information about nonstructural hazards and general disaster preparedness can be obtained from your local chapter of the American Red Cross. Assessing a commercial or residential building for earthquake hazards may result simply in greater peace of mind or taking a few simple steps to reduce risks to human safety. Alternatively, you may find that a full-scale seismic retrofit is well worth the investment.

The good news that rarely accompanies the frightening images is that earthquake hazards can be reduced. As practicing engineers and engineering research analysts have studied the damage associated with recent quakes, they have identified structural characteristics common to hazardous buildings and refined analytical tools and engineering techniques to mitigate potential damage.

Often, the prescribed corrective is relatively simple and inexpensive. Wood-frame houses can be bolted to their foundations and have crawlspace walls reinforced, usually for less than the cost of remodeling a bathroom. Masonry chimneys can be tied in to the house to prevent collapse. The brick parapets, or low walls, often found along the rooflines of commercial buildings are exceptionally vulnerable to collapse during earthquake shaking. Reinforcing them may require only a series of steel brackets fastened to parapet and roof framing.

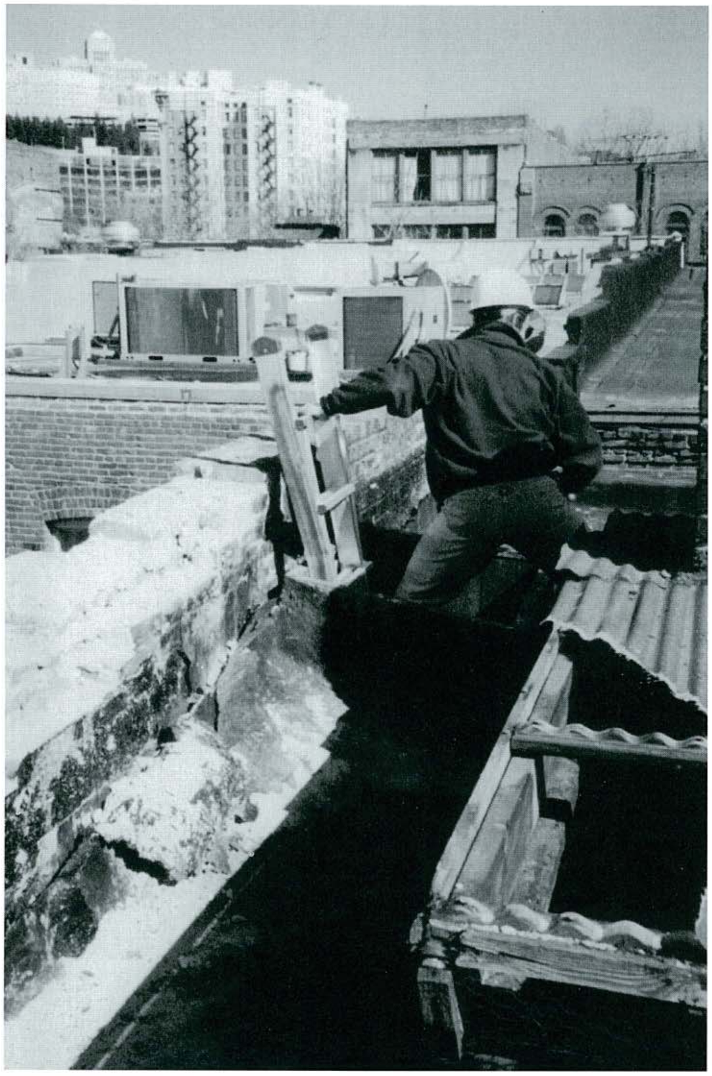
A seismic retrofit before an earthquake strikes is often well worth the investment. Historic materials that are damaged or destroyed in an earthquake are often impossible to replace. This historic home in Salinas, Calif., sustained more than $400,000 in damage during the 1989 Loma Prieta Earthquake.

— Photo courtesy of the National Trust Western Office

It is difficult to make a categorical statement about the costs of seismic upgrades, because every building poses individual challenges and construction costs vary widely. But it is clear that reinforcement is far less costly than reconstruction. Like regular building maintenance, earthquake-hazard reduction represents the ounce of prevention that eliminates the need for a pound of cure. What's more, with historic structures, waiting for a quake before investing in improvements risks the loss of historical value. Historic materials that are damaged or destroyed are often impossible to replace, and introducing modern materials not only damages a building's integrity but also may compound maintenance problems.

Cover: Wood-frame buildings are often jolted off their foundations during an earthquake, causing porches to separate from the body of the building. A seismic upgrade using bolts and braces to "tie" the building together will reduce damage to the building during a future quake.

— Photo courtesy of the National Trust for Historic Preservation



Freestanding sections of masonry, such as chimneys and parapets, are often prone to collapse during an earthquake, as seen in this photo taken in Seattle following the 2001 Nisqually Earthquake.

— Photo by Mike Buhler

Reducing earthquake hazards in older properties also poses particular challenges. Meeting building code requirements without damaging historic fabric requires the skills of an engineer or architect experienced with historic structures and comfortable with a range of engineering options. Solutions should, and can, be designed to preserve important features and respect original design.

