

## 3.1 INTRODUCTION

This chapter describes how earthquake hazards can affect site selection and planning, and the process for identification of site and regional factors that impact seismic design. Site selection is typically determined by initial land costs, land use criteria such as zoning, proximity to transportation, and utility infrastructure. Additional site location factors that should be considered include environmental and geotechnical site conditions that would impact building performance, and factors that influence structural design criteria that would impact costs and performance.

The importance of a design team comprised of the client, architect, the geotechnical civil engineer and structural engineer is emphasized, and a process for geotechnical assessment of a site is identified. Regional factors of earthquake probabilities and ground motions are identified and reviewed at the project level. The interaction of the regional risk, building program, and client expectations is discussed in the context of performance objectives. Site hazards are identified, and mitigation approaches are presented.

## 3.2 SELECTING AND ASSESSING BUILDING SITES IN EARTHQUAKE COUNTRY

In earthquake hazard areas, selection and evaluation of the site will be critical to meeting client expectations on project performance. Identification and analysis of the threat posed by earthquakes to a specific location or site are more complex and frequently less precise than analysis for hazards such as flood or wind, where information about frequency and intensity of events is well documented. For example, the threat of flood is defined by 100-year flood zones delineated by the National Flood Insurance Program<sup>1</sup> (1% probability of being exceeded per year) and is mapped at the parcel level. A site is either in or out of the flood zone. Areas at risk to earthquake damage encompass entire regions, not just the areas adjacent to faults. The zones of potential damage are not neatly defined or delineated. There are numerous fac-

<sup>1</sup> notes will be found at the end of the chapter

tors in addition to shaking that will affect a building's performance and its continued function. Therefore, at the onset of a project, a thorough examination should be undertaken of regional potential for earthquakes and the areas that will be damaged by ground faulting, ground shaking, subsidence and liquefaction, utility disruption and from the secondary hazards and impacts from earthquake-caused fires, floods, and hazardous materials releases.

### **3.2.1 Performance Criteria, Site Selection, and Evaluation**

Site selection criteria should be derived from the building's program and performance-based design criteria. A simple project may only be designed to the minimum level of performance - life safety. Such a structure is only expected to protect the lives of occupants and may be so extensively damaged after a quake that it will have to be demolished. With a small project where client performance criteria are limited, the site evaluation criteria will be focused on the immediate site environment, on-site hazards, and adjacent structures and land uses. Geotechnical investigations focus primarily on the site. Mitigation is usually accomplished by providing a setback to separate new construction from adjacent hazards and through design of the foundations and structure to meet the building code. Where the client has higher expectations of building performance, such as minimizing damage and maintaining business operations, the assessment will need to be more rigorous, and the scope of the site investigations will extend far beyond the "property line" to include all of the potential hazards that would influence continuity of operations, including land uses in proximity to the site and area access and egress, utility performance, the need for alternative lifeline capability (back-up generators, water and waste water processing and storage, alternate telecommunications, etc.).

For facilities designed to performance-based criteria, including minimum disruption and continued operation, the location of the site within the region may play a critical role in meeting client expectations. The definition of "site" becomes the region within which the facility is located, and "vulnerability assessments" must examine both facilities and the connections the facilities have to raw materials, personnel and distribution to markets. This is a more holistic view of building design and vulnerability, that addresses disruption of operations and the economic impacts of disasters.

### 3.2.2 Building Program and Site Evaluation

The development of the program for the building and the definition of performance criteria are iterative processes that take into account the needs of the client, the characteristics of the earthquake hazard, the characteristics of the site (or alternate sites) and availability and cost of engineering solutions to mitigate the hazard (Figure 3-1). If the client wishes the building to withstand a major earthquake without damage and be able to maintain operations, the program will establish both performance and site selection criteria to achieve their goal. The program will also establish utility, access, and egress performance expectations that will influence location.

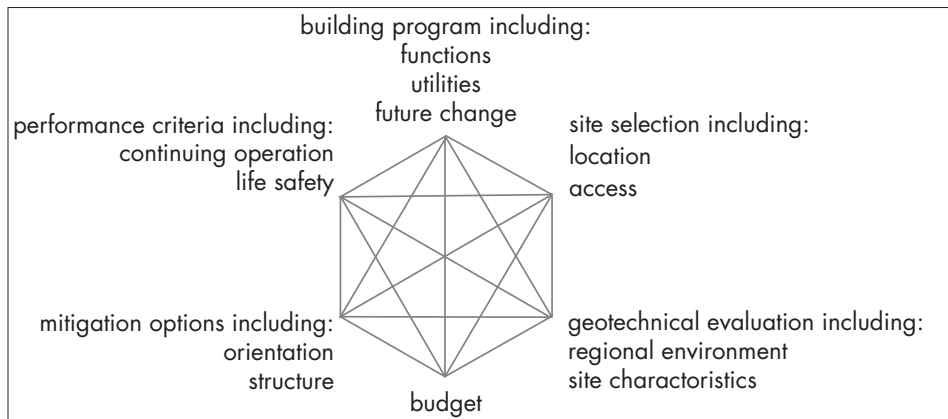


Figure 3-1: Interrelationships of performance expectations, building program and site characteristics.

### 3.3 THE IMPORTANCE OF THE RIGHT TEAM— GEOTECHNICAL ENGINEERING EXPERTISE

Understanding and incorporating the earthquake threat and its impact on a location or facility is a complex assessment process requiring an understanding of the earthquake hazard, how a site will respond to arriving ground motions, and how a structure will interact with the site's motions.

It is therefore essential that the client, architect and structural engineer retain the services of a Geotechnical Engineer to provide input to the assessment of alternate sites, and to assist in the structural design of the programmed facility.

