The Seismic Retrofit of Historic Buildings
Keeping Preservation in the Forefront

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A NOTE TO OUR USERS: The web versions of the **Preservation Briefs** differ somewhat from the printed versions. Many illustrations are new, captions are simplified, illustrations are typically in color rather than black and white, and some complex charts have been omitted.

Violent, swift, and unpredictable, earthquakes result from sudden movements of the geological plates that form the earth's crust, generally along cracks or fractures known as "faults." If a building has not been designed and constructed to absorb these swaying ground motions, then major structural damage, or outright collapse, can result, with grave risk to human life. Historic buildings are especially vulnerable in this regard. As a result, more and more communities are beginning to adopt stringent requirements for seismic retrofit of existing buildings. And despite popular misconceptions, the risks of earthquakes are not limited to the West Coast.

Although historic and other older buildings can be retrofitted to survive earthquakes, many retrofit practices damage or destroy the very features that make such buildings significant. Life-safety issues are foremost and, fortunately, there are various approaches which can save historic buildings both from the devastation caused by earthquakes and from the damage inflicted by well-intentioned but insensitive retrofit procedures. Building owners, managers, consultants, and communities need to be actively involved in preparing documents and readying irreplaceable historic resources from these threats.

This Preservation Brief provides essential information on how earthquakes affect historic buildings, how a historic preservation ethic can guide responsible decisions, and how various methods of seismic retrofit can protect human lives *and* historic structures. Because many of the terms used in this Brief are technical, a glossary is provided at the end. The Brief focuses on unreinforced masonry buildings because these are the most vulnerable of our older resources, but the guidance is appropriate for all historic buildings. Damage to non-structural elements such as furnishings and collections is beyond the scope of this Brief, but consideration should be given to securing and protecting these cultural resources as well.

Planning the retrofit of historic buildings *before* an earthquake strikes is a process that requires teamwork on the part of engineers, architects, code officials, and agency administrators. Accordingly, this Brief also presents guidance on assembling a professional team and ensuring its successful interaction. Project personnel working together can ensure that the architectural, engineering, financial, cultural, and social values of historic buildings are preserved, while rendering them safe for continued use.

Balancing Seismic Retrofit and Preservation

Reinforcing a historic building to meet new construction requirements, as prescribed by many building codes, can destroy much of a historic building's appearance and integrity. This is because the most expedient ways to reinforce a building according to such codes are to impose structural members and to fill irregularities or large openings, regardless of the placement of architectural detail. The results can be quite intrusive. However, structural reinforcement can be introduced sensitively. In such cases, its design, placement, patterning, and detailing respect the historic character of the building, even when the reinforcement itself is visible.

Before

Before

After rehabilitation

After

After rehabilitation

After

Both exteriors and interiors can be severely damaged in an earthquake. This Craftsman Style bungalow was successfully rehabilitated and seismically upgraded after the Northridge earthquake in California.

Photos: Courtesy, Historic Preservation Partners in Earthquake Response.

Three important preservation principles should be kept in mind when undertaking seismic retrofit projects:

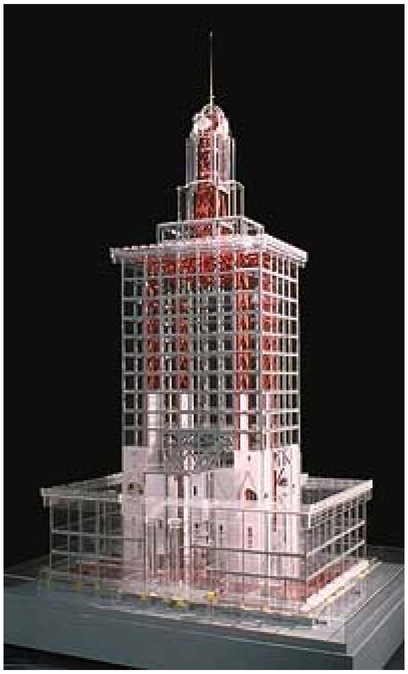
- *Historic materials should be preserved and retained to the greatest extent possible and not replaced wholesale in the process of seismic strengthening;*
- *New seismic retrofit systems, whether hidden or exposed, should respect the character and integrity of the historic building and be visually compatible with it in design; and,*
- *Seismic work should be "reversible" to the greatest extent possible to allow*

removal for future use of improved systems and traditional repair of remaining historic materials.

It is strongly advised that all owners of historically significant buildings contemplating seismic retrofit become familiar with *The Secretary of the Interior's Standards for the Treatment of Historic Properties*, which are published by the National Park Service and cited in the bibliography of this publication. These standards identify approaches for working with historic buildings, including preservation, rehabilitation, and restoration. Code-required work to make buildings functional and safe is an integral component of each approach identified in the *Standards.* While some seismic upgrading work is more permanent than reversible, care must be taken to preserve historic materials to the greatest extent possible and for new work to have a minimal visual impact on the historic appearance of the building.