Yet these caveats should not discourage the owner of an older building, whether commercial or residential, from carefully considering a seismic retrofit. This booklet contains background information needed to approach the subject with confidence, focusing primarily on unreinforced masonry, that is, structures with no steel reinforcing within a masonry wall. It outlines the steps to take to consider the risk for your particular building, to identify your goals, and to select and work productively with an engineer or other qualified professional to evaluate engineering and design options. It discusses financing issues and offers examples to illustrate the process. A bibliography at the end lists sources of additional information.

Understanding the Threat

A safe, sound building must be able to withstand certain forces. Its ability to support its own weight, along with the weight of its contents, occupants, and any occasional loads such as snow, is known as its vertical loading capacity. Building codes define what vertical loads a building must be able to support. They also define its lateral loading capacity, or the ability to resist transient horizontal forces such as wind and earthquake shaking.

Vertical and lateral loads are supported by the building's structural system—the interlocking framework of joists, beams, studs, walls, columns, and foundations. Construction materials, including wood, steel, masonry, and concrete, also contribute to the strength of a building. All the elements play critical, yet varying roles, depending on the building, in providing a stable, sturdy, and safe structure.

An engineer uses knowledge of the structural system of a building, along with building weight, to analyze how it would respond to different intensities of ground shaking. A building's ability to withstand an earthquake depends on how it resists the "equivalent lateral forces" that engineers use to express the complex inertial forces generated within a building by seismic vibrations. Modern steel-frame buildings are designed to bend, or deflect, with these forces, dissipating the earthquake energy without collapsing. Similarly, a wood-frame building, old or new, is flexible enough as a unit to absorb energy, although the absorption is often revealed by cracked wall and ceiling finishes.

Unreinforced masonry buildings, on the other hand, where floors and roof are usually supported by the walls themselves, are commonly damaged in strong ground shaking. Without appropriate reinforcement, they are usually most vulnerable at the top of the building, where the walls may be poorly anchored to beams or joists and may be excessively slender (that is, too tall for their thickness). Freestanding sections of masonry such as chimneys and unanchored parapets are also prone to collapse.

Identifying the potential property damage associated with various levels of shaking allows earthquake-hazard reduction schemes to be developed. The weight of a building is determined by careful measurement and the identification of materials, whose average weights are known in advance. The engineer also should consider the building as a chain of interconnected components, thus identifying the relative importance of the various parts during ground shaking. In a wood-frame building raised several feet off the foundation, for instance, the weak link is usually the short wall connecting the foundation with the first floor. This element, often called the cripple wall, frequently lacks the interior finishes, such as plaster or gypsum board, that strengthen the walls above. If not anchored adequately to the foundation, it is especially vulnerable to earthquake damage. In addition, it is often weakened by moisture fluctuations and insect infestations.

Assessing the Risks

When the owner of an older building undertakes routine maintenance, it is usually for a clear and present reason. If the roof leaks, water will penetrate the building and rot will set in. But deciding whether, and at what level, to reinforce against earthquakes often seems a complex project undertaken for unclear reasons, like an abstract game of "what if?"

Sometimes, the decision to reinforce will be made for you. Building owners planning other significant changes or improvements may find that seismic upgrading to a given level is part of building code requirements. Seismic improvements may also be required when the use of a building is changed. In parts of California, the strengthening of unreinforced masonry buildings is now required by law, except for dwellings with fewer than five units.

Otherwise, deciding what to do about earthquake reinforcement means making decisions based on probabilities and observed building performances in past earthquakes. First, one must consider the probability of a seismic event and what source and duration it is most likely to have. Then one considers the most probable kinds of damage and, from there, what damage is acceptable and what is not.

Modern buildings that conform to current building codes are constructed to seismic standards that minimize the possibility of collapse and emphasize the reduction of property damage that threatens life safety. Since earthquake-related deaths are almost always caused by falling objects, mitigation strategies for older buildings usually begin with the reinforcement of masonry chimneys in residences and the bracing and anchorage of parapets and walls that could topple, crushing adjacent structures or injuring people directly. A second level of priority might be the protection of significant building elements, from a magnificent portico to extraordinarily detailed plasterwork.

No building—not even a new building—can be made completely earthquake proof. But once you accept that earthquake damage, and the resulting costs, must be discussed in terms of probabilities, you can begin to make judgments about a sensible course of action. Four variables are particularly important to consider as you think about reinforcing your building.

How Dangerous Is Your Site?

Earthquakes are caused by the motion of the tectonic plates that compose the earth's outer crust. When the plates slide past or go under one another, stresses accumulate along the boundaries, or faults, so that proximity to a fault increases the risk of damage when the stresses are released in an earthquake.

