IDENTIFYING AND ASSESSING EARTHQUAKE-RELATED HAZARDS 3

3.1 INTRODUCTION

This chapter provides an overview of earthquake-related hazards affecting buildings as well as guidance on how to consider these hazards in the site selection process for new buildings. While seismic shaking is potentially the greatest threat, the collateral seismic hazards of fault rupture, liquefaction, soil differential compaction, landsliding, and flooding (inundation) could also potentially occur at a site. In addition, there are other hazards associated with the built environment that may affect building performance in the earthquake aftermath. These include: (1) hazards arising from external conditions to the site, such as vulnerable lifelines (transportation, communication, and utility networks) and hazardous adjacent structures, including buildings close enough to pound against the building that is to be constructed at the site; (2) storage and distribution of hazardous materials, and (3) postearthquake fires.

Section 3.2 discusses seismic shaking hazards, including the current technical and code approaches for quantifying the shaking hazard. Section 3.3 identifies and discusses the collateral seismic hazards that should be considered in selecting an appropriate site for a new building (fault rupture, liquefaction, soil differential compaction, landsliding, and flooding). The other collateral hazards that could affect site selection decisions (vulnerable lifelines, hazardous adjacent structures, storage and distribution of hazardous materials, and postearthquake fires) are discussed in Section 3.4. Specific guidance on actions to be taken to assess earthquake-related hazards during the site selection process, including a checklist for site analysis, are provided in Section 3.5. Resources for further reading are provided in Section 3.6. All sections are written in technical terminology appropriate for design professionals to aid in communicating with building owners and managers.

3.2 EARTHQUAKE GROUND SHAKING HAZARD

The effects of ground shaking on building response are well known and extensively documented. Severe ground shaking can significantly damage buildings designed in accordance with seismic codes (Figures 3-1 and 3-2) and cause the collapse of buildings with inadequate seismic resistance (Figures 3-3 and 3-4).

Figure 3-1 Six-story concrete-moment-frame medical building that was severely damaged by the magnitude-6.8 Northridge, California, earthquake of January 17, 1994. The building was subsequently demolished without removing contents. (photo courtesy of the Earthquake Engineering Research Center, University of California at Berkeley)

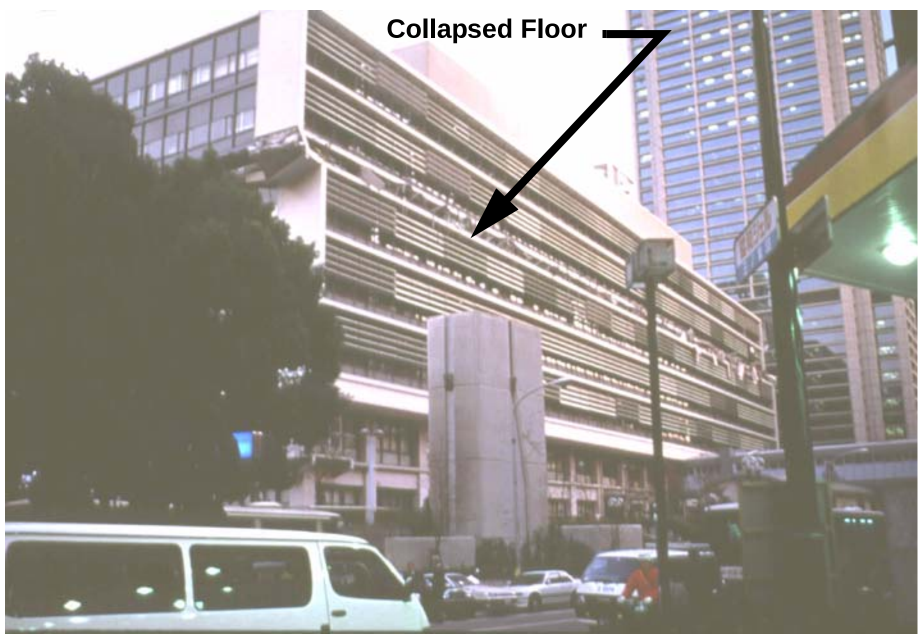

Figure 3-2 Eight-story reinforced-concrete-frame office building in Kobe, Japan that partially collapsed during the magnitude-7.8 earthquake of January 17, 1995. Note that the sixth floor is missing, due to collapsed columns at that level. Seismic codes in Japan are essentially equivalent to those in the United States. (photo courtesy of C. Rojahn)

Figure 3-3 Older five-story reinforced concrete frame building in Managua, Nicaragua, that had inadequate seismic resistance and collapsed during the magnitude-6.2 earthquake of December 23, 1972. (photo courtesy of C. Rojahn)

Figure 3-4 Preseismic-code ten-story reinforced-concrete-frame building in Bucharest, Romania, that partially collapsed during the 1977 magnitude-7.2 earthquake approximately 65 miles north of Bucharest. (photo courtesy of C. Rojahn)

Quantifying the Earthquake Ground Shaking Hazard

Seismic shaking is typically quantified using a parameter of motion, such as acceleration, velocity, or displacement. In current seismic codes, seismic design forces are defined in terms that relate to acceleration in the horizontal direction. A typical acceleration time-history of strong ground shaking is shown in Figure 3-5.