### **3.3.1 The Site Assessment Process**

The California Geological Survey (CGS) provides guidance in the use of geotechnical and civil engineering expertise in *Guidelines for Evaluating and Mitigating Seismic Hazards in California*.<sup>2</sup> The Guideline emphasizes the need for both geotechnical engineering to identify and quantify the hazard, and civil engineering to develop mitigation options for the architect and owner. Chapter 3 of the Guideline provides recommended site investigations for assessing seismic hazards and is summarized below.

### **3.3.2 Geotechnical Report Content**

The geotechnical investigation of the site is a vital resource to designer and structural engineer in designing and building an earthquake-resistant structure. The CGS recommends that a geotechnical report include the following data:

- Description of the proposed project location, topography, drainage, geology, and proposed grading.
- Site plan indicating locations of all tests.
- Description of the “seismic setting,” historic seismicity and location of closest seismic records used in site evaluation.
- Detail (1:24,000) geologic map of the site indicating pertinent geologic features on and adjacent to the site.
- Logs of all boring or other subsurface investigations.
- Geologic cross section of the site.
- Laboratory test results indicating pertinent geological data.
- Specific recommendations for site and structural design mitigation alternatives necessary to reduce known and/or anticipated geologic and seismic hazards.

### **3.3.3 Additional Investigations to Determine Landslide and Liquefaction**

Additional tests may be necessary to determine if there is a potential for earthquake induced landslides and/or liquefaction. These tests and procedures are identified in Recommendation Procedures for Implementation of California Department of Mines and Geology (CDMG) Special Publication 117: *Guidelines for Analyzing and Mitigating Liquefaction in California*; and *Recommended Procedures for Implementation of DMG Special Publication 117: Guidelines for Analyzing and Mitigating Landslide Hazards in California*.<sup>3</sup>

### **3.3.4 Information Sources for the Site Assessment Process**

In evaluating or selecting a site, the objective will be to identify those natural and man-made forces that will impact the structure, and then to design a site plan and the structure to avoid or withstand those forces. It is necessary to start the site evaluation process with research of information available from local building and planning departments, the National Weather Service, FEMA's National Flood Insurance Program (NFIP), the United States Geological Survey, state geological surveys, university geology departments and published research, and a geotechnical engineering firm familiar with the region and sources of local information. Include, where available, hazard mapping zones of ground faulting, liquefaction, landslides and probabilistic assessments of ground motions.

Where sites are within a mapped hazard zone, a site-specific investigation should be conducted by a geotechnical engineer to identify or demonstrate the absence of faulting, liquefaction or landslide hazards. When a hazard is identified and quantified, recommendations for mitigation should be provided. The following information will assist in assessing the geotechnical hazards in a region or on a site:

- Topographic, geologic and soil engineering maps and reports, and aerial photographs
- Water well logs and agricultural soils maps.
- State hazard evaluations maps.

FEMA's *Understanding Your Risks: Identifying Hazards and Estimating Losses* (FEMA 386-2)<sup>4</sup> provides an excellent example of a hazard assessment process that can be adapted to your practice.

When a site is outside a mapped hazard zone, ensure that proposed development and alterations to the site do not increase susceptibility to hazards (such as cuts and fills that increase ground water percolation or increase the likelihood of earthquake-induced landslides).

### **3.4 LOCAL GOVERNMENT HAZARD ASSESSMENTS—DMA 2000**

In 2000, Congress amended the Stafford Act (federal legislation that provides pre- and post-disaster relief to local and state governments), adding requirements that local governments, states and tribes identify and develop mitigation plans to reduce losses from natural hazards. The Disaster Mitigation Act of 2000 (DMA 2000)<sup>5</sup> requires these governments to identify and map all natural hazards that could affect their jurisdictions. Beginning in November 2004, local and state governments were to be able to provide an architect or engineer with hazard and risk assessments for earthquakes, flooding, landslides, tsunamis, and coastal erosion. The risk assessments<sup>6</sup> are intended to be the basis for land use development decisions and for setting priorities for local and federal mitigation funding, but they will also provide a basis for initial site selection and evaluation.

### **3.5 TOOLS FOR GETTING STARTED**

As noted in Chapters 2 (Section 2.6.2) and 4, earthquakes produce complex forces, motions and impacts on structures. Between the earthquake and the structure is the site, which determines how the building experiences the earthquake, and what secondary hazards are triggered by ground motions. These additional hazards include surface rupture or faulting; near-source effects of strong ground motions; ground failure and landslides, subsidence; and lateral spreading and liquefaction. In coastal regions, in areas within dam inundation zones, or areas protected by earth levies, flooding can occur as a result of dam or levy failure triggered by ground motions, or, in coastal areas, by earthquake-triggered tsunamis. Each of these primary and secondary hazards should be identified in the site assessment and mitigated where they would adversely

impact building performance. The following sections will elaborate on each of these site hazards and identify mitigation alternatives.

### **3.5.1 Understanding Regional Earthquake Risk- Big Picture of Expected Ground Motions**

There are a number of resources available that provide a regional view of the earthquake hazard. Overall assessments of risk are expressed as probabilities that mapped ground motions will exceed a certain level over a period of time. A common measure is the 10% probability that peak ground acceleration (violence of ground shaking) will be larger than the value mapped, over a 50-year period. These maps provide an assessment of the relative intensity of ground motions for a region.