Earthquake Damage to Historic Buildings: Assessing Principal Risk Factors

Typical earthquake damage to most older and historic buildings results from poor ductility--or flexibility--of the building and, specifically, poor structural connections between walls, floors, and foundations combined with the very heavy weight and mass of historic materials that are moved by seismic forces and must be resisted. In buildings that have not been seismically upgraded, particularly unreinforced masonry buildings, parapets, chimneys, and gable ends may dislodge and fall to the ground during a moderate to severe earthquake. Walls, floors, roofs, skylights, porches, and stairs which rely on tied connections may simply fail. Interior structural supports may partially or totally collapse. Unreinforced masonry walls between openings often exhibit shear (or diagonal) cracking. Upper stories may collapse onto under-reinforced lower floors with large perimeter openings or atriums. Unbraced infill material between structural or rigid frame supports may dislodge. Adjacent buildings with separate foundations may move differently in an earthquake creating damage between them. Poorly anchored wood frame buildings tend to slide off their foundations. Ruptured gas and water lines often cause fire and water damage. Many of these vulnerabilities can be mitigated by understanding how the forces unleashed in an earthquake affect the building, then planning and implementing appropriate remedial treatments.



This computer model illustrates the comprehensive methods used to fully reinforce a building for the future. Oakland City Hall, CA. Computer Model ©Douglas Symes, San Francisco.

Six principal factors influence how and why historic buildings are damaged in an earthquake:

(1) depth of the earthquake and subsequent strength of earthquake waves reaching the surface

(2) duration of the earthquake, including after-shock tremors

(3) proximity of the building to the earthquake epicenter, although distance is not necessarily a direct relationship

(4) geological and soil conditions

(5) building construction details, including materials, structural systems, and plan configuration; and

(6) existing building condition, including maintenance level.

The first three factors--**the depth, duration, and proximity to the fault**--are beyond human control. Recent earthquakes have shown the fourth factor, geological soil conditions, to be as important as any of the other factors because loose, soft soils tend to amplify ground motion, thereby increasing damage. Further, there is the tendency of soft, unstable soils to "liquefy" as the ground vibrates, causing the building foundations to sink unevenly. This fourth factor, geological and soil conditions, is difficult to address in a retrofit situation, although it can be planned for in new construction. The last two factors--**the building's construction type and its existing physical condition**--are the two factors over which building owners and managers have control and can ultimately affect how the historic property performs in an earthquake.

Although historic buildings present problems, the way they were constructed often has intrinsic benefits that should not be overlooked. Diagonal subflooring under tongue-and-groove nailed flooring can provide a diaphragm, or horizontal membrane, that ties the building together. Interior masonry walls employing wire lath with plaster also add strength that binds materials together. The typical construction of older buildings with partition walls that extend from floor to ceiling (instead of just to the underside of a dropped ceiling) also provides additional support and load transfer during an earthquake that keeps shifting floors from collapsing. Moreover, buildings constructed of unreinforced masonry with a wall thickness to height ratio that does not exceed code requirements can often survive shaking without serious damage. The stability of unreinforced masonry walls should not be underestimated; while the masonry may crack, it often does not shift out of plumb enough to collapse.

Type of Building and Construction

A historic building’s construction and materials determine its behavior during an earthquake. Some buildings, such as wooden frame structures, are quite ductile and, thus, able to absorb substantial movements. Others, such as unreinforced brick or adobe buildings comprised of heavy individual load-bearing units, are more susceptible to damage from shaking. If an earthquake is strong, or continues for a long time, building elements that are poorly attached or unreinforced may collapse. Most historic buildings still standing in earthquake zones have survived some shaking, but may be structurally weakened.

Buildings of more rigid construction techniques may also have seismic deficiencies. Masonry infill-wall buildings are generally built of steel or concrete structural frames with unreinforced masonry sections or panels set within the frame. While the structural frames may survive an earthquake, the masonry infill can crack and, in some cases, dislodge. The reaction of concrete buildings and concrete frame structures is largely dependent upon the extent and configuration of iron or steel reinforcement. Early buildings constructed of concrete are often inadequately reinforced, inadequately tied, or both, and are thus susceptible to damage during earthquakes.

Recognition of the configuration of the historic structure and inherent areas of weakness are essential to addressing appropriate alternatives for seismic retrofit. For example, the plan and elevation may be as important as building materials and structural systems in determining a historic building’s survival in an earthquake. Small round, square, or rectangular buildings generally survive an earthquake because their geometry allows for equal resistance of lateral forces in all directions. The more complex and irregular the plan, however, the more likely the building will be damaged during an earthquake because of its uneven strength and stiffness in different directions. Structures having an "L," "T," "H," "U," or "E" shape have unequal resistance, with the stress concentrated at corners and intersections. This is of particular concern if the buildings have flexible structural systems and/or an irregular layout of shear walls which may cause portions of the building to pull apart.

