FINAL REPORT

NONSTRUCTURAL EARTHQUAKE MITIGATION GUIDANCE MANUAL

FEMA

Prepared for
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PURPOSE

The purpose of this Non-Structural Earthquake Mitigation Guidance Manual is to help the Federal Emergency Management Agency (FEMA), State, and local officials, and other stakeholders answer two central questions about non-structural seismic hazard mitigation projects.

1. Are the levels of seismic hazard (i.e., the frequency and severity of earthquakes) high enough in a given community to warrant consideration of seismic hazard mitigation projects for some buildings or facilities? If not, then a community's mitigation efforts and resources can better be focused on other hazards that pose a more serious risk for the community.
2. If the level of seismic hazard is sufficiently high to warrant consideration, how does a community identify the best cost-effective, non-structural seismic hazard mitigation projects from the wide range of possible projects?

This Guidance Manual addresses non-structural seismic mitigation projects. Non-structural seismic mitigation projects address contents or building elements that will not cause a building to collapse if they fail, but might cause injury and might temporarily affect the use of the structure, i.e., result in a loss of function. Non-structural seismic hazard mitigation projects include mitigation projects for:

1. **Building contents--**such as furnishings and equipment, bookcases, file cabinets, cubicle wall partitions, computers or wall hangings;
2. **Exterior building elements**--such as parapets, chimneys, and exterior facing windows, and doors;
3. **Interior building elements**--such as partition walls, suspended ceilings and fixtures, and raised computer floors; and
4. **Building utilities**--such as equipment, pipes/ducts and connections for heating, ventilation and air conditioning (HVAC), electricity, gas, water, wastewater, communications, and elevator systems.

This Guidance Manual does not address structural seismic hazard mitigation projects. Structural mitigation projects address the major building elements that hold up a building, such as foundations, walls, floors, beams, columns, and roofs.

This manual is not intended to be a complete guide to earthquake engineering, to replace a benefit-cost analysis (BCA) for specific mitigation projects, or provide detailed instructions for conducting BCAs. Rather, by helping to answer the two central questions above, this manual is intended to help applicants find the best non-structural seismic hazard mitigation projects in their communities. The best seismic hazard mitigation projects are those that provide the greatest reduction in damage, economic impacts, and casualties for the lowest cost.

The information in this Guidance Manual is specifically focused on non-structural seismic hazard mitigation projects in areas of moderate to moderately high seismic risk, including portions of the central United States. However, the information is generally applicable to all areas of the United States. This guidance is applicable not only to FEMA-funded seismic hazard mitigation projects but also to projects funded by State, local or private funds. See the Appendices for a brief introduction to FEMA's hazard mitigation programs.

SEISMIC HAZARD

Seismic "hazard" refers to the frequency and severity of damaging earthquakes. For a given community, the higher the level of seismic hazard, the more likely it is that any specific seismic mitigation project will be cost-effective.

In the United States, earthquakes are most commonly associated with California due to the high seismic hazard level in many parts of California. However, many other parts of the country also face significant seismic hazards. State-of-the-art seismic data compiled by the U.S. Geological Survey (USGS) indicate that portions of more than 40 states have significant levels of seismic hazard.

There are only a handful of states were the level of seismic hazard is essentially negligible statewide, including Delaware, Florida, Iowa, Michigan, Minnesota, and Wisconsin. Nearly every other state has some areas where the level of seismic hazard may be significant. Indeed, seismic hazard mitigation is a national issue that affects most states to some extent.

SEISMIC RISK

Seismic risk refers to the threat to the built environment (i.e., the potential for damage, economic losses, and casualties). For a given community, the level of seismic risk depends on seismic hazard: the higher the seismic hazard (frequency and severity of earthquakes) the higher the seismic risk. Seismic risk also depends on the vulnerability of buildings and other facilities to earthquakes.

In many areas of the United States with moderate to moderately high levels of seismic hazard, the level of seismic risk may be nearly as high as in California or even higher, because of the greater vulnerability of many buildings and other facilities to earthquake damage. Because of this greater vulnerability, many areas of the United States have high levels of seismic risk and thus, correspondingly, have the potential for many mitigation projects to reduce this seismic risk. There are many cost-effective seismic hazard mitigation projects, not only in areas with the highest levels of seismic hazard, but also in areas with moderately high or moderate seismic hazard, as well.

SEISMIC HAZARD MITIGATION PROJECTS

Seismic hazard mitigation projects are intended to reduce the level of seismic risk. That is, these projects reduce the potential for damage, losses, and casualties. Some seismic hazard mitigation projects involve mapping of hazards or mitigation planning. However, most projects, and the focus of this Guidance Manual, involve constructed measures to reduce damage, economic losses, and casualties. Constructed seismic hazard mitigation projects are commonly classified as "structural" or "non-structural."

Structural elements of a building or structure refer to the load-bearing skeleton that holds up the structure and supports other building elements. Structural seismic hazard mitigation projects are those that improve, strengthen, or replace structural elements to better resist earthquake forces. Evaluation of structural seismic hazard mitigation projects requires specialized engineering expertise and is not included in this Guidance Manual.

Non-structural elements refer to everything in or on a building other than the structural elements. Unlike structural elements, if non-structural elements fail, the building will not collapse. Non-structural seismic hazard mitigation projects improve, strengthen, or brace non-structural building elements to reduce damage, economic losses and casualties in earthquakes.

The best non-structural seismic hazard mitigation projects are those that are cost-effective and mitigate (reduce or eliminate) a high level of seismic risk. As stated previously, seismic risk (the threat to the built environment or the potential for damage, economic losses, and casualties) depends not only on seismic hazard (the probability and severity of earthquakes) but also on the value, importance, and vulnerability of the non-structural element being protected.

For each non-structural mitigation project, the determination of whether or not the project is – cost-effective depends on the specific elements of each project. The specific project elements include:

1. Level of seismic hazard
2. Benefits achieved by the project (i.e., the reduction in damage, losses, and casualties)
3. Project cost

Generally, non-structural projects in higher seismic hazard areas are much more likely to be – cost-effective than identical projects in lower seismic hazard areas.

GENERAL GUIDANCE FOR NON-STRUCTURAL SEISMIC MITIGATION PROJECTS

General guidance about the importance of seismic mitigation and the likelihood of finding cost-effective mitigation projects in a community can be obtained by determining the level of seismic hazard from a USGS national or regional seismic hazard map. It is important to recognize that even in the highest seismic hazard areas not all non-structural mitigation projects will be cost-effective. For communities with progressively lower levels of seismic hazard, progressively fewer and fewer non-structural mitigation projects will be cost-effective. As the level of seismic hazard drops, only projects that mitigate a high risk to life safety, protect very vulnerable and very expensive contents, or preserve important functions will be cost-effective. For communities with low levels of seismic hazard, all or nearly all mitigation efforts are most likely better focused on other hazards that pose a significant threat to the community.

DECISION MAKING PROCESS FOR EVALUATING NON-STRUCTURAL SEISMIC HAZARD MITIGATION PROJECTS

The body of this Guidance Manual contains a three-step process for evaluating non-structural seismic hazard mitigation projects. The methodologies for using these three steps are discussed in this Guidance Manual:

- Step 1 – Determine Seismic Hazard
  - Determine the Level of Seismic Hazard

  - Determine Local Soil and Groundwater Conditions
  - Determine Potential Secondary Impacts

- Step 2 – Identify High Priority Buildings
  - Identify Potential Buildings for Non-Structural Mitigation Projects
  - Evaluate Special Situations
  - Screen for Factors That May Preclude Projects

- Step 3 – Selecting Non-Structural Mitigation Projects
  - Selecting Non-Structural Mitigation Projects
  - Mitigation Objectives
  - Technical Notes

1.1 PURPOSE

The purpose of this Non-Structural Earthquake Mitigation Guidance Manual is to help the Federal Emergency Management Agency (FEMA), State, and local officials, and other stakeholders answer two central questions about non-structural seismic hazard mitigation projects.

1. Are the levels of seismic hazard (i.e., the frequency and severity of earthquakes) high enough in a given community to warrant consideration of seismic hazard mitigation projects for some buildings or facilities? If not, then a community’s mitigation efforts and resources can better be focused on other hazards that pose a more serious risk for the community.
2. If the level of seismic hazard is sufficiently high to warrant consideration, how does a community identify the best (most cost-effective) non-structural seismic mitigation projects from the wide range of possible projects?

The three-step process outlined in this Guidance Manual provides FEMA, State, and local officials and other stakeholders with a simple evaluation methodology for non-structural seismic hazard mitigation projects.

1.2 HOW TO USE THIS GUIDANCE MANUAL

The Guidance Manual is a non-technical guidance document for FEMA, State, and local officials. The Manual provides a step-by-step process to identify viable non-structural seismic mitigation projects and provide guidance to help communities identify the best possible projects. This Guidance Manual is not intended for use as design specifications, and a structural engineer with knowledge of seismic construction requirements and methods should be consulted before undertaking most non-structural earthquake mitigation measures.

The Guidance Manual outlines the process of how to determine if a potential project might be a good candidate for earthquake mitigation. It is important to remember, however, that none of the measures in this manual should be considered “pre-approved” mitigation measures that are automatically eligible for FEMA project funding.

1.3 INFORMATION FOUND IN THIS GUIDANCE MANUAL

The core of this Guidance Manual is the three-step process for evaluating potential non-structural seismic hazard mitigation projects. Each of these steps is covered in turn:

- **Step 1: Determine the Community’s Level of Seismic Hazard**
- **Step 2: Identify High Priority Buildings**
- **Step 3: Determine the Best Mitigation Projects for the Highest Priority Buildings**

1.4 DIFFERENCE BETWEEN STRUCTURAL AND NON-STRUCTURAL BUILDING ELEMENTS

The main focus of the Guidance Manual is on earthquake mitigation of buildings, although similar concepts apply to non-building mitigation projects. When using this manual it is important to recognize the distinction between *structural* and *non-structural* building elements.

Structural elements of a building act as a skeleton to support the rest of the building, and include the foundation, load-bearing walls, beams, columns, floor system, and roof system as well as the connections between these elements (Figure 1-1). A failure of one or more of these structural elements can lead to a collapse of the entire building. Similarly, for bridges and other non-building structures, structural elements are those elements that support or hold up the structure.

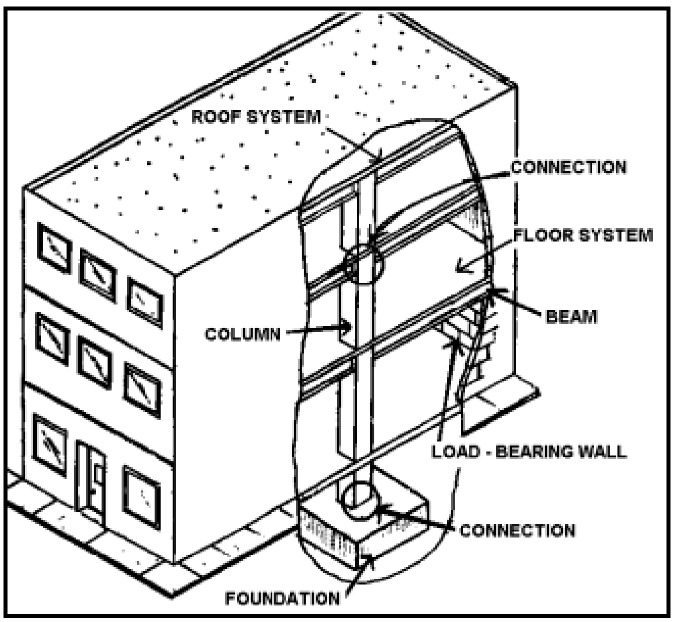


Figure 1-1: Typical Structural Building Elements

Source: *Earthquake Hazard Mitigation Handbook for Public Facilities,* FEMA Region X, February 28, 2002

Non-structural elements are those elements that will not cause a building or structure to collapse if they fail. These elements rely on structural elements for support, and include exterior elements, interior elements, building utilities, and contents. A breakdown of these elements is listed below:

1. **Exterior elements** include parapets, chimneys, exterior facing, windows, and doors;
2. **Interior elements** include non-load bearing interior walls, partition walls, suspended ceilings, lights, and raised computer floors;
3. **Building utilities** include electrical, mechanical, and plumbing equipment, cables, pipes, ducts and connections for heating, ventilation, and air conditioning (HVAC), electricity, gas, water, wastewater, communications and elevator systems; and

4. **Building contents** include all furnishings and equipment such as tables, chairs, bookcases, file cabinets, cubicle wall partitions, computers, or wall hangings.

This Guidance Manual addresses mitigation of these non-structural building elements by retrofitting or applying other mitigation techniques to reduce or eliminate earthquake damage.

STEP 1 – DETERMINE SEISMIC HAZARD

- Determine the Level of Seismic Hazard
- Determine Local Soil and Groundwater Conditions
- Determine Potential Secondary Impacts

STEP 2 – IDENTIFY HIGH PRIORITY BUILDINGS

- Identify Potential Buildings for Non-Structural Mitigation Projects
- Evaluate Special Situations
- Screen for Factors That May Preclude Projects

STEP 3 – SELECTING NON-STRUCTURAL MITIGATION PROJECTS

- Selecting Non-Structural Mitigation Projects
- Mitigation Objectives
- Technical Notes

2.1 WHAT IS AN EARTHQUAKE?

A crust of solid rock that varies from approximately 10 to 100 miles thick covers the surface of the earth. This crust floats on top of a layer of heavier, softer rock known as the mantle. The earth's crust is divided into large and small sections that geologists call plates. Most large-scale geologic processes, including earthquakes and volcanoes, are the result of plate tectonics. Plate tectonics is the movement of these plates of crust relative to one another.

Most earthquakes occur when these geologic plates slide against each other or move over or under each other. Thus, most earthquakes occur at boundaries between tectonic plates. Earthquakes on the San Andreas Fault in California are an example of earthquakes that occur along a boundary between two plates. However, some earthquakes occur within plates at weak points or points of high stress due to plate motions. Earthquakes in the New Madrid Fault zone in Missouri and Arkansas and earthquakes in South Carolina are examples of earthquakes within plates. Other geologic processes, such as volcanic eruptions, also can cause earthquakes.

Earthquakes occur when parts of the earth's rocky crust break or rupture along zones of weakness or faults. The ground shaking from earthquakes results from shock waves that propagate from points along fault zones where the crust ruptures. Some earthquake faults reach the earth's surface, while others occur only at depths below the surface. Many earthquakes are too insignificant to be noticed by people and can be detected only by sensitive instruments. Such insignificant earthquakes do not cause damage. However, larger earthquakes may be felt over hundreds or even thousands of miles and can cause widespread damage. Refer to Appendix D for additional information on how earthquakes are measured.

2.2 PRIMARY EARTHQUAKE EFFECTS

The primary effects of earthquakes include ground motions due to seismic shaking and soil effects such as settlement, displacement, and liquefaction. Earthquakes produce ground motions that are both lateral (sideways) and vertical (up-and-down). These lateral and vertical ground motions generate similar motions in buildings and contents. Earthquake ground motion can be large enough to apply forces to buildings and their contents. At low levels of ground shaking, buildings and contents may shake without damage. At higher levels of ground shaking, building elements may deform, bend, crack, break, or collapse. At higher levels of ground shaking, contents may be toppled or moved about rooms.

The vast majority of damage from earthquakes arises directly from the effects of ground motions on buildings, other structures, and contents. The level of ground shaking at a given location during an earthquake depends on the size of the earthquake, the distance between the earthquake and the affected site, the soil or rock conditions at the site, and on several other technical factors. Lateral earthquake ground motions can create large forces that accelerate the building both sideways and vertically (Figure 2-1a). The building response or floor acceleration generally varies with the height of the building (Figure 2-1b). As a consequence, the effect of building response on non-structural elements also varies with building height (Figure 2-1c). Building damage is shown on Figure 2-2.

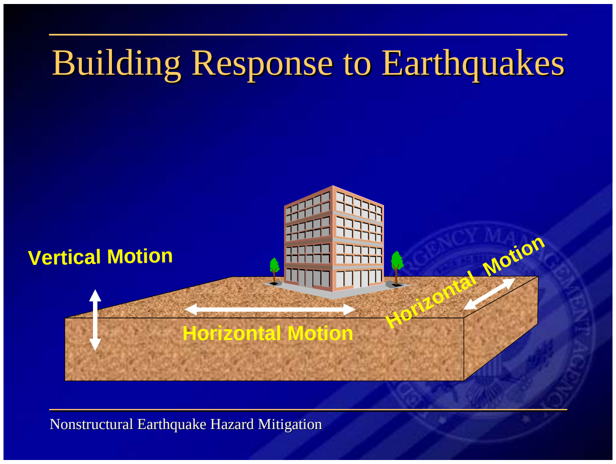


Figure 2-1a: Building Response to Earthquakes

Source: Training Materials for Earthquake Hazard Mitigation for Non-Structural Elements (FEMA, in preparation)

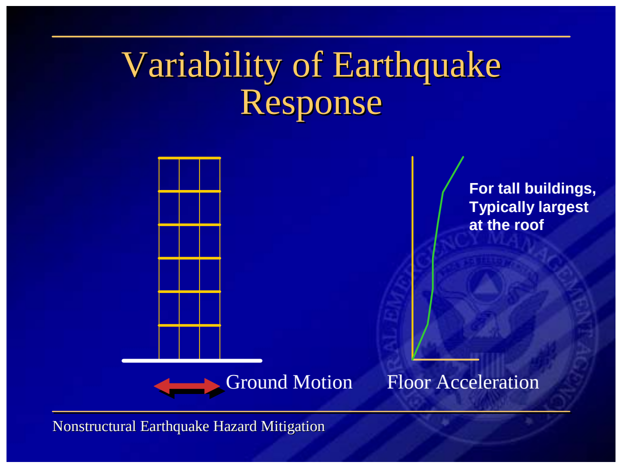


Figure 2-1b: Variability of Building Response with Building Height

Source: Training Materials for Earthquake Hazard Mitigation for Non-Structural Elements (FEMA, in preparation)

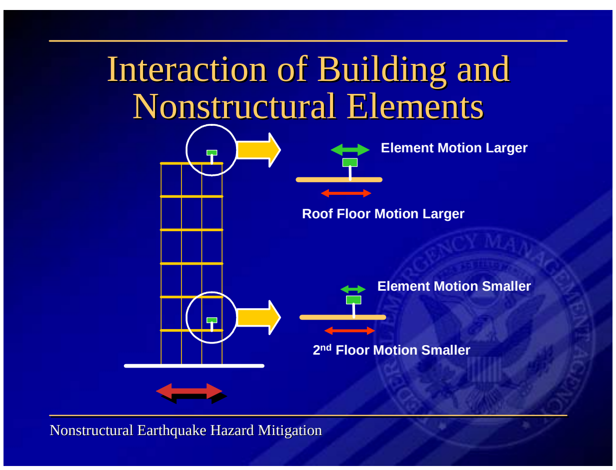


Figure 2-1c: Variability of Interaction between Building and Non-Structural Elements with Building Height

Source: Training Materials for Earthquake Hazard Mitigation for Non-Structural Elements (FEMA, in preparation)

Figure 2-2: Earthquake Damage Due to Ground Motions

Source: FEMA— photo of damage from an earthquake in Southern California

During an earthquake, ground motions displace the foundation more than the rest of the building, causing deformations and stresses in the building elements. The size of these displacements is typically determined by the various building properties such as the shape, weight, and stiffness of the building. Excessive displacements, such as those that occur during an earthquake, can bring a building frame out of plumb, allowing vertical gravity forces to deform it further (Figures 2-3 and 2-4a). This is a phenomenon known as the "P-delta effect." Ductility is the property of certain building materials (such as wood or steel) to withstand large deformations without failing. As discussed in Section 6, Common Non-Structural Elements and Mitigation Projects, the ductility of building elements and connections is important to resist earthquake displacements. Non-structural elements might respond to ground motion and building response by sliding and/or overturning (Figure 2-4b).

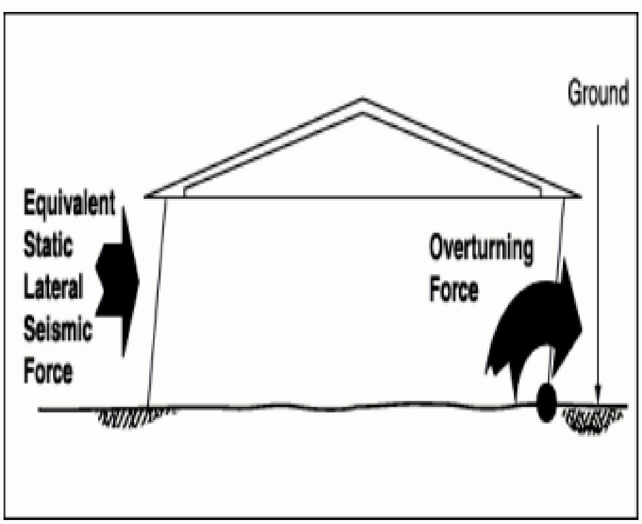


Figure 2-3: P-delta Effects on a Building

Source: Coastal Construction Manual, FEMA 55, 3rd Edition, June 2000

Figure 2-4a: Earthquake Damage Due to Excessive Displacements

Source: http://autoinfo.smartlink.net/quake/

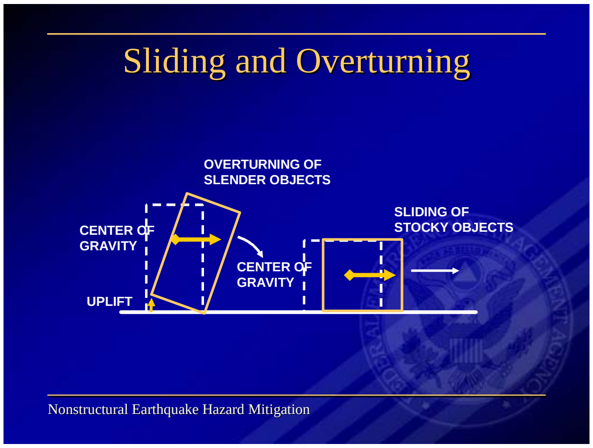


Figure 2-4b: Variability of Lateral and Overturning Effects with Centers of Gravity

Source: Training Materials for Earthquake Hazard Mitigation for Non-Structural Elements (FEMA, in preparation)

As noted previously, most earthquake damage is caused directly by earthquake ground motions. However, earthquake ground motions may also cause soil effects that result in additional damage to buildings and other structures. These soil effects include settlement, displacement (also called lateral spreading), and liquefaction. Settlement and displacement refer to downward soil movement (settlement) or sideways soil movement (displacement). Such earthquake induced soil movement can damage building foundations and infrastructure and may result in additional damage beyond that caused directly by ground shaking.