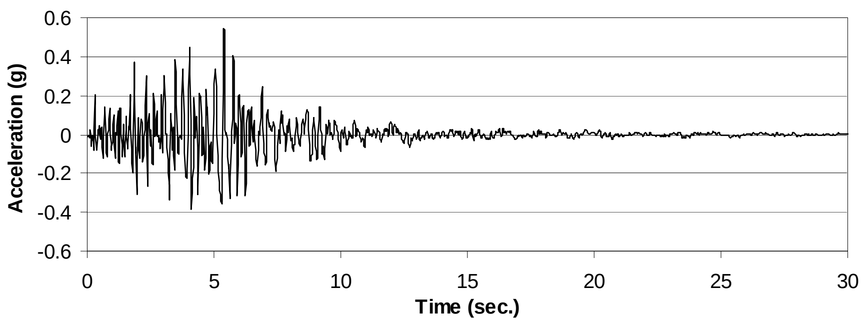

Figure 3-5 Typical acceleration time history of strong ground shaking.

RISK CONSIDERATION

The earthquake ground shaking hazard for a given site can be determined in two ways: deterministically or probabilistically. A deterministic hazard assessment estimates the level of shaking at the building site for a selected or scenario earthquake. Probabilistic hazard assessment expresses the level of ground shaking at the site with a specific probability of being exceeded in a selected time frame (normally 50 years)

The earthquake ground shaking hazard for a given region or site can be determined in two ways: deterministically or probabilistically. A deterministic hazard assessment estimates the level of shaking, including the uncertainty in the assessment, at the building site for a selected or scenario earthquake. Typically, that earthquake is selected as the maximum-magnitude earthquake considered to be capable of occurring on an identified active earthquake fault; this maximum-magnitude earthquake is termed a characteristic earthquake. A deterministic analysis is often made when there is a well-defined active fault for which there is a sufficiently high probability of a characteristic earthquake occurring during the life of the building. The known past occurrence of such an earthquake, or geologic evidence of the periodic occurrence of such earthquakes in the past, are often considered to be indicative of a high probability for a future repeat occurrence of the event.

Probabilistic hazard assessment expresses the level of ground shaking with a specific, low probability of being exceeded in a selected time period, for example 10% probability of being exceeded in 50 years, or 2% probability of being exceeded in 50 years, where 50 years is commonly chosen as the building design life. The seismic loading criteria in current U.S. building codes define design force levels based on ground motions specified in probabilistic seismic hazard maps. Such maps include those showing expected peak ground acceleration and those showing expected peak spectral acceleration response at different building periods of vibration. Figure 3-6, which was prepared by the U.S. Geological Survey National Seismic Hazard Mapping Project, illustrates a probabilistic seismic hazard map showing the regional variation of ground shaking hazard in the contiguous United States.

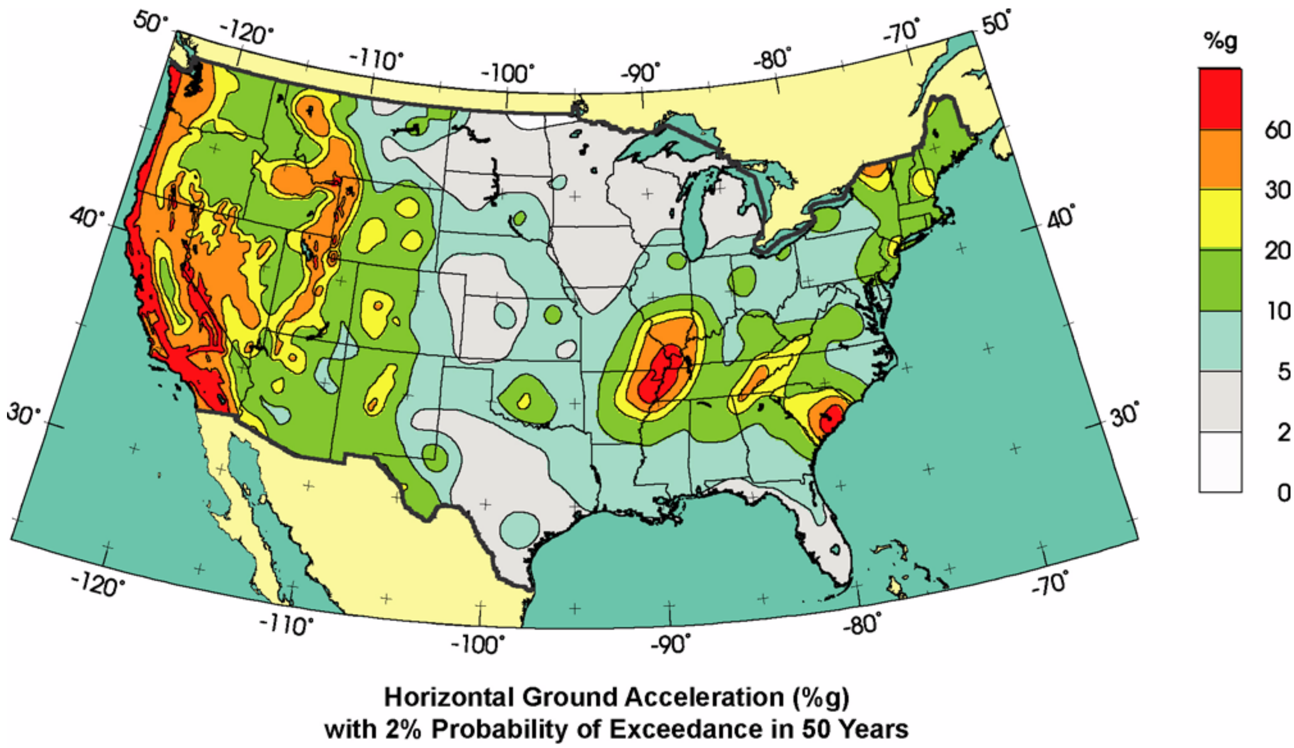

Figure 3-6 Probabilistic seismic hazard maps showing ground shaking hazard zones in the contiguous United States. (from USGS National Seismic Hazard Mapping Project website: geohazards.cr.usgs.gov).