#### ● USGS 2002 Ground Motion Maps

The building code uses the Maximum Considered Earthquake (MCE) maps which are based on the USGS Seismic Hazard Maps with a 2% probability of being exceeded in about 2,500 years (figure 3-2). See section 2.6.2. These maps depict areas that have an annual probability of approximately 1 in 2,300 of the indicated peak ground acceleration being exceeded, and account for most known seismic sources and geological effects on ground motions. The areas of intense orange, red, brown and black are the most likely areas to experience violent ground shaking greater than 30% of the force of gravity in the next 50 years. The maps provide a general assessment of relative ground motions, but are at a scale that does not help in a site selection process. It is clear from the map, however, that violent ground motions are more likely in the coastal regions of California, Oregon and Washington, the Sierra Nevada range of California, and the Wasatch Range of Utah than in Colorado, Kansas and Oklahoma.

#### ● State Survey Risk Maps

Many states provide geological data that can assist in assessing regional seismic risk. In California, for example, the CGS in cooperation with the USGS has taken the data from the above map and provided a more detailed set of regional maps. The map of the Bay Area (Figure 3-3) depicts the peak ground accelerations with a 2% probability of being exceeded in 50 years at a regional scale and combines probability of occurrence of large ground motions and soil and geological conditions that would amplify ground motions. The areas depicted in red through gray are the

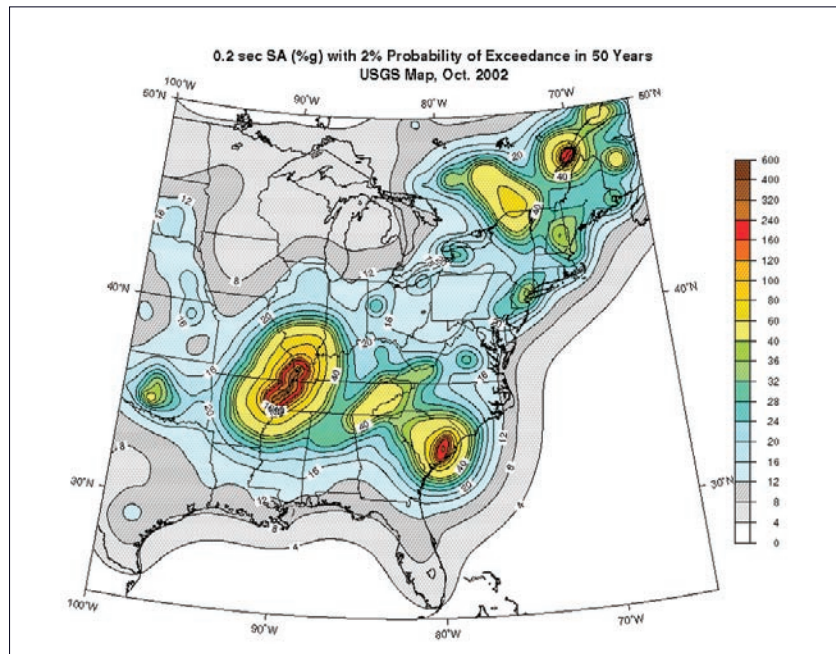


Figure 3-2: USGS Map of 0.2 sec spectral acceleration with a 2% Probability of Exceedance in 50 Years

SOURCE: USGS §201.6(C)(2), 44 CFR PART 201, STATE AND LOCAL PLAN INTERIM CRITERIA UNDER THE DISASTER MITIGATION ACT OF 2000 <sup>7</sup>

areas where the most violent ground shaking will most frequently occur. These areas are adjacent to active faults capable of producing violent ground motions and areas where soils conditions will increase ground motions. Thus, areas in gray are adjacent to active faults and along the margins of the San Francisco Bay, where unconsolidated soils will amplify ground motions. It is important to note, however, that the map depicts probability of relative shaking and that damaging ground motions can occur anywhere in the region depicted on the map.

Both the USGS and CGS depict the ground motions that are produced by all earthquakes on all faults that could influence a particular location. These maps can be extremely helpful to the architect and client in determining the relative risk of alternative sites and the trade-offs of location, vulnerability and offsetting costs for a structure that will resist ground motions.