2.2.1 Liquefaction, Settlement, and Lateral Spreading

Liquefaction occurs when loose, wet, granular soil is shaken by an earthquake and becomes unstable so that the soil is transformed into a nearly fluid mass (Figure 2-5). Settlement, displacement, and liquefaction of soils occur most commonly in loose, wet soils, such as conditions found in locations near rivers, streams, lakes, and coastlines. Soil settlements and displacements can range from a fraction of an inch to several feet or more. Settlements or displacements of even a few inches often can cause major damage to buildings and infrastructure. Large settlements and displacements of several feet may result in structure collapse. Liquefaction can range from minor tilting of structures to total collapse in extreme cases.

The extent that soils at a given site are susceptible to settlement, displacement, or liquefaction requires a geotechnical or soils engineering analysis. Areas subject to such soil effects are sometimes shown on hazard maps. Any areas of soft, wet soils near bodies of water should be considered as a potential subject to damaging soil effects during earthquakes.

Figure 2-5: Earthquake Damage Due to Liquefaction

Source: Internet photo of liquefaction damage to a building

2.3 SECONDARY EFFECTS

In addition to primary effects, there are several secondary effects of earthquakes than can also cause high levels of damage in localized areas. The major secondary effects of earthquakes include landslides, tsunamis, fire, hazardous materials incidents, and inundation.

2.3.1 Landslides

Landslides can occur when unstable soils or rock along a natural or man-made slope experience earthquake-related settlements or liquefaction, resulting in a sudden downward movement of the unstable soil or rock mass. Landslides can cause major damage to buildings and other structures (roads, utility lines) built in the landslide area or down slope from the landslide area (Figure 2-6).

Figure 2-6: Landslide Due to Earthquake

NOAA National Data Center - photo of landslide at Dunne Avenue east of Morgan Hill, California, April 12, 1984

www.ngdc.noaa.gov/seg/hazard/slideset/9/9_slides.shtml

2.3.2 Tsunamis

Tsunamis, which are often incorrectly referred to as tidal waves, are actually seismic waves in oceans that result from undersea earthquakes. When these water waves approach shorelines, the wave heights may increase greatly due to the water becoming shallow and cause catastrophic damage to buildings and other structures along the coast and loss of life. The effects of tsunamis are often localized in areas where local topography results in unusually high wave heights. Hazard maps of coastal areas subject to tsunamis often include tsunami hazard zones.

2.3.3 Fire Following Earthquakes

Fire is another common secondary effect from earthquakes. Fire ignitions are often triggered by earthquake damage to contents and buildings (gas line breaks, etc.). Especially under dry windy conditions, numerous earthquake fire ignitions combined with extensive damage to water systems results in a potential for widespread fire damage following earthquakes (Figure 2-7).

Figure 2-7: Fire Following Earthquake

http://gallery.unl.edu/picinfo/2969.html

2.3.4 Hazardous Materials Incidents

Earthquakes can also result in hazardous materials (HAZMAT) incidents from failures of tanks or other storage containers at locations affected by strong ground motions. HAZMAT incidents can also result from railroad derailments when tracks deform in earthquakes. The severity of HAZMAT incidents can range from minor, localized events to major events affecting large areas, depending on the volume and type of hazardous materials released.

2.3.5 Inundation

The last common secondary effect of earthquakes is inundation (flooding). Inundation following an earthquake may result from the failure of dams, levees, or water pipes (especially large-diameter, high-volume transmission line pipes), or large water tanks. Inundation damage from dam or levee failure may be widespread, while damage from pipeline or water tank failure is generally localized.

2.3.6 Secondary Effects Summary

Most earthquake damage occurs directly as a result of earthquake ground motions. However, in localized areas, damage may be substantially exacerbated by local soil effects, including liquefaction, settlement, and lateral spreading.

In addition, some localized areas may be subject to secondary effects of earthquakes, including landslides, tsunamis, fire following earthquake, HAZMAT incidents, or inundation. Damage from such secondary effect can range from minor to complete, catastrophic damage.

Planning for all seismic hazard mitigation projects, should consider not only earthquake ground motions but also the potential for secondary effects for the project site. When such secondary effects are important at a given project site, the engineering design for the mitigation project must take the secondary effects into account. In some cases, a pronounced secondary effect may be so serious (e.g., lead to building collapse) that consideration of non-structural seismic hazard mitigation projects may be precluded.

2.4 EARTHQUAKE MITIGATION

Earthquake mitigation refers to measures taken to reduce the risk of damage, economic losses, and casualties during earthquakes. Such mitigation has been successful in greatly reducing the potential for earthquake damage in the United States. Over the past 30 years, building code upgrades alone have led to improved seismic design and construction of facilities that are safer for occupants and more resistant to severe earthquake damage or collapse.

In considering seismic mitigation projects, it is important to recognize that seismic mitigation projects rarely, if ever, make a building or other facility “earthquake proof.” Rather, typical seismic mitigation projects often greatly reduce the potential for damage and casualties, especially for slight to moderate levels of ground shaking. However, even with seismic mitigation, damage and casualties may still occur during earthquakes that result from high levels of ground shaking at the project site. There are two major approaches to earthquake mitigation: *structural* and *non-structural mitigation.*

2.4.1 Structural Mitigation

Structural Mitigation involves retrofitting of a building's structural elements to reduce or eliminate earthquake damage. As stated previously, the structural elements of a building act as a skeleton that supports the rest of the building, and include the foundation, load-bearing walls, beams, columns, floor system, and roof system as well as the connections between these elements. A failure of one or more of these structural elements can lead to a collapse of the entire building. Structural mitigation measures may also be applied to non-building structures, such as bridges, dams, and utility system elements.

2.4.2 Non-Structural Mitigation

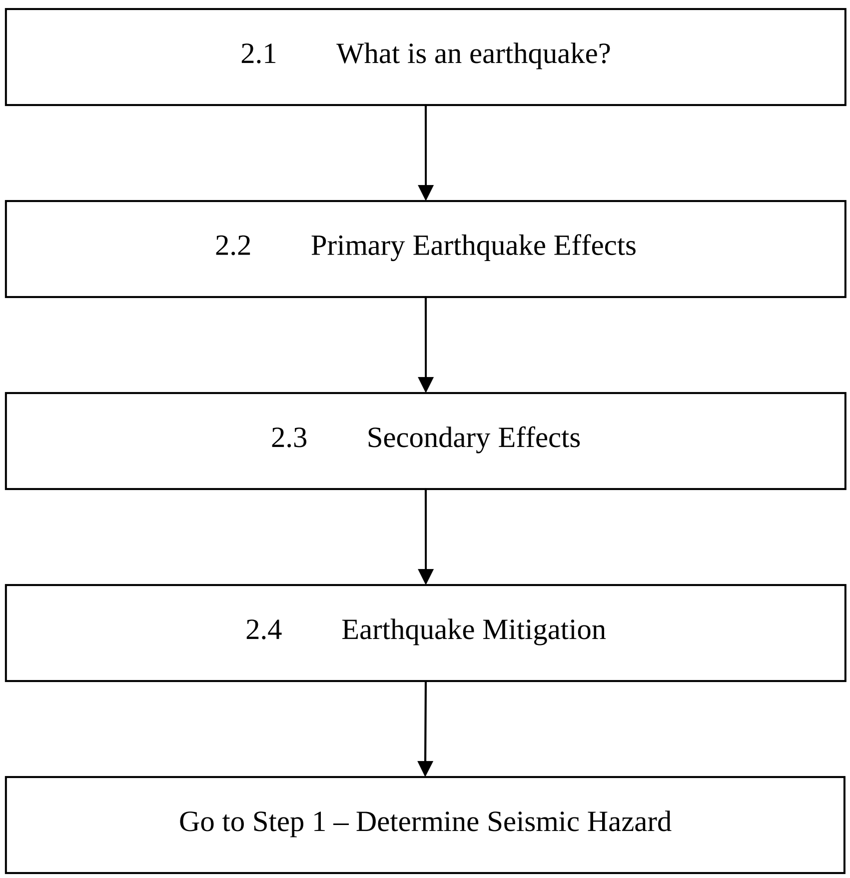
Non-Structural Mitigation involves retrofitting a building's non-structural elements. The non-structural elements of a building are those elements that will not cause a building to collapse if they fail, and include exterior elements, interior elements, building electrical, mechanical and plumbing systems, and contents. A breakdown of common non-structural mitigation techniques is presented below.

1. **Brace Exterior Elements –** Reduce or eliminate damage to exterior elements (parapets, chimneys, exterior facing, windows, and doors) by bracing, strengthening, reinforcing, or replacing elements or connections to withstand earthquake forces. Mitigation measures include bracing parapets, anchoring or replacing cornices and architectural elements, bracing chimneys, securing wall panel anchors, bracing large windows, or replacing window glass.
2. **Anchor Interior Elements –** Anchor interior non-structural elements (non-load bearing interior walls, partition walls, suspended ceilings, and raised computer floors) by strengthening or reinforcing elements or connections to withstand earthquake forces and movements. Mitigation measures include securing of un-braced suspended (drop) ceilings and overhead lighting fixtures with wires and struts, bracing of interior partitions, and anchoring raised computer floors at their pedestal supports.
3. **Protect Building Electrical, Mechanical, and Plumbing Systems –** Anchor heavy building utility equipment and secure utility connections and supply lines to protect them against earthquake forces and movements. Heavy building utility equipment can be anchored by protecting springs on vibration isolators, securing gas tanks with metal straps, and bracing and restraining elevator counterweights and rails. Utility connections and supply lines can be secured by bracing overhead utility pipes and HVAC ducts with metal brackets, installing flexible pipes or conduits at connections, and installing seismic shutoff valves on gas lines.
4. **Secure Building Contents –** Secure furnishings and other building contents to reduce movement from earthquake-induced ground shaking. Desktop computers and equipment can be restrained with chains, cables, clips, or cords. Metal anchors can be used to secure bookcases and large filing systems to floors, walls, or each other. Hazardous materials and other miscellaneous furnishings (tables, chairs, cubicle wall partitions, wall hangings, etc.) can be secured with straps, anchors, angle brackets, and sturdy hooks.

Other mitigation techniques that may be included under non-structural mitigation include earthquake hazard mitigation planning and preparedness.

2.4.3 Mitigation Summary

This brief primer about earthquakes has focused on the results of earthquakes that result in damage to buildings and structures. Most earthquake damage is directly due to ground shaking. However, local soil effects such as liquefaction, settlement, and lateral spreading may increase building damage levels. In addition, some locations may be subject to increased damage from secondary effects of earthquakes, including landslides, tsunamis, fire following earthquake, HAZMAT incidents, or inundation. Additional information about measuring earthquakes, soil rock classifications used in building codes, and other seismic engineering issues are covered in Appendices D, E, and F.



3.1 STEP 1: DETERMINE THE LEVEL OF SEISMIC HAZARD

For any community considering possible non-structural seismic mitigation projects, there are two central questions:

1. **Are the levels of seismic hazard (i.e., the frequency and severity of earthquakes) high enough in a given community to warrant consideration of seismic hazard mitigation projects for some buildings or facilities?** If not, then a community can better focus its mitigation efforts and resources on other hazards that pose a more serious risk for the community.
2. **If the level of seismic hazard is sufficiently high to warrant consideration, how does a community identify the most cost-effective non-structural seismic mitigation projects from the wide range of possible projects?**

The first step in evaluating the need for non-structural seismic mitigation projects is to determine the level of seismic hazard for the community. Answering this question will determine the extent to which a community needs to seriously evaluate non-structural seismic mitigation projects. The three general hazard categories and potential responses by communities include:

1. For **high or moderately high seismic levels**, the community may decide that non-structural mitigation is a high priority and implement a community-wide mitigation program.
2. For **moderate seismic levels**, the community may decide to consider only a few non-structural mitigation projects for facilities that are both vulnerable to seismic damage and critical to the community.
3. For **low or negligible seismic hazard levels**, the community may decide to focus mitigation efforts on other hazards that pose a higher risk for the community. If the level of seismic hazard is at a low level, then few, if any, non-structural seismic mitigation projects are likely to be cost-effective.

The seismic hazard level for any community can be easily and quickly determined from national maps of seismic hazard levels. If the community has a high enough level of seismic hazard to warrant serious consideration of non-structural seismic hazard mitigation projects, this chapter provides guidance on how to fine-tune the hazard assessment by considering local soil conditions and possible secondary effects of earthquakes.

The fundamental questions about seismic hazard mitigation can easily be answered by reviewing the national seismic hazard maps prepared by the U.S. Geological Survey (USGS). Figure 3-1 shows current USGS information regarding seismic hazards in the United States.

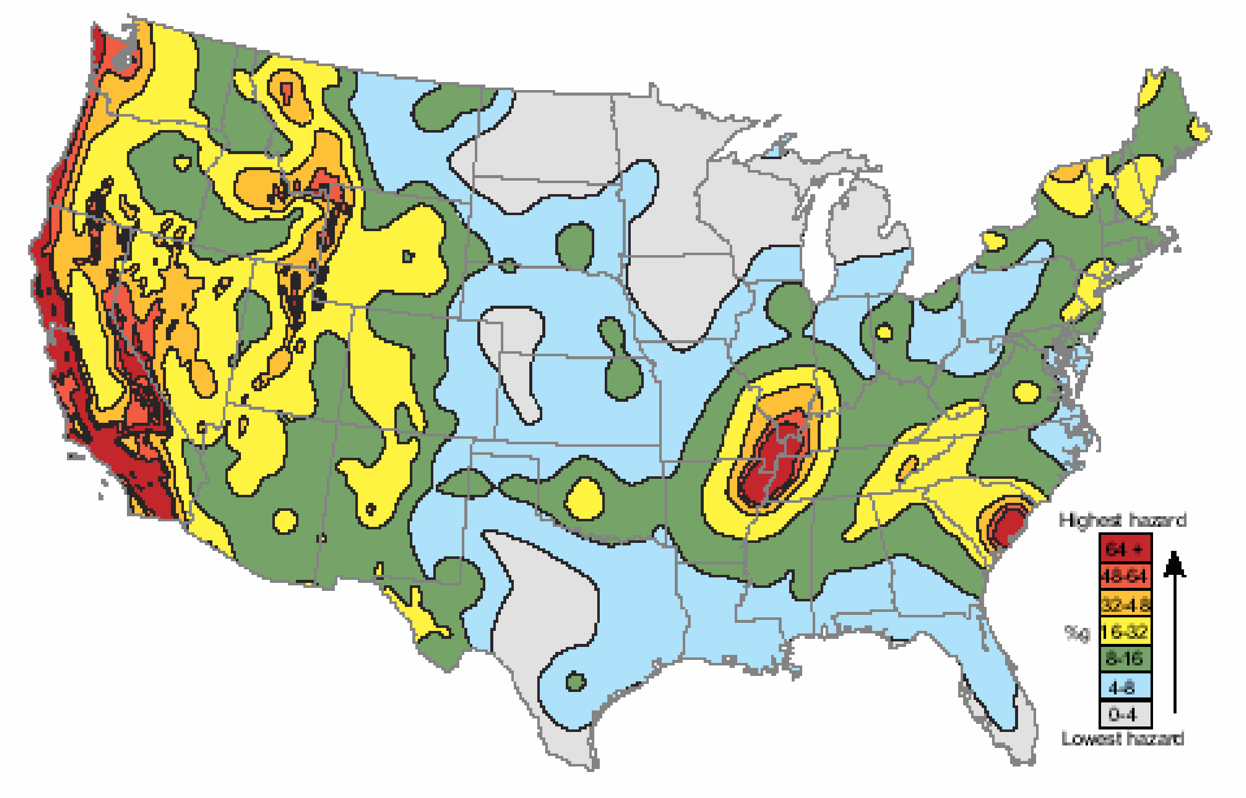


Figure 3-1: USGS Earthquake Hazard Map

Source: U.S. Geological Survey Fact Sheet FS-131-02, October 2002 (http://pubs.usgs.gov/fs/fs-131-02/)

The highest seismic hazard areas are shown in red on the map. Moderately high and moderate seismic hazard areas are shown in dark and light orange, respectively. Moderately low seismic hazard areas are shown in yellow. Low seismic hazard areas are shown in green. Very low seismic hazard areas are shown in blue and areas with negligible seismic hazard are shown in gray. The color contours on the seismic hazard map represent the expected (probabilistic) level of ground shaking expected with a 2% chance of being exceeded in a 50-year period. In technical terms, the levels of ground shaking are shown as peak ground acceleration (% of g, the acceleration of gravity). Refer to Appendix A for additional details on the earthquake hazard map and other earthquake hazard factors.

Suggestions for interpreting and responding to the seismic hazard level (color) for a community are given in Table 3-1 below. A community may want to consider contacting the State Emergency Management Office to talk with the State Earthquake Program Manager or the State Hazard Mitigation Officer to obtain a more state-specific hazard map and assistance.

Table 3-1
Suggested Community Seismic Hazard Programs Based on Seismic Hazard Levels

Map Color	Seismic Hazard Level	Suggested Community Seismic Hazard Mitigation Program	Comments on Cost-Effectiveness
Red	**High**	Extensive program Mitigation of these facilities first priority.	Many, but not all mitigation projects.
Red Orange	**Moderately High**	Substantial program Mitigation of these facilities a high priority.	Some, but not all mitigation projects.
Light Orange	**Moderate**	Mitigation of highly critical and highly vulnerable facilities should be considered.	Few mitigation projects
Yellow	**Moderately Low**	Mitigation of very critical and very vulnerable facilities should be considered.	Very few projects
Green	**Low**	Mitigation of exceptionally critical and exceptionally vulnerable facilities should be considered.	Mitigation projects will rarely be cost-effective except in unique circumstances
Blue	**Very Low**	Seismic risk probably not significant. Mitigation of these facilities a low priority.	Mitigation projects are most likely not required or not cost-effective
Gray	**Negligible**	Seismic risk negligible. Mitigation not required.	Mitigation not required

It is important to recognize that not all non-structural seismic mitigation projects will be cost-effective or worthwhile, even in the highest seismic hazard areas. Projects that mitigate a significant risk to life safety, protect valuable contents, or preserve important functions are more likely to be cost-effective. However, projects that mitigate minimal risks to life safety, protect low value contents, or do not preserve important functions are very unlikely to be cost-effective. For communities with progressively lower levels of seismic hazard, a smaller number of non-structural mitigation projects will be cost-effective. As the level of seismic hazard drops, only mitigation projects that mitigate a high risk to life safety, protect vulnerable and expensive contents, or preserve important functions are likely cost-effective.

More detailed guidance on how to identify high priority buildings for seismic mitigation and how to determine the best non-structural mitigation projects for the highest priority buildings are given in the following sections of this manual.

3.2 DETERMINE LOCAL SOIL AND GROUNDWATER CONDITIONS

In addition to the USGS map, an evaluation of the local soils and rock can provide additional details about the seismic hazard for a specific location. Areas of loose, soft, wet soils may cause amplification of earthquake ground motions and increase the hazard level beyond the level shown on the national seismic hazard map. Thus, buildings situated on areas of loose, soft, wet soils are at greater risk of earthquake damage and typically experience higher damage levels than similar buildings located on firm soil or rock sites. In addition, areas of loose, soft, wet soils are also prone to settlement, displacement, or liquefaction. All of these soil effects increase the potential for earthquake damage. Areas with these types of soils are most often found near bodies of water, such as lakes, ponds, streams, or rivers. Areas that previously contained bodies of water that have been filled and not properly compacted can also be problematic during earthquakes.

Local soil conditions may vary markedly within the same site or area. The most accurate characterization of possible soil effects on the level of seismic hazard requires detailed mapping (subsurface and surface) by geotechnical engineers or geologists. In many areas of the country, detailed county soil maps are available that identify areas with loose, soft, wet soils.

The following approach is suggested as a simple screening method to account for the approximate impacts due to poor soils. For mitigation planning purposes, raise the seismic hazard by one color level from that shown on the national seismic hazard map if all or portions of the community are located on loose, soft, wet soils. For example, if the community is located in a moderate (yellow) seismic hazard area, and portions of the community contain loose, soft, wet soils, the seismic hazard level would be considered as moderately high (orange).

This suggested approach, is approximate and is not a replacement for detailed geotechnical studies of local soil conditions. It is intended to help communities focus mitigation attention on areas within their community that may be more vulnerable to earthquake damage. This adjustment for poor soils corresponds to a higher priority for non-structural projects located on such sites (all other factors being equal).

Note that for some small areas of very poor soils that are subject to major settling or displacement (several feet), or are extremely susceptible to liquefaction, the soil effects may be so serious as to preclude non-structural mitigation measures. Therefore, if the site has such extremely poor soil conditions that buildings are likely to experience major damage or collapse during an earthquake, non-structural mitigation measures will not be cost-effective. It requires a geotechnical engineer or engineering geologist to identify such poor soil conditions. Fortunately, areas like this are rare.

General soil and groundwater conditions within a community can be obtained from a local geotechnical engineer, geologist, or from county soil surveys. Soil surveys are produced by the Natural Resources Conservation Service (NRCS) and have a wide range of information on soil and groundwater conditions at various locations throughout the United States. Many of these surveys are available via the Internet (Figure 3-2). Appendix E has further details on the soil/rock classification schemes used in building codes.