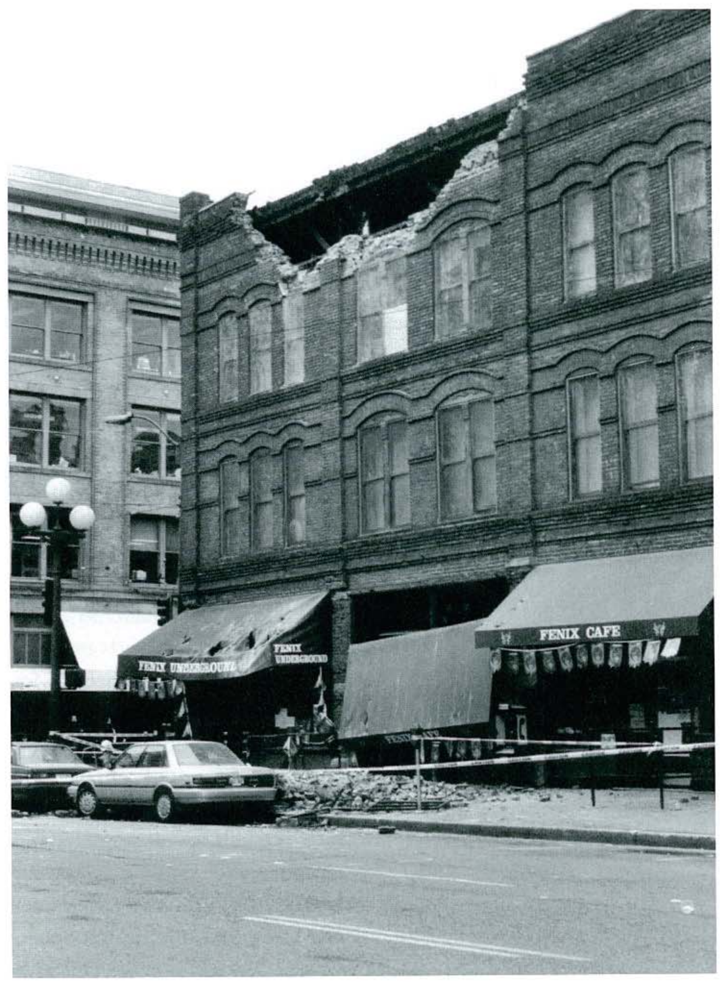
In California and Alaska, where destructive quakes have occurred within recent memory, most residents are well aware that they live near major faults. Yet there are many other areas near geological faults where the earthquake hazard is less commonly recognized. Areas around St. Louis; Salt Lake City; Charleston, S.C.; Helena, Mont.; and Puget Sound in the Pacific Northwest are also at risk, for example, and Boston has experienced earthquakes in the past.

Past earthquakes have taught that the soil conditions below a building and along the route back to the fault are often more important than the building structure in determining earthquake damage. A rock substrate, for instance, is known to dampen ground motion, while poorly compacted fill and mud can actually accelerate it. In San Francisco during the 1989 Loma Prieta earthquake, houses in the Marina District, many miles from the quake's epicenter near Santa Cruz, were severely damaged because the sandy soil and landfill beneath them liquefied during the earthquake.

If you live in a high-seismicity area, your city or county planning department may have maps show-

Since most earthquake-related deaths are caused by falling objects, mitigation strategies for older buildings usually begin with the bracing and anchorage of parapets and walls that could topple during a quake.

— Photo by Heather MacIntosh



Although wood-framed houses generally perform well in terms of life safety, a quake can seriously damage masonry elements such as chimneys and stairways as seen in this home damaged during the Loma Prieta Earthquake.

— Photo courtesy of the National Trust Western Office

ing different zones of soil condition. California, for example, has undertaken a major mapping program. The U.S. Geological Survey, state soils offices, and local building departments may also offer guidance. For a more detailed analysis, a licensed geologist or soils engineer can perform a geological investigation of your site—a step that can save money in the long run, especially for large projects. Determining what kind of soil conditions exist on your property will enable the engineer to develop a more accurate prediction of how ground motion will be transmitted to your building, so that mitigation strategies can be tailored to the need.

What Structural Type Is Your Building?

There are a number of basic structural systems prevalent in American residential and commercial buildings. Each system has different characteristics in terms of its response to earthquake forces.

Wood-Frame Buildings

Wood-frame buildings contain vertical framing of wood studs or posts and horizontal framing of joists and rafters or beams. Whether sheathed with clapboard or stucco, they generally perform well in terms of life safety. The wooden framing members that support the building and tie it together tend to distort but not break under earthquake stress.

Yet for owners of homes and stores damaged by earthquakes, the effects can still seem devastating. In the 1992 Humboldt County quakes in northern California, numerous wood-frame houses were jolted off their foundations, causing porches and additions to separate from the body of the building and damaging such masonry elements as chimneys and stairways. Water and gas lines were disrupted and electrical service was lost. Many of the houses literally came apart at the seams, and interior finishes and contents were badly damaged. The buildings could be jacked up and restored, but only at considerable expense and after weeks when the owners could not live in their homes.

The Humboldt County houses were extreme examples of the two commonest shortcomings of wood-frame buildings. First, they often are not adequately fastened to their foundations. Buildings bolted directly to a concrete slab—a common practice after about 1940—almost never suffer earthquake damage at the foundation.

Second, the wall between the foundation and the first floor, or cripple wall, is often unsheathed on the interior, making it weaker and more subject to moisture and insect damage than the rest of the house and vulnerable to buckling. In Humboldt County, the foundations themselves were often minimal and/or poorly maintained, as well. Many of the houses stood on wooden posts resting directly on the earth or on small concrete footings. In some instances, houses with even minimal bracing between the posts suffered less damage than houses with no horizontal strengthening.

Both potential problems are relatively easy and inexpensive to solve as long as there is adequate access to the foundation. By looking in the basement or crawl space of your building, you can probably determine whether or not it has been bolted to the foundation (see illustration, page 5). If it has, and the bolts appear old, loose, or damaged, you can hire a registered building inspector or contractor to check the anchor bolts' attachment to the foundation using a calibrated torque wrench.