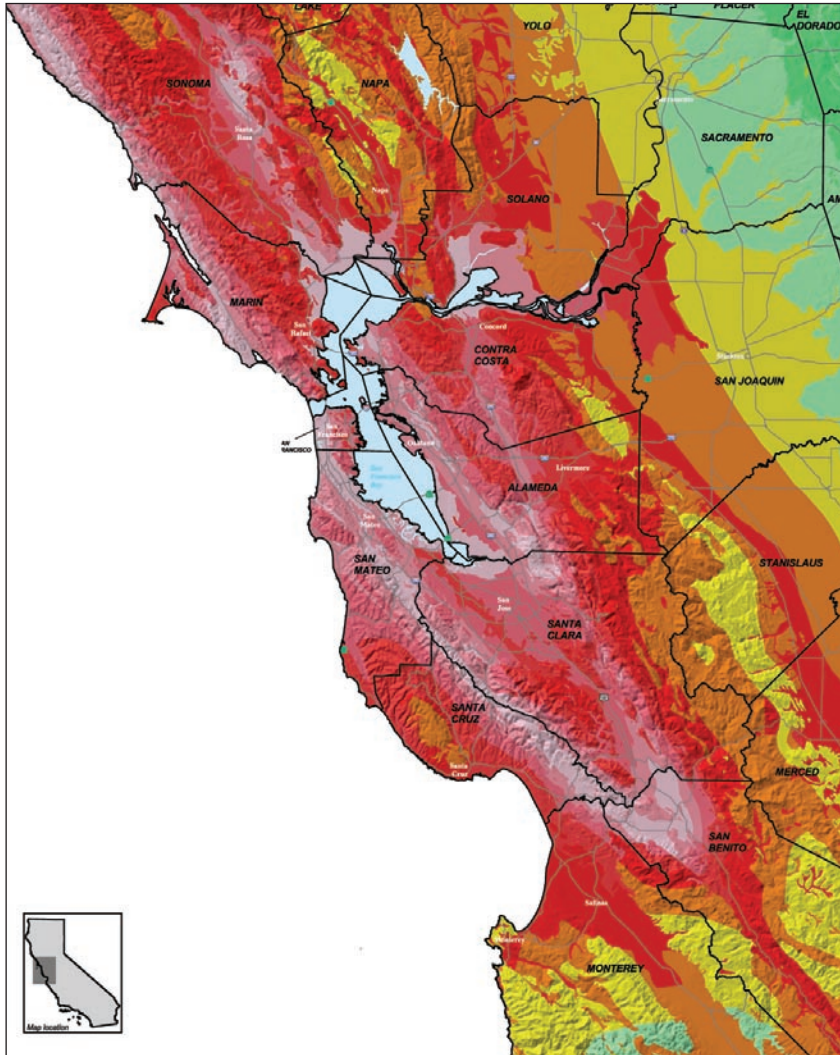


Figure 3-3: USGS and CGS Map of Relative PGA with a 2% Probability of Being Exceeded in 50 Years

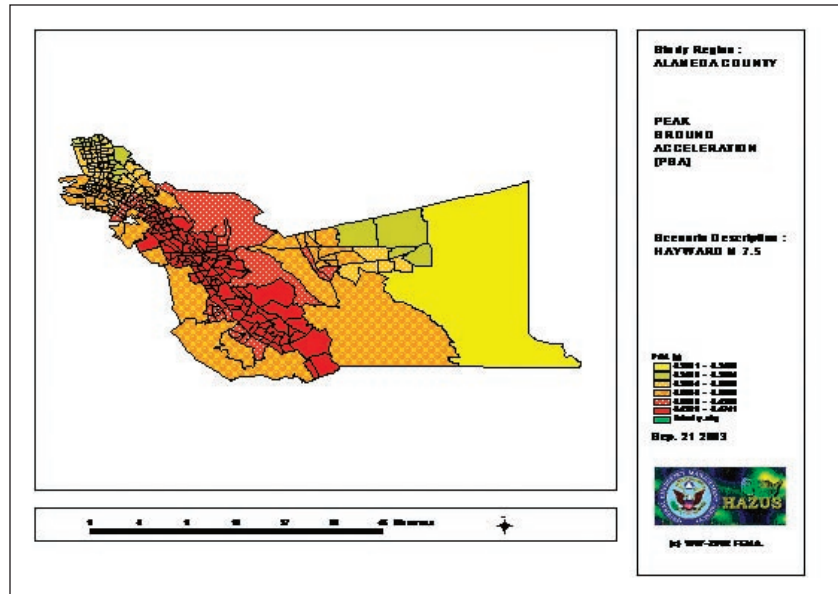
SOURCE: CALIFORNIA SEISMIC SAFETY COMMISSION, USGS, CGS AND OES, 2003 <sup>8</sup>

- **HAZUS Earthquake Loss Estimates<sup>9</sup>**

The Federal Emergency Management Agency (FEMA) has developed a software program that can be used to estimate earthquake damage and losses at a regional level. HAZUS (Hazards United States) provides estimates of damage and losses to infrastructure such as highway bridges, electrical and water utilities, casualties and requirements for shelter

Figure 3-4

HAZUS Estimate of Peak Ground Acceleration (PGA) by Census Tract, Alameda County, California.



for displaced households. The quality of a HAZUS estimate of losses will depend on the detail of information input to the program. Local soil data and building inventory will determine the accuracy of the loss estimates. Estimates can be produced for specific faults, for specific scenarios, or for annualized losses over a period of years. In each case, the loss estimate is helpful in understanding the “risk context” for a project -what damage and disruption will occur in the community surrounding the project. Below are two HAZUS maps (Figures 3-4 and 3-5) illustrating intensity of ground motions in PGA and Total Economic Losses, by census tract for a M7.5 earthquake on the Hayward Fault in Alameda County, California. Similar estimates can be produced for other areas of the country where an earthquake threat would influence site selection. While HAZUS is helpful in understanding regional vulnerability and patterns of damage and loss, it is not appropriate for assessment of damage on an individual building site.

Information about HAZUS is available from your local and state emergency services office, and from FEMA at [www.fema.gov/hazus/hz\\_index.shtm](http://www.fema.gov/hazus/hz_index.shtm) and [www.hazus.org](http://www.hazus.org).