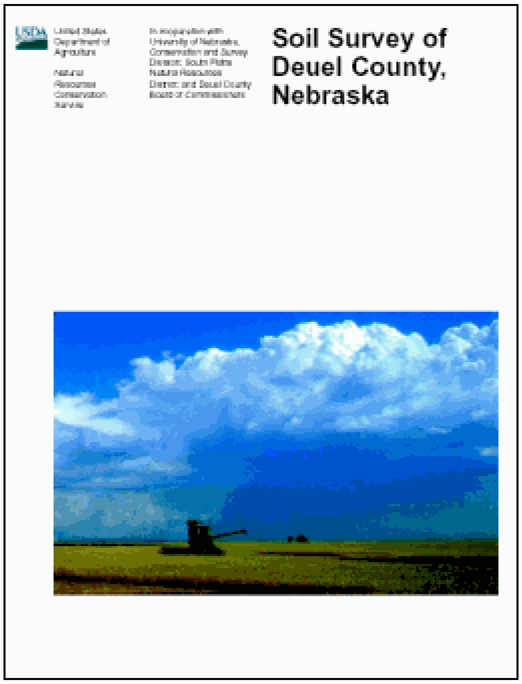


Figure 3-2: Typical Soil Survey Information

Source: Natural Resources Conservation Service internet website (http://www.ne.nrcs.usda.gov/technical/Soil_Surveys/Deuel/Document/NE_DEUEL.PDF)

3.3 DETERMINE POTENTIAL SECONDARY IMPACTS

In addition to ground shaking and soil effects, earthquakes can also result in a variety of damaging secondary effects, such as landslides, tsunamis, and fire following earthquake, hazardous materials releases, and inundation. (See Section 2, Earthquake Primer). If a community or portions of a community are subject to these secondary impacts, the potential for additional damage must be considered when evaluating non-structural hazard mitigation projects. In the relatively rare cases were a building has a high probability of being destroyed, for example, by a landslide or a dam failure, implementing non-structural mitigation measures in the building would not be cost-effective. Instead, mitigation measures may be required to remediate the landslide hazard or strengthen the dam. An alternative measure may be to relocate the at-risk facility to a different location in the community that is not subject to the secondary hazard.

Identifying potential secondary hazards can help determine areas or facilities within the community that need mitigation. In addition, identifying these impacts is an important part of the State and local planning process, and will aid in the preparation of community plans for emergency response, recovery, and multi-hazard mitigation. Refer to the FEMA How-To Planning Guide 386-2 (August 2001) for additional information on assessing these and other secondary impacts.

3.4 STEP 1 SUMMARY

Determining the level of seismic hazard for a community provides information about the extent to which a community should consider non-structural seismic mitigation projects. General determinations can be made using the seismic hazard map to identify the hazard level (color) for a community. For sites with soft, loose, wet soils, increasing the hazard level by one step on the hazard map can adjust for poor soils.

Communities with a high or moderately high level of seismic hazard should probably consider non-structural mitigation. Communities with moderate or moderately low levels of hazard should consider selective use of non-structural mitigation projects and focus only on facilities that are vulnerable and critical to the community. Communities with low, very low, or negligible levels of seismic hazard should focus their mitigation efforts on other hazards that pose a greater threat to their communities.

For communities with higher levels of seismic hazard to warrant more detailed consideration of non-structural mitigation projects, the evaluation process continues with Step 2 in the next section. Additional detailed guidance is provided regarding how to identify buildings that are likely to have high priority for non-structural mitigation.

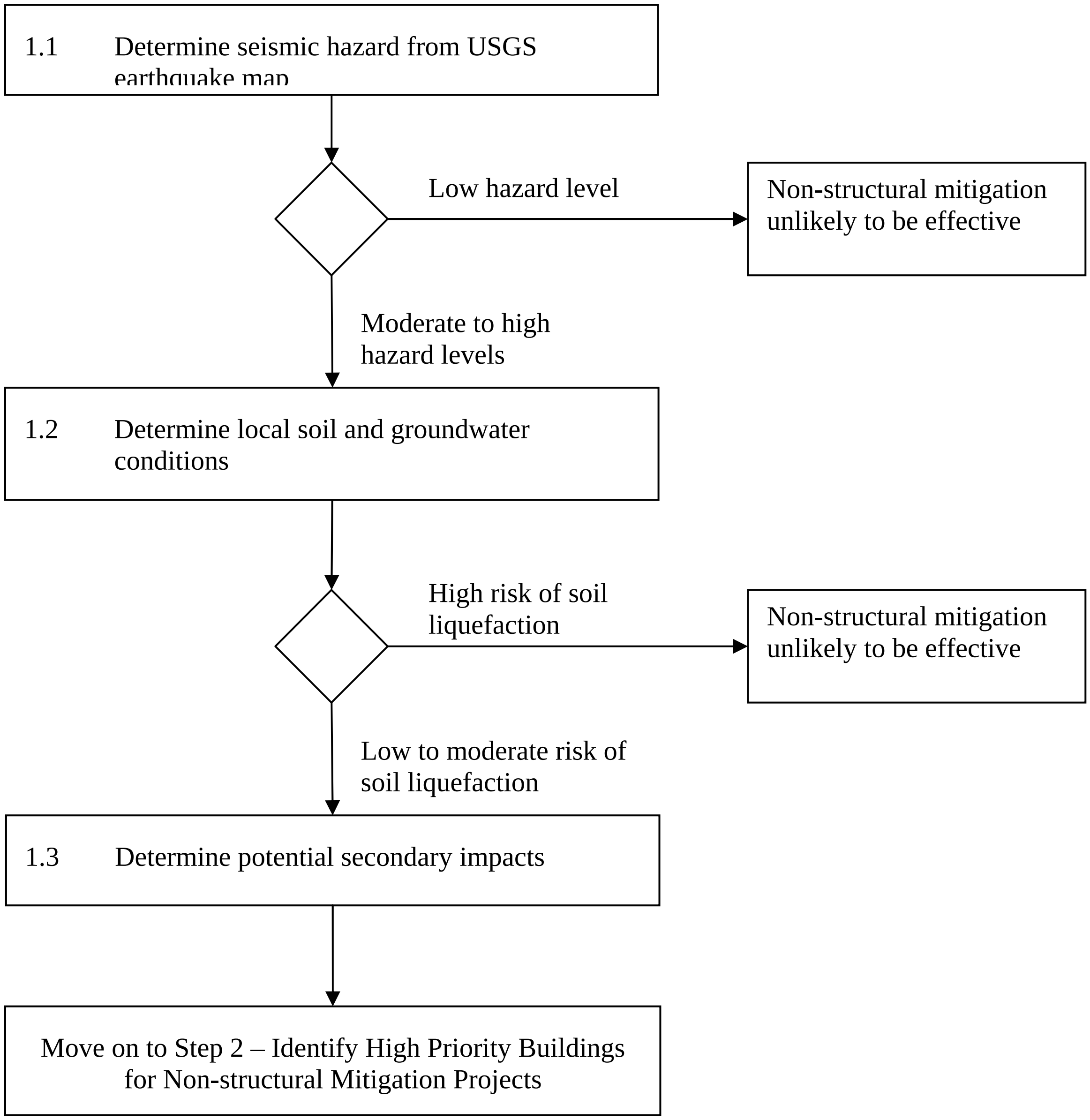


Figure 3-3: Process Flow Chart for Step 1

Determine the Level of Seismic Hazard

4.1 STEP 2: IDENTIFY HIGH PRIORITY BUILDINGS FOR NON-STRUCTURAL MITIGATION PROJECTS

Even small communities often have dozens of buildings, while larger communities may have hundreds, or thousands, of buildings and structures with seismic risk. For each building there are generally several possible non-structural hazard mitigation projects. The number of options can expand with the sizes of the buildings. For larger buildings, there may be several non-structural hazard mitigation projects to choose from.

To identify non-structural mitigation projects for high priority buildings or structures, a community must answer two questions:

1. **What characteristics distinguish the best non-structural mitigation projects from less desirable or poor non-structural mitigation projects?**
2. **How can a community select the best non-structural mitigation projects?**

This chapter provides general guidance on characteristics that distinguish the best non-structural mitigation projects from less effective projects and then outlines three sub-steps under Step 2 to help communities identify the highest priority buildings for non-structural seismic mitigation projects.

4.2 CHARACTERISTICS OF EFFECTIVE NON-STRUCTURAL MITIGATION PROJECTS

To a large extent, setting priorities for non-structural seismic mitigation projects is a matter of community choice. One community may choose to focus on hospitals. Another community may choose to focus on schools, while a third community may focus on fire stations, 911 call centers, and Emergency Operations Centers (EOCs). All of these choices are valid and each community is free to set its own priorities.

However, there are important underlying principles that distinguish effective mitigation projects from other, less effective mitigation projects. That is, there are definable characteristics that make it more likely, less likely, or very unlikely that particular non-structural projects will be cost-effective. A mitigation project that is cost-effective, with benefits greater than the cost, is justified or worthwhile from an economic perspective. In other words, the community as a whole is better off making the investment in a cost-effective mitigation project than not making the investment.

Mitigation projects that are not cost-effective are not justified or worthwhile from an economic perspective. When a specific mitigation project is found not to be cost-effective, this does not mean that mitigation is not worth doing. Rather, it means that there are likely other mitigation projects in the community that would provide more benefits for the mitigation dollars spent. An important goal of mitigation planning is to maximize mitigation benefits when possible. That is, the best mitigation projects provide the greatest reduction in damage, losses, and casualties for the least mitigation project cost.

4.3 SEISMIC HAZARD LEVEL

One primary factor that separates the best non-structural mitigation projects from less effective projects is the level of seismic hazard for a given community. As shown in Step 1 (Table 3-1), the higher the level of seismic hazard, the more likely it is to find cost-effective non-structural mitigation projects.

For communities with high or moderately high seismic hazard levels there are most likely many cost-effective non-structural mitigation projects. For communities with moderate or moderately low seismic hazard levels there may be a few (or very few) cost-effective non-structural mitigation projects for facilities that are both very important to the community and very vulnerable to seismic damage. For communities with low, very low, or negligible seismic hazard levels there are most likely few cost-effective mitigation projects. For such communities, mitigation efforts are better focused on other natural hazards that pose a greater threat to the community.

Once the seismic level of a community has been evaluated, there are three considerations for determining higher priority buildings for non-structural seismic mitigation projects in a community:

1. Identify potential high priority buildings for non-structural mitigation projects.
2. Evaluate special situations for other potential high priority projects.
3. Screen potential high priority buildings for factors that may preclude non-structural mitigation projects.

4.4 STEP 2.1: IDENTIFY POTENTIAL BUILDINGS FOR NON-STRUCTURAL MITIGATION PROJECTS

The first sub-step in finding effective non-structural mitigation projects is to identify possible high priority buildings in the community. Selection of high priority buildings is most commonly based on importance of function, occupancy, and value of contents, as discussed below.

When identifying high priority buildings for non-structural mitigation projects, it is important for communities to be selective. Identifying a list of 200 high priority buildings is not particularly useful if the community only has funds for five non-structural mitigation projects. It would be more useful to prioritize the list of high-priority buildings, which would likely focus near-term mitigation efforts on more cost-effective projects. Relatively less cost-effective projects can be pursued as funding becomes available at a later date.

Using the guidance in this section, each community should define high priority buildings for non-structural seismic hazard mitigation projects. Depending on the community's priorities, high priority buildings can be selected based on occupancy (life safety), critical facilities (life safety and economic impacts), or on value of contents (avoided damage).

4.4.1 Importance of Function

Some buildings and their functions are more important to a community than others. Buildings providing critical services for the community such as hospitals and other medical facilities, police and fire stations, 911 call centers, and EOCs are more important than buildings providing ordinary services. Ordinary services are services or functions that could be interrupted without resulting in significant life safety or economic impacts on the community.

Critical services are often defined as services that directly affect life safety, the loss of which would have a large economic impact on the community. For example, loss of electric power or potable water would have a large economic impact on a community and create potential health effects. Essential utility services are often referred to as “lifeline” services. Because of the large economic impact of losing such services, non-structural retrofits for critical elements of utility systems may warrant a high priority.

Many communities also consider schools to be critical buildings due to use as emergency shelters or because a high priority is placed on protecting children. Some communities also consider important historical buildings to be critical because of their historical, cultural, or economic importance to the community.

4.4.2 Occupancy

Occupancy is an important factor because in general, the higher the occupancy, the greater the potential for casualties during earthquakes. Thus, for non-structural earthquake projects with a primary objective of improving life safety, high priority is generally placed on high occupancy buildings.

For planning purposes, the relevant occupancy for buildings is the average occupancy over the entire year, not the peak occupancy. The average occupancy is a better measure than peak occupancy because it is impossible to predict when earthquakes will occur. For example, consider two hypothetical identical buildings. The first building has 100 occupants, 24 hours per day, 7 days per week, 365 days per year. The second building has 1,000 occupants during only one hour per week and is empty the rest of the time. Averaged over an entire year, the average occupancy of the second building is only about 6 people. Therefore, if a community only has funds for one mitigation project, the better choice is to improve life safety for the first building with an average occupancy of 100 people. Statistically, basing life-safety seismic mitigation projects on an average occupancy maximizes the benefits of reducing casualties.

4.4.3 Value of Contents

The value of contents protected by non-structural hazard mitigation projects is important, because, everything else being equal, mitigation projects that protect high value contents are usually given higher priority than mitigation projects that protect low value contents. Thus, mitigation projects to protect a high value mainframe computer center in a county office building or expensive medical equipment in a hospital or artwork with high appraised values in a city museum are much more likely to be cost-effective than projects that protect low value contents. In simple terms, the higher the value of the contents being protected, the higher the priority for the mitigation project and the more likely that it will be cost-effective.

4.5 STEP 2.2: EVALUATE SPECIAL SITUATIONS

The previous section provided general guidance for selecting high priority buildings as candidates for non-structural seismic mitigation projects. Most communities select fairly obvious priorities for non-structural mitigation projects, such as hospitals, schools, fire and police stations, etc. In addition, there are often special situations that should be considered for high priority, non-structural seismic mitigation projects. Such special situations are often overlooked. Special situations include facilities that would not normally have a high priority for mitigation, but may warrant consideration because of specific conditions, such as a high life-safety risk, high economic impact or historical importance.

A few examples are listed below to illustrate the “special situations” concept.

1. Non-structural retrofits for potable water or wastewater treatment plants might be deemed less important than mitigation projects for hospitals or schools. However, if such facilities contain chlorine tanks, then the potential life-safety risks from failure of these tanks suggests that seismic bracing of such tanks might be a high priority.
2. Similarly, any facility than contains significant quantities of very hazardous materials may warrant consideration for non-structural mitigation.

Many examples of a special situation involve specific, one of a kind life safety issues. For example, a library may normally have a lower priority for seismic retrofit than a school or hospital, but if the library has very tall heavy bookcases that pose a substantial life-safety risk, then the priority for mitigation may be higher than normal.

For life safety, there are many unique examples. A city hall may have a tall marble sculpture or a large heavy chandelier in the lobby that poses significant life-safety risks. Most special situations can be evaluated by common sense, and, if appropriate, such buildings or other facilities can be added to the high priority building list, at least for the specific special situations identified.

4.6 STEP 2.3: SCREEN FOR FACTORS THAT MAY PRECLUDE PROJECTS

Once a community has identified a small number of buildings with very high priority for non-structural projects, there is one more essential sub-step before selecting a specific project. Non-structural seismic hazard mitigation projects can only be effective if the building itself is relatively damage resistant during earthquakes. If a building, however important to the community, is highly vulnerable to significant damage or collapse in earthquakes, undertaking non-structural projects for the building will most likely not be viable or cost-effective. Bolting a bookcase to the wall, for example, is not worthwhile if the building collapses. Rather, in such circumstances, the community should first consider a structural retrofit or relocation of the occupants or services prior to installing non-structural mitigation measures.

This section provides some general guidance on types of buildings that are often highly vulnerable to earthquake damage. If one or more of the buildings identified by a community as high priority for non-structural hazard mitigation falls into one of these categories, the non-structural mitigation should not proceed until a detailed engineering analysis has been completed. In some cases, the building may be suitable while in other cases the building may require a structural retrofit before a non-structural project can be considered effective. Finally, the building may be so vulnerable that demolition and replacement may be warranted.

The guidance below (Table 4-1) is intended primarily for regions of the country, such as the Central United States, with moderate levels of seismic hazard and without a long history of seismic provisions in the building codes. The guidance is also applicable to higher hazard areas with some exceptions. Particularly vulnerable building types are summarized in the Table below.

More detailed information about building structural types, with drawings and examples are given in Appendix F.

Table 4-1
Seismic Design Deficiencies for Common Building Types

Building Type	Seismic Design Deficiencies	Comments
Unreinforced masonry (URM)	More than two stories high One or two stories with weak roof and wall connections or with soft first story	Small one- or two-story URM buildings with strong roof and wall connections and walls in good condition, without too many openings, may perform relatively well in moderate earthquakes
Wood frame	Sill plate not bolted to foundation Cripple wall or unbraced post foundations	Other types of wood frame structures generally perform well in earthquakes
Pre-cast concrete structures	Weak connections	Many of these type of structures will perform poorly in earthquakes
Tilt-up concrete structures	Poor roof/wall connections	With strong roof/wall connections, structures generally perform fairly well
Concrete frame structures without concrete shear walls	Tall, thin columns without adequate reinforcements Soft first stories	Concrete frame structures designed to seismic standards generally perform well

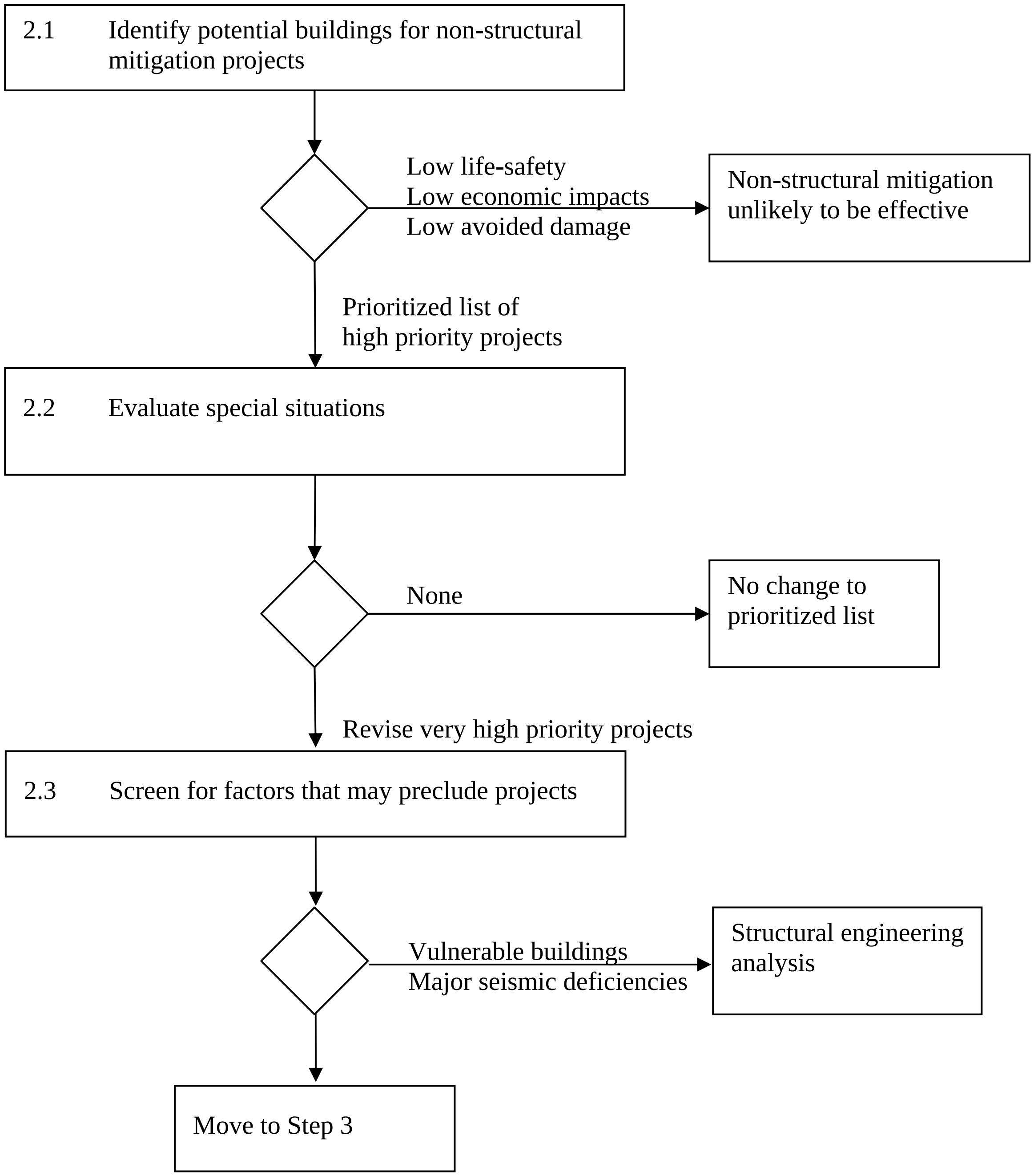
If buildings on a community's high priority list for non-structural seismic hazard mitigation projects fall into any of the above categories or have other identified major seismic deficiencies, a non-structural mitigation project should not proceed before having a structural engineering analysis of the building.

4.7 STEP 2 SUMMARY

At this point, the first two steps in determining effective non-structural seismic mitigation projects for a community are complete:

1. Determine a Community's Level of Seismic Hazard
2. Identify High Priority Buildings for Non-Structural Mitigation

By completing these two steps, a community will have evaluated the extent to which non-structural mitigation is required (based on seismic hazard level) and identified a small number of high priority buildings for non-structural mitigation. The last step in determining effective non-structural mitigation projects is to identify specific non-structural mitigation projects for the high priority buildings.



5.1 STEP 3: SELECTING NON-STRUCTURAL MITIGATION PROJECTS

At this point in the mitigation planning process, the community should have completed the first two steps and developed a list of high priority buildings for potential non-structural mitigation projects. These buildings should have been screened to ensure that none of them are so vulnerable to major damage or collapse in an earthquake that they preclude proceeding with non-structural mitigation measures. Effective mitigation projects involve a determination of the mitigation objectives and the value of the assets (including lives) being protected.

5.2 STEP 3.1: MITIGATION OBJECTIVES

For each building on the high priority list from Step 2, the first consideration involves a determination of the primary mitigation objective among life safety, preservation of critical functions, and reducing damage to expensive contents.

5.2.1 Life-Safety Projects

Almost every non-structural seismic hazard mitigation project has some degree of life safety protection. By reducing the potential for falling building elements and contents, nearly all non-structural projects reduce the potential for casualties to some extent. However, just because a non-structural project is labeled as a life-safety mitigation project does not mean that it is worth completing or cost-effective.