You can also look at the peripheral wall that connects the foundation with the first floor. If it is open, or only partially sheathed, you may want to consider sheathing it with plywood or installing "x bracing"—wooden studs running diagonally between floor framing and sill plates—to prevent the walls from buckling. A side benefit of the plywood sheathing could be improved energy efficiency and increased comfort, since enclosing the crawl space will keep the floor warmer. Be sure to design adequate ventilation for any enclosed crawl space.

Another problem common to older wood-frame buildings is the separation of individual elements such as additions and porches that, because of their foundation system or poor connections with the main structure, move independently during an earthquake. An architect or engineer can identify ways to tie the building elements together.

Wood-Frame Buildings with Masonry Veneer

Many buildings that appear to be brick, or other types of masonry, are in fact wood-frame buildings with a single thickness of the masonry units laid against the sheathing. This system is fairly common in 20th-century buildings. You can usually see the wood framing by checking the peripheral walls in the attic or crawl space.

Veneer buildings will generally behave like wood-frame buildings with one important exception. If the masonry veneer becomes dislodged, it can threaten life safety. For this reason, the attachment of masonry veneer should be evaluated, especially in a building's upper stories. Normally, a small zone of veneer is carefully removed to verify bonding and anchorage patterns, if any. Nondestructive test methods exist for the anchors in place. The veneer sample can be replaced. It is possible to increase the bond between veneer and back-up wall by pressure grouting.

Infilled-Frame Masonry Buildings

This type of masonry building contains an independent framework of steel or concrete that supports the loads of the building while the masonry fills in the walls and provides additional lateral resistance but does not support vertical loads. It is commonly found among older, multistory commercial buildings, usually in older downtowns. A masonry building of more than four stories usually contains a frame, but making a certain identification can be tricky. A concrete framework may be visible either inside or out, but a steel framework is usually clad with masonry for fire protection. If available, review the original construction drawings and then verify conditions by field inspection.

Infilled-frame masonry buildings are generally considered to be less hazardous than unreinforced masonry buildings, but additional reinforcement may still be advisable—or, under certain circumstances, required—in seismically active areas.

Unreinforced Masonry Bearing-Wall Buildings

In this most common of masonry building types, the masonry walls —whether brick, stone, terracotta, adobe, concrete block, or fieldstone—actually support the weight of the floors and roof. The wooden beams, joists, and rafters usually rest in pockets in the masonry. It is considered to be the most hazardous building type and has received the most attention following recent earthquakes.

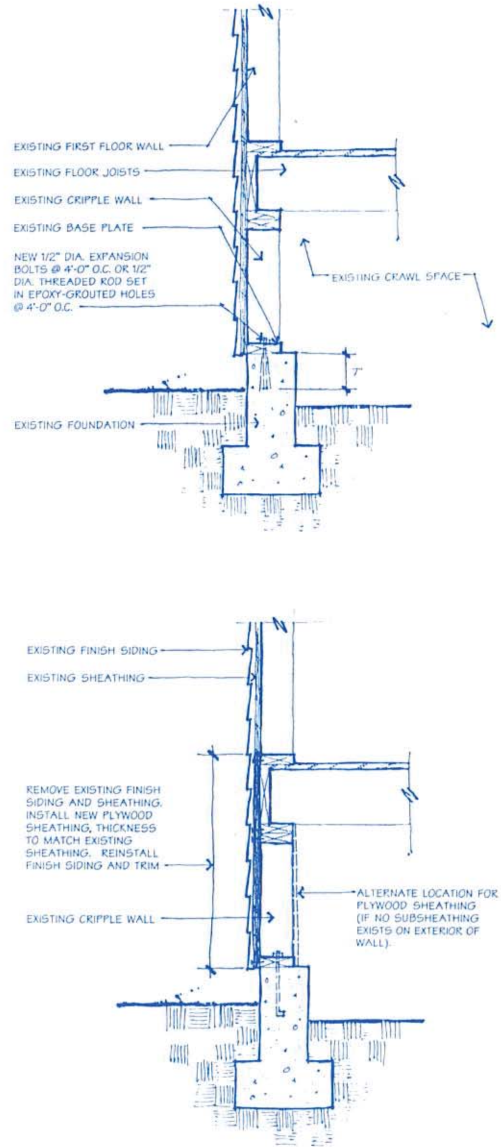
URMS, as they are often called, can be identified by the configuration of the masonry and the thickness of the walls. For brick, the wall thickness is usually equal to a multiple of four inches plus one, since bricks are usually four inches wide. The brickwork can take many patterns, but generally speaking the presence of "header" bricks, laid crosswise so that the short end rather than the long side is visible, is a sign that a wall is solid masonry. The pattern of the brick and the thickness of the walls will affect how they respond to earthquake shaking.

The best place to check the masonry pattern is at the side or back of a building, in stairwells and elevator shafts, or behind a parapet, since facades may be covered in brick veneer. To check wall thickness, measure at a doorway or window. Another rule of thumb: an unreinforced bearing-wall building is extremely unlikely to be more than six stories tall. Usually, it is three stories or less.