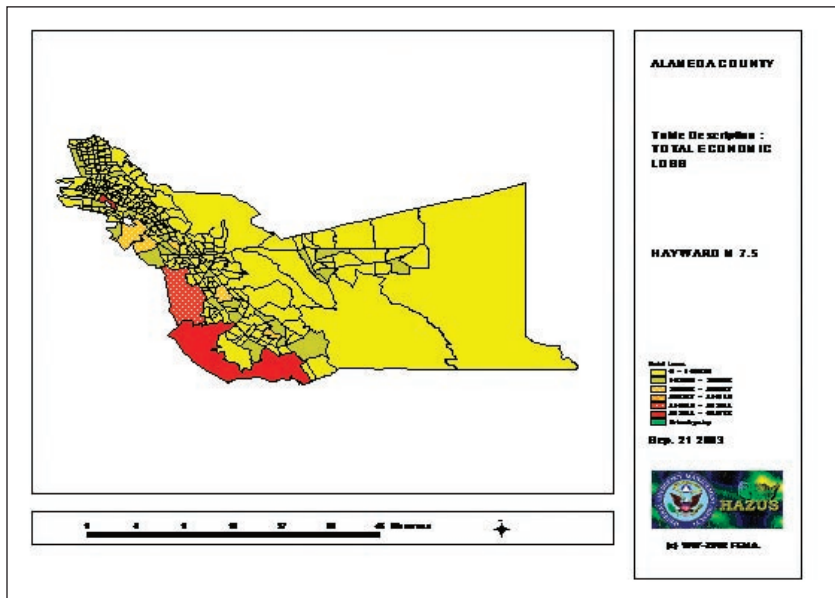


Figure 3-5  
HAZUS Estimate of Total Economic Loss by Census Tract

### 3.6 EARTHQUAKE HAZARDS TO AVOID

The most obvious manifestations of earthquakes are earthquake fault offset, liquefaction, landslides, and ground shaking (Figures 3-6 and 3-9). Each of these hazards can be mitigated through careful site planning. Examples in this section are drawn from California, where a broad range of hazard identification and mitigation approaches is available. Hazard data and land regulation practices vary from state to state and within states. A geotechnical consultant is your best source of local data.

#### 3.6.1 Earthquake Fault Zones

The United States Geological Survey and many state geological surveys produce maps of active earthquake faults - that is, faults that exhibit "Holocene surface displacement" or ruptured within the last 11,000 years. These maps depict faults where they have ruptured the ground surface, as fault movements usually recur in geologically weak zones. In California, the legislature mandated the mapping of active faults after the 1971 San Fernando earthquake (Alquist-Priolo Earthquake Fault Zoning Act)<sup>10</sup>. The Fault Hazard Zones Act maps are published by the state, and location of a site within a Fault Hazard Zone requires disclosure of the hazard at point of sale. Local governments are responsible for reviewing

Figure 3-6

Landers-Big Bear Earthquake (1992).  
Ground faulting extended for nearly  
50 miles.



geologic reports and approving those reports before approving a project (Figure 3-7).

Fault mapping is a continuing process of discovery, analysis, and mapping. However, it is important to note that not all earthquake faults rupture to the surface and not all earthquake faults are currently mapped. In the 1989 Loma Prieta earthquake (M6.7), the fault did not rupture to the surface, yet caused more than \$6 billion in damage and resulted in more than 60 deaths. For some active faults, there may not be a surface manifestation indicating recent activity. Both the 1971 San Fernando and 1994 Northridge earthquakes occurred on blind thrust faults, where faulting did not reach the surface, so the hazard was not recognized until the earthquake occurred. Nonetheless, fault zones pose a clear danger to structures and lifelines, and where formally mapped or inferred from geologic reports, site plans should provide a setback to protect structures from fault movement.

### ● Mitigating Fault Zone Hazards

The Alquist-Priolo Earthquake Fault Zoning Act<sup>12</sup> provides reasonable guidance that should be applied in site selection and site design. Requirements include:

- Disclosure that a property is within a mapped Seismic Hazard Zone. The zones vary in width, but are generally  $\frac{1}{4}$  of a mile wide and are defined by “turning points” identified on the zone maps. Figure 3-8

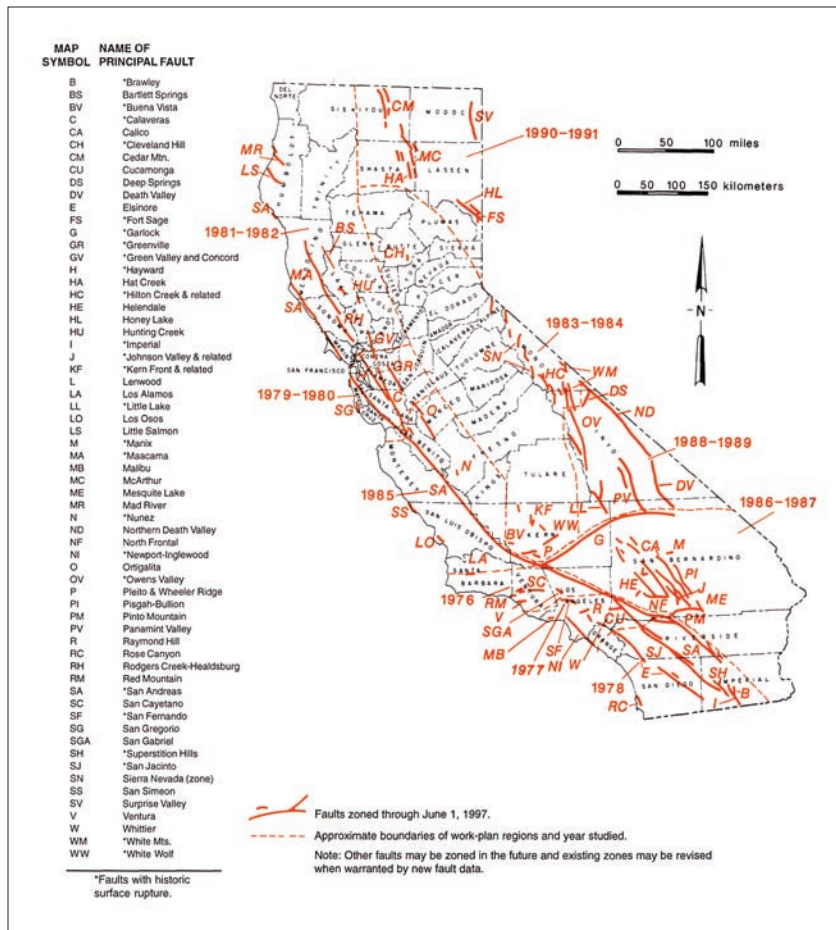


Figure 3-7  
Principal Active Fault  
Zones in California

SOURCE: CGS, SPECIAL  
PUBLICATION 1999

shows a zone map that identifies active traces of the fault, the date of last rupture, and defines the “fault zone” within which special studies are required prior to development. The zone boundary, defined by turning points, encompasses known active traces of the fault and provides approximately 200 meters setback between the fault trace and the boundary line. Check with local government planning agencies for the most current maps.