This map indicates that, although the level of earthquake activity is high in California, most parts of the United States are also exposed to a significant earthquake ground shaking hazard. In fact, large historic earthquakes in the United States have occurred outside California, in Missouri, Arkansas, South Carolina, Nevada, Idaho, Montana, Washington, Alaska, and Hawaii. Furthermore, current geologic studies have shown increasing evidence for large earthquake potential in areas that are popularly believed to be relatively quiet. Examples include the now-recognized subduction zones in Oregon and Washington, the Wasatch fault zone in Utah, and the Wabash Valley seismic zone in Illinois and Indiana.

RISK CONSIDERATION

Although the level of earthquake activity is high in California, most parts of the United States are also exposed to a significant earthquake ground shaking hazard.

Probabilistic estimates of ground shaking at a given site can also be determined from a probabilistic ground shaking analysis for the site (often termed a "probabilistic seismic hazard analysis" or PSHA), whereby a geotechnical engineer determines and integrates contributions to the probability of exceedance of a ground motion level from all earthquake faults and magnitudes that could produce potentially damaging ground shaking at the site. Figure 3-7 illustrates relationships, termed "hazard curves," which indicate the level of peak ground acceleration and annual frequency of exceedance for specified locations in seven major cities in the United States (which have been obtained from the USGS National Seismic Hazard Mapping Project). From relationships such as those shown in Figure 3-7, ground motions can be readily obtained for any selected probability of exceedance and building design life.

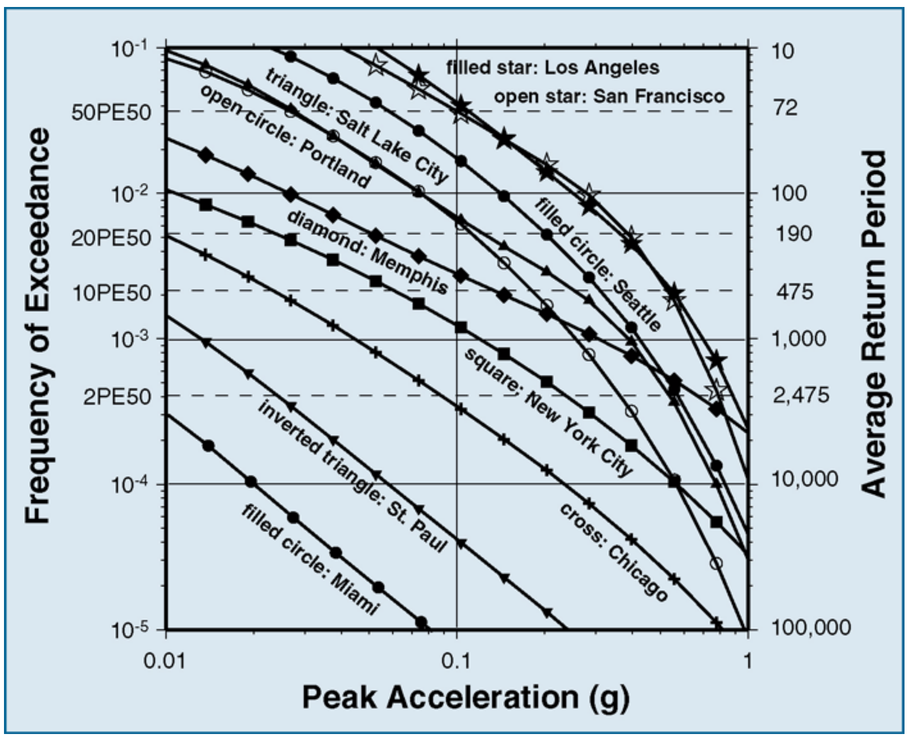

Figure 3-7 Hazard curves for selected U.S. cities.

For applications in performance-based design (see Chapter 4), both a probabilistic approach and a deterministic approach for the ground shaking hazard assessment may be used. Using a probabilistic approach, the seismic hazard can be integrated with the building resistance characteristics to estimate expected damage or loss, or the probability of exceeding some level of damage or loss, during a time period of significance such as the anticipated building life or the period during which the building will have a particular use. Using a deterministic approach, the expected damage or loss, or the probability of exceeding either a specified damage level or a specified loss, may be assessed for an earthquake considered to be sufficiently likely that satisfactory building performance during the earthquake is desired.

Determining Design Ground Motions for a Specific Site

Design ground motion for a given site can be obtained from national ground motion maps, such as the map shown in Figure 3-6, which defines ground shaking for a reference (standard) rock condition. When using the national ground motion maps (e.g., Figure 3-6) to define design ground motions for a given site, published soil factors are used to adjust the mapped values to reflect the soil conditions at the site. National ground motion maps include purely probabilistic hazard representations (peak acceleration response with a 2% probability of exceedance in 50 years, or 10% probability of exceedance in 50 years), as developed by the U.S. Geological Survey (Frankel et al., 1996; Frankel et al., 2000; Frankel and Leyendecker, 2000). Maps of modified levels of these hazards incorporate deterministic bounds on ground motions near highly active faults. Maps containing deterministic bounds, which are termed Maximum Considered Earthquake (MCE) maps, are found in the 2000 *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* (FEMA 368 report) and its companion Commentary (FEMA 369 report), or in the 2000 *International Building Code* (*IBC*). Site factors to adjust the level of ground shaking from the reference rock condition to various softer soil conditions are also contained in the FEMA 368 *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* (BSSC, 2001) and the *IBC* (ICC, 2000).