Similarly, the more complex and irregular a building elevation, the more susceptible it is to damage, especially in tall structures. Large or multiple openings around the building on the ground level, such as storefronts or garage openings, or floors with columns and walls running in only one direction are commonly known as "soft stories" and are prone to structural damage.

Building Condition

Much of the damage that occurs during an earthquake is directly related to the building’s existing condition and maintenance history. Well maintained buildings, even without added reinforcement, survive better than buildings weakened by lack of maintenance. The capacity of the structural system to resist earthquakes may be severely reduced if previous alterations or earthquakes have weakened structural connections or if materials have deteriorated from moisture, termite, or other damage. Furthermore, in unreinforced historic masonry buildings, deteriorated mortar joints can weaken entire walls. Cyclical maintenance, which reduces moisture penetration and erosion of materials, is therefore essential. Because damage can be cumulative, it is important to analyze the structural capacity of the building.

Over time, structural members can become loose and pose a major liability. Unreinforced historic masonry buildings typically have a friction-fit connection between horizontal and vertical structural members, and the shaking caused by an earthquake pulls them apart. With insufficient bearing surface for beams, joists, and rafters against the load bearing walls or support columns, they fail. The resulting structural inadequacy may cause a partial or complete building collapse, depending on the severity of the earthquake and the internal wall configuration. Tying the building together by making a positive anchored or braced connection between walls, columns, and framing members, is key to the seismic retrofit of historic buildings.

Putting a Team Together


The use of fiber composite materials can enhance the shear capacity of existing structural components. Photo: The Crosby Group.

The two goals of the seismic retrofit in historic buildings are life safety and the protection of older and historic buildings during and after an earthquake. Because rehabilitation should be sensitive to historic materials and the building’s historic character, it is important to put together a team experienced in both seismic requirements and historic preservation. Team members should be selected for their experience with similar projects, and may include architects, engineers, code specialists, contractors, and preservation consultants. Because the typical seismic codes are written for new construction, it is important that both the architect and structural engineer be knowledgeable about historic buildings and about meeting building code equivalencies and using alternative solutions. Local and state building officials can identify regulatory requirements, alternative approaches to meeting these requirements, and if the jurisdiction uses a historic preservation or building conservation code. Even on small projects that cannot support a full professional team, consultants should be familiar with historic preservation goals. The State Historic Preservation Office and the local historic preservation office or commission may be able to identify consultants who have been successful in preserving historic buildings during seismic retrofit work. Once the team has been assembled, their tasks include:

Compiling documentation. The team should review all available documentation on the historic building, including any previous documentation assembled to nominate the structure to the National Register of Historic Places, and any previous Historic Structures Reports. Original plans and specifications as well as those showing alterations through time often detail structural connections. Early real estate or insurance plans, such as the *Sanborn Maps,* note changes over time. Historic photographs of the building under construction or before and after previous earthquakes are invaluable. Base maps for geological or seismic studies and utility maps showing the location of water, gas, and electric lines should be also identified. The municipal or state office of emergency preparedness can provide data on earthquake hazard plans for the community.

Evaluating significant features and spaces. The team must also identify areas of a historic building and its site that exhibit design integrity or historical significance which must be preserved. It is critical, and a great challenge, to protect these major features, such as domes, atriums, and vaulted spaces or highly decorative elements, such as mosaics, murals, and frescoes. In some cases, secondary areas of the building can provide spaces for additional reinforcement behind these major features, thus saving them from damage during seismic retrofit work. Both primary and secondary spaces, features, and finishes should, thus, be identified.

Assessing the condition of the building and the risk hazards. The team then assesses the general physical condition of the building's interior and exterior, and identifies areas vulnerable to seismic damage. This often requires a structural engineer or testing firm to determine the strength and durability of materials and connections. A sliding scale of potential damage is established, based on the probability of hazard by locale and building use. This helps the owner distinguish between areas in which repairable damage, such as cracking, may occur and those in which life-threatening problems may arise. These findings help guide cost-benefit decisions, especially when budgets are limited.

Evaluating local and state codes and requirements. Few codes consider historic buildings, but the California State Historical Code and the Uniform Code for Building Conservation provide excellent models for jurisdictions to adopt. Code officials should always be asked where alternative approaches can be taken to provide life safety if the specified requirements of a code would destroy significant historic materials and features. Some jurisdictions require the removal of parapets, chimneys, or projecting decoration from unreinforced masonry buildings which is not a preservation approach. Professionals on the team should be prepared with alternatives that allow for mitigating potential damage to such features while retaining them through reattachment or strengthening.

Developing a retrofit plan. The final task of the project team is to develop a retrofit plan. The plan may require multiple treatments, each more comprehensive than the last. Treating life-safety issues as well as providing a safe route of exit should be evaluated for all buildings. Developing more comprehensive plans, often combined with future rehabilitation, is reasonable. Long-term restoration solutions phased in over time as funding is available should also be considered. In every case, owners and their planning teams should consider options that keep preservation goals in mind.