- Local governments must require a geologic report for any project within the fault hazard zone to ensure that no structure is built across an active fault trace.
- No structures for human habitation shall be built within 50 feet of an identified fault trace (an exception is provided for single-family residential structures when part of a development of four or fewer structures).

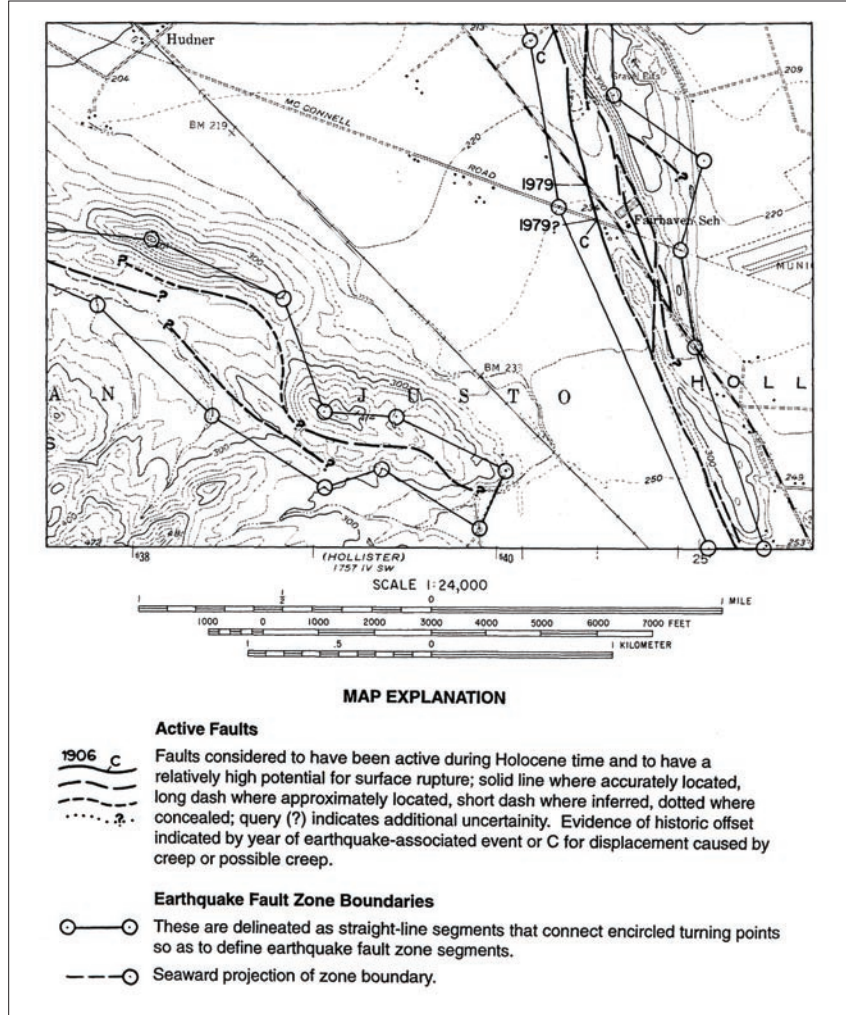


Figure 3-8: Alquist Priola Special Studies Zone (Earthquake Fault Zone).

SOURCE: CGS 1999, *FAULT - RUPTURE HAZARD ZONES IN CALIFORNIA*, SPECIAL PUBLICATION 42. AVAILABLE AT FTP://FTP.CONSRV.CA.GOV/PUB/DMG/PUBS/SP/SP42.PDF

In states where seismic hazard zones are not identified, the geologic report for a project should locate identified or suspected fault traces, and recommend mitigation measures, including those identified above, to reduce the risk posed

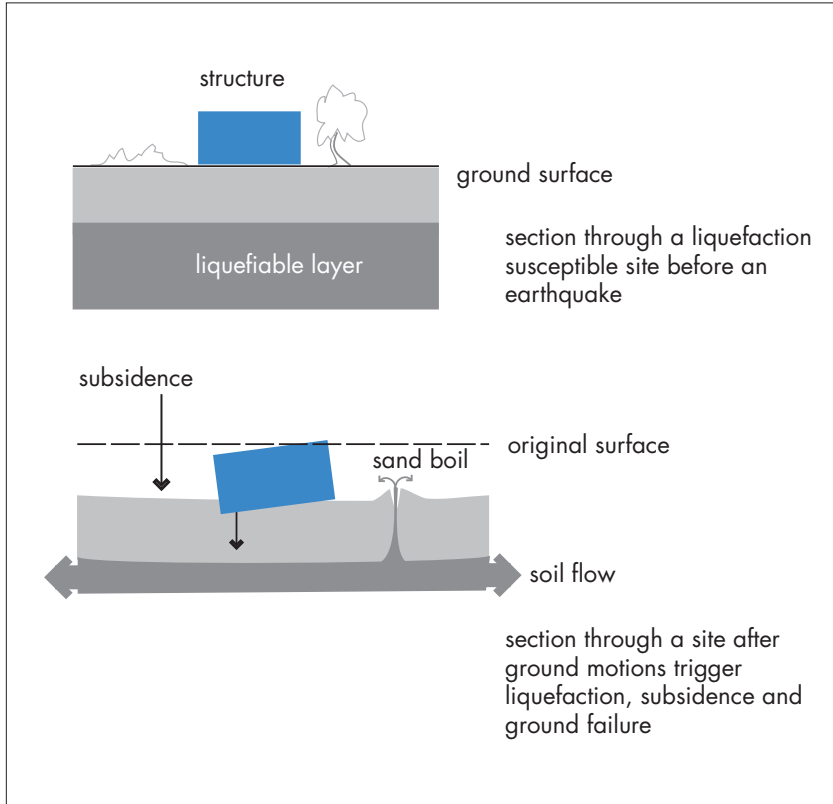


Figure 3-9

Cross section through a site where liquefaction and subsidence could occur.