In general, a masonry building, like a wood-frame building, will benefit from good maintenance. Cracks and loose mortar should be repaired. Cracks that run all the way through the wall thickness or that propagate many feet parallel to the wall surface horizontally, vertically, or at an angle merit a call to an engineer or architect. Keep in mind that old brick must be repointed with compatible mortar and often requires periodic inspection by a registered masonry inspector as part of earthquake-hazard reduction ordinances. High parapets should be braced, chimneys should be anchored, and protruding ornamentation should be firmly attached.

How is the Building Used?

Occupancy level and type of use—that is, how many people use the building—affect the level of structural analysis that an engineer uses to develop earth-



Foundation bolts and sheathed cripple wall.

— Drawing courtesy of Architectural Resources Group

A Few Basics

Some potential problems and basic precautions are relevant regardless of building type.

- Good maintenance practices are a basic starting point for all buildings. Earthquake damage can rarely be traced to a single cause, and any deteriorated condition in a building may be exacerbated by shaking. Well-maintained buildings have been observed to sustain less damage in earthquakes than buildings in poor condition.
- Foundations should be in good repair. Even unreinforced masonry foundations can perform adequately if the mortar quality is good and bricks are sound (see box, page 7).
- Large wall openings, such as garage doors or large windows, can rack, or distort, during strong ground shaking. Buildings that contain a "soft story"—a home or apartment atop a garage for example—may require the installation of a steel frame to strengthen the opening. Glass breakage was observed in storefronts with large openings in several communities in Humboldt County after the 1992 earthquakes. Often there was inadequate space in the mullions or muntins to accommodate glass distortion.
- Chimneys are another feature commonly damaged during strong ground shaking. They too should be maintained by repointing damaged mortar and resetting loose bricks (see box, page 7). Tying the chimney into the house structure wherever possible will help it to move with the house during shaking. An interior chimney can be anchored where it passes through floors and roof, for instance. Exterior chimneys may be strapped to the house or braced to the roof. Adding a chimney liner, or new flue, of stainless steel or terra-cotta can improve seismic response without altering the chimney's appearance, if the liner is chosen correctly. Often, reinforcing bars are placed between liner and masonry and held in place with concrete.

While chimneys are potentially hazardous building elements, they are also important character-defining features of the architecture. In cases where reinforcement may significantly alter the appearance of the house or destroy historic material, one should seek advice from an architect experienced with historic restoration. Generally speaking, it is preferable to add an element, such as a brace, rather than to lose original materials—by tearing down and then rebuilding a reinforced chimney, for instance.

quake-hazard reduction schemes. To analyze an auditorium, for example, where many people congregate on a regular basis, an engineer must use higher equivalent lateral forces than for, say, a house museum, where the number of visitors is strictly controlled.

Beyond building code requirements, how a building is used should figure into your cost-benefit considerations. Damage to a vacation home that may be out of commission for a few months will be far less inconvenient than damage to your principal residence or place of business, for instance. Mitigation of threats to life safety should be emphasized regardless of the occupancy.

What Are Your Financial Parameters?

Earthquake reinforcement costs can range from inexpensive—as when a homeowner installs anchor bolts in the sills of his wood-frame house—to an extensive reinforcement of an old commercial masonry building rehabilitated as an investment. In both cases the money invested must be weighed against the future payoff.

In the case of a commercial venture, reinforcement costs are, of course, part of the capital costs of the project—usually required by building codes—and will be repaid as the building turns a profit. But it is also worth considering the cost of lost business if your building is unusable for a few weeks or a few months after a quake and of long-term business lost as customers learn to go elsewhere.

For a homeowner, reinforcement costs can be weighed against the probable costs of repairing potential damage. Earthquake insurance is usually so costly, with such high deductibles, that it is not a cost-effective alternative to reinforcement. Another factor to consider is the cost of time when, in the event of a major quake, the structure may become uninhabitable. Can you afford to spend anywhere from a few days to several months living elsewhere, possibly without access to your home, while repairs are made? Might not that money be better spent now to prevent such an eventuality? It will be easier to secure the services of qualified engineers, architects, and contractors prior to a seismic event than afterward, when they will be greatly in demand.

Another important consideration is whether or not your building is due for repairs or remodeling. It makes sense in the long run to include seismic improvements in your work plans, since you will already be paying to get professional advice and open up the building for work.

Another possible money saver is to share some of the expenses with neighbors who are also interested in having their buildings surveyed by an architect, engineer, or contractor. You will probably realize a per person savings on a visual survey of the buildings if you ask for the work to be done as a package. In areas of California where surveys of unreinforced masonry buildings are required by law, some towns have hired engineers or engineer-architect teams to survey and make preliminary recommendations for all the buildings at once. The success of such surveys depends on finding well-qualified engineers and architects familiar with older materials and building types. More detailed assessments of individual building requirements demand close scrutiny of each building, however, and little money is likely to be saved by seeking this level of engineering analysis as a group.

Developing a Plan of Action

(1) Check Regulations

You will need to determine who are the "reviewing authorities" for any changes you wish to make. Although they may be as simple as a single building inspector, in a historic district, with a landmark building, or with a large project, there may be additional levels of review, such as a local historic district commission, city planning commission, or, in the case of a historic tax credit project, the state historic preservation office and the National Park Service. Begin by calling your local building department to determine permitting and approval procedures, or ask an architect, engineer, or contractor about them. Be aware that you may need to work closely with building officials to gain approval of any approaches to reinforcement that are sometimes required to meet preservation objectives.