The key factor for life-safety projects is determining whether an element failure during an earthquake causes death or major injury. If the answer is yes, then the project has the potential to be being cost-effective, especially if the site is located in either high or moderately high seismic hazard areas. If the answer is no, then the project is not likely to be cost-effective, even in high hazard areas. In this case, there are probably more effective non-structural mitigation projects to consider.

To assist in evaluating this factor, there are two items to be determined:

1. The relevant occupancy of a building, floor, or room. This is the occupancy of the "fall area" and not necessarily the entire building.
2. The probability of the element failure causing death or major injury.

The best life-safety mitigation projects involve situations where a highly vulnerable heavy element is likely to fall on a heavily occupied area. Examples include parapet walls or chimneys above high traffic areas, such as building entrances, and contents or equipment that are tall, heavy, and located in high occupancy areas. Mitigation projects in such situations have higher benefits because they have high potential to avoid deaths or major injuries.

Another type of life-safety project that can be effective and cost-effective is to brace tanks and other containers that contain particularly hazardous materials, including chlorine tanks at water treatment plants. Because failures of such tanks can cause long term health hazards, death, serious injury, fires, explosions, or environmental damage, mitigation of these elements can offer high life-safety benefits.

Less effective life-safety projects are those that either protect heavy elements in low traffic or low occupancy areas or that protect light elements in higher occupancy areas. For example, bracing a parapet wall above an area with only shrubbery will not be cost-effective because the life-safety risk being mitigated is negligible.

Many non-structural projects that are proposed as life-safety projects may actually have only minor life-safety benefits. Common examples include bracing light elements that have the potential to result in minor injuries if they fail but little or no potential to cause major injury or death. Common examples of such projects that are unlikely to be cost-effective, especially in moderate seismic hazard areas, include bracing light, suspended ceilings, low value contents items (including computer monitors), and window retrofits. However, for projects such as bracing light-weight elements, such as suspended ceilings, the type of occupant should be considered because the potential injury rates might be greater for small children in a school and for senior citizens in a nursing home.

5.2.2 Preserving the Functions of Critical Facilities

Some non-structural mitigation projects are intended primarily to help ensure the continued function of critical facilities after earthquakes. The evaluation process for these projects is quite similar to that discussed above for life-safety projects.

The key factor for preserving the functions of critical facilities is to determine whether the failure of an element would substantially impact the functions of the critical facility. If the answer is yes, then the project has the potential to be cost-effective in moderate or moderately high seismic hazard areas. If the answer is no, then the project is not likely to be cost-effective. Non-structural mitigation projects, even for critical facilities, will not be cost-effective if they do not maintain the continuity of service for the critical facilities. For example, bracing ordinary contents in hospitals or other critical facilities may have only minor impacts on ensuring service continuity and thus may not be cost-effective except for high seismic hazard areas.

A few examples of non-structural projects that help to ensure the continued function of critical facilities include:

1. Brace battery racks in a 911 call center or EOC
2. Secure or reinforce emergency generators for critical facilities
3. Brace critical medical equipment in hospitals
4. Brace critical pumps for potable water systems
5. Secure or reinforce critical elements for electric power systems

For benefit-cost analyses (BCAs), the value of a critical service is determined in two parts. The first part is the base value or the cost of providing the service. For example, if a hospital has an annual operating budget (or revenues) of $1,000,000 per day, then the value of services provided by the hospital is valued at $1,000,000 per day.

The second part is a “continuity premium” that is added to some public services that are essential immediately after an earthquake or other disaster. The continuity premium is, in effect, a multiplier that places a higher value on critical services. A FEMA draft document, *What is a*

Benefit? Draft Guidance for Benefit-Cost Analysis (Version 2.0, May 2001[1]), provides guidance on assigning value to public services for hospitals and other medical facilities, police and fire stations, 911 call centers, EOCs, several types of critical utilities, roads, and bridges. This guidance is very important for preparing BCAs of non-structural mitigation projects for these types of critical facilities.

5.2.3 Protecting Valuable Contents

Some non-structural mitigation projects are designed mostly to protect valuable contents from damage. Evaluation of these projects is easy: the more valuable the contents are the more likely the project is to be cost-effective. Thus, bracing or restraining expensive vases or sculptures in a museum, expensive medical or scientific equipment, or any other high value contents are more likely to be cost-effective than bracing a $200 computer monitor or other less expensive contents.

5.3 TECHNICAL NOTES

The above guidance is intended to help users make preliminary evaluations of non-structural seismic mitigation projects. However, a full evaluation of any specific non-structural (or structural) seismic mitigation project requires engineering evaluation by an experienced seismic engineer.

The seismic performance of any specific non-structural building element or contents item will vary depending on the design and condition details of each non-structural item. Furthermore, the seismic performance of non-structural elements also depends on the seismic characteristics of the building in which the element is located. Therefore, detailed evaluations of the seismic performance of any non-structural must include specialized engineering analysis, expertise, and judgment.

The above guidance regarding engineering evaluation notwithstanding, it is possible for technical users to make some evaluations of the performance of non-structural elements. *Non-Structural Module for Benefit-Cost Analysis of Seismic Mitigation Projects* contains information about the seismic performance of the most common non-structural elements including:

1. Parapet walls and chimneys
2. Racks and library shelves
3. Diesel, gas, or electric generators
4. Cable elevators
5. Fire sprinkler systems
6. HVAC equipment
7. Ceilings
8. Electrical cabinets

[1] Available by calling the BCA helpline toll free at 866-222-3580 or sending an e-mail to bchelpline@urscorp.com

9. Generic equipment and contents

General examples for selecting non-structural seismic hazard mitigation projects are summarized in Table 5-1, which contains examples of potentially effective and ineffective projects.

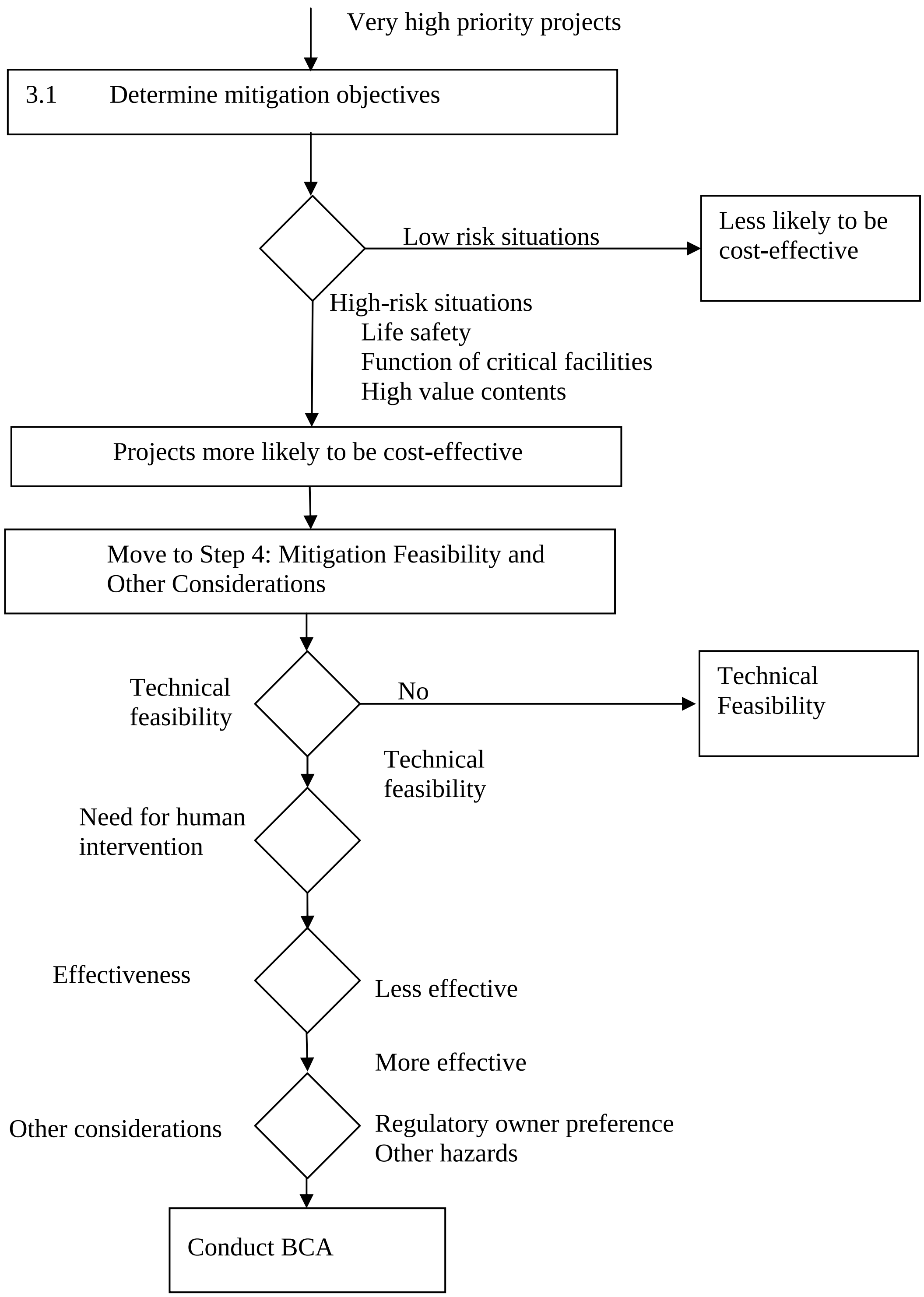
Table 5-1
Examples of Non-Structural Seismic Hazard Mitigation Objectives

Mitigation Objectives	Potentially Cost-Effective	Probably Not Cost-Effective
Life safety	Retrofit parapet wall or chimney above main entrance for school	Retrofit parapet wall or chimney on side of school above area containing only shrubbery
Life safety	Anchor tall, heavy bookcase in high traffic area of school	Anchor low, light bookcase in low traffic area of school
Life safety	Anchor chlorine tank in water treatment plant or tanks for other toxic or flammable materials at an industrial site	Anchor storage bin containing non-toxic supplies in water treatment plant
Damage reduction	Anchor expensive vase in an art museum	Anchor inexpensive computer monitor
Damage reduction	Anchor/brace expensive medical equipment in hospital	Anchor inexpensive shop equipment in municipal garage building
Preserve critical services	Anchor batteries on rack in 911 call center or EOC	Brace ordinary contents in office building
Preserve critical services	Anchor emergency generator at hospital or other critical facility	Anchor welder in municipal garage building
Preserve critical services	Anchor pump in water system or brace key elements in electric power system	Anchor water cooler in fire station

5.4 STEP 3 SUMMARY

Finding effective non-structural projects involves finding high-risk situations where potential earthquake damage poses a major threat to life safety, the function of critical facilities, or to high value contents. If the risk level is high, then the benefits of mitigating the risk are also high and it is likely that cost-effective non-structural mitigation projects can be identified.

Remember that risk is based on a combination of seismic hazard and the value and vulnerability of property or people exposed to earthquake damage. Higher seismic hazard areas will have more high-risk situations and thus will have more cost-effective projects than moderate or low seismic hazard areas. However, even in moderate or low seismic hazard areas there will be some situations with high risk where the vulnerability of non-structural elements poses a major threat to life safety, to critical functions, or to high value contents.



6.1 COMMON NON-STRUCTURAL ELEMENTS AND MITIGATION PROJECTS

The most common non-structural elements and damage scenarios are reviewed in this chapter. The chapter is based on information from the *Earthquake Mitigation Handbook for Public Facilities* produced by FEMA Region X (February 28, 2002) and other sources.

Non-structural seismic mitigation projects can be categorized based on the non-structural element(s) of a building that are to be mitigated: exterior elements, interior elements, building utilities, and building contents.

Common mitigation projects for each of these elements will be covered in the paragraphs that follow based on the FEMA Region X *Earthquake Mitigation Handbook* and other references. Note that the projects listed in this manual or the measures listed below should not be considered “pre-approved” mitigation measures that are automatically eligible for FEMA funding.

6.2 EXTERIOR ELEMENTS

Exterior non-structural elements of a building include parapets, chimneys, exterior facing, windows, and doors. These elements are generally composed of weak, brittle materials such as glass, URM, or stone. Since many of the elements are also located on the upper floors of buildings and are very heavy, they can be extremely hazardous and, if they fall, can cause serious injury or death to nearby pedestrians. Earthquake vulnerabilities of exterior non-structural elements are described in the remaining text in this section.

Many exterior non-structural elements do not have bracing or connections sufficient to withstand earthquake forces. As a result, these elements may fail during an earthquake, creating falling hazards and causing additional damage. Damage to non-structural exterior elements can be reduced or eliminated by bracing, strengthening, reinforcing, or replacing elements and/or connections to withstand earthquake forces.

Damage to exterior non-structural elements can affect the vulnerability and values of earthquake building damage, casualties, or functional downtime. Most exterior non-structural elements can be determined by visual inspection of the outside of the building, discussion with the building owner or manager, or review of maintenance and insurance records.

It should be noted that because exterior non-structural elements are supported by structural elements, a structural engineer should be consulted to identify whether certain mitigation measures are appropriate for a given building. Some non-structural measures included in this section are not appropriate for all buildings. It is possible that choosing the wrong measure may cause more problems than not doing any retrofit at all.

6.2.1 Parapets

Brick parapets are typically mounted along the tops of URM buildings. Parapets provide a firebreak between adjacent buildings and can also provide ornamentation to a building. Parapets are heavy, brittle, and typically collapse near the centers of long walls or at corners (Figure 6-1).

Figure 6-1: Typical Parapet Damage

Source: Training Materials for Earthquake Hazard Mitigation for Non-Structural Elements (FEMA, in preparation)

Mitigation - Parapets can be braced from the rear using steel angle braces anchored into the parapet and connected to the roof framing (Figure 6-2 and Figure 6-3). Parapets can also be braced using reinforced concrete or shotcrete placed behind the parapet and anchored. Reducing the height of parapets also reduces the seismic forces on the parapet by reducing the weight.

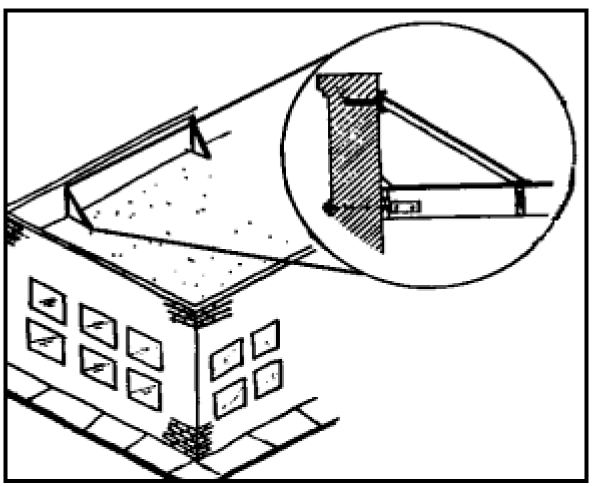


Figure 6-2a: Typical Parapet Bracing

Source: FEMA Region X Earthquake Hazard Mitigation Handbook for Public Facilities, February 28, 2002

Figure 6-2b: Typical Parapet Bracing

Source: Training Materials for Earthquake Hazard Mitigation for Non-Structural Elements (FEMA, in preparation)

6.2.2 Architectural Elements

Decorative elements such as cornices and corbels or other architectural elements are common among historic, URM structures. Such elements are generally constructed of stone or other heavy, brittle materials, and often fail due to poor anchoring or bracing.

Mitigation - Architectural building elements such as cornices, corbels, and spandrels can be anchored from the outside by installing anchors with exterior washer plates, or from the inside using either countersunk plates and/or epoxy anchors (Figure 6-3). For heavy and ornate cornice work, the cornice can be removed and reconstructed by using a lighter material, such as lightweight concrete or plaster.

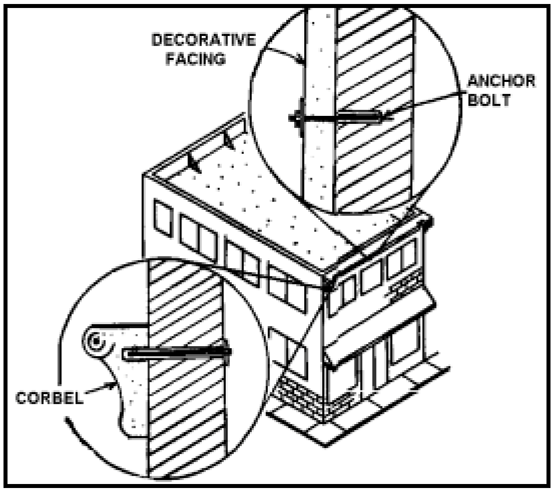


Figure 6-3: Typical Anchoring of Architectural Elements

Source: FEMA Region X Earthquake Hazard Mitigation Handbook for Public Facilities, February 28, 2002

6.2.3 Chimneys

Brick chimneys are a common element in most of residential construction and a few older, non-residential buildings. Chimneys are heavy, brittle, and can fail unless reinforced near the top and supported by the building roof and adjacent walls (Figure 6-4).

Figure 6-4: Typical Chimney Damage

Source: Training Materials for Earthquake Hazard Mitigation for Non-Structural Elements (FEMA, in preparation)

Mitigation - Several retrofit methods can be used to mitigate chimney damage during earthquakes. First, chimney extensions above the roofline can be secured with steel straps anchored to the roof framing with steel angle braces (Figure 6-5). Next, the chimney flue enclosure can be reinforced using vertical and horizontal bars encased in concrete. Finally, for multi-storied buildings, chimneys can be anchored at each floor level using steel wrap ties that are anchored to the floor joists.

Figure 6-5: Typical Chimney Bracing

Source: Training Materials for Earthquake Hazard Mitigation for Non-Structural Elements (FEMA, in preparation)

6.2.4 Stone Facing or Wall Panels

Architectural stone facing is common among historic structures; while pre-cast concrete wall panels are typically used in buildings with concrete framing or tilt-up construction. Stone facing and pre-cast concrete wall panels typically fail where anchoring is poor or at sections of the building that experience large deflections (Figure 6-6).

Figure 6-6: Typical Exterior Facing Damage

Source: Training Materials for Earthquake Hazard Mitigation for Non-Structural Elements (FEMA, in preparation)

Mitigation - During an earthquake, rigid wall panels attached to the exterior of steel-framed structures can be damaged due to insufficient flexibility in the connections to the frame. The wall panel should be rigidly anchored at the base and a flexible rod at the top to better withstand shaking during an earthquake.

6.2.5 Windows

Glass windows come in all shapes and sizes and are common to nearly all residential, commercial, and public buildings. Glass windows, particularly large windows, typically crack or shatter when the frames are distorted or damaged (Figure 6-7).

Figure 6-7: Typical Window Damage

Source: NOAA National Data Center – photo of broken windows due to frame distortion caused by the 1989 Loma Prieta earthquake in Watsonville, California

Mitigation - Stiffening bracing or redesigning of the window frame can reduce earthquake damage from window frame distortion and inadequate edge clearance around the glass. Bracing usually consists of steel tie rods anchored to the corners of the window frame and connected by a turnbuckle (Figure 6-8, left side). Another method is to use specially designed windows that use wider frames and include a compressible material between the frame and the window glass to avoid direct contact between the window and the frame (Figure 6-8, right side).

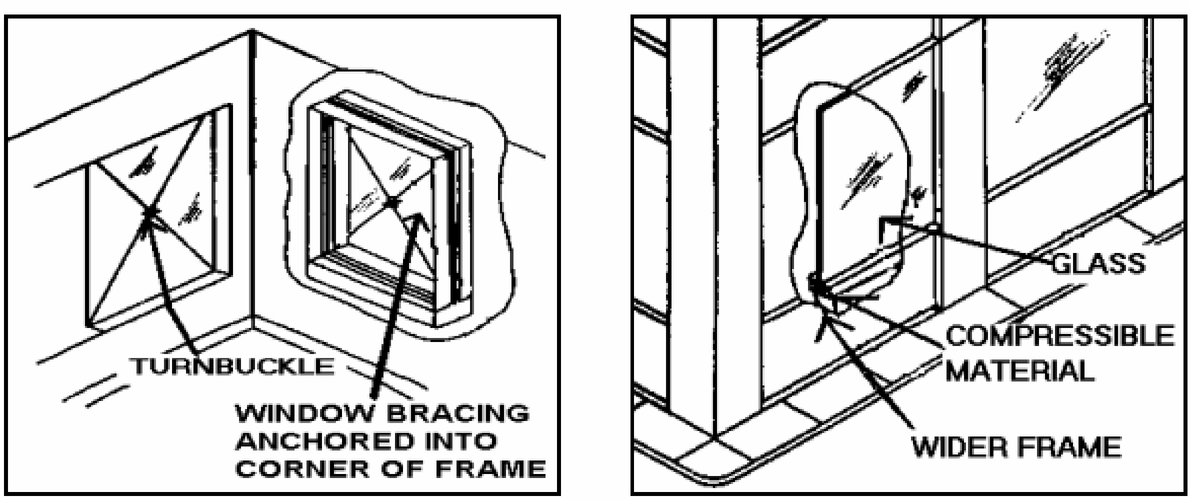


Figure 6-8: Window Anchoring (left) and Window Frame Reinforcement (right)

There are several other ways of strengthening window glass to reduce breakage during an earthquake while also reducing hazards afterwards. Conventional glass can be replaced with tempered glass that is stronger and breaks into smaller, less dangerous fragments. Wire-reinforced glass, or adhesive film applied to existing windows, can hold the glass fragments together, reducing damage and falling hazards.

6.3 INTERIOR ELEMENTS

Interior non-structural elements of a building include partition walls, suspended ceilings, and raised computer floors. These elements often lack sufficient anchoring or connections to withstand earthquake forces and movements. This can lead to failure, falling elements or debris hazards for building occupants, and additional damage to building contents. Vulnerabilities of interior non-structural elements during earthquakes are described in the following bullets:

- Damage to interior non-structural elements can affect the vulnerability and values of earthquake building damage, casualties, and functional downtime. Information on interior non-structural building elements can be determined by visual inspection of the inside of the building, discussion with the building owner or manager, or review of maintenance and insurance records.
- Many interior non-structural elements do not have anchoring or connections sufficient to carry earthquake forces and movements. As a result, these elements may fail during an earthquake, creating falling hazards and causing additional damage. Anchoring interior non-structural elements by strengthening or reinforcing elements and connections to withstand earthquake forces and movements can reduce or eliminate damage.