### 3.6.2 Ground Failure Due to Liquefaction

Liquefaction occurs when water-saturated soils, sands, or gravels flow laterally or vertically like a liquid. This occurs when earthquake ground motions shake the material until the water pressure increases to the point that friction between particles is lost, and the ground flows, losing its strength (Figure 3-9). Liquefaction is most likely to occur where the soils are not consolidated (near rivers and streams, in basins, near coastlines and in areas of unconsolidated alluvium) and where ground water is within three to four meters of the surface. Liquefaction can occur at greater depths, resulting in large-scale ground failure that can destroy pavement, underground utilities, and building foundations (Figure 3-10). The subsidence of Turnagain Heights in Anchorage during the 1964 earthquake is an example of deep-seated liquefaction and ground failure. When a soil liquefies, it can flow laterally, eject vertically as a sand boil, or result in subsidence and ground failure (Figure 3-11).

Figure 3-10

Liquefaction in San Francisco's Marina District (1989)

SOURCE: USGS



Sand boils and flows on the surface can displace and damage structures and utilities. Lateral liquefaction flows will result in subsidence, loss of foundation integrity, disruption of underground utilities and damage to structures resting on the soil surface, including roadways and utility structures. Liquefaction susceptibility and potential should be identified in the site geotechnical investigation, as explained in Section 3.3.3.

#### ● Liquefaction Hazard Zones

Liquefaction susceptibility can be determined from site geologic investigations and from a review of geologic and soil maps and water well and bore hole logs. In California, liquefaction potential mapping is part of

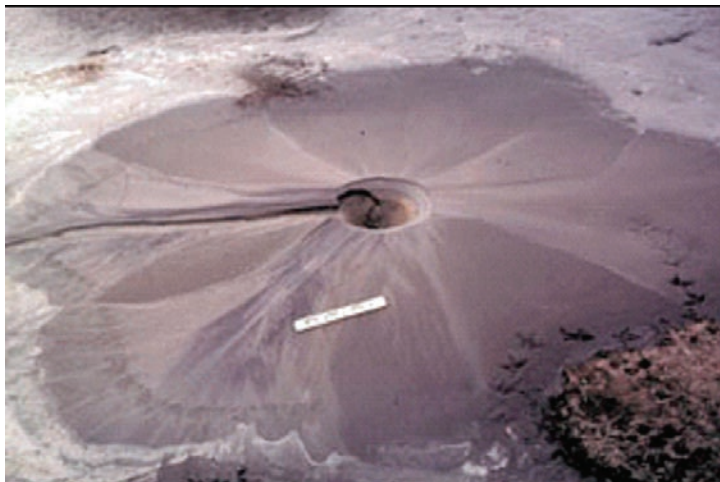


Figure 3-11: Sand Boil.



the CGS's Earthquake Hazard Mapping Program. Liquefaction hazard zone maps have been completed for sections of the Los Angeles and San Francisco Bay Regions (Figures 3-12 and 3-13).

Within an identified liquefaction hazard zone, maps of liquefiable soils, prepared by a geotechnical engineer, should identify the location and extent of “cohesionless silt, sand, and fine-grained gravel in areas where the ground water is within 50 feet of the surface.” Procedures for testing and criteria for determining liquefaction susceptibility are contained in *Recommended Procedures for Implementation of DMG Special Publication 117: Guidelines for Analyzing and Mitigating Liquefaction in California*.<sup>13</sup>

### ● Mitigation Options for Liquefiable Sites

There are structural solutions for mitigating liquefaction potential that address the design of foundation systems that penetrate the liquefiable layers. It should be noted that while it is frequently cost effective to design structures to withstand liquefaction, making access and egress routes, parking and storage facilities and above and underground utilities “liquefaction-resistant” is prohibitively expensive. “A whole-site solution” may be more practical when site choice is limited and susceptibility is significant. See the mitigation approaches below.

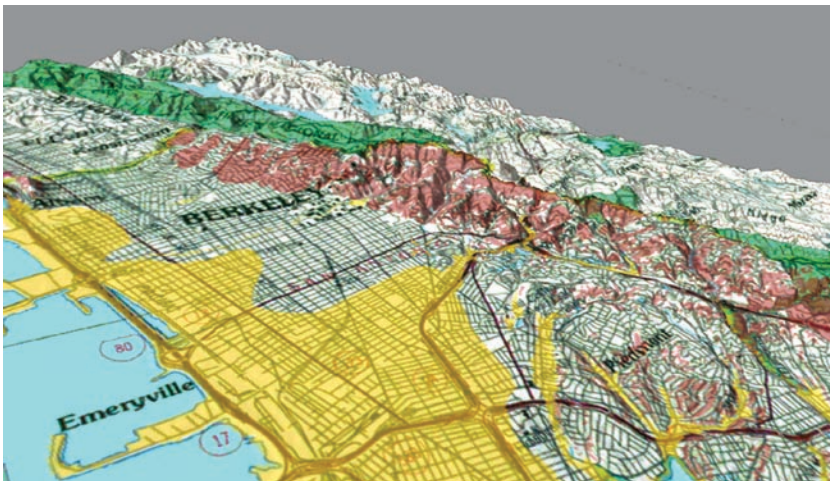


Figure 3-12: 3-D image of Liquefaction and Landslide Hazard Zone Map for Berkeley and Emeryville. Yellow indicates liquefaction, which is related to soil type and proximity to ground water.