In California, a building listed on any official survey of historic buildings must use the State Historical Building Code (SHBC) as a performance standard in conjunction with local prescriptive codes. The SHBC sets general performance standards that emphasize mitigation of potential property damage that threatens life safety or disrupts the historic fabric. The engineer can use judgment in meeting these standards, often allowing for less costly alternatives. For a prescriptive code that recognizes the unique characteristics of archaic materials, the *Uniform Code for Building Conservation* is a useful reference.

Occasionally, local building departments are unfamiliar with performance-based codes. Your architect and/or engineer should be prepared to negotiate a consensus about an earthquake-hazard reduction scheme that realizes reasonable safety goals and protects the building's historic qualities. In California, if a consensus cannot be reached at the local level, it is possible to appeal local decisions to the State Historical Building Safety Board in Sacramento.

(2) Hire a Qualified Professional

In seismic risk areas, especially after a tremor, there are often many contractors who offer to "earthquake proof" homes quickly and even cheaply. Be wary, for they may not be sensitive to historic buildings and may suggest a few quick fixes without adequately assessing your specific risks.

On the other hand, contractors are not necessarily unqualified. The goal is to find a licensed, professional engineer, architect, or contractor (or a team of all three) who is knowledgeable about archaic construction materials and experienced with planning and executing seismic retrofits in older buildings. Often, finding a preservation architect will lead to the right engineer, or a good contractor can recommend a good architect, and so on. A structural engineer has received more specialized training than a civil engineer, but a civil engineer experienced with seismic reinforcement may be acceptable. An architect, especially a preservation architect, can work with an engineer to develop strengthening plans that minimize the impact on the building's appearance and functioning and protect character-defining features and finishes.

Once you have found several names, call them for references, then go see their work. Ask them in advance what they would charge for a consultation—some charge to write a proposal for services, others do not. Once you have identified three or four you feel comfortable with, set up individual meetings, buying an hour or two of their time if necessary. Getting a few opinions will make you more knowledgeable about your particular problems and potential solutions and will allow you to consider each individual's advice in perspective.

Plan in advance what questions to ask, not only about your building but about the services they will provide. Then don't be afraid to press for answers. For example: What information will be included in your assessment? Will it be in a form ready to take to a contractor? How long will it take? Do I need to bring in any other professionals (architect, engineer, soils specialist)?

Taking the necessary time to select the right person to work with—someone who shares a sensitivity to historic preserva-

Masonry Repair

Repairing deteriorated mortar joints will strengthen historic masonry. But the process of repair, or repointing, must be executed carefully to prevent new damage to archaic bricks.

Repointing involves removing by hand deteriorated mortar from the joints of a masonry wall and replacing it with new mortar. It is extremely important that the new mortar be compatible with the existing bricks. It should match the historic mortar in color and texture and must be as soft, or softer, than the historic mortar in order to prevent damage to the bricks. To preserve the appearance of the building, the mortar joints also should be tooled, or detailed, to match the existing joints.

A detailed treatment of mortar joint repair in historic brick buildings is published by the technical assistance division of the National Park Service as part of the "Preservation Briefs" series. To obtain a copy of *Preservation Briefs 2, Repointing Mortar Joints in Historic Brick Buildings*, contact your state historic preservation office. (The full text is available at *www.nps.gov*)

Finding the Best Advice

Several professional organizations can assist in the search for the right engineer, architect, and contractor. Other useful resources might be the local homeowners' association, historical society, or preservation group. Each state has a historic preservation office in the capital, and most have a private, nonprofit statewide group that also should be a strong source for advice. Your state department of consumer affairs can tell you if an individual is licensed.

American Society of Civil Engineers (ASCE)
(World headquarters)
1801 Alexander Bell Drive
Reston, VA 20191-4400
(800) 548-2723

1015 15th Street, NW #600
Washington, DC 20005-2605
(202) 789-2200

Structural Engineers Association of California (SEAOC)
1730 I Street #240
Sacramento, CA 95814-3017
(916) 447-1198

National Society of Professional Engineers (NSPE)
1420 King Street
Alexandria, VA 22314
(703) 684-22800

American Institute of Architects
1735 New York Avenue, NW
Washington, DC 20006
(202) 626-7300

The regional offices of the National Trust for Historic Preservation are listed on the inside back cover of this booklet.

tion—is well worthwhile. For no matter how much research you do and how many questions you ask, there will be times when you will have to trust their judgment.

(3) Define the Scope of Work

You will need to work with the professionals you choose to define exactly what services they will perform. Tell them up front what your preservation and service requirements are. *The Secretary of the Interior's Standards for Rehabilitation* are considered the standard for all rehabilitation work on historic buildings, particularly those seeking tax credits. Review the standards, determine how they apply to your building, and discuss them with your architect and engineer. Are there features of the house that you are particularly concerned not to alter during construction? One architect suggests that owners of historic buildings begin their retrofits by locating the most important zones to save from damage, not only in an earthquake but also during construction.

Ask for an analysis of the risk for your building, not just a prescription for strengthening it. You need to know the rationale for each of the steps suggested, so that if you must choose among them for cost reasons you can make a sound decision.