There are significant advantages of completing a seismic survey and analysis even if resources for implementing a retrofit are not yet available. Once the retrofit plan is finished, the project team will have a document by which to assess future damage and proceed with emergency repairs. If construction is phased, its impact to the whole building should be understood. Some partially completed retrofit measures have left buildings more rigid in one area than in others, thereby contributing to more extensive damage during an ensuing earthquake.

Planning for Seismic Retrofit: How Much and Where?

The integrity and significance of the historic building, paired with the cost and benefit of seismic upgrading, need to be weighed by the owner and the consulting team. Buildings in less active seismic areas may need little or no further bracing or tying. Buildings in more active seismic zones, however, may need more extensive intervention. Options for the level of seismic retrofit generally fall into four classifications, depending on the expected seismic activity and the desired level of performance. Realistically, for historic buildings, only the first three categories apply.

Upon completion, the changes to this ca. 1932 Gothic Revival building to add base isolation at the foundation were not visually apparent. Photo: © Jonathan Farrer

1) *Basic Life Safety.* This addresses the most serious life-safety concerns by correcting those deficiencies that could lead to serious human injury or total building collapse. Upgrades may include bracing and tying the most vulnerable elements of the building, such as parapets, chimneys, and projecting ornamentation or reinforcing routes of exit. It is expected that if an earthquake were to occur, the building would not collapse but would be seriously damaged requiring major repairs.

2) *Enhanced Life Safety.* In this approach, the building is upgraded using a flexible approach to the building codes for moderate earthquakes. Inherent deficiencies found in older buildings, such as poor floor to wall framing connections and unbraced masonry walls would be corrected. After a design level earthquake, some structural damage is anticipated, such as masonry cracking, and the building would be temporarily unusable.

3) *Enhanced Damage Control.* Historic buildings are substantially rehabilitated to meet, to the extent possible, the proscribed building code provision. Some minor repairable damage would be expected after a major earthquake.

4) *Immediate Occupancy.* This approach is intended for designated hospitals and emergency preparedness centers remaining open and operational after a major earthquake. Even most modern buildings do not meet this level of construction, and so for a historic building to meet this requirement, it would have to be almost totally reconstructed of new materials which, philosophically, does not reflect preservation criteria.

Devising the most appropriate approach for a particular historic building will depend on a variety of factors, including the building's use, whether it remains occupied during construction, applicable codes, budgetary constraints, and projected risk of damage. From a design perspective, the vast majority of historic buildings can tolerate a well-planned hidden system of reinforcement. Utilitarian structures, such as warehouses, may be able to receive fairly visible reinforcement systems without undue damage to their historic character. Other more architecturally detailed buildings or those with more finished interior surfaces, however, will benefit from more hidden systems; installation of such systems may even require the temporary removal of significant features to assure their protection. Most buildings, particularly commercial rehabilitations, can incorporate seismic strengthening during other construction work in a way that ensures a high degree of retention of historic materials in place.

Assessing the Cost of Seismic Retrofit

Cost plays a critical role in selecting the most appropriate retrofit measure. It is always best to undertake retrofit measures before an earthquake occurs, when options are available for strengthening existing members. Once damage is done, the cost will be substantially higher and finding engineers, architects, and contractors available to do the work on a constricted schedule will be more difficult.

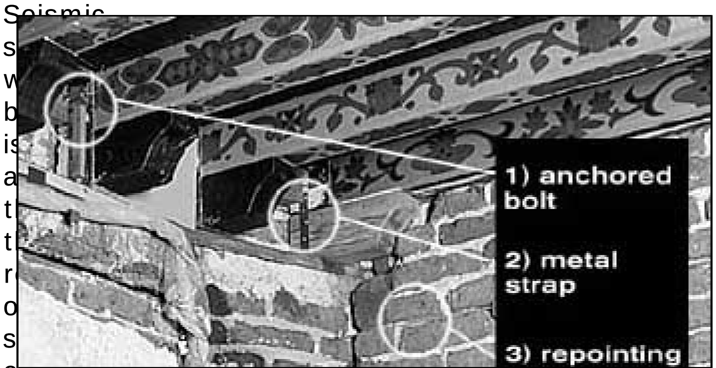
Planned seismic retrofit work may add between $10 and $100 per square foot to the cost of rehabilitation work depending on the level of intervention, the condition of the building, and whether work will be undertaken while the building is occupied. Costs can exceed several hundred dollars a square foot for combined restoration and seismic upgrade costs in major public buildings, in order to provide a level of structural reinforcement that would require only minor repairs after a major earthquake. But maintenance and incremental improvements to eliminate life-safety risks are within the cost realm of responsible upkeep.

Each property owner has to weigh the costs and benefits of undertaking seismic retrofit in a timely manner. Owners may find that an extended engineering study evaluating a wide range of options is worthwhile. Not only can such a study consider the most sensitive historic preservation solution, but the most cost-effective one as well. In many cases, actual retrofit expenses have been lower than anticipated because a careful analysis of the existing building was made that took the durability and performance of existing historic materials into consideration. Most seismic retrofit is done incrementally or incorporated into other rehabilitation work. In large public buildings, seemingly expensive "high-tech" solution such as installing foundation base isolators can turn out to be justified because significant historic materials do not have to be removed, replaced, or replicated. The cost for a fully retrofitted building can offset the potential loss of income, relocation, and rebuilding after an earthquake. Without careful study, these solutions often are not evaluated.