6.3.1 Suspended Ceilings and Fixtures

Suspended (drop) ceilings and overhead lighting fixtures are commonly encountered in various public and commercial buildings. These elements typically fail where anchoring is poor, or the runners that support the panels and lights are too weak to withstand large lateral earthquake forces (Figures 6-9 and 6-10).

Figure 6-9: Typical Suspended Ceiling and Lighting Fixture Damage

Source: Training Materials for Earthquake Hazard Mitigation for Non-Structural Elements (FEMA, in preparation)

Figure 6-10: Typical Overhead Lighting Fixture Damage

Source: Training Materials for Earthquake Hazard Mitigation for Non-Structural Elements (FEMA, in preparation)

ngdc.noaa.gov/seg/hazard/slideset/5/5_slides.shtml

Mitigation - Unbraced suspended ceilings can swing independently of the supporting floor and be damaged or fall. Installing four-way diagonal wire bracing and compression struts between the ceiling grid and the supporting floor will significantly improve the ceiling's seismic performance. In addition to the struts, the connections between the main runners and cross runners should be capable of transferring tension loads (Figure 6-11). During seismic shaking, overhead lighting fixtures can fail when the suspended ceiling sways and distorts, leaving electrical wires as the only support for these fixtures. Independent wire ties connected from each fixture corner to the supporting floor can be added (Figure 6-12). Also, safety wires can reduce damage. Threaded metal conduit can protect the electrical wiring and support the fixture, and wire straps or cages may prevent fluorescent tubes from falling.

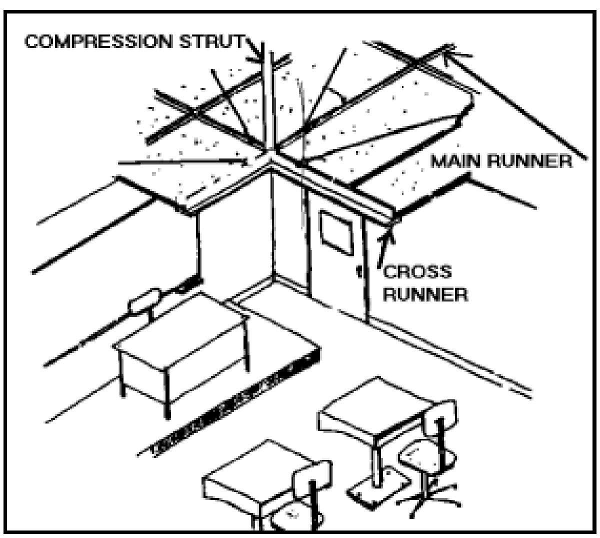
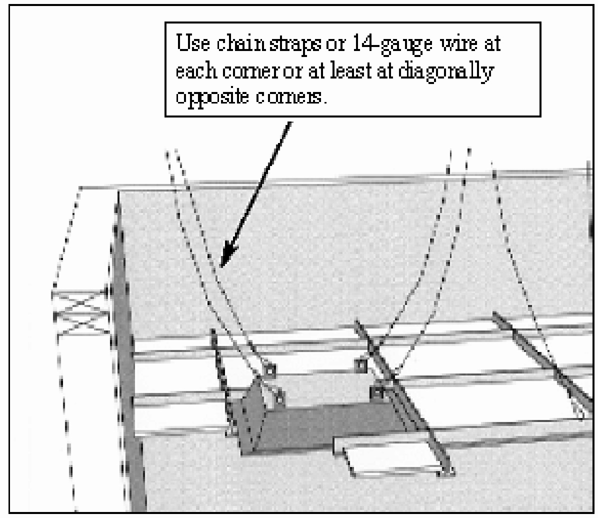


Figure 6-11: Typical Anchoring of Suspended Ceilings

Source: FEMA Region X Earthquake Hazard Mitigation Handbook for Public Facilities, February 28, 2002

Figure 6-12: Typical Anchoring of Overhead Lighting Fixtures

Source: Institute for Business & Home Safety (IBHS) and Project Impact, A Homeowner's Guide to Non-Structural Earthquake Retrofit, 2001 – sketch of typical detail for anchoring overhead lighting fixtures



6.3.2 Interior Partitions

Interior partitions of various materials and styles (half vs. full, stationary vs. movable), can fail when not secured to the floor or roof system. In addition, partitions in older buildings may be constructed of heavy, brittle materials, and can topple unless they are braced against the floor or roof of the building.

Mitigation - Retrofitting interior partitions can be done with connections that restrict the sideways movement while allowing vertical movement (Figure 6-13, left). Interior partitions generally need lateral support from ceilings or from the floor or roof framing. Unbraced partitions that do not extend to the ceiling or roof framing should be attached to the framing by bracing or straps (Figure 6-13, right). Steel channels are sometimes provided at the top of the partition to provide lateral support, and allow some floor or ceiling movement without imposing any loads on the partition. URM partitions can also be replaced with drywall partitions.

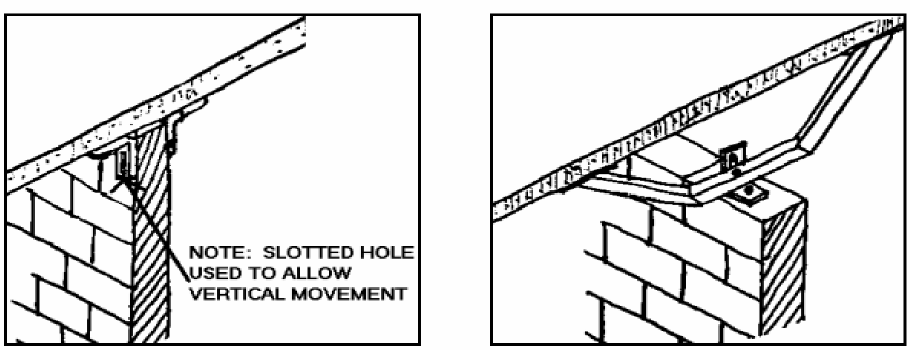


Figure 6-13: Methods of Bracing Interior Partitions

Source: FEMA Region X Earthquake Hazard Mitigation for Public Facilities, February 28, 2002

6.3.3 Raised Computer Floors

Raised floors that support computer equipment are found in many modern commercial and public buildings. These floors and the equipment they support can be damaged or destroyed due to inadequate anchoring to the floor's structure.

Mitigation - To reduce the risk of collapse during an earthquake, pedestals that support the raised flooring can be anchored to the building floor and secured to the floor slab.

6.4 BUILDING UTILITIES

Building utilities include HVAC, electricity, gas, water, wastewater, communications, and elevator systems. The basic components of building utility systems include supply and storage equipment, pipelines, and ductwork, as well as the connections between these components. Building utilities suffer earthquake damage for a variety of reasons. First, heavy building utility equipment such as HVAC compressors often do not have adequate anchoring to carry earthquake forces and can topple over or break loose during an earthquake. Second, connections between supply line sections and equipment are commonly not strong or flexible enough to carry earthquake forces. Finally, some utility supply lines are not properly braced to withstand lateral earthquake forces, causing the lines to crack, leak, or collapse. These situations can trigger additional damage ranging from water leaks to electrical fires and gas explosions.

Damage to building utility systems can be prevented by anchoring, securing, or protecting heavy utility equipment, utility connections, and supply lines to withstand earthquake forces and movements. Damage to building utilities can affect the vulnerability and values of earthquake building damage, casualties, or functional downtime. Information on building utilities may be determined by visual inspection with an understanding that utility lines and connections may be located inside load-bearing or partition walls and suspended ceilings. Other sources of information on building utilities include discussion with the building owner or property manager, information provided by utility companies, or review of maintenance and insurance records.

6.4.1 Heavy Equipment

Heavy equipment is commonly mounted on roofs or in basements of residential, commercial, and public buildings. Damage occurs during an earthquake when the equipment is not supported or anchored properly (Figure 6-14).

Figure 6-14: Typical Heavy Equipment Damage

Source: IBHS, A Homeowner's Guide to Earthquake Retrofit, 2001 – photo of unbraced gas water heater which fell over and burned during an earthquake in California

Mitigation - Seismic forces, combined with heavy equipment weight, can stretch vibration isolator springs beyond their ability to rebound, causing the isolators to fail, equipment to be overturned, and/or utility line connections to break. Anchoring equipment directly to the floor or another suitable part of the building is preferable to mounting equipment on vibration isolators. If isolators are used, they should be securely anchored and installed with "snubbers" that allow small equipment movement but prevent the equipment from moving beyond the limits of the springs (Figure 6-15).

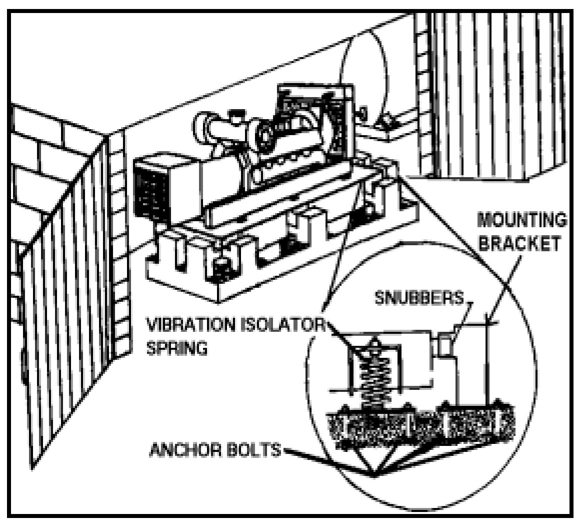


Figure 6-15: Typical Anchoring of Heavy Equipment

Source: FEMA Region X Earthquake Hazard Mitigation Handbook for Public Facilities, February 28, 2002

6.4.2 Elevator Systems

Most elevator systems consist of a passenger cab and counterweight connected to each other by cables. The cab and counterweight run along two sets of vertical rails that are housed within the elevator shaft. Earthquake damage to elevators typically occurs where the elevator counterweight rails are not adequately braced, allowing the elevator counterweight to swing loose from its rails and collide with the walls of the shaft or the cab. This can result in serious damage and injuries.

Mitigation - Counterweights should be properly secured by bracing the rails. Both bracing and rails should be securely anchored to the building with lag bolts or bracing. Retainer plates can be added to the top and bottom of the counterweights and to the cars to prevent the counterweights from becoming dislodged from the rails (Figure 6-16). Other measures to reduce elevator damage include:

- Anchor elevator machinery and controller units to prevent the units from sliding or toppling;
- Place guards on the rail brackets so that ropes, chains, and/or cables will not snag; and
- Install a seismic cutoff system that prevents collision of the elevator cab with the counterweight during an earthquake.

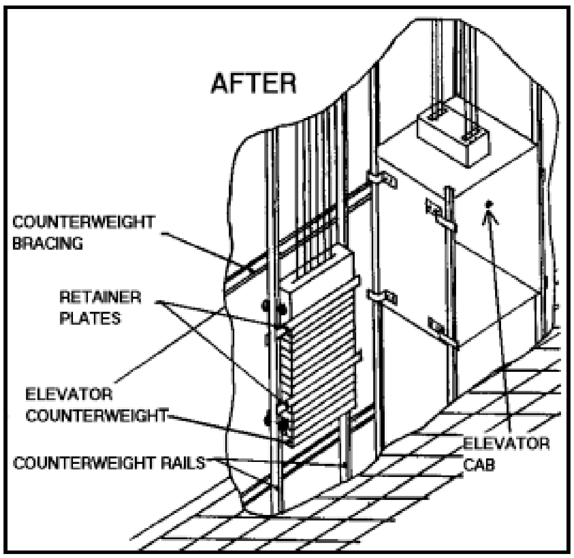


Figure 6-16: Typical Protection for Elevator Systems

Source: FEMA Region X Earthquake Hazard Mitigation Handbook for Public Facilities, February 28, 2002

6.4.3 Supply Lines

Supply lines for building utilities include pipes and joints for gas, water, and wastewater, electrical conduits, and HVAC ductwork. These lines run along or within walls, floors, and ceilings. Damage typically occurs along unsupported line sections. Secondary damage may include water damage from leaking water or wastewater lines. Fire or an explosion can also result from leaking gas or damaged electrical lines.

Mitigation - Tanks and cylinders should be anchored and braced with metal straps (Figure 6-17). To secure a compressed gas cylinder to a wall, use two lengths of chain around the cylinder. Overhead utility pipes and HVAC ducts frequently become loose and fall, damaging the utility system during an earthquake. Bracing and restraining pipes and ducts can greatly reduce earthquake damage (Figure 6-18). There are several bracing methods available including hangers, straps, stirrups, and angle braces. Larger horizontal pipes, ducts, and fittings should be braced at every joint, branch, and change of direction.

Figure 6-17: Typical Bracing of Hot Water Heater

Source: Internet photo –bracing of hot water heater, Dewberry[SM].

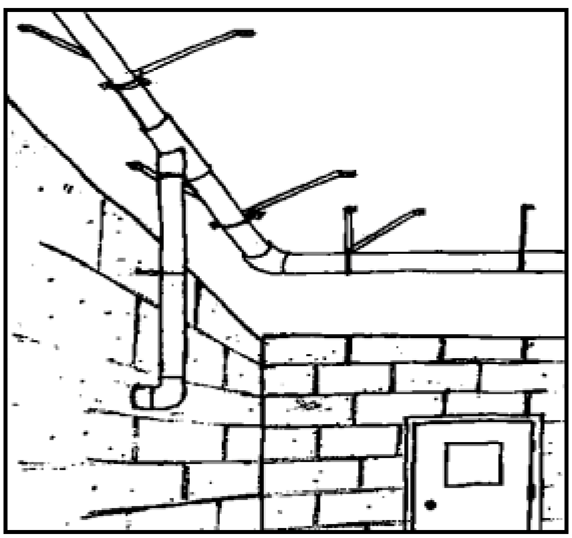


Figure 6-18: Typical Bracing of Overhead Utility Pipes

Source: FEMA Region X Earthquake Hazard Mitigation Handbook for Public Facilities, February 28, 2002

6.4.4 Connections

Connections between supply lines are encountered in various locations throughout most buildings. Damage usually occurs where connections are not strong or flexible enough to withstand movements between the lines and the equipment (Figure 6-19). Secondary damage may include water, fire, or explosion damage caused by leaking lines.

Figure 6-19: Typical Supply Line Connection Damage

Source: EQE International - photo of damaged steel building from EQE Summary Report on the January 17, 1994 Northridge, California earthquake, March 1994

Mitigation - Because most utility lines are rigid, the lines can be torn from their connection points during an earthquake. Flexible connection pipes or conduits between equipment and their supply lines will reduce future damage (Figure 6-20). Flexible lines should follow a U-shaped or curving path to allow relative movement in all directions. Seismic gas shut-off valves cut the flow of gas in the event of an earthquake, preventing fires and explosions that can occur from ruptured gas lines. The valve has a mechanism to block the flow of gas when ground movement occurs (Figure 6-21). An alternate to seismic shut-off valves is a gas protection system that stops the flow of gas when a sensor detects a gas leak or a higher than expected flow rate.

Figure 6-20: Typical Flexible Connection

Source: Internet– photo of flexible connection between hot water heater and gas supply line, Dewberry[SM]

Figure 6-21: Typical Seismic Gas Shutoff Valve (Circled)

Source: FEMA – photo of seismic gas shutoff valve at gym Centralia College in Centralia, Washington, May 2001

6.5 BUILDING CONTENTS

Building contents include all furnishings and equipment such as tables, chairs, bookcases, file cabinets, cubicle wall partitions, computers, wall hangings, etc. While these contents are generally not connected to structural building elements, they rely on structural elements for support. As a result, building contents can shake and move around during earthquakes. In addition, heavier contents can fall over and injure occupants or block exits.

Contents such as furnishings and equipment are often not secured to protect against movement caused by earthquake-induced ground shaking. As a result, such items can tip over or fall during an earthquake, damaging the equipment and creating additional hazards. Securing building contents to resist movement from earthquake-induced ground shaking can reduce or eliminate damage.

6.5.1 Heavy Furnishings

Heavy furnishings such as large bookcases and tall file cabinets are found in a wide variety of buildings. These heavy furnishings are often top-heavy or overloaded, and can fall over unless they are anchored to the floors and/or walls of the building (Figure 6-22).

Mitigation - Heavy, freestanding tall bookcases and file cabinets can be anchored to reduce damage and prevent injuries. Anchoring tall bookcases and file cabinets can be accomplished using angle brackets that are bolted to the floor and/or the walls. Additional anchorage can be installed using wood studs or longer angle brackets to secure bookcases to the walls and to each other (Figure 6-23). Whenever possible, redistribute heavy items on to lower shelves or drawers to stabilize weight.

6-22: Typical Bookcase Damage

Source: NOAA National Data Center - photo of unfastened heavy bookcases which fell over during the 1989 Loma Prieta earthquake at an office building Menlo Park, California

(ftp://geopubs.wr.usgs.gov/pub/dds/dds-29/web_pages/menlo.html)

Figure 6-23: Typical Anchoring of Tall Bookcases (Circled)

Source: FEMA – photo of braced library bookshelves at Centralia College in Centralia, Washington, May 2001

6.5.2 Computers and Equipment

Computers, monitors, and other equipment are common in public and commercial buildings, and may be critical to operations. These items are heavy, fragile, and can fall unless they are secured to the furnishings that support them (Figure 6-24).

Mitigation - Tremors can easily move personal computers and other small equipment causing them to fall. Restraining these items can protect small equipment from earthquake damage (Figure 6-25). Some methods, such as Velcro® fasteners, require no tools. Other methods, which include using chains, cables, or elastic cords, require simple hand tools. To reduce additional risks, anchor the ends of chains, cables, clips, or elastic cords to either the wall or the surface of the desk, table, or counter using eyehooks, rings, screws and washers, or other types of mounts.

Many public buildings house records in heavy, filing system carousels that can fall during an earthquake, and cause damage and serious injuries. To reduce damage and injuries, automated filing systems can be secured to the floor using seismic anchor bolts on all four corners, so that they remain upright during a seismic event. The seismic anchors should be long enough to secure the carousels into the floor slab.

Figure 6-24: Typical Equipment Damage

Source: Internet—photo damage to computers and equipment at the SEATAC Airport control tower during the 2001 Nisqually earthquake

(http://www.jcpreports.com/html/articles/seattle_pics.html)

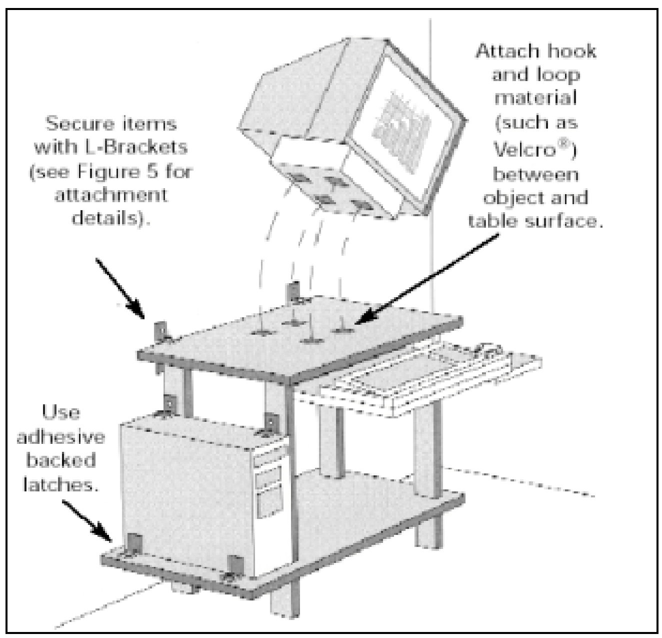


Figure 6-25: Typical Restraints for Desktop Computers

Source: IBHS and Project Impact, A Homeowner's Guide to Non-Structural Earthquake Retrofit, 2001 – sketch of typical detail for anchoring overhead lighting fixtures

6.5.3 Hazardous Materials

Compressed air tanks, corrosive chemicals, and other hazardous materials are found in some public, commercial and industrial buildings. These items are heavy, dangerous, and can fall, leak, or rupture unless they are anchored to walls or secured to furnishings that support them. Secondary damage can include damage from leaking chemicals, or fire or explosion damage.

Mitigation - Seismic-activated shutoff valves should be installed on hazardous materials supply lines, with flexible connections provided at the storage tanks. Bottles of laboratory chemicals should be prevented from breaking by using plastic containers (when appropriate) or secondary containment and from falling by using elastic straps, shelf lips, or cabinet door locks.

6.5.4 Miscellaneous Furnishings

Heavy chairs, couches, desks, display cases, wall hangings, and other miscellaneous furnishings are found in various buildings. These furnishings are heavy and can move or fall over unless they are secured to the floors or walls that support them (Figure 6-26).

Figure 6-26: Typical Wall Hanging Damage

Source: IBHS and FEMA Project Impact, A Homeowner's Guide to Non-Structural Earthquake Retrofit, 2001 – photo of picture frames damaged by the 1994 Northridge, California earthquake

Mitigation - Miscellaneous furnishings such as freestanding partitions, display cases, heavy objects on high shelves, and framed pictures can be secured in various ways (Figure 6-27) as discussed below.

1. Anchor freestanding partitions to the floor, attach to other stable furnishings, or arrange in a zigzag pattern.
2. Secure display cases to walls with angle brackets and bolt to the floor (metal wire or elastic guardrails added to top shelves to hold back contents).
3. Anchor furniture using screws long enough to go through the wall and the stud.
4. Redistribute heavy items to lower shelves to stabilize weight.
5. Secure framed pictures and mirrors to walls by using either long-shank or open eyehooks screwed securely to the frame (instead of just a wire across the back of the frame).