Ask for maintenance suggestions and a consideration of the overall condition of the building as well, so that you can accomplish other objectives with seismic improvements.

Ask about materials testing as part of the assessment. The intrinsic strength of the materials that compose the building will affect its existing earthquake resistance. What's more, the strength of old materials is not a given, as it is with new materials. Such nondestructive testing as a mortar quality testing program for an unreinforced masonry building or a torque test for existing foundation anchor bolts is a relatively inexpensive step that can save money by avoiding unnecessary strengthening. Existing bolts in unreinforced masonry walls, often called "government anchors," should not be tested because the procedure is destructive. These anchors can be supplemented to improve their resistance to future ground shaking.

Ask for reasonably complete drawings to substantiate recommendations. The drawings should be based on engineering computations. You may discover that doing nothing is an acceptable course, but if you go ahead with a retrofit, you will need drawings to get a building permit anyway, as well as to get accurate pricing from contractors.

Ask for alternative solutions during the preliminary phase of the project. Seismic reinforcement is not an exact science and opinions often diverge on how much reinforcement is enough. Even if the building code prescribes a minimum resistance for the building, it will not tell you exactly how to achieve it, and there are usually several ways to meet a given goal.

Ask how the proposed solutions will be achieved—in other words, what parts of your building will be opened up—so that you know what parts of your house will be disrupted on the way to being improved. This way, you can consider what historic fabric may be affected. There is usually more than one way to complete a given procedure, and if you have an unusual cornice on your living room ceiling, for instance, you should advise the contractor to work from the roof or floor above. You will also want to understand in advance which parts of your building will be unusable and for how long.

(4) Estimate Costs

Show the engineering drawings to a few different contractors and ask them to itemize their estimates for the work. If you already have the specific analysis and preliminary drawings from the engineer, the contractor should be able to "count quantities" and itemize costs. If you accept an unsubstantiated lump sum, you don't know what you are paying for. With a detailed bid, you can again consider your alternatives and negotiate a final price more effectively, or the architect or engineer can do it for you.

(5) Work with an Appropriate Contractor

Like the engineer and architect, the contractor should be knowledgeable about the materials involved and the engineering techniques employed. It is often useful to retain the services of a contractor early in the process, to help with the assessment of alternatives both financially and pragmatically; however, these services are not substitutes for engineering consultations.

Assessing Your Options

Choosing the best hazard-reduction techniques for an older building is often a balancing act. Level of safety, construction costs, preservation of historic fabric, and building appearance must all be weighed, and trade-offs are often unavoidable. Getting good advice from an architect or engineer knowledgeable about historic buildings can go a long way toward reaching a good decision.

As a general rule, a respect for aesthetics and preserving your building's original appearance are essential parts of the equation.

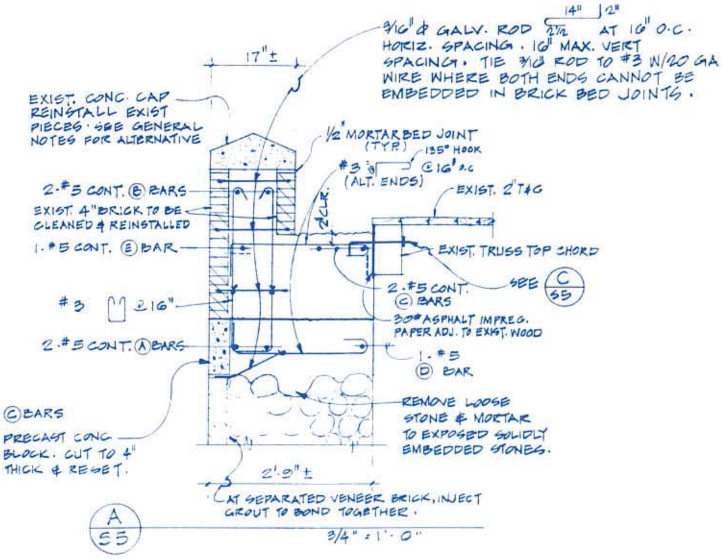
Every building poses a different problem, yet there are some standard solutions that, depending on building type, you can almost predict. While the exact procedure for carrying out any of these reinforcement techniques will vary from building to building, they are described here in ascending order of complexity, along with guidelines for assuring a job appropriate to a historic building. The simplest techniques are recommended for all buildings where earthquakes are a probability, while the more complex solutions are appropriate only in the areas of highest risk. For all buildings, good maintenance practices are an essential first step.

Reinforcing Hazardous Elements

Any poorly anchored or slender building element located above head level could pose a threat to life safety if it falls. Consequently, the basic and best investment in earthquake safety is to anchor loose or protruding elements—masonry ornamentation that could separate, chimneys that extend above the building, parapets that extend above the roof line. The key to preserving the appearance of a building is to make the anchorage as unobtrusive as possible while striving to preserve historic materials.