SOURCE: CGS



Figure 3-13: Liquefaction Hazard Zone Map for West Oakland and Emeryville.

SOURCE: CGS EARTHQUAKE HAZARD MAPPING PROGRAM

- **Location of the Structure**

The simplest way to mitigate the potential of liquefaction is to avoid those locations in a region or on a site where the potential for ground failure is identified in the geotechnical investigation. Locate structures where ground water is low, where soils are compacted, and where soils are not homogeneous sands or gravels.

- **Intervention on the Site**

While avoidance is the optimum solution, it is not always possible. Mitigating liquefaction potential involves changing the characteristics of the site. The following options are all costly and vary in extent of risk mitigation. Seek advice from geotechnical and civil engineering consultants about the most cost-effective intervention.

- Site Compaction

On sites with unconsolidated soils, the response of the site can be improved by compacting the soil, compressing it so that soil particles are forced together, reducing water-filled voids and increasing the friction between soil particles.

- Change Soil

The performance of the site can also be improved by excavation of the liquefiable soils and replacement with compacted heterogeneous fill. By changing the soil, the susceptibility of the site to liquefaction will be significantly reduced. However, for both this approach and the compaction alternative, site performance is improved by construction of barriers to the infiltration of water so that the groundwater level of the site is lowered.

- Dewatering the Site

An alternative to “reconstituting the site” by replacing the soil is to dewater the site. This approach requires constructing wells to pump out and lower the ground water level to reduce liquefaction susceptibility. To reduce the demand for continuous pumping, dewatering should be combined with the construction of infiltration barriers. A back-up power source to ensure post-disaster pump operations should be provided.

- **Special Design Considerations**

As noted above, the potential for liquefaction of a site poses severe problems for maintenance of access and egress and performance of lifelines including power, telecommunications, water sewer and roadways. For facilities that are expected to be in continuous operation after disasters, redundant access to utility networks, multiple access and egress paths, and back-up power and communication systems should be provided. Liquefaction potential may be difficult to assess, so a conservative approach to the design of continuous operation facilities is essential.

### **3.6.3 Areas of Intensified Ground Motions**

Local geology, proximity to faults and soil conditions play significant roles in how earthquake forces impact a structure. The Loma Prieta

earthquake (1989) provided a striking example of how local soils and regional geology can determine damage. Sixty miles from the earthquake's epicenter in the Santa Cruz Mountains, the soils determined the pattern of damage to the Cypress Viaduct in Oakland. As illustrated below, the damage corresponded to the quality of the ground. On bedrock materials in the East Bay hills of Oakland, ground motions were small and there was little damage. On sandy and gravel soils between the East Bay hills and the San Francisco Bay, the amplitude of ground motions increased, but there were few collapsed structures. However, on the soft mud adjacent to the Bay, the amplitude of the ground motions and the duration of strong shaking increased. The Cypress Structure, where it passed from "sand and gravel" to "soft mud" collapsed (Figure 3-14).

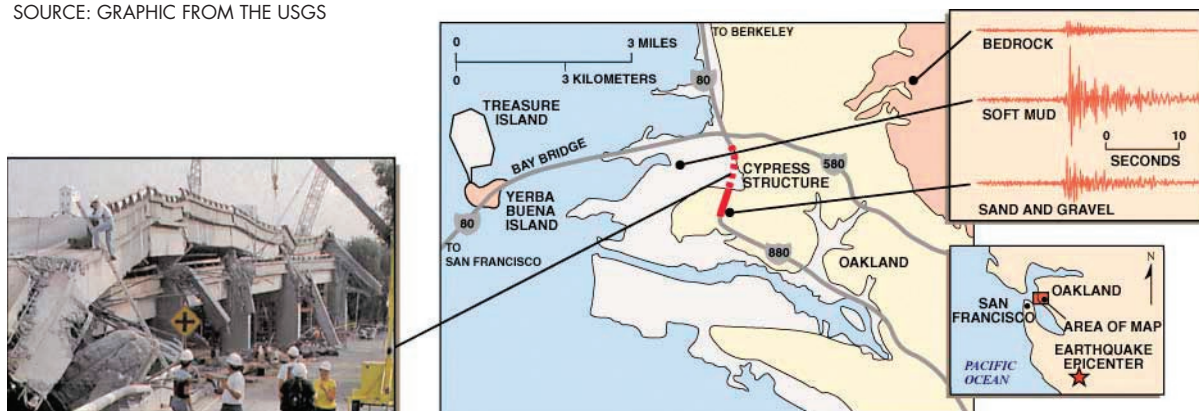
A similar condition existed in the Marina District of San Francisco where soft soils liquefied, amplified motions and extended the duration of shaking until several structures collapsed, while elsewhere in San Francisco, on firmer ground, there was little or no damage.

Figure 3-15 was developed by the USGS and predicts amplification of ground motions based on soil types adjacent to San Francisco Bay. According to the USGS, "this map shows the capability of the ground to amplify earthquake shaking in the communities of Alameda, Berkeley, Emeryville, Oakland, and Piedmont. The National Earthquake Hazards Reduction Program recognizes five categories of soil types and assigns amplification factors to each. Type E soils in general have the greatest

Figure 3-14

Comparison of ground motions under the Cypress Viaduct, Loma Prieta Earthquake 1989.

SOURCE