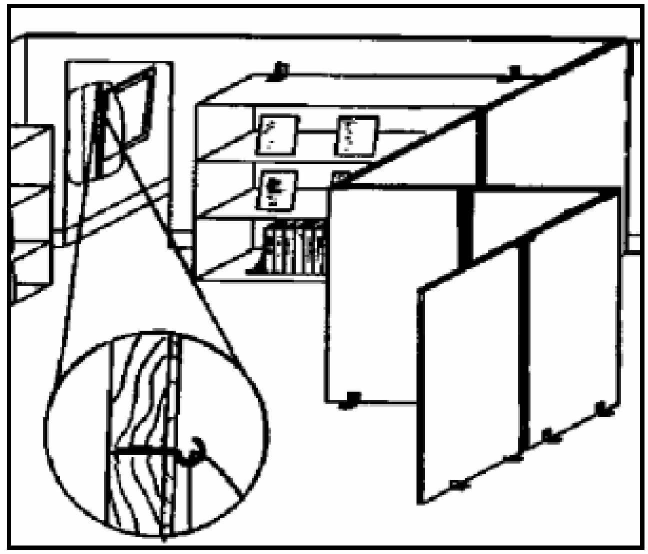


Figure 6-27: Typical Measures to Secure Miscellaneous Furnishings

Source: FEMA – photo of braced library bookshelves at Centralia College in Centralia, Washington, May 2001

7.1 STEP 4: MITIGATION FEASIBILITY AND OTHER CONSIDERATIONS

As noted previously, evaluating the seismic vulnerability of non-structural building elements or contents requires an engineering evaluation. Similarly, evaluating the feasibility and effectiveness of proposed non-structural mitigation measures also requires an engineering evaluation. Experienced seismic engineers should prepare these evaluations. However, for reference purposes, a general outline of the process of evaluating the feasibility of non-structural mitigation measures is presented in the following paragraphs.

If non-structural earthquake mitigation measures are determined to be effective, a feasibility assessment of the selected measures should be prepared. A feasibility assessment addresses the anticipated effectiveness of mitigation measures and directly affects the value of project benefits used for BCAs. The assessment is based on three important considerations:

1. Technical feasibility;
2. Need for human intervention to ensure that the mitigation measure is in-place; and
3. General effectiveness.

7.2 TECHNICAL FEASIBILITY

The purpose of feasibility evaluation for a proposed mitigation project is to determine whether the measure be designed, constructed, installed, or maintained without being cost prohibitive as part of a retrofit to an existing structure. In general, measures that are the simplest to implement are generally less expensive and more likely to be cost-effective. The technical feasibility of mitigation measures may be determined from visual inspection, or through a discussion with the building owner or manager, structural engineer, or a contractor. Additional information can be obtained by reviewing FEMA Hazard Mitigation Grant Program (HMGP) proposal and FEMA publications, including the Region X *Earthquake Mitigation Handbook*.

7.3 HUMAN INTERVENTION

The need for human intervention indicates whether a mitigation measure is considered active or passive. Active mitigation measures require human intervention or preparation time to ensure that the measure is effective. Examples of active measures include the use of clips or straps to secure computers and other equipment, but these measures only work if someone secures the clips or straps prior to an earthquake. Passive mitigation measures require no human intervention or preparation time to ensure that the measure is effective. Examples of passive mitigation measures include the installation of parapet bracing and anchoring bookcases in a building. Passive mitigation measures are preferable to active measures. Since earthquakes essentially occur without warning, active mitigation measures should be avoided whenever possible because they are unlikely to be in-place to reduce damage and therefore less likely to be effective or cost-effective. Determination of active versus passive mitigation measures may be obtained from visual inspection or through a discussion with the building owner or manager.

7.4 EFFECTIVENESS OR LEVEL OF PROTECTION

The effectiveness or level of protection for a proposed seismic hazard mitigation project is determined by two factors:

1. The measure's ability to eliminate or reduce earthquake damage
2. The amount of protection (damage reduction) provided for earthquakes from low to high hazard levels

Some mitigation alternatives are more effective at reducing damage than others. Many earthquake mitigation measures, particularly non-structural mitigation measures, are subject to limitations of effectiveness based on earthquake severity or intensity, building structural response, and other factors. For example, the effectiveness of strengthening window glass varies with the size of the window. This mitigation measure is very effective at reducing damage to smaller windows, but less effective for larger windows. In some cases, the effectiveness of a mitigation measure is greater when combined with one or more other measures.

Understanding the effectiveness provided by the measure is essential to measuring the cost-effectiveness because project benefits are based on avoided damage for various future events. In general, measures that provide maximum effectiveness result in less damage, increased benefits, and are more likely to be cost-effective. The effectiveness or level of protection of mitigation measures may be determined from visual inspection; discussion with the building owner or manager, structural engineer, or contractor. Note that exact determinations of effectiveness for earthquake mitigation measures may be difficult due to the wide variation in the intensity and direction of earthquake forces and displacements.

7.5 REVIEW OTHER CONSIDERATIONS

If the proposed mitigation measures are technically feasible, then the next step is to review other considerations (other than cost-effectiveness) that may affect selection of the mitigation measures. Other considerations address the indirect benefits of mitigation measures and can affect the value of project benefits used to conduct BCAs. These other considerations include regulatory requirements, owner preferences, and other hazards, and are described in the paragraphs that follow.

7.5.1 Regulatory Requirements

Consideration of regulatory requirements reflects whether the proposed mitigation measure is in compliance with Federal, State, and local regulations. Although not part of BCA, regulatory compliance may increase project costs or limit effectiveness. The regulations include the National Environmental Policy Act (NEPA), the National Historic Preservation Act (NHPA), the National Flood Insurance Program (NFIP), and local building codes. For example, if adding window bracing to a certain building in a historic district is not be permitted, the measure is not eligible to receive HMGP funding and cannot be considered when preparing BCAs. In general, mitigation measures that have no restrictions are preferable over measures with restrictions.

Information on regulatory requirements may be determined from a review of the regulations; discussion with the applicant or building owner, the Regional Environmental Officer (REO) and or the State Historic Preservation Officer (SHPO). FEMA publications, including the Region X

Earthquake Mitigation Handbook and the *How-To Mitigation Planning Guide No. 6* can provide additional information.

7.5.2 Owner Preferences

Owner preferences are an important consideration in the selection of non-structural earthquake mitigation measures. Although this consideration is not used directly in a BCA, mitigation measures must comply with owner requirements and other preferences such as aesthetics if they are to be implemented and maintained effectively. As a rule of thumb, mitigation measures already applied to other buildings and facilities as part of a past seismic retrofit project are considered preferable to those that have not been used previously. Information on owner preferences may be determined by discussion with the applicant or from a review of the HMGP application (if available).

7.5.3 Other Hazards

This consideration asks whether the proposed mitigation measure will negatively impact operations or increase risk from another hazard. Some non-structural earthquake mitigation measures may have a negative impact on a building's future use and appearance while other measures can actually increase the potential for damage from other types of hazards such as floods.

As stated previously, since non-structural elements are supported by structural elements, a structural engineer will need to identify which mitigation measures are appropriate for a given building and verify that the mitigation does not create more problems than it solves. Although these considerations are not used directly in a BCA, mitigation measures that increase risks from other hazards can lower the value of project benefits and thereby reduce the cost-effectiveness of the project. In general, mitigation measures that minimize other impacts are preferable. Information on other hazards may be determined from visual inspection; discussion with the applicant or the building manager; a review of the HMGP proposal (if available); and FEMA publications including the Region X *Earthquake Mitigation Handbook* and the *How-To Mitigation Planning Guide* series.

7.5.4 Review Other Considerations - Summary

After reviewing the regulatory requirements, owner preferences, and other hazards associated with the selected mitigation measures have been reviewed, the user should determine what impact (if any) these considerations will have on the selection of the proposed mitigation measures. Mitigation measures that do not comply with regulatory requirements, go against owner preferences, or have increased the risk of other hazards are generally not eligible for FEMA funding, may not be implemented, and may do little to reduce the damage risk. Therefore, if the proposed mitigation measure does not comply with these other considerations, then the measure should be rejected and another mitigation alternative should be considered.

7.6 CONDUCT COST ASSESSMENT

If the proposed mitigation measures are technically feasible, comply with regulatory requirements and hazard considerations, then a cost assessment is prepared to determine the cost-effectiveness of the mitigation measures. Cost assessments are performed using the FEMA

Benefit-Cost Analysis (BCA) software. A detailed discussion of the BCA process is beyond the scope of this manual.

In general, as stated in Section 3, there are limited geographic locations for cost-effective non-structural seismic hazard mitigation projects; it is important to recognize that not all non-structural seismic mitigation projects will be cost-effective or worthwhile, even in the highest seismic hazard areas. In addition, under FEMA's PDM-C program (Appendix B), the applicant must submit a BCA using FEMA's software to demonstrate that the project is relatively more cost-effective and worthy of funding.

Appendix A
Glossary

Active mitigation measures	Requires human intervention to operate properly and are usually less effective than passive mitigation measure.
Architectural elements	Exterior elements on a building or structure including cornices, corbels, decorative features, and lighting. These and other architectural elements are common among historic, unreinforced masonry structures. Such elements are generally constructed of stone or other heavy, brittle materials, and often fail during an earthquake due to poor anchorage or bracing.
Average occupancy	Occupancy of a building or a room averaged over an entire year. Therefore, the average occupancy of an office building will be higher over one year than the average occupancy of a public meeting room that is used only once per month.
BCA	Benefit-cost analysis (FEMA).
BCR	Benefit-cost ratio (benefits divided by costs). This ratio must be equal to or greater than 1.0 for a project to be considered cost-effective.
Benchmark	Date when building codes began to contain lateral force resisting requirements sufficient for a life-safety performance level. Knowing the building type, date of construction, date of the building code used, and a history of seismic upgrades, a building owner can determine if their building is pre- or post- benchmark.
Braced frames	Braced frames are generally constructed with steel, and they are most commonly encountered in rigid steel frame structures.
Building	A structure that has walls and a roof and is occupied on a regular basis. Examples include homes, city hall, office building, etc.
CERI	Center for Earthquake Research and Information.
Continuity premium	Multiplier (or adjustment) that places a higher dollar value on critical services.
Critical services	Services that either directly affect life safety or whose loss would have a large economic impact on a community.
CUSEC	Central United States Earthquake Consortium.
Depth	The distance, in miles below sea level to the point of origin (hypocenter) of an earthquake. A default depth for shallow earthquakes is 20 miles below sea level.

Ductility	The property of certain construction elements, such as wood or steel, to withstand large deformations without failing.
Duration	Length, in time, of an earthquake. This can affect the amount of damage to buildings and infrastructure. In general, smaller magnitude earthquakes have a much shorter duration of shaking.
EOC	Emergency Operations Center.
Epicenter	The point on the Earth's surface directly above the focus (or hypocenter) of an earthquake.
Exposure	The quantity, value, and vulnerability of the built environment (inventory of buildings and infrastructure) in a particular location subject to one or more hazards.
FEMA	Federal Emergency Management Agency.
Fragility curves	Detailed seismic vulnerability analyses of buildings, non-structural components, or infrastructure.
Full data module	Software for Benefit-Cost Analysis of Seismic Hazard Mitigation Projects (Version 5.22, December 31, 1998) based on full data or input parameters.
Hazard	Natural or technological events that potentially may cause damage, losses, or casualties.
HMGP	The FEMA Hazard Mitigation Grant Program provides grants to States and local governments to implement long-term hazard mitigation measures after a major disaster declaration. The purpose of the program is to reduce the loss of life and property due to natural disasters and to enable mitigation measures to be implemented during the immediate recovery from a disaster. The HMGP is authorized under Section 404 of the Stafford Act.
HVAC	Heating, ventilation, and air conditioning
Hypocenter	The point of origin of an earthquake (the location at which rupture commences).
IBC	International Building Code.

Inelastic deformation	Deformations of structural building elements where the element does not return to the original shape after the force is removed. This is the result of the large forces in buildings that are far in excess of normal conditions during an earthquake.
Intensity	The strength of shaking produced by an earthquake at given locations. Intensity varies depending not only on the magnitude of the earthquake, but on local soil conditions and the distance from the epicenter.
Inundation	Flooding, in the aftermath of an earthquake, due to the failure of dams, levees, reservoirs, water transmission lines, or large water tanks.
Life safety	Avoidance of potential casualties by mitigation that prohibits or reduces the potential for falling building elements or contents.
Limited Data Module	Software for Benefit-Cost Analysis of Seismic Hazard Mitigation Projects (Version 5.22, December 31, 1998) based on limited data or input parameters. (For use by experts, only in California.)
Liquefaction	Occurs when loose, wet, granular soil is shaken by an earthquake and becomes so unstable that the soil is transformed into a nearly fluid mass.
Magnitude	Measure of the strength or the amount of energy released at the source of the earthquake, and can be expressed as a single number for each earthquake. The original scale to measure earthquake magnitude was invented by Charles Richter.
Maintenance cost	The long-term costs of maintaining the effectiveness of a given mitigation measure. Maintenance costs are important in determining the true value of a non-structural earthquake mitigation project.
Mitigation	Measures taken to reduce the risk of damage, economic losses, or casualties.
Modified Mercalli Intensity (MMI) Scale	A qualitative descriptive scale to measure earthquake intensity.
NEHRP	National Earthquake Hazard Reduction Program.
NEPA	National Environmental Policy Act.
NFIP	National Flood Insurance Program.

NHPA National Historic Preservation Act.

Non-structural building elements Building or structure elements that will not cause the structure to collapse if the elements fail. These include exterior or interior elements, such as electrical, mechanical, plumbing systems, decorative features, and contents.

Non-structural seismic hazard mitigation projects Projects that improve, strengthen, or brace non-structural elements of a building or a structure to reduce damage, losses, and casualties during an earthquake. This includes retrofitting, bracing, or reinforcing the non-structural elements of a building or structure.

NRCS Natural Resources Conservation Service.

Ordinary services Services or functions that could be interrupted without resulting in significant life safety or economic impacts on a community.

PA FEMA's Public Assistance (PA) Mitigation Program provides funds for States and local governments for restoration of disaster-damaged infrastructure. Under this program, FEMA may fund hazard mitigation measures as part of the cost of restoration. The use of these funds is limited to public facilities that have been damaged by the declared disaster event. Mitigation through the PA Program is authorized under Section 406 of the Stafford Act.

Parapets Brick parapets are typically mounted along the tops of unreinforced masonry buildings and can provide either a firebreak between adjacent buildings or ornamentation. Parapets are heavy, brittle, and typically collapse near the centers of long walls or at corners.

Passive mitigation measures Mitigation measures that require no human intervention to be effective.

P-delta effect Excess building or structure displacement during an earthquake that can bring the building frame out of plumb and allow the force of gravity to deform the building or structure further.

PGA Peak ground acceleration.

Primary effects Ground motion due to seismic shaking and site soil effects (settlement, displacement, or liquefaction).

Project cost The total costs of designing and installing a given mitigation measure as part of a retrofit to an existing building (excluding maintenance costs).

Proximity	The distance from the epicenter of the earthquake and nearby earthquake faults to a specific location. In general, the closer the site is to the epicenter, the greater the damage.
Relevant occupancy	Average occupancy of a potential “fall area” within a building during an earthquake. (This is not peak occupancy or the occupancy of the entire building.)
REO	Regional Environmental Officer (FEMA).
Richter scale	Charles Richter invented the original scale used to measure earthquake magnitude. The Richter Scale is a logarithmic scale, meaning that an increase of one unit of magnitude represents a 10-fold increase in wave amplitude on a seismogram or approximately a 30-fold increase in the energy released.
Risk	The potential for damage, losses, and casualties arising from hazards. Risk results from the combination of hazard and exposure.
Secondary effects	Additional (after primary), indirect earthquake effects that include landslides, tsunamis, fire, hazardous material incidents, and inundation.
Seismic damage functions	Percent damage relative to replacement value.
Seismic hazard	The frequency and severity of damaging earthquakes.
Seismic risk	Threat to the built environment in the form of damage, economic losses, and casualties caused by earthquakes.
Seismograph	Equipment used to measure the magnitude of an earthquake.
Shear walls	Large structural walls that carry forces from floor and roof systems across the building and down to the foundation and the supporting soils. Shear walls are typically constructed of reinforced concrete, but may also be constructed of reinforced masonry or even wood framing. Braced frames consist of beams and columns with stiff diagonal braces that perform the same job as shear walls, but with less material.
SHPO	State Historic Preservation Officer.
SHMO	State Hazard Mitigation Officer.

Soft first story	The lowest floor of a building containing large open spaces, (for parking or interior storage), that are used to support one or more heavier upper floors.
Soil displacement	Lateral (sideways) spreading of soil due to earthquake ground motion.
Soil settlement	Vertical (downward) spreading of soil due to earthquake ground motion.
Spectral acceleration	Ground motions at specified frequencies or periods.
Structural building elements	Building or structure elements that act as a skeleton to support the rest of the building or structure. These include the foundation, load-bearing exterior and interior walls, beams, columns, floor systems, and roof systems. A failure of one or more structural elements may result in the collapse of the building or structure.
Structural seismic hazard mitigation projects	Projects that improve, strengthen, or replace structural elements of a building or structure to better resist earthquake forces. This includes retrofitting, bracing, or reinforcing the structural elements of a building or structure.
Structure	A building with sides and a roof, but generally not occupied on a regular basis, with the exception of maintenance. An example is a stormwater pump structure.
Tilt-up structures	Construction usually involving casting concrete walls at the site and tilting the walls up into place.
UBC	Uniform Building Code.
URM	Unreinforced masonry (buildings).
USGS	U. S. Geological Survey.

Appendix B

FEMA Mitigation Programs

When a Presidential Disaster is declared, FEMA provides assistance to communities to help repair damaged facilities. However, in many cases, applicants requesting assistance want to add mitigation measures to improve the facilities beyond the current or pre-disaster condition so that they can reduce potential damage or injuries in the next disaster. For these applicants, financial aid for mitigation is available from three major funding sources: the FEMA HMGP, the Public Assistance (PA) Mitigation Program, and more recently, from the Pre-Disaster Mitigation-Competitive (PDM-C) Grant Program.

B.1 HAZARD MITIGATION GRANT PROGRAM

The HMGP provides grants to States and local governments to implement long-term hazard mitigation measures after a major disaster declaration. The purpose of the program is to reduce the loss of life and property due to natural disasters and to enable mitigation measures to be implemented during the immediate recovery from a disaster. The HMGP is authorized under Section 404 of the Stafford Act.

HMGP funding is only available to applicants that reside in a state with a Presidential Disaster. Eligible applicants include State and local governments, Indian tribes or other tribal organizations, and certain non-profit organizations. HMGP funds may be used to fund projects that will reduce or eliminate losses from disasters. Projects must provide a long-term solution to a problem. In addition, the project must be cost-effective with the potential savings being equal to or greater than the cost of implementing the project. Examples of projects for earthquakes include, but are not limited to:

- Retrofitting structures and facilities to minimize damage from earthquakes
- Post-disaster building code related activities that support building code officials during the reconstruction process

For additional details on HMGP eligibility requirements, refer to the Code of Federal (CFR) Regulations, 44 CFR, Chapter 1, Subchapter D, Part 206.434, Subpart N on the FEMA website (http://www.fema.gov/fima/hmgp/44cfr_206434.shtm).

The State prioritizes and selects project applications developed and submitted by local jurisdictions. The State's administrative plan governs how projects are selected for funding. However, proposed projects must meet certain minimum criteria to ensure that cost-effective and appropriate projects are selected for funding. The State forwards applications consistent with State mitigation planning objectives to the appropriate FEMA Regional Office where they are reviewed to ensure compliance with Federal laws and regulations.

The amount of funding available for the HMGP under a particular disaster declaration is limited. The program may provide a State with up to 15 or 20 percent of the total disaster grants awarded by FEMA. States that meet higher mitigation planning criteria may qualify for 20 percent under the Disaster Mitigation Act of 2000. Since funding for this grant program is limited, States and local communities must make difficult decisions as to the most effective use of grant funds. For more information on the Hazard Mitigation Grant Program, contact the State Hazard Mitigation Officer (SHMO), the Regional FEMA Federal Insurance and Mitigation Division, or the FEMA website (http://www.fema.gov/fima/hmgp/).

B.2 PUBLIC ASSISTANCE PROGRAM (406 MITIGATION)

The FEMA PA Program also provides another source of funds for States and local governments to implement hazard mitigation measures after a major disaster declaration. However, the use of these funds is limited to public facilities that have been damaged by the declared disaster event. The PA Program is authorized under Section 406 of the Stafford Act.

Like the HMGP Program, the purpose of the PA Program is to reduce the loss of life and property due to natural disasters and to enable mitigation measures to be implemented during the immediate recovery from a disaster. However, there are several key differences between the two programs. These differences are outlined below in Table B-1.

Table B-1
Differences Between the FEMA HMGP and PA Programs

HMGP (404 Mitigation)	PA (406 Mitigation)
Administered by the State, with program funds capped at 20% of the total disaster funds spent in the State	Administered by the PA Program, with no program-wide limits on funds
Mitigation funds may be applied throughout the State	Mitigation funds must apply to the damaged element(s) of the facility
BCA is required to determine cost-effectiveness for mitigation proposals	BCA is not required to determine cost-effectiveness for mitigation proposals if: Mitigation cost is $\leq$ 15% of the total eligible repair cost; or Mitigation measure is listed in Appendix A of FEMA RR Policy 9526.1 and costs $\leq$ 100% of the total eligible repair cost
Categories of benefits in BCAs can include avoided physical damage, loss of function, economic impacts, casualties, and emergency management costs for the facility and the surrounding infrastructure	Categories of benefits in BCAs limited to damage and other categories of disaster impacts covered by FEMA 406 programs

B.3 PRE-DISASTER MITIGATION COMPETITIVE GRANT PROGRAM

The Fiscal Year 2003 budget provided $150 million under the National Pre-Disaster Mitigation Fund to initiate a competitive program for pre-disaster mitigation activities. The intent of this program is to provide a consistent source of funding to State, Tribal, and local governments for pre-disaster mitigation planning and projects primarily addressing natural hazards. Funding these plans and projects reduces overall risks to the population and structures, while also reducing reliance on funding from actual disaster declarations. Funding for the program is provided to assist States and local governments (including Indian Tribal governments) in implementing cost-effective hazard mitigation activities that complement a comprehensive mitigation program. All applicants must be participating in the National Flood Insurance Program (NFIP) if they have been identified through the NFIP as having a Special Flood Hazard Area (a Flood Hazard Boundary Map (FHBM) or Flood Insurance Rate Map (FIRM) has been issued). In addition, the community must not be suspended or on probation from the NFIP.