Site-specific studies can also be done to supplement or bypass the national ground motion maps. Such studies are most often undertaken for sites having soft soil conditions not covered by site factors published in the EMA 368 *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* or the *IBC*, for sites close to earthquake faults, and for buildings considered to be of sufficient importance to warrant additional focus on regional and area-specific factors affecting ground shaking. Site-specific studies offer the potential for a more detailed analysis of the uncertainty in the seismic ground shaking hazard, as discussed below. If site-specific studies are conducted, they should be comprehensive and be subjected to detailed peer review.

Uncertainty in Hazard Assessment

Whether the seismic shaking hazard is estimated probabilistically or deterministically, there is always uncertainty in the hazard assessment and in the assessment of building performance. To provide a robust assessment of hazard, it is important to incorporate the uncertainty in aspects such as:

- magnitude of the largest (i.e., characteristic) earthquake that can occur on an earthquake fault;
- recurrence rates of earthquakes of different magnitudes on a fault;
- the most applicable ground-motion-estimation relationship for a particular site, given the available models published in the technical literature; and
- site response effects.

Each of these examples of uncertainty will have a different impact on a seismic ground shaking hazard assessment, and studies to assess the sensitivity of the hazard uncertainty on building performance are often conducted by multidisciplinary teams containing both seismologists and engineers.

3.3 COLLATERAL SEISMIC HAZARDS

RISK CONSIDERATION

Most current seismic design codes are not intended to prevent damage due to surface fault rupture; liquefaction, landslides, ground subsidence, or inundation.

In addition to strong ground shaking, there are other (collateral) seismic hazards – surface fault rupture, soil liquefaction, soil differential compaction, landsliding, and flooding (inundation) – that are potentially so severe that they could impact development costs to such a degree as to cause the site to be rejected. Although such a severe condition is uncommon, the potential occurrence of these hazards during earthquakes should be considered during the site selection process. It should be noted that most current seismic design codes are not intended to prevent damage due to collateral seismic hazards. The codes provide minimum required resistance to earthquake groundshaking without consideration of settlement, slides, subsidence, or faulting in the immediate vicinity of the structure. Following are brief descriptions of these collateral hazards and their potential consequences.

Figure 3-8 Example of surface fault rupture; 1971 San Fernando, California, earthquake (a thrust fault earthquake). (Photo courtesy of the Earthquake Engineering Research Institute.)

Surface Fault Rupture. Surface fault rupture is the abrupt shearing displacement that occurs along a fault that extends to the ground surface when the fault ruptures to cause an earthquake (Figure 3-8). Generally, a fault rupture extends to the ground surface only during earthquakes of magnitude 6 or higher. Surface fault shear displacements typically range from a few inches to a foot or two for a magnitude 6 earthquake, to 10 feet or more for a magnitude 7.5 earthquake. Because fault displacements tend to occur along a relatively narrow area defining the fault zone, large displacements may have catastrophic effects on a structure located directly astride the fault.

Soil Liquefaction. Soil liquefaction is a phenomenon in which a loose granular soil deposit below the ground water table may lose a substantial amount of strength due to earthquake ground shaking. There are many potential adverse consequences of liquefaction, including small building settlements, larger settlements associated with reduction of foundation bearing strength, and large lateral ground displacements that would tend to shear a building apart. An often cited soil liquefaction failure is shown in Figure 3-9.

Soil Differential Compaction. If a site is underlain by loose natural soil deposits, or uncompacted or poorly compacted fill, earthquake ground shaking may cause the soil to be compacted and settle, and differential settlements may occur due to spatial variations in soil properties.

Figure 3-9 Aerial view of leaning apartment houses resulting from soil liquefaction and the behavior of liquefiable soil foundations, Niigata, Japan, earthquake of June 16, 1964. (Photo courtesy of National Oceanic and Atmospheric Administration, National Data Service).

Landsliding. Hillside and sloped sites may be susceptible to seismically-induced landslides. Landslides during earthquakes occur due to horizontal seismic inertia forces induced in the slopes by the ground shaking. Buildings located on slopes, or above or below slopes but close to either the top or the toe of the slope, could be affected by landslides. Landslides having large displacements have devastating effects on a building. An example of a building damaged by a landslide is shown in Figure 3-10.

Inundation. Earthquake-induced flooding at a site can be caused by tsunami (coastal waves caused by some large offshore earthquakes), seiche (waves in bounded bodies of water caused by ground motion), landslides within or entering bodies of water, and the failure of dams. Such hazards are uncommon but need to be considered because of the potentially devastating consequences for sites located in inundated areas. The tilting of a structure caused by tsunami is shown in Figure 3-11.

3.4 OTHER COLLATERAL HAZARDS

In addition to the seismic shaking hazards described in Section 3.2 and the collateral seismic hazards described in Section 3.3, there are other

Figure 3-10 Government Hill School, Anchorage, destroyed by landslide during the magnitude-8.4 Alaska earthquake of 1964. (Photo courtesy of National Oceanic and Atmospheric Administration, National Data Service).