Some municipalities and states provide low-interest loans, tax relief, municipal bonds, or funding grants targeted to seismic retrofit. Federal tax incentives for the rehabilitation of income-producing historic buildings include seismic strengthening as an allowable expense. Information on these incentives is available from the State Historic Preservation Office. It is also in the best interest of business communities to support the retrofit of buildings in seismically active areas to reduce the loss of sales and property taxes, should an earthquake occur.

Seismic Strengthening Approaches

Seismic s w b is a t t r o s elements. Such reinforcement can include anchored ties, reinforced mortar joints, braced frames, bond beams, moment-resisting frames, shear walls, and horizontal diaphragms. Most historic buildings can use these standard, traditional methods of strengthening successfully, if properly designed to conform to the historic character of the building. In addition, there are new technologies and better designs for traditional connection devices as well as a greater acceptance of alternative approaches to meeting seismic requirements. While some technologies may still be new for retrofit, the key preservation principles previously outlined should be applied, to ensure that historic buildings will not be damaged by them.



Limited intervention should correct obvious structural deficiencies, such as tying vulnerable elements together and repointing masonry. Upon replastering and painting these reinforcements will not be visible. Photo: Courtesy, Historic Preservation Partners for Earthquake Response.

There are varying levels of intervention for seismically retrofitting historic buildings based on the owner's program, the recommendations of the team, applicable codes, and the availability of funds.

Maintenance / Preparedness

Adequate maintenance ensures that existing historic materials remain in good condition and are not weakened by rot, rust, decay or other moisture problems. Without exception, historic buildings should be well maintained and an evacuation plan developed. Expectation that an earthquake will occur sometime in the future should prepare the owner to have emergency information and supplies on hand.

- Check roofs, gutters, and foundations for moisture problems, and for corrosion of metal ties for parapets and chimneys. Make repairs and keep metal painted and in good condition.
- Inspect and keep termite and wood boring insects away from wooden structural members. Check exit steps and porches to ensure that they are tightly connected and will not collapse during an emergency exit.
- Check masonry for deteriorating mortar, and never defer repairs. Repoint, matching the historic mortar in composition and detailing.
- Contact utility companies for information on flexible connectors for gas and water lines, and earthquake activated gas shut-off valves. Strap oil tanks down and anchor water heaters to wall framing.
- Collect local emergency material for reference and implement simple household or office mitigation measures, such as installing latches to keep cabinets from flying open or braces to attach tall bookcases to walls. Keep drinking water, tarpaulins, and other emergency supplies on hand.

Basic / Traditional Measures

This is not an exhaustive list, but illustrates that most measures to reduce life-safety risks rely on using mechanical fasteners to tie a building together. Incorporating these measures can be done incrementally without waiting for extensive rehabilitation. An architectural or engineering survey should identify what is needed. Care should be taken to integrate these changes with the visual appearance of the building.

- Bolt sill plates to foundations and add plywood stiffeners to cripple wall framing around wood frame buildings. Keep reinforcement behind decorative crawlspace lattice or other historic features.

- Reinforce floor and roof framing connections to walls using joist hangers, metal straps, threaded bolts, or other means of mechanical fasteners. Tie columns to beams; reinforce porch and stair connections as well.

- Repair weakened wooden structural systems by adding, pairing, or bracing existing members. Consider adding non-ferrous metal straps in alternating mortar joints if extensive repointing is done in masonry walls.

- Reinforce projecting parapets and tie parapets, chimneys, balconies, and unsecured decorative elements to structural framing. Make the connections as unobtrusive as possible. In some cases, concrete bond beams can be added to reinforce the top of unreinforced masonry or adobe walls.

- Properly install and anchor new diaphragms, such as roof sheathing or subflooring, to the walls of a structure prior to installing finish materials.

- Avoid awkwardly placed exposed metal plates or rosettes when using threaded bolts through masonry walls. When exposed plates will interfere with the decorative elements of the facade, use less visible grouted bolts or plates that can be set underneath exposed finished materials.

- Use sensitively designed metal bracing along building exteriors to tie the unsupported face of long exterior walls to the floor framing. This is often seen along side or party walls in commercial or industrial buildings.

Rehabilitation

When buildings are being rehabilitated, it is generally the most cost effective time to make major upgrades that affect the structural performance of the building. New elements, such as concrete shear walls or fiber reinforcing systems can be added while the structure is exposed for other rehabilitation or code compliance work.

X-brace to dampen and transfer seismic loads

Shown here is an interior diagonal frame which will dampen and transfer seismic loads in a designed path from foundation to roof. Photo: David Look, AIA.

- Inspect and improve all lateral tie connections and diaphragms.