Anchoring Masonry Walls

The observation that an unreinforced masonry wall can separate from the roof or floors during earthquake shaking is quite common. Installing anchors to connect masonry walls to floors and roofs reduces the risk of separation, and adding anchors is probably the commonest retrofit procedure. For all-masonry buildings, anchorage accomplishes much of the necessary reinforcement and reduces most threats to life safety. Anchor bolts, usually 3/4 inch in diameter, are attached at one end to joists or rafters and then passed through holes drilled through the masonry to a metal plate on the face of the wall, which, like the washer on a common household bolt or screw, disperses the force on the wall and prevents the bolt from dislodging. The plates may serve as decorative elements in a building facade: star-shaped, round, and cruciform government anchors are features of many historic buildings.



Engineer's drawing for parapet reinforcement and veneer anchoring that retain the original materials and appearance of the building.

— Drawing courtesy of Kariotis and Associates

Newly developed alternative anchors that do not completely penetrate the exterior walls have also been tested and approved. This technique avoids the necessity of scaffolding on the exterior to attach the plates, retains the original appearance of the building, and may be less costly than through anchorage. It is recommended for use in historic facades.

If through anchorage is recommended for your building, consider in advance where the exterior plates will be located so that they will be as unobtrusive as possible. Use stainless or galvanized steel bolts to prevent rust streaks and paint them to further protect them from weathering. Align them carefully to avoid a haphazard appearance and be sure they do not intrude on areas of relief ornamentation.

Mitigating Slender Walls

Unreinforced masonry walls which are excessively slender have been observed to become unstable and partially collapse in recorded strong ground shaking. This damage is generally observed at the top of a building where the walls are the thinnest and unsupported at an attic. Anchorage of these walls to ceilings, roofs and floors reduces the slenderness. Steel or wood members can be added along the wall to further reduce slenderness.

Another technique to mitigate excessive slenderness is the addition of exterior buttresses, usually of wood or steel. This technique can destroy the visual character of the building exterior and may even require the removal of decorative elements. However, adding exterior buttresses can be an acceptable alternative to damaging a highly significant interior. In these cases, the buttresses should be designed to blend with the building's original lines and to avoid obscuring or damaging decorative elements.

An alternative approach is to thicken the existing walls by, in effect, attaching a new reinforced concrete wall to one side of them. The new wall is blown on to the old in the form of shotcrete or gunite. A very costly technique, it requires the removal or concealment of the finish on one side of a wall. Because of this permanent damage to historic fabric, it should be considered a technique of last resort.

Reducing Horizontal Displacements

Sheathed assemblies in houses, such as plaster, plywood, gypsum board, and clapboard absorb energy during an earthquake and limit horizontal displacements. For this reason, interior partitions should be removed with discretion. Often, they can be reinforced with plywood and tied in to the building frame to add additional resistance. Partitions of hollow clay tile—common in the 1920s and 1930s, especially in the West, and dangerous in earthquakes because the tile tends to explode—can be retrofitted and kept in place by providing a steel lath and concrete covering.

In unreinforced masonry buildings the addition of steel frames or walls behind glass fronts also limits horizontal displacements and protects against glass breakage. Adding frames, braces, or walls in the interior of a building will reduce horizontal displacements of floors and roofs and protect wall and ceiling finishes. Adding additional sheathing to roofs and floors can be an alternative to new interior frames and walls if they would disrupt interior service requirements.

Another relatively simple method of strengthening unreinforced masonry walls is to fill window or door openings with reinforced masonry. However, this technique should be considered extreme, since it alters the overall architectural effect of a building. It may be more acceptable in side and back walls than in a public facade.

If it is unavoidable, care should be taken to preserve visually the location of the openings. By recessing the new masonry above the sill, one can retain a sense of the original visual rhythm of the facade. The new infill material should either match the surrounding material or create a deliberate contrast through the use of color or texture.

Vertical Coring with Grouted Reinforcement

Reinforcing masonry buildings to mitigate slenderness can also be achieved by vertical coring, reinforcing, and grouting at regular intervals. To save the steeple of the Church of the Ascension, an important 19th-century building in Sierra Madre, Calif., for instance, engineers used a technique known as core drilling, which involves boring long vertical holes through the masonry (in this case, solid granite) and installing steel reinforcing bars. The reinforced hole is then grouted solid. This costly technique is justified only in certain installation situations, but it has the advantage of leaving both the interior and the exterior of a building intact.

Financing a Retrofit

After a major earthquake, the Federal Emergency Management Agency and the Small Business Administration offer limited funds to help victims rebuild, and state and federal governments may allocate additional emergency help targeted to specific problems. But financing seismic retrofits before disaster strikes is generally left to the building owner. Usually, the best approach is to treat it as you would other renovations or maintenance work and finance it accordingly, with a bank loan if necessary. For income-producing property—a commercial structure or apartment or condominium building—listed in or eligible for the National Register of Historic Places, the federal rehabilitation tax credits may help to defray costs. The work must be a "substantial" rehabilitation—defined as $5,000 or an amount over the adjusted basis of the building.

In California, some towns and cities subject to the Unreinforced Masonry Building Law have established assessment districts and issued bonds as part of local incentive programs to help building owners defray the cost of building analysis. Other cities have used Redevelopment Agency funds to provide grants and loans for everything from engineering evaluation to construction costs, sometimes in conjunction with financing programs from local banks.

Creative financing methods are best developed community by community. Contact local and state community development and housing agencies. Consider acting collectively. In an older downtown or historic neighborhood, you could commission a cooperative analysis, then incorporate retrofit into other plans for rehabilitation and repair.

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