Figure 3-11 Overturned lighthouse at Aonae, Okushiri, from the tsunami following the 1993 Hokkaido-Nansei-Oki earthquake. (Photo courtesy of Yuji Ishiyama, Hokkaido University, Sapporo, Japan)

hazards that are indirectly related to earthquake events. In general, these hazards relate to conditions external to the building site that affect the postearthquake situation, but are outside the control of the building owner and the site selection team. These include: (1) hazards such as vulnerable lifelines (transportation, communication, and utility networks) and hazardous adjacent structures, including buildings close enough to pound against the building that is to be constructed at the site; (2) the storage and distribution of hazardous materials, and (3) postearthquake fires. These other collateral hazards and their potential impacts are described below.

RISK CONSIDERATION

Earthquake-related hazards also include nearby vulnerable lifelines, hazardous adjacent structures, improperly stored hazardous materials, and postearthquake fires.

Vulnerable Lifeline Systems. Earthquake damaged lifeline systems (transportation, communication, and utility networks) may impede the provision of necessary utility functions, or access to the building site in the postearthquake aftermath. Such eventualities are largely outside the control of building designers and managers. The loss of potable water as a result of damage to water storage and distribution systems would make most facilities unusable, as would loss of power due to damage to electric power generation facilities and electric power regional and local distribution lines. Access to certain facilities, such as hospitals, can also be problematic, as for example, in the case of a hospital that is otherwise operable but is inaccessible because of damage to access highways and bridges.

There are numerous examples of transportation lifeline failures during earthquakes and the consequent disruption to facility access. These include freeway bridges damaged during the 1989 Loma Prieta earthquake near San Francisco, and freeway bridges damaged during the 1971 San Fernando and 1994 Northridge earthquakes near Los Angeles. One of the most serious lifeline losses in recent years was the collapse of an upper-deck span on the Oakland-San Francisco Bay bridge during the Loma Prieta earthquake, which resulted in the closure of the bridge for one month for damage repair. This closure impacted the economy on both sides of the San Francisco Bay, because the 250,000 daily users of the bridge had to find alternative routes or postpone the transportation of goods and services, commuting to work, and traveling for other purposes, such as to schools, medical facilities, shopping centers, and other business operations.

Pounding and Hazardous Adjacent Structures. In dense urban settings, there exists the potential for closely spaced buildings to pound against each other (Figure 3-12). Pounding occurs when buildings with differ-

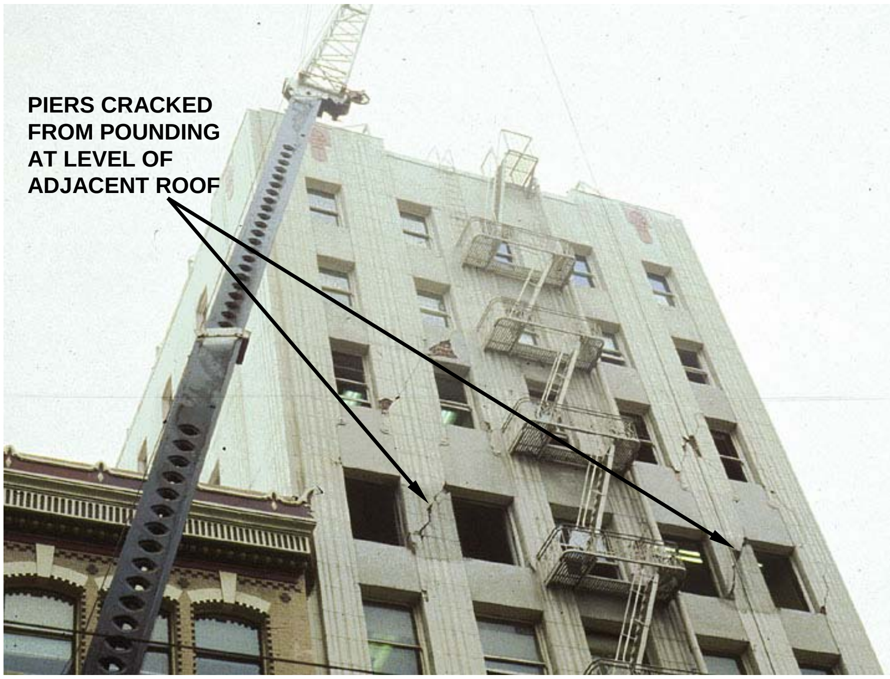

Figure 3-12 Photo showing damage caused by the pounding of a 10-story steel-frame building (with masonry infill walls) against a seven-story building. Most of the cracking damage to the piers of the taller building was at the roof line of the shorter building (Most of the cracking damage to the piers of the taller building was at the roof line of the shorter building. ATC-20 Training Slide Set photo)

ent dynamic response characteristics, which are governed by building stiffness (period of vibration), floor height, and number of stories, vibrate or sway out of sync when subjected to ground shaking. The potential for pounding is most acute when the story heights of adjacent buildings are dissimilar. Pounding has caused severe damage and even collapse in urban earthquakes, such as during the magnitude-8.1 earthquake that affected Mexico City in 1985. Although building codes call attention to this problem, building designers are often reluctant to provide the necessary space between buildings to eliminate the problem, principally because the required space would reduce available square footage in the building being developed. Consequently, adequate seismic gaps between buildings are seldom implemented in densely populated urban areas of seismically hazardous regions of the United States. In Japan, even with the acute shortage of space in its largest cities, the problem is taken seriously, with new buildings seldom built closer than a meter or so from adjacent structures. In suburban or campus-type site planning in which building sites tend to be much larger, the problem seldom arises.