- Reinforce walls and large openings to improve shear strength in locations of doors, windows, and storefront openings. Carefully locate "X" and "K" bracing to avoid visual intrusion, or use moment frames, which are a hidden perimeter bracing in large openings. From a preservation perspective, the use of a more hidden system in finished spaces is generally preferable.

- Strengthen masonry walls or columns with new concrete reinforcement or fiber wrap systems. Avoid the use of heavy spray concrete or projecting reinforced walls that seriously alter the historic relationship of the wall to windows, trim, and other architectural moldings or details.

- Selectively locate new shear walls constructed to assist the continuous transfer of loads from the foundation to the roof. If these walls cannot be set behind historic finishes, they should be located in secondary spaces in conjunction with other types of reinforcement of the primary spaces or features.

- Consider the internal grouting of rubble masonry walls using an injected grout mixture that is compatible in composition with existing mortar. Ensure that exposed areas are repaired and that the mortar matches all visual qualities of the historic mortar joints in tooling, width, color and texture.

- Evaluate odd-shaped buildings and consider the reinforcement of corners and connections instead of infilling openings with new construction. Altering the basic configuration and appearance of primary facades of buildings is damaging to those qualities that make the building architecturally significant.

Specialized Technologies

Base isolator allows horizontal movement

The new base isolator allows the structural support member at the foundation to move horizontally as it absorbs the earthquake forces. Photo: ©Jonathan Farrer.

New technologies, being developed all the time, may have applicability to historic preservation projects. These specialized technologies include: vertical and center core drilling systems for unreinforced masonry buildings, base isolation at the foundations, superstructure damping systems, bonded resin coatings, and reproducing lost elements in lighter materials. However, many new technologies may also be non-reversible treatments resulting in difficulties of repair after an earthquake. The reinforcement of historic materials with special resins, or the use of core drilling to provide a reinforced vertical connection from foundation to roof may not be as repairable after an earthquake as would more traditional means of wall reinforcement. New technologies should be carefully evaluated by the design team for both their benefits as well as their shortcomings.

Using computer modeling of how historic buildings may act in an earthquake suggests options for seismic upgrade using a combination of traditional methods and new technologies. While most projects involving base isolation and other complex damping systems constitute only a small percentage of the projects nationwide that are seismically reinforced, they may be appropriate for buildings with significant interior spaces that should not be disturbed or removed during the retrofit. Each building will needs its own survey and evaluation to determine the most appropriate seismic reinforcement.

Post-Earthquake Issues

New structural steel and restoration of the historic stucco and decorative tile work and a repaired tile roof reinstated this earthquake damaged building as a major element of the historic district. Northridge, CA
Photo: Courtesy of Historic Preservation Partners for Earthquake Response.

Should a historic building suffer damage during an earthquake, it is the owner *who has a plan in place* who will be able to play a critical role in determining its ultimate fate. If the owner has previously assembled a team for the purpose of seismic upgrading, there is a greater chance for the building to be evaluated in a timely fashion and for independent emergency stabilization to occur. In most municipalities, a survey, often by trained volunteers, will be conducted as soon as possible after an earthquake, and buildings will be tagged on the front with a posted notice according to their ability to be entered. Typically red, yellow, and green tags are used to indicate varying levels of damage--*no entry, limited entry, and useable*--to warn citizens of their relative safety. Heavily damaged areas are often secured off-limits and many red tagged, but repairable, buildings have been torn down unnecessarily because owners were unable to evaluate and present a stabilization plan in time. Owners or members of the preservation community may engage their own engineers with specialized knowledge to challenge a demolition order. Because seismic retrofit is complex and many jurisdictions are involved, the coordination between various regulatory bodies needs to be accomplished *before* an earthquake.

During times of emergencies, many communities, banks, and insurance agencies will not be in a position to evaluate alternative approaches to dealing with damaged historic buildings, and so they often require full compliance with codes for new construction for the major rehabilitation work required. Because seismic after-shocks often create more damage to a weakened building, the inability to act quickly--even to shore up the structure on a temporary basis--can result in the building's demolition. Penetrating rain, uneven settlement, vandalism, and continuing after-shocks can easily undermine a building’s remaining structural integrity. Moreover, the longer a building is unoccupied and non-income-producing, the sooner it will be torn down in a negotiated settlement with the insurance company. All of these factors work against saving buildings damaged in earthquakes, and make having an action plan essential.

Having an emergency plan in place, complete with access to plywood, tarpaulins, bracing timbers, and equipment, will allow quick action to save a building following an earthquake. Knowing how the community evaluates buildings and the steps taken to secure an area will give the owner the ability to be a helpful resource to the community in a time of need.