The Pre-Disaster Mitigation (PDM) Program was authorized by §203 of the Robert T. Stafford Disaster Assistance and Emergency Relief Act (Stafford Act), 42 USC, as amended by §102 of the Disaster Mitigation Act of 2000. For additional details on PDM-C eligibility, the application process, application review, the ranking and evaluation process and the award process, refer to the Pre-disaster Mitigation Overview on the FEMA website (http://www.fema.gov/doc/fima/pdmoverview.doc).

For more information on the PRM-C program including guidance and guidelines for benefit-cost analysis, refer to the PDM-C website at (http://www.fema.gov/fima/pdm/shtm).

Appendix C

Benefit-Cost Analysis

C.1 BENEFIT-COST ANALYSIS (BCA)

The FEMA BCA software provides a standardized, systematic process for evaluating the benefits of a mitigation project and for comparing these benefits to the project costs. A complete BCA counts all of the significant direct benefits of a mitigation project and involves reevaluating damage and losses before mitigation and after mitigation. For mitigation projects that affect life safety, a BCA must also consider the statistical monetary value of casualties avoided. The benefits of a mitigation project are the difference in expected damage and losses before and after the mitigation project is completed. A BCA also accounts for the probabilities of various levels of natural hazards, damage, the useful life of the mitigation project, and the time value of money, or discount rate.

A BCA is used to determine the economic viability of a mitigation project to reduce future damage and losses. BCAs compare the risks before and after the project, and the project cost. Risk is defined as the possibility of suffering harm or economic loss. Risk can be calculated as an expression of damage from historical data or the probability of damage.

When performing a BCA, the following factors must be evaluated:

- **Probability** - a measure of how likely it is that some event will occur
- **Vulnerability** - susceptibility to damage
- **Value** - an amount considered a fair and suitable equivalent for something

The benefits considered are avoided damage and losses that are expected to accrue as a result of the mitigation project. The costs considered are those necessary to implement the specific mitigation project under evaluation. Costs are generally determined for projects with engineering design studies. Benefits, however, must be estimated based on probability because they depend on the improved performance of the building or facility in events, the timing and severity of which also must be estimated on probability.

The benefits considered include avoided damage to the building and contents, avoided displacement costs, avoided rental and business income losses, avoided loss of public/nonprofit services and avoided casualties. The benefits calculated by the program are expected benefits that are estimated over the useful lifetime of the mitigation project. To account for the time value of money, a net present value calculation must be performed. This calculation is done automatically in the program, using the discount rate and project useful life entered by the analyst. Results of a BCA are presented in two ways: first, the benefit-cost ratio (BCR), which is benefits divided by costs, and second, the present value criterion (benefits minus costs).

The term BCA is used to denote economic analyses that apply either the maximum present value criterion or the BCR criterion to evaluate prospective actions. Both costs and benefits are discounted to their net present value. The maximum present value criterion subtracts costs from benefits to determine if benefits exceed costs. BCRs provide an alternative evaluation: prospective actions in which benefits exceed costs have BCRs above 1.0. The logic of BCA requires that BCRs, and/or the present value criterion, be compared across competing alternatives.

Monetizing different types and levels of damage places a value on all items to be taken into consideration when making a determination on the benefits of a project. Some items include damage to buildings and contents, loss of function, casualties, and emergency management costs.

The FEMA HMGP, PA and PDM-C programs require BCAs to meet the letter and intent of the Stafford Act and the Code of Federal Regulations. The determination can be done with limited amounts of data to provide a reasonable estimate of the cost-effectiveness of the project. Cost-effective projects can be prioritized to assist a community in planning mitigation projects before a disaster event. A BCA is an important element of the hazard mitigation planning process. For more information, please refer to the FEMA How-To Planning Guide 386-5 – *Using Benefit-Cost Analysis in Mitigation Planning*.

Uses of BCA

- To meet the letter and intent of laws and regulations – including the Stafford Act, 44 CFR, and Office of Management and Budget (OMB) requirements
- To provide a determination of project effectiveness
- To prove that projects work in reducing future damage
- To provide a means of comparing and prioritizing projects

C.2 BUILDING LOSS OF FUNCTION DATA

For BCAs, several inputs are required to determine the total value of lost public or nonprofit services (also known as functional downtime) from earthquake damage to the building. Note that these values apply only to public and nonprofit service buildings, and default estimates of functional downtime will vary based on building damage at various levels of earthquake intensity.

1. **Annual Budget of Public/Nonprofit Agencies** – First, input the total annual operating budget of all the public/nonprofit agency functions located in the building, including rental costs where available. If rent is not included in the annual budget, the program will compute a default or proxy rent based on the building value and the discount rate. Annual operating budgets and rents can be obtained from the HMGP proposal, or by contacting the affected agencies or the applicant.
2. **Post-Disaster Continuity Premium –** Next, input a continuity premium ($/day) as a way to assign additional value to certain public/nonprofit services that are more important to post-disaster response and recovery efforts. Continuity premiums can vary from 50% of the normal daily costs up to ten times the normal daily cost depending on the criticality of restoring those services following a disaster. Related information can be found in the FEMA publication *How to Determine Cost-Effectiveness of Hazard Mitigation Projects, (A New Process for Expediting Application Reviews)*, Interim Edition, December 1996, which is commonly referred to as the FEMA "Yellow Book" for BCAs. Additional guidance is also presented in the FEMA publication, *What Is A Benefit? Draft Guidance for Benefit-Cost Analysis* (FEMA Mitigation BCA Toolkit CD, Version 1.0, July 2003).
3. **Rent and Business Income** – Input the total monthly rent paid by all tenants in the building, excluding public and private nonprofit agencies, as well as the estimated net income of commercial business that may be housed in the building. These values (expressed in dollars per month) can be obtained from the owner and/or the building tenants.

C.3 COST ASSESSMENT

A cost assessment analyzes mitigation measures and estimates the project costs used to compute BCAs. The cost assessment is based on two primary considerations: project cost and maintenance cost.

The project cost is the total, up front cost of designing and installing a given mitigation measure as part of a retrofit to an existing building, excluding maintenance costs. Some non-structural earthquake mitigation projects such as securing furniture are simple measures with no design costs and minimal labor and material costs; while others are more complex and require engineering analysis and higher labor and material costs. The lower the mitigation project cost, the more likely that the project will be cost-effective. The project cost for mitigation measures should be based on current year costs and may be obtained from the applicant’s proposal, estimated based on design and construction costs provided by a contractor, or using a nationally recognized unit cost guides, such as *R. S. Means* or *Marshall & Swift*. A majority of the national guides are updated on an annual basis.

The maintenance cost is the long-term costs of maintaining the effectiveness of a given mitigation measure. Maintenance costs are an important consideration in determining the true value of a non-structural earthquake mitigation project for several reasons. First, some low-cost mitigation measures can have high maintenance costs that increase the overall project cost and lower cost-effectiveness. Also, mitigation measures with high maintenance costs are often less effective over time which can reduce the BCR. Finally, maintenance costs may be an indication that the mitigation project employs active measures that are generally less effective than passive measures. The maintenance cost of mitigation measures may be obtained from the applicant’s HMGP proposal, estimated based on a discussion with the building superintendent or maintenance contractor.

C.4 FULL DATA MODULE

The Full Data Module for Benefit-Cost Analysis of Seismic Hazard Mitigation Projects (Version 5.22, December 31, 1998) is the primary module for developing BCAs for seismic hazard mitigation projects. This module, which is similar to the widely used Riverine Full Data Module, provides a complete template for BCAs of seismic hazard mitigation projects. The full data seismic module includes sections for:

1. Probability of earthquakes (based on geographic location and soil types)
2. Seismic damage functions for buildings
3. Damage functions for structure contents
4. Displacement times and costs
5. Functional downtimes
6. Values of lost public or non-profit services
7. Casualties

The Limited Data Module for Benefit-Cost Analysis of Seismic Hazard Mitigation Projects (Version 5.22, December 31, 1998) was developed to facilitate user-entry of project-specific seismic damage functions for non-structural and infrastructure mitigation projects. The Limited Data Module differs from the Full Data Module in two main aspects:

1. There are no seismic damage functions or relationships for displacement time or functional downtime, or casualty rates; and
2. The data entry format for seismic hazard data is California specific, with formats used only on hazard maps prepared jointly by the California Division of Mines and Geology (CDMG) and the USGS.

It is important to note that this seismic Limited Data Module is conceptually different from the commonly used Riverine Limited Data module. The Riverine Limited Data module uses historical damage data to develop frequency-damage relationships. For earthquakes, no location in the United States has a sufficient history of earthquake damage to use the frequency-damage relationship method. Thus, the frequency damage approach should never be used for BCAs of seismic hazard mitigation projects. Rather, the seismic Limited Data Module is simply an abbreviated version of the Full Data Module with all the typical or default data removed. This truncation was designed to expedite entry of user-determined seismic damage functions and other user-determined data.

Appendix D
Earthquake Information

D.1 MEASURING EARTHQUAKES

There are several measures of the severity of earthquakes, including magnitude and intensity.

D.1.1 Magnitude

Magnitude is a measure of the strength of an earthquake or the amount of energy released by it and is measured by a device known as a seismograph. The scale used to measure earthquake magnitude was originally defined by Charles Richter, and is commonly referred to as the Richter scale. The Richter scale is a logarithmic scale, meaning that an increase of one unit of magnitude represents a 10-fold increase in wave amplitude on a seismogram or approximately a 30-fold increase in the energy released. For example, a Richter magnitude 6.7 earthquake produces wave amplitudes 10 times higher than a 5.7 earthquake, and it takes about 30 earthquakes at magnitude 5.7 to equal the energy released in a single 6.7 earthquake.

D.1.2 Intensity

Intensity is a measure of the effects of an earthquake at a particular place on people, structures, or the land itself. Historically, earthquake intensity has often been reported by a qualitative, descriptive scale known as the Modified Mercalli Intensity (MMI) scale. The intensity at a point depends not only upon the strength of the earthquake, but also upon the distance from the earthquake to a point and the local geology of that point.

It should be noted that magnitude and intensity measure different characteristics of earthquakes. Magnitude measures the energy released at the source of the earthquake, and can be expressed as a single number for each earthquake. Magnitude is determined from measurements on seismographs. As a rule, most earthquakes with magnitudes below 6.0 produce little damage, or at most, localized minor damage near the epicenter of the earthquake. As earthquake magnitudes increase above 6.0, the level of damage and the geographic areas subject to damage increase markedly with increasing magnitude. Large magnitude earthquakes (8.0 or greater) cause heavy damage over large areas.

Intensity measures the strength of shaking produced by the earthquake at given locations. Intensity varies depending not only on the magnitude of the earthquake, but also with distance from the epicenter and on local soil conditions. For example, sites with soft wet soils often experience amplified (higher) levels of ground shaking than nearby areas on firm soil or rock. Intensity is determined from effects on people, human structures, and the natural environment.

The MMI Scale, shown in Table D-1, has been widely used in the past, but it is rather archaic and outdated. More modern measures of earthquake intensity are based on quantitative measures of ground motion rather than on qualitative descriptions as used in the MMI scale.

Table D-1
Modified Mercalli Scale

Intensity	Description
I	**I**. Not felt except by a very few under especially favorable conditions.
II - III	**II**. Felt only by a few persons at rest, especially on upper floors of buildings. **III**. Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV – V	**IV**. Felt indoors by many, outdoors by a few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably. **V**. Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI - VII	**VI**. Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight. **VII**. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII - IX	**VIII**. Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, and walls. Heavy furniture overturned. **IX**. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X or higher	**X**. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent. **XI**. Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly. **XII**. Damage total. Lines of sight and level are distorted. Objects thrown into the air.

Source: USGS Website (http://neic.usgs.gov/neis/general/mag_vs_int.html)

D.2 PEAK GROUND ACCELERATION

Earthquake shaking or ground motion is the movement of the earth's surface produced by waves that are generated by a sudden rupture on a fault and travel through the earth and along its surface. In addition to magnitude and intensity, another common measure of earthquake shaking along the earth's surface is known as Peak Ground Acceleration (PGA). PGA expresses acceleration along the earth's surface as a percentage of "g," the acceleration due to gravity (32.2 ft/s^2). Table D-2 shows a comparison of earthquake intensity to Peak Ground Acceleration. These values are used in the FEMA BC module for earthquake mitigation projects.

Table D-2
Comparison of Earthquake Intensity vs. Peak Ground Acceleration

MMI	PGA (% of gravity)
VI	4 – 8
VII	8 – 16
VIII	16 – 32
IX	32 – 55
X	55 – 80
XI	80 – 100
XII	>100

Source: FEMA Earthquake Benefit-Cost Full Data Module, Version 5.2.2 (December 31, 1998)

D.3 SPECTRAL RESPONSE ACCELERATION

Another important measure of earthquake intensity is spectral response acceleration. Spectral accelerations are widely used by engineers in the seismic design of structures to measure the intensity of ground motions at specified frequencies (or wavelengths). This is used because various types of structures have characteristic frequencies and their seismic performance is governed by how much energy from an earthquake is near the structure's frequency. Short stiff (i.e., inflexible) buildings have shorter frequencies, while tall, more flexible buildings have longer frequencies.

The spectral response accelerations are measured at different periods of vibration, known as reference periods, which correspond to periods of vibration that are common to various building types. Like PGA, spectral response accelerations are expressed as a percentage of g, the acceleration due to gravity (32.2 ft/s^2).

Spectral response acceleration maps have been created for the Uniform Building Code (UBC) and the International Building Code (IBC). The UBC measures spectral accelerations at three reference periods: 0.3, 1.0 and 3.0 seconds. The IBC measures spectral accelerations at reference periods of 0.2 and 1.0 seconds. Spectral response acceleration maps for various locations nationwide may be found through the following links:

- UBC Spectral Response Acceleration Maps (http://www.icbo.org)
- IBC Spectral Response Acceleration Maps (http://eqhazmaps.usgs.gov/)

Spectral accelerations are used primarily by earthquake engineers. For non-technical users and for benefit-cost analysis, PGA is the most common measure of ground motions.

D.4 USGS EARTHQUAKE HAZARD RISK MAP INFORMATION

The USGS Earthquake Hazard Risk Maps (also known as shaking-hazard maps) for the United States are based on information about the rate at which earthquakes occur in different areas and on how far shaking extends from earthquake sources. Colors on this particular map (Figure 2-1) show the levels of horizontal shaking that have a 1-in-50 chance of being exceeded in a 50-year period. Shaking is expressed as a percentage of g.

The degree of earthquake hazard depends on a variety of factors described throughout this document. The level, or probability, of damaging earthquakes varies markedly by location in the United States. Although many States and territories have some level of earthquake hazard, the highest hazard areas in the United States are near active faults in California and Alaska, as well as the New Madrid Fault in the Midwest. Annualized damage and losses before mitigation and the benefits of preventing or reducing them are directly proportional to seismic probabilities. Therefore, all other factors being equal, the higher the seismic hazard, the greater the benefits of mitigation and the more likely that a given project is cost-effective. Because of this local variation in seismic hazard, some projects will be cost-effective in higher hazard areas that would not be cost-effective in lower hazard areas.

D.5 OTHER EARTHQUAKE HAZARD FACTORS

Three other earthquake hazard factors are proximity, depth, and duration. However, a detailed study of these factors is not necessary for the process of selecting non-structural earthquake projects in Central United States.

D.5.1 Proximity

The proximity of an earthquake will have a significant impact on the level of damage to buildings and other infrastructure. The proximity depends on the distance from the epicenter of the earthquake and nearby earthquake faults. In general, the closer a location is to the epicenter of the earthquake, the greater the damage. Also, known surface faults can be a useful guide to where earthquakes are likely to occur. For this reason, earthquake mitigation projects are more likely to be cost-effective when located in close proximity to active earthquake faults. However, studies conducted by the USGS National Earthquake Information Center indicate that the location of individual known faults and fault lines are not reliable guides in the likelihood of earthquakes east of the Rocky Mountains (http://neic.usgs.gov/neis/general/faults_east.html).

Furthermore, plate tectonics, local geology and the refraction of earthquake waves through the earth's mantle will also affect the level of earthquake ground shaking. For example, California is considered to be a high risk for earthquakes due to the large number of active faults and frequency of seismic events; however, the effects of most of these earthquakes are limited to a confined geographical area. By contrast, the New Madrid Fault, although less active, represents a greater hazard because earthquake effects would be felt over a wider area due to plate tectonics and other geologic features. Additional information on earthquake proximity may be found on the USGS website (http://eqhazmaps.usgs.gov/).

D.5.2 Depth

The depth to the point of origin, or hypocenter, of an earthquake will also play a role in the amount of damage to buildings and other infrastructure at the ground surface. Depth is measured as distance below sea level in miles: 20 miles is used as a default depth for shallow earthquakes without a determined depth. Default depths of three or six miles are usually used in mid-continental areas and on mid-ocean ridges, since earthquakes in these areas are usually shallower than 20 miles.

In general, earthquakes that occur at shallow depths generate larger ground motions and cause more damage than deep-seated earthquakes. Examples of shallow depths include the earthquakes along San Andreas Fault in California and the New Madrid Fault. Faults found in parts of Washington State tend to be more deep-seated. However, the type of local soil and rock formations present also have a significant effect on actual earthquake ground shaking. Additional information on determining earthquake depths may be found on the USGS website (http://neic.usgs.gov/neis/general/depth.html).

D.5.3 Duration

In addition to proximity and depth, the duration of an earthquake can affect the amount of damage to buildings and other infrastructure. In general, smaller magnitude earthquakes have much shorter durations of shaking. For example, shaking during the 1989 magnitude 7.1 Loma Prieta (San Francisco) earthquake lasted 15 seconds and for the 1906 magnitude 8.3 San Francisco earthquake it lasted about 40 seconds. Shaking during the 1964 magnitude 9.2 Alaska earthquake lasted three minutes. Duration also depends on soil conditions at each site. Soft soil sites may experience longer duration shaking than nearby firm soil or rock sites.

In the United States, very long duration shaking and high damage levels are expected from large magnitude earthquakes in California or Alaska, in the Pacific Northwest and in the New Madrid Fault zone. Additional information on earthquake durations may be found on the USGS website (http://earthquake.usgs.gov/faq/meas.html#8).

D.6 SOIL TYPES, CLASSIFICATION SYSTEMS, AND INFORMATION SOURCES

The types of soils at a given location have a major impact on the likelihood of earthquake damage. For this reason, it is important to understand the type and classification of foundation soils used at mitigation project locations. There are four basic types of soils: gravels, sands, silts, and clays. These basic soil types are defined below using the Unified Soil Classification System and based on the size of the materials that make up the soil, known as grain size.

- **Gravel** – coarse-grained soil that consists primarily of large granular materials, such as rock fragments, boulders, and cobbles (grain size range: 75 mm to 4.75 mm)
- **Sand** – medium-grained soil which consists primarily of medium granular materials that are smaller than gravel (grain size range: 4.75 mm to 0.075 mm)
- **Silt** – fine-grained soil which consists primarily of small materials of lower plasticity (grain size range: less than 0.075 mm)
- **Clay** – fine-grained soil which consists primarily of small materials of higher plasticity (grain size range: less than 0.075 mm)

Note that nearly all soils contain one or more of these basic soil types; the key is to identify which soil type is the predominant one. Gravels and sands can be easily identified by visual inspection and distinguished by their grain size. Silts and clays can be identified by visual inspection and generally distinguished by their level of plasticity. This can be accomplished by means of touch: silts tend to leave a grainy residue on the fingers when rubbed, while clays can be rolled into sticks or balls. The level of plasticity provides an indication of bonding, or cohesion, between soil particles. Plasticity also shows the potential for soils to absorb water, which can cause them to expand, or swell. A geotechnical engineer or engineering geologist should be consulted to determine actual soil composition.

Both the UBC and the IBC have developed a system of classifying soil types based on their suitability of use in earthquake-prone areas. Both systems classify soils based on the type of soil and level of compaction. A summary of these classifications systems is provided in Tables D-3 and D-4.

Table D-3
UBC Soil Types

UBC Soil Type	Basic UBC Soil Description
S0	Hard rock
S1	Rock
S2	Firm soil
S3	Soft soil
S4	Very soft soil

Source: FEMA Earthquake Benefit-Cost Full Data Module, Version 5.2.2 (December 31, 1998)

Table D-4
IBC Soil Types (Site Class)

IBC Site Class	Basic IBC Site Class Description
A	Hard rock
B	Rock
C	Very dense soil and soft rock
D	Stiff soil profile
E	Soft soil profile
F	"Very soft" soil profile

Source: 2000 International Building Code

In general, rock and stiff soils (gravels) are considered the best foundation soils for supporting buildings and other structures. This is because these materials require minimal preparation and/or compaction and can support very large loads with little or no settlement. Also, these materials do not amplify shaking effects. Sands can also act as good foundation soils provided they are relatively dry and well compacted. By contrast, soft soils (uncompacted sands, silts, and clays) are generally the worst foundation materials. This is because silts and clays are difficult to compact and are subject to expansion (swelling) or contraction (shrinking) depending on the level of ground water surrounding the materials. In addition, these materials actually amplify shaking effects, and uncompacted soils saturated by groundwater can lose stability during an earthquake and flow like a liquid, a phenomenon known as liquefaction. For this reason, buildings and facilities supported on liquefiable soils often experience extensive damage during an earthquake. For example, USGS records of ground motion obtained during the 1989 Loma Prieta earthquake and its aftershocks vividly confirmed that soft clay soil shakes more violently than firmer sandy soil, which in turn shakes more than hard rock. Log onto the USGS website (http://quake.wr.usgs.gov/prepare/factsheets/BetterDesign/) to find additional information on this case.