RISK CONSIDERATION

Building designers are often reluctant to provide the necessary space between buildings to eliminate pounding, principally because the required space would reduce available square footage in the building being developed.

Closely spaced buildings in dense urban environments are also subjected to the failure of hazardous adjacent buildings or building components. The problem is most acute if there is an older adjacent building, built to less stringent seismic codes, that is taller than the new building being constructed. Designers should carefully assess neighboring structures and design against possible falling objects from them (e.g., unreinforced parapets, walls, or chimneys). In the 1989 Loma Prieta earthquake, several fatalities were caused when a large portion of an unreinforced masonry building collapsed onto the roof of a lower adjoining building. A typical failure is shown in Figure 3-13.

Storage and Distribution of Hazardous Materials. Hazardous materials, such as stored toxic chemicals in industrial buildings, laboratories, and other facilities, can be extremely dangerous to building occupants and neighboring facilities if released during an earthquake due to the fall and failure of containment vessels. The release of natural or liquefied petroleum gas from earthquake damaged storage or pipeline distribution systems can also be potentially hazardous, not only from the toxic standpoint but because of the potential for postearthquake fires (see below).

Postearthquake Fires. Historically, fires have been one of the most common and damaging hazards associated with earthquakes. Extensive fire damage occurred following the San Francisco earthquake of 1906, and the destruction and life loss in 1923 in Tokyo were largely the result of postearthquake fires (Figure 3-14). More recently, entire neighborhoods were destroyed by fire after the 1995 earthquake in Kobe, Japan.

The potential for postearthquake fires depends on the number and proximity of ignition sources, the availability of fuel, and the fire-fighting capability, which relates to available manpower, available fire-fighting equipment, and available water for fighting fires. Building codes in the United States have extensive provisions ensuring that the materials of construction reduce the fuel content of buildings and that building planning and construction, including the provision of space around buildings for vehicular access and for fire-fighting equipment, provides for the safety of occupants. Modern construction codes have significantly reduced the risk for steel and reinforced concrete buildings, but wood-frame construction, the most dominate type of construction in the United States, remains extremely vulnerable to postearthquake fires because of the flammability of the material. Sources of ignition include overturned gas water heaters and earthquake damaged gas distribution pipelines, which often occurs during moderate and large earthquakes,