If the federal government is asked to intervene after a natural disaster, technical assistance programs are available. Often after a disaster, grant funds or low-cost loans from federal, state, and congressional special appropriations are targeted to qualified properties, which can help underwrite the high cost of rehabilitation (see information about FEMA)

Conclusion

Recent earthquakes have shown that historic buildings retrofitted to withstand earthquakes survive better than those that have not been upgraded. Even simple efforts, such as bracing parapets, tying buildings to foundations, and anchoring brick walls at the highest, or roof level, have been extremely effective. It has also been proven that well maintained buildings have faired better than those in poor condition during and after an earthquake. Thus, maintenance and seismic retrofit are two critical components for the protection of historic buildings in areas of seismic activity. It makes no sense to retrofit a building, then leave the improvements, such as braced parapets or metal bolts with plates, to deteriorate due to lack of maintenance.

Damage to historic buildings *after* an earthquake can be as great as the initial damage from the earthquake itself. The ability to act quickly to shore up and stabilize a building and to begin its sensitive rehabilitation is imperative. Communities without earthquake hazard reduction plans in place put their historic buildings--as well as the safety and economic well-being of their residents -- at risk.

Having the right team in place is important. Seismic strengthening of existing historic buildings and knowledge of community planning for earthquake response makes the professional opinions of the team members that much more important when obtaining permits to do the work. Local code enforcement officials can only implement the provisions of the model or historic preservation codes if the data and calculations work to ensure public safety. Buildings do not need to be over-retrofitted. A cost-effective balance between protecting the public and the building recognizes that planned for repairable damage can be addressed after an earthquake. Engineers and architects, *who specialize in historic buildings* and who have a working knowledge of alternative options and expected performance for historic structures, are critical to the process.

It is clear that historic and older buildings can be seismically upgraded in a cost-effective manner while retaining or restoring important historic character-defining qualities. Seismic upgrading measures exist that preserve the historic character and materials of a buildings. However, it takes a multi-disciplined team to plan and to execute sensitive seismic retrofit. It also takes commitment on the part of city, state, and federal leaders to ensure that historic districts are protected from needless demolition after an earthquake so that historic buildings and their communities are preserved for the future.

SEISMIC RISK ZONES

Most local jurisdictions measure seismic risk based on seismic zones established by code, such as the Uniform Building Code with its 4 risk zones [1=low to 4=high]. There are also maps, such as this one, which identify the Effective Peak Acceleration (EPA) which further reflect the light, moderate, and severe shaking risks as a percentage of the acceleration of gravity that can be expected in an area.

In the United States, the greatest activity areas are the western states, Alaska, and some volcanic island areas. However, noted historical earthquakes occurred in Massachusetts (1755), Missouri (1811), South Carolina (1886), and Alaska (1964). The Caribbean Islands and Puerto Rico have been sites of severe earthquakes. The history of earthquakes in the United States has been recorded for over 200 years and new areas of concern include moderate risk areas in southern and mid-western states.

The Richter Magnitude Scale, first published in 1935, records the size of an earthquake at its source, as measured on a seismograph. Magnitudes are expressed in whole numbers and decimals between 1 and 9. An earthquake of a magnitude of 6 or more will cause moderate damage, while one of over 7 will be considered a major earthquake. It is important to remember that an increase of one whole number on the Richter Scale is a tenfold increase in the size of the earthquake.

The Federal Emergency Management Agency

The Federal Emergency Management Agency -- FEMA -- is an independent agency of the federal government, reporting to the President. Since its founding in 1979, FEMA's mission has been to reduce loss of life and property and protect our nation's critical infrastructure from all types of hazards through a comprehensive, risk-based, emergency management program. FEMA works with the state and local governments and the private sector to stimulate increased participation in emergency preparedness, mitigation, response and recovery programs related to natural disasters. To minimize damage-repair-damage cycles, FEMA carries out and encourages preventive activities referred to as hazard mitigation.

The FEMA Hazard Mitigation Program, established in 1988 with the passage of the Robert T. Stafford Disaster Relief and Emergency Assistance Act, offers a framework for protecting historic structures from natural disasters. In the event of a federally declared disaster, state and local governments as well as eligible non-profit applicants may receive financial and technical assistance to identify and carry out cost-effective hazard mitigation activities.

FEMA encourages hazard mitigation projects, including the restoration of buildings, by providing technical assistance and funding through the Hazard Mitigation Grant Program (HMPG), which can underwrite up to 50% of the cost of the project.

FEMA's public-assistance program provides financial and other assistance to rebuild disaster-damaged facilities that serve a public purpose, such as schools, hospitals, government buildings and public utilities.

In terms of technical assistance, FEMA, under a cooperative agreement with the Building Seismic Safety Council has produced two volumes of comprehensive material dealing with the seismic retrofit of existing buildings (see Further Reading). In addition an ongoing project ATC-43 involves earthquake analysis procedures for Unreinforced Masonry Buildings and Reinforced Concrete Buildings. These documents contain nationally applicable technical criteria intended to ensure that buildings will withstand earthquakes better than before. There is a great deal of information that is applicable to historic buildings, although historic buildings are not necessarily identified as a category. Write for FEMA publications at:

FEMA, PO Box 70274, Washington, DC 20024

For current information about emergency activities, federally declared disaster areas, or how to contact regional offices see the FEMA website:
http://www.cr.nps.gov/scripts/intercept.asp?http://www.fema.gov/

Questions To Ask When Planning Seismic Retrofit:

These questions should be asked with the assistance of the team to determine acceptable alternatives. Since there is never a single right answer, the design team and code officials should work together to determine the appropriate level of seismic retrofit with the lowest visual impact on the significant spaces, features, and finishes of both the interior and exterior of historic buildings.

As with the illustrations above, this guide is not intended to proscribe how seismic retrofit should be done, but rather, to illustrate that every physical change to a building will have some consequence. By asking how impacts can be reduced, the owner will have several options from which to choose.

» Can bracing be installed without damaging decorative details or appearance of parapets, chimneys, or balconies?

» Are the visible features of the reinforcement, such as anchor washers or exterior buttresses adequately designed to blend with the historic building?

» Can hidden or grouted bolts be set on an angle to tie floors and walls together, instead of using traditional bolts and exposed washers or rosettes on ornamental exteriors?

» Are diagonal frames, such as X, K, or struts located to have a minimal impact on the primary facade? Are they set back and painted a receding color if visible through windows or storefronts?

» Can moment frames or reinforced bracing be added around historic storefronts in order to avoid unsightly exposed reinforcement, such as X braces, within the immediate viewing range of the public?

» Can shorter sections of reinforcement be "stitched" into the existing building to avoid removal of large sections of historic materials? This is particularly true for the insertion of roof framing supports.

» Can shear walls be located in utilitarian interior spaces to reduce the impact on finishes in the primary areas?

» Are there situations where thinner applied fiber reinforced coating would adequately strenghten walls or supports without the need for heavier reinforced concrete?

» Can diaphragms be added to non-significant floors in order to protect highly decorated ceilings below, or the reverse if the floor is more ornamental than the ceiling?

» Are there adequate funds to retain, repair, or reinstall ornamental finishes once structural reinforcements have been installed?

» Should base isolation, wall damping systems, or core drilling be considered? Are they protecting significant materials by reducing the amount of intervention?

» Are the seismic treatments being considered "reversible" in a way that allows the most amount of historic materials to be retained and allows future repair and restoration?

Further Reading

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Glossary

Anchor Ties or bolts: Generally threaded rods or bolt which connect walls to floor and roof framing. Washers, plates, or rosettes anchor the bolt in place.

Base isolation: the ability to isolate the structures from the damaging effects of earthquakes by providing a flexible layer between the foundations and vertical supports.

Diagonal Braces: the use of diagonal, chevron or other type of bracing (X or K) to provide lateral resistance to adjacent walls.

Core drilling: a type of vertical reinforcement of masonry walls that relies on drilling a continuous vertical core that is filled with steel reinforcing rods and grouting to resist in-plane shear and out-of-plane bending.

Cripple wall: A frame wall between a building's first floor and foundation.

Diaphragm: A floor, roof, or continuous membrane that provides for the transfer of earthquake loading to the exterior or interior shear walls of the structure.

Fiber wrap reinforcement: A synthetic compound of filaments that increase the shear capacity of structural members.

Grouted bolts: anchor bolts set, generally on an angle, in a concrete grout mixture, avoid the problem of using an exposed washer. Requires a greater diameter hole than an anchor bolt with washer.

Lateral forces: Generally the horizontal forces transferred to the building from the dynamic effects of wind or seismic forces.

Life-safety: providing a level of assurance that risk of loss of life is kept to minimal levels. For buildings, this includes strengthening to reduce 1)structural collapse, 2) falling debris, 3)blocking exits or emergency routes, and 4) prevention of consequential fire.

Moment-resisting frame: A steel frame designed to provide in-plane resistance to lateral loads particularly by reinforcing the joint connection between column and beams without adding a diagonal brace. Often used as a perimeter frame around storefronts or large door and window openings.

Seismic retrofit: All measures that improve the earthquake performance of a building especially those that affect structural stability and reduce the potential for heavy structural damage or collapse.

Shear stress: A concept in physics where forces act on a body in opposite directions, but not in the same line. Horizontal forces applied to a wall that is insufficient to move with these forces will crack, often in a diagonal or X pattern. Connections at beams and walls will also crack from shear stress.

Shear wall: A wall deliberately designed to transfer the building's loads from the roof and floors to the foundation thereby preventing a building from collapse from wind or earthquake forces.

Unreinforced Masonry (URM): This designation refers to traditional brick, block,and adobe construction that relies on the weight of the masonry and the bonding capacity of mortar to provide structural stability.

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Home page logo: Earthquake damaged building. Photo: NPS files.

This publication has been prepared pursuant to the National Historic Preservation Act of 1966, as amended, which directs the Secretary of the Interior to develop and make available information concerning historic properties. Technical Preservation Services (TPS), Heritage Preservation Services Division, National Park Service prepares standards, guidelines, and other educational materials on responsible historic preservation treatments for a broad public.