Additional information on soil types and earthquake hazards for various locations nationwide may be found through UBC and IBC, as well as the following links:

- Natural Resources Conservation Service – Soil Data (http://soils.usda.gov/)
- USGS – Soil Type and Shaking Hazard (http://quake.wr.usgs.gov/prepare/soil_type/index.html)

D.7 ADDITIONAL SOURCES OF SEISMOLOGY INFORMATION

Additional information on seismology in the United States, particularly the Midwest, can be found at the following websites:

- USGS: Earthquake Hazards Program - National Seismic Hazard Mapping Project (http://eqhazmaps.usgs.gov/)
- CERI: Center for Earthquake Research and Information - Recent Central U.S. Earthquake Activity Map (http://folkworm.ceri.memphis.edu/recenteqs/index.html)

Appendix E

Engineering Information

E.1 BUILDING CONSTRUCTION TYPES

Building materials also play an important role during an earthquake. Under normal conditions, building elements deform as force is applied, and then the element returns to its original shape when the force is removed. This is known as elastic deformation. However, earthquakes often create large forces in buildings that are far in excess of normal conditions, resulting in deformations where a building element does not return to its original shape after the force is removed. This is known as inelastic deformation.

E.2 DUCTILITY

This is the property of certain materials to absorb a large amount of inelastic deformation before failing. Building elements constructed with ductile materials have a greater reserve capacity to resist overloads generated by earthquakes. Consequently, buildings constructed of more ductile framing materials such as steel and timber tend to withstand earthquakes better than those constructed of more brittle materials such as unreinforced masonry (URM). Ductility is important in a BCA as an indicator of vulnerability and value of building damage anticipated in an earthquake. Ductility can be determined from visual observations of the building, insurance appraisal data, building construction plans, or discussion with the building owner or manager.

E.3 FRAGILITY CURVES

In the event of an earthquake, a building may sustain various degrees of damage, from no damage to total collapse. The level of damage is dependent on the level of ground acceleration and the building type. One method of expressing the seismic vulnerability of buildings is through the use of fragility curves, which display the probabilities of a building damaged beyond a specified damage state at various levels of ground shaking. Basic fragility curves are embedded in the FEMA Full Data Benefit-Cost Module for Earthquake and can be used to compute the probability and value of earthquake building damage before mitigation. Similar information for earthquakes may be found in FEMA's How-To Planning Guide 386-2: *Understanding Your Risks – Identifying Hazards and Estimating Losses* or the Applied Technology Council (ATC) publication *ATC-13*.

In addition to fragility curve data available from FEMA, the Center for Earthquake Research and Information (CERI) has developed a series of fragility curves which can be found on the internet at: (http://www.ceri.memphis.edu/research/index.shtml).

These curves were developed for various levels of damage based on existing buildings in the Memphis, Tennessee area using six types of structural systems: URM, reinforced masonry, reinforced concrete, steel frame with URM, light metal, and wood frame. These fragility curves reflect the fact that most existing buildings in the Midwest were not designed to resist earthquakes, and these buildings in general are more vulnerable to earthquakes than those located in California.

E.4 BUILDING CONSTRUCTION DATE

As stated in FEMA Publication 310, *Handbook for Seismic Evaluation of Buildings - A Pre-standard*, the updates to building codes and standards have led to the establishment of benchmarks for various buildings types. Pre-benchmark buildings are defined as buildings constructed prior to the year in which building codes generally began to contain lateral force resisting requirements sufficient for a life-safety performance level. Knowing the building type, date of construction, date of the building code used, and a history of any seismic upgrades, a building owner can determine if their building is pre- or post-benchmark. If a building was constructed prior to the benchmark year for its type, it was probably designed using a code without structural provisions that meet a life-safety performance level. Hence, such a building would be classified as pre-benchmark. Conversely, if a building was built or seismically upgraded after the benchmark year, it is possible that it meets a life-safety performance level. As outlined in Table E-1, building types with no benchmark year can be considered as pre-benchmark. However, all communities do not have building codes and all communities do not adopt building codes in the year the code goes into effect. One cannot assume that a building is protected based on the year in which the code was either issued or adopted.

Table E-1
Summary of Standard Building Types and Benchmark Years

Building Type	Description of Building Type	Benchmark Year
1	Wood, Light Frame (W1)	1976
2	Wood, Commercial and Industrial (W2)	1976
3	Steel Moment Frame (S1)	1994
4	Steel Braced Frame (S2)	1988
5	Steel Light Frame (S3)	No Bench Year
6	Steel Frame with Concrete Shear Walls (S4)	1976
7	Steel Frame with URM Infill (S5)	No Bench Year
8	Concrete Moment Frame (C1)	1976
9	Concrete Shear Walls (C2)	1976
10	Concrete Frame with URM Infill (C3)	No Bench Year
11	Pre-cast / Tilt-up Concrete Walls (PC1)	1997
12	Pre-cast / Concrete Frames (PC2)	No Bench Year
13	Reinforced Masonry Bearing Walls with Flexible Diaphragms (RM1)	1997
14	Reinforced Masonry Bearing Walls with Stiff Diaphragms (RM2)	1976
15	URM Bearing Wall Buildings	No Bench Year

Source: FEMA 310 - Handbook for the Seismic Evaluation of Buildings – A Pre-standard (January 1998)

Note that benchmark years shown in Table E-1 are based on seismic design provisions in the UBC. "No Bench Year" refers to the lack of a comprehensive seismic requirement existing for these buildings.

E.5 STRUCTURAL EARTHQUAKE MITIGATION TECHNIQUES

Basic structural earthquake mitigation techniques are described below. For additional information, refer to the FEMA Region X *Earthquake Hazard Mitigation Handbook for Public Facilities* (February 28, 2002).

1. **Improve Wall Bracing** – Reduce damage to load-bearing walls by strengthening, reinforcing, or protecting them to withstand lateral earthquake forces. Mitigation measures include reinforcement of walls using shear walls or cross bracing, bracing long walls with cross walls, adding bracing to crawlspace (cripple) walls, and protecting walls by stiffening floors.
2. **Strengthen Floor and Roof Systems –** Strengthen weak floor and roof systems by adding components that resist lateral earthquake forces. Floor and roof systems can be strengthened using steel chords and collectors (drag struts) to connect portions of the floor or roof system to load-bearing walls.
3. **Strengthen Connections** - Strengthen weak connections to allow building elements to work as a unit to resist earthquake forces and movements. Mitigation measures include anchoring the sill plates of buildings to their foundations, and installing tension ties and/or shear anchors between the walls and the floor and roof systems.
4. **Eliminate Soft Story Condition –** A soft story condition occurs where the lowest floor of a building contains large open spaces, such as parking or interior storage, and is used to support one or more heavier upper floors. This lowest floor, or soft story, is vulnerable to damage or collapse from lateral earthquake forces unless it is reinforced using mitigation measures such as steel moment frames, shear walls, cross bracing, and infilling openings at the soft story level.
5. **Add Reinforcement and Confinement** - Reinforce walls and/or confine columns constructed of concrete or masonry that are at risk of damage or collapse so the walls or columns can withstand lateral earthquake forces and movements. Load-bearing walls can be reinforced with shotcrete or carbon fiber sheets. Reinforcing steel in columns can be confined using fiberglass or carbon fiber wraps.
6. **Improve Seismic Response –** The behavior of buildings with poor seismic characteristics can be improved to reduce earthquake damage. Isolating a building from the shaking ground with vibration isolation bearings and installing dampers will help to absorb movements and increase a building's seismic resistance.

A structural engineer should be consulted to identify whether certain structural mitigation techniques or measures are appropriate for a given building. Be aware that some structural measures included in this section are <u>not</u> appropriate for all buildings. Choosing the wrong measure may cause more problems than not doing any retrofit at all.

E.6 REPORTED BUILDING CONDITION - ADDITIONAL SOURCES OF INFORMATION

One of the main factors used to determine the reported building condition is the quality of construction. However, determining the quality of construction is often a judgment call due to the lack of consistent nationwide standards. To reduce this difficulty, some reference materials have been developed to allow inspectors to make determinations of construction quality that are more consistent and objective. Nationally recognized reference materials to consult are the *Residential Cost Handbook* and *Property Appraisal Guide* produced by Marshall & Swift. These reference materials provide detailed building descriptions and unit costs associated with various levels of construction quality and include photographs of actual buildings that match the descriptions. This allows inspectors of residential and non-residential buildings to determine quality of construction by matching them to the descriptions and photographs provided by Marshall & Swift. Additional information on Marshall & Swift can be found on the company's website (http://www.marshallswift.com/index.asp).

E.7 SOURCES OF INFORMATION ON NON-STRUCTURAL MITIGATION MEASURES

Additional information on non-structural earthquake mitigation alternatives may be obtained from the following sources:

- FEMA Region X Earthquake Mitigation Handbook for Public Facilities
- FEMA 74: Reducing the Risks of Non-Structural Earthquake Damage
- NEHRP website sources (http://quake.wr.usgs.gov/info/othersites.html)
- FEMA's website (http://www.fema.gov/hazards/earthquakes/)

Appendix F

Building Structure Types

Determination of building construction type is based on two items: the type of framing materials used in the structure, and the type of system used to resist lateral earthquake forces. Both of these items provide an important indicator of how a building will respond to an earthquake, and are described in the following sections. For earthquake engineering, the type of structural materials (i.e., wood, concrete, steel) and the design of load bearing elements are commonly referred to as the "structural system" for a building.

F.1 FRAMING TYPE

The framing type will depend on the type of materials used to construct the building and is important for identifying the overall earthquake risk, quantities of damage, and the seismic mitigation measures that can be considered for a given building. For example, if the building framing type is URM, the building will be at high risk of severe structural damage or collapse, and it is unlikely likely that non-structural mitigation measures will be effective at reducing such damage. In general, framing types can be determined using simple visual observation and building inspection. However, if the framing type is unknown, please consult a structural engineer or building inspector to make the determination. Other sources of information for identifying framing type include insurance records (appraisal reports), structural building plans, and discussions with the building owner or manager.

F.1.1 Wood Frame Structures

Wood frame structures typically consist of timber floors and beams supported by timber columns and load-bearing walls. A typical wood frame structure is shown in Figure F-1. Most residential homes and some commercial buildings are wood frame structures. Well-designed wood structures have generally performed well in earthquakes. Failures are often due to lack of foundation anchorage or unbraced crawlspace (cripple) walls (Figure F-2).

Figure F-1: Typical Wood Frame Structure

Source: Dewberry– photo from Humboldt State University, California,, February 2002

Figure F-2: Typical Wood Frame Structure Damage Due to Lack of Foundation Anchorage

Source: USGS – photo of damage in Watsonville, California, from the 1989 Loma Prieta Earthquake

F.1.2 Steel Frame Structures

Steel frame structures typically consist of steel decking supported by steel beams and columns that are welded or bolted together. These structures generally perform better than other structure types. A typical steel frame structure is shown in Figure F-3. Many large commercial and industrial buildings are steel frame structures. During an earthquake, steel frame structures may suffer damage to primary members, distress at moment connections, movement between floor levels (story drift), and broken or buckled braces and connections (Figure F-4).

Figure F-3: Typical Steel Frame Structure

Source: Internet photo – One Kansas City Place, Kansas City, Missouri (http://kcskyscrapers.com/displaybuilding.php?displaytype=1&order=1)

Figure F-4: Typical Steel Frame Structure Damage Due to Story Drift

Source: EQE International – photo of damaged steel building in Sannyomiya, Japan, from the EQE Summary Report on the January 17, 1995 Kobe Earthquake, April 1995

F.1.3 Concrete Structures

Many commercial and public buildings are concrete structures and typically consist of concrete floor decks and beams supported by concrete columns and load-bearing walls. Typical concrete structures (Figure F-5 may be cast-in-place or pre-cast. Cast-in-place concrete buildings can be damaged or can collapse, particularly at the piers, beams, columns, and construction joints (Figures F-5 and F-6). Pre-cast structures can experience damage in joints and connections.

Figure F-5: Typical Concrete Structure

Source: Dewberry– photo from California State University Hayward, California, February 2002

Figure F-6: Typical Concrete Structure Damage Due to Inadequate Connections

Source: NOAA National Data Center – photo of damaged State Theater Building from May 2, 1983, Coalinga, California, Earthquake

F.1.4 Tilt-up Structures

Tilt-up construction usually involves casting concrete walls at the site and tilting them up into place. A typical tilt-up structure is shown in Figure F-7. Many commercial and public buildings are tilt-up frame structures. The most common failure mode is wall-roof separation resulting from inadequate ties (Figure F-8). Other problems include weak connections between individual wall panels, failure of diaphragms and exterior elements, and failure in panels with large openings.

Figure F-7: Typical Tilt-Up Structure

Source: Dewberry– photo from California State University Hayward, California,, February 2002

Figure F-8: Typical Tilt-Up Structure Damage Due to Inadequate Wall-to-Roof Ties

Source: EQE International – photo of damaged tilt-up building in the San Fernando Valley from the EQE Summary Report on the January 17, 1994 Northridge, California Earthquake, March 1994

F.1.5 Masonry Structures

There are two kinds of masonry construction: URM and reinforced. structures, particularly bearing walls, are the form of construction most vulnerable to earthquake damage. Typical URM buildings are shown in Figure F-9. Many older commercial, industrial and public buildings are URM structures. Floors and walls of these structures are often not tied together, or, when tied together, are only weakly connected. Some older structures have mortar that has deteriorated. Long, URM wall sections are particularly prone to severe cracking or failure due to the lack of bracing or reinforcing steel (Figure F-10). Chimneys in older buildings are commonly damaged or destroyed, creating falling hazards.

Figure F-9: Typical URM Buildings

Source: Internet photo from Urban 75 website – corner of Spring and Lafayette Streets, New York, NY

(http://www.urban75.org/photos/newyork/ny176.html)

Figure F-10: Typical Damage to URM Buildings due to Poor Walls, Connections

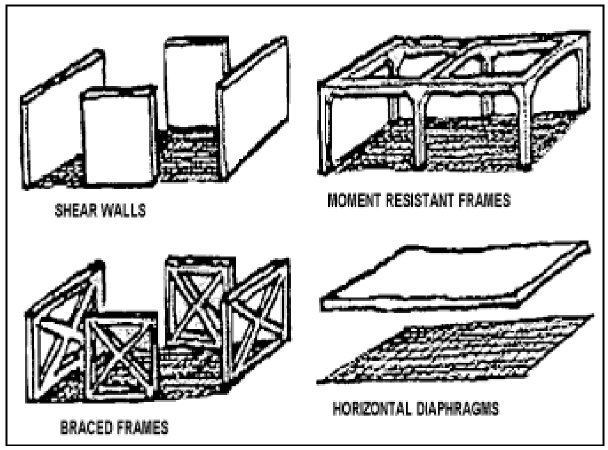
Source: USGS – photo of damage in San Francisco, California area from the October 17, 1989 Loma Prieta Earthquake

F.2 LATERAL FORCE RESISTANCE

Most buildings are primarily designed to resist vertical loads imposed by gravity. However, earthquakes and other hazards can generate large horizontal or lateral loads on a building. There are four basic structural systems used to resist lateral forces from earthquakes: shear walls, braced frames, moment resistant frames, and horizontal diaphragms (Figure F-11). Buildings equipped with one or more of these components are much more likely to survive an earthquake with less damage than buildings not equipped with them.

Figure F-11: Basic Lateral Force Resistance Systems

Source: FEMA Region X Earthquake Hazard Mitigation Handbook for Public Facilities, February 28, 2002



The lateral force resistance system is a key determinant of the vulnerability of a building to earthquakes. In addition, the type of lateral force resistance system is important for identifying seismic mitigation measures that can be considered for a given building. Although the presence of lateral force resistance system types may be determined using simple visual inspection of the building, the components of lateral force resistance systems are often covered by walls and floor finishes. For this reason, an experienced structural engineer or building inspector is usually needed to make the determination. Other sources of information may be needed to identify these systems, including insurance reports, structural building and retrofit plans, and discussions with the building owner or manager.

F.2.1 Shear Walls

Shear walls are large structural walls that carry forces from floor and roof systems across the building and down to the foundation and the supporting soils. Shear walls are typically constructed of reinforced concrete, but may also be constructed of reinforced masonry or even wood framing. Shear walls may be found in many modern buildings constructed of wood, concrete, or steel.

F.2.2 Braced Frames

Braced Frames consist of beams and columns with stiff diagonal braces that perform the same job as shear walls, but with less material. Braced frames are generally constructed with steel, and are most commonly encountered in rigid steel frame structures.

F.2.3 Moment Resistant Frames

Moment resistant frames, also known as steel moment frames, generally consist of steel beams welded to one or more columns. The frames perform the same job as shear walls or braced frames but take up less space (Figure F-12). Moment resisting frames are generally constructed of steel and are most often found in steel frame and concrete structures with open space floor plans.

Figure F-12: Typical Moment Resistant Frame

Source: Internet photo - steel moment frame retrofit for an existing concrete frame warehouse, Dewberry[SM]

F.2.4 Horizontal Diaphragms

Horizontal Diaphragms are floor and roof deck systems that carry lateral forces across the building to shear walls, braced frames, and/or columns. Diaphragms can be constructed of various materials and are found in nearly all construction types in one form or another.

F.3 BUILDING TYPE - SUMMARY

Once framing type and lateral forces resisting system used in the building have been identified, the user can use Table F-2 to determine the vulnerability of a building in terms of earthquake damage. Note that Table F-2 indicates that existing tilt-up and URM structures are most vulnerable to earthquake damage. Also, building construction type and building condition are closely related to one another. Therefore, if the existing building is composed of tilt-up or URM framing and is in poor condition, it will be at high risk of severe structural damage or collapse, and it is not likely that non-structural mitigation measures will be effective at reducing damage.

Table F-2
Earthquake Vulnerability by Building Construction Type

Framing Type	Typical Lateral Force Mitigation Resistance System(s)	Vulnerability to Earthquake Damage
Wood Frame Structures	Shear Walls Horizontal Diaphragms	Generally low except for structures not bolted to foundations or with cripple walls
Steel Frame Structures	Shear Walls Braced Frames Moment Resistant Frames Horizontal Diaphragms	Low to Medium
Concrete Structures	Shear Walls Moment Resistant Frames Horizontal Diaphragms	Low, with shear walls to High, with non-ductile frames
Pre-Cast Concrete Structures	Shear Walls Moment Resistant Frames Horizontal Diaphragms	Generally High
Tilt-Up Structures	Horizontal Diaphragms	Medium to High, depending on roof/wall connections
Reinforced Masonry Structures	Horizontal Diaphragms	Medium
URM Structures	Horizontal Diaphragms	Highest

Source: Based on FEMA Earthquake Benefit-Cost Full Data Module, Version 5.2.2 (December 31, 1998)

NOTE: Table F-2 applies to most existing buildings in the Midwest, which were not typically designed to resist earthquakes and are generally more vulnerable to earthquakes than those located in California.

F.3 DETERMINE EXISTING BUILDING CONDITION

Determining the existing condition of a building depends on two important factors: the construction date and the reported building condition. Both of these factors help provide an indication of how a building will behave during an earthquake, and are described in the following paragraphs.

F.3.1 Construction Date

Earthquake-resistant design and construction techniques have improved significantly in California over the past 50 years. Lessons learned as a result of major earthquakes in the United

States and throughout the world have led to the steady improvement of building codes nationwide governing seismic design. This has resulted in buildings that are more resistant to damage or collapse seismic events. Consequently, buildings constructed during the past five to ten years are generally more resistant to earthquake damage than those constructed before 1950. However, older buildings that have undergone one or more seismic retrofits or other mitigation may behave better in an earthquake than buildings that were constructed more recently. The building codes represent the minimum design standards and because the principal goal of seismic design codes is to avoid building collapse and loss of life, and not necessarily avoid significant building damage.

In evaluating the significance of building construction dates, it is essential to consider the specific building code history for the building location. Different states have upgraded seismic provisions of building codes at different times and thus it is the State or local building code history that governs.

The building construction or retrofit date can provide important clues to determining other factors such as building construction type and anticipated earthquake building damage. Building construction dates can be obtained from the HMGP application, insurance reports, or original construction plans. For public buildings, the original construction date may appear on a dedication stone or plaque located in or on the building. In addition, dates of seismic retrofits can be determined from the building owner, manager, or structural retrofit plans.

Additional information on benchmark years for building codes can be found in Table E-1.

F.3.2 Reported Building Condition or Damage State

Seismic vulnerability depends to some extent on building condition. Buildings in poor condition may be more vulnerable to seismic damage. However, in many cases, a poor condition may only affect architectural details and finishes, as well as electric, mechanical and plumbing systems, but not the structural system for the building. In general, buildings that are well maintained and have not been damaged by past earthquakes or other events are less prone to damage than buildings that are poorly maintained and have been weakened by damage from previous earthquakes.

If a building has experienced seismic damage, then evaluation of the seismic vulnerability requires a detailed evaluation by a structural engineer. Non-technical staff do not have the expertise necessary to determine whether the damage is largely cosmetic or whether the damage has significantly compromised the structural systems of the building.

The damage state of buildings that have been impacted by a previous earthquake or other disaster event may be determined based on visual inspection of damage and repairs, as well as documentation from the applicant's insurance records and contractor invoices. If the event was a Presidential Disaster declaration, detailed damage information may be available from a FEMA Project Worksheet or Damage Survey Report.

F.4 CHECK SOIL CONDITIONS AT SITE

A building's vulnerability to seismic damage depends largely on the structural systems for the building. However, buildings constructed on soft soil sites are often subject to greater levels of damage because soft soils may amplify earthquake ground motions or be subject to soil failures, such as liquefaction, settlement, or lateral spreading (Table F-3).

Table F-3
Earthquake Vulnerability by Site Soil Conditions

Site Soil Conditions	IBC Site Class	UBC Soil Type	Vulnerability to Earthquake Damage for a Given Structural System
Hard rock	A	S0	Typical
Rock	B	S1	Typical
Very dense soil and soft rock	C	S1 or S2	Typical
Stiff soils	D	S2	Typical
Soft soils	E	S3	Somewhat higher
Very soft or liquefiable soils	F	S4	Significantly higher

Sources: 2000 International Building Code and FEMA Earthquake Benefit-Cost Full Data Module Version 5.2.2 (December 31, 1998)

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Phone: 303-497-6826
Fax: 303-497-6513
http://www.ngdc.noaa.gov/seg/hazard/slideset/9/9_slides.shtml

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University of Nebraska Press
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http://www.kcskyscrapers.com/displaybuilding.php?displaytype=1&order=1

Southern California Earthquake Data Center
http://autoinfo.smartlink.net/quake/

USGS National Center
12201 Sunrise Valley Drive
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Phone: (703) 648-4000
http://www.usgs.gov