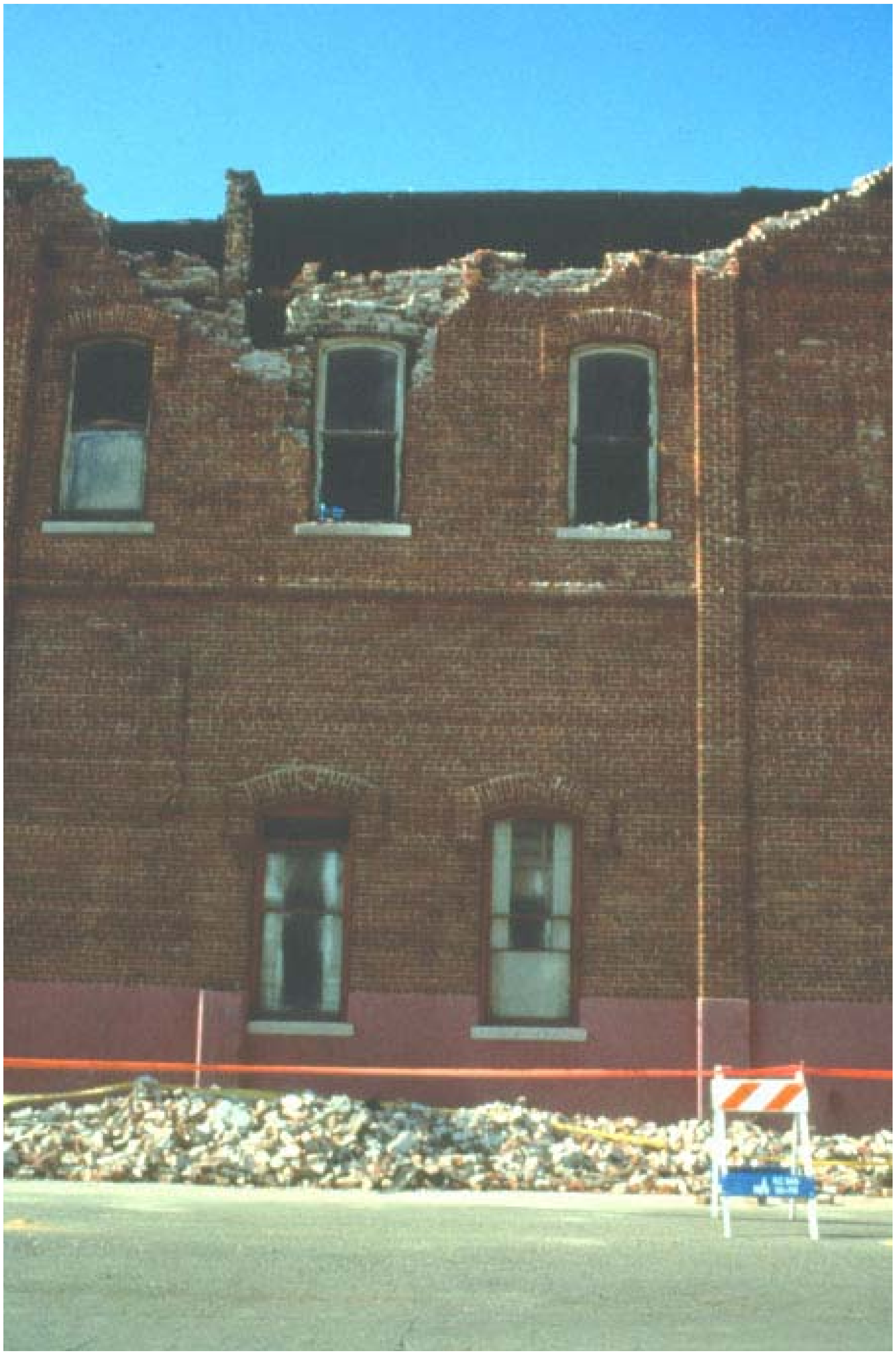

Figure 3-13 Photo showing fallen parapets from an earthquake-damaged unreinforced masonry building. (ATC-20 Training Slide Set photo)

together with sparks or fires from damaged electrical distribution lines and other sources. The earthquake aftermath may result in special impediments to fire-fighting that do not exist in the ordinary course of events, including wide-spread and multiple fires, damage to fire stations and equipment, injuries to personnel, impeded access to the building sites, and failures in the water supply system.

Figure 3-14 Photo showing the burning of the Tokyo Police Station following the magnitude-8.3 Tokyo/Kanto earthquake of 1923.

3.5 GUIDANCE FOR ASSESSING EARTHQUAKE-RELATED HAZARDS

The design team, which consists of the architect, structural engineer, geotechnical engineer and possibly others, has the responsibility for advising the owner on important earthquake-related hazards, including those affecting site selection and those that can be reduced in the design and construction process. The owner has final authority on site selection, but likely needs advice on earthquake hazard reduction. All members of the team have roles to play in determining and mitigating earthquake-related hazards for the site. The roles merge and become less rigid depending, for example, on the knowledge, experience, authority, and confidence of the owner and the individuals on the design team.

The assessment of potential earthquake-related hazards should be carried out during the site evaluation process. The evaluation of a site for a new building should consider: (a) zoning restrictions and the local authority's planning restrictions; (b) regional geology and its associated regional seismicity, on a scale that spans, for example, from tens to hundreds of miles, providing information on the regional ground shaking hazard, and locations of historically active faults; (c) site soil conditions, on a scale that spans, for example, from tens to hundreds of yards, providing information for foundation support and the local ground shaking hazard; (d) the earthquake survivability of service utilities, transportation infrastructure, other lifelines, and access for employees; and (e) hazards from outside the property boundary, including unfavorable topography (e.g., potential landslides), the potential for inundation due to tsunami or dam failure, neighboring buildings that are so close that pounding is a potential hazard, adjacent buildings that have potentially hazardous components that may fail and fall on the building, and hazardous building contents. The design team's report to the owner should include the impact of the sum of all these evaluations on the desired performance level attained by the completed building in future earthquakes.

A site evaluation checklist is provided in Figure 3-15. A complete evaluation should address the issues shown in this checklist. This checklist is intended to assist in identifying those issues with which the individuals on the design team should be familiar, and the areas where further consultant help may be necessary.

It is clear from the checklist in Figure 3-15 that a geotechnical engineer, and other specialists, should participate in evaluation of the following seismic-related hazards:

- ground shaking hazard;
- seismogeologic hazards that could result, for example, in ground failure beneath the building; and
- collateral on-site and off-site hazards, such as damage to utilities or transportation infrastructure that results from ground failure and could adversely affect an organization's operations.

Specific guidance on the evaluation of strong ground shaking, the evaluation of collateral seismic hazards, and the evaluation of other collateral hazards follows.

Evaluating the Ground Shaking Hazard

Although ground shaking is the primary hazard affecting building performance at most sites, it is often not explicitly considered in site selection because it does not provide the site with a fatal flaw. That is, the cost to design to a higher, or the maximum, ground shaking level would generally not cause a site to be rejected outright. Nevertheless, if alternative sites are being considered, it is desirable to have a geotechnical engineer evaluate the differences in estimated levels of ground shaking among sites because of the potential influence on project costs. The level of shaking is influenced by the characteristics of the faults in the

SITE EVALUATION CHECKLIST

- ☐ Is there an active fault on or adjacent to the site?
- ☐ Will the site geology increase ground shaking?
  - ○ Does the site contain unconsolidated or man-made fills?
- ☐ Is the geology stable?
- ☐ Is the site susceptible to liquefaction?
- ☐ Are adjacent up-slope and down-slope soils stable?
- ☐ Are postearthquake access and egress secure?
- ☐ Are transportation, communication and utility lifelines unusually vulnerable to disruption and failure?
- ☐ Are there adjacent land uses that could be hazardous after an earthquake?
- ☐ Are hazardous materials used or stored in close proximity?
- ☐ Are building setbacks adequate to prevent pounding from adjacent structures?
- ☐ Are adjacent structures collapse hazards that might impact your structure?
- ☐ Is the site subject to inundation from tsunami? seiche? dam failure? flooding?
- ☐ Are there areas of the site that should be left undeveloped due to:
  - ○ Landslide potential?
  - ○ Inundation potential?
  - ○ High liquefaction potential?
  - ○ Expected surface faulting?
  - ○ More violent or longer duration ground shaking than the code design values?
  - ○ Needed separation from adjacent uses or structures?
- ☐ Is there adequate space on the site for a safe and "defensible" area of refuge from hazards for building occupants?
- ☐ Does the site plan increase potential for earthquake-induced landslides by:
  - ○ cutting unstable slopes,
  - ○ increasing the surface runoff, or
  - ○ increasing the soil water content?

Figure 3-15 Site evaluation check list.

site region, the distance of the site from the faults, source-to-site ground motion attenuation characteristics, and site soil conditions. Ground motion attenuation is, in turn, influenced by the source-to-site geology. If alternative sites are located at sufficiently different distances from seismic sources in the same region or are located in different regions, then expected levels of shaking at the sites may be different even if site soil conditions are similar. However, for close sites in the same region, the primary factor causing differences in ground shaking levels is the local soil condition. Resources such as national or state ground shaking maps and site factors, for example in the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* (BSSC, 2001) and the *International Building Code* (ICC, 2000), enable an experienced geotechnical engineer to make an assessment of differences in expected ground shaking levels among sites.

RESOURCES

Ground Shaking Maps and Site Factors

1. The *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* (BSSC, 2001)
2. The *International Building Code* (ICC, 2000)

Evaluating Collateral Seismic Hazards

Guidelines for screening and evaluating potential building sites for collateral seismic hazards (surface fault rupture, soil liquefaction, soil differential compaction, landslide, and inundation) are presented in a number of publications including the FEMA 273 report, NEHRP *Guidelines for the Seismic Rehabilitation of Buildings* (ATC/BSSC, 1997a), the companion FEMA 274 report, *Commentary on the NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (ATC/BSSC, 1997b), the FEMA 356 report, *Prestandard and Commentary for the Seismic Rehabilitation of Buildings* (ASCE, 2000) and the U.S. Army Corps of Engineers publication TI809-04 for the seismic design of buildings (USACE, 1998).

RESOURCES

Evaluating Collateral Seismic Hazards

1. The FEMA 273 report, *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (ATC/BSSC, 1997a),
2. The FEMA 274 report, *Commentary on the NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (ATC/BSSC, 1997b),
3. The FEMA 356 report, *Prestandard and Commentary for the Seismic Rehabilitation of Buildings* (ASCE, 2000)
4. The U.S. Army Corps of Engineers publication TI809-04 for the seismic design of buildings (USACE, 1998).

Surface Fault Rupture. Generally, it is not feasible to design a building to withstand large fault displacements. Sites transected by active faults should generally be avoided unless the probability of faulting during the building life is sufficiently low.

Soil Liquefaction. The assessment of the vulnerability of a site to soil liquefaction must address the hazard severity, the potential effects on the building and utility connections, and any need for design measures to mitigate the hazard. The hazard consequences may range from essentially no adverse effects and no increase in development costs to catastrophic effects that cannot be economically mitigated.

Soil Differential Compaction. In general, seismically-induced soil differential settlements will not be large enough to have a major effect on site development or building design costs. Unusual sites may contain thick layers of uncompacted or poorly compacted fill, where seismic (and static) differential settlements could be large and difficult to predict. Even for such sites, building settlements can be minimized, for example, by using deep pile foundations extending below the fill.

Landsliding. During site selection, the focus should be on identifying unstable or marginally stable hillside slopes that could experience large landslide displacements and require significant cost to mitigate. Slopes having pre-existing active or ancient landslides are especially susceptible to landsliding during future earthquakes.

RESOURCES

Tsunami Run-Up

Ziony, J.I., Editor, 1985, *Evaluating Earthquake Hazards in the Los Angeles Region—An Earth-Science Perspective,* U.S. Geological Survey, Professional Paper 1360.

Inundation. During site selection, earthquake-induced flooding should be considered, recognizing that tsunami, seiche, landslides within or entering bodies of water, and the failure of dams are uncommon. Such hazards may exist in coastal areas, near large bodies of water, and in the region downstream from large dams. Guidance on tsunami run-up elevations is available in publications such as the U.S. Geological Survey Professional Paper 1360. Guidance on the potential for landslides within or entering bodies of water should be obtained from a geotechnical engineer. Locations of large dams and the potentially affected downstream area should dam failure occur are typically available from dam regulatory agencies.

Evaluating Other Collateral Hazards

The existence of other collateral hazards that emanate from outside the property boundary, such as neighboring buildings that are so close that pounding is a potential hazard, adjacent buildings that have potentially hazardous components that may fail and fall on the building, and hazardous building contents, should be identified as part of a site selection study if alternative sites are under consideration, and the hazards are evaluated in terms of both the probability of occurrence within a certain period and their consequences. Possible collateral hazards related to a selected site should be identified and procedures for their mitigation should form part of the postearthquake building emergency response plan.

In particular, building owners and the design team responsible for site selection should be familiar with hazardous materials stored and used on the building site, as well as the potential for storage in nearby facilities. Planning for the release of hazardous materials is essential if investigation shows that the building site is vulnerable to such hazards. Similarly, building owners and the design team responsible for site selection should consider the potential for damage caused by adjacent structures, either by pounding or the collapse of nearby hazardous buildings or their components.

The means for reducing lifeline system seismic hazards, which could result in the failure of transportation and utility systems as well as the means for reducing the potential for regional fires following earthquakes, are generally outside the control of the building owner and design team.

3.6 REFERENCES AND FURTHER READING

The following publications are suggested resources for further information.

Guidelines, Pre-Standards, and Codes with Information on Evaluating Ground Shaking and Collateral Hazards

ASCE, 2000, *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*, prepared by the American Society of Civil Engineers; published by the Federal Emergency Management Agency, FEMA 356 Report, Washington, DC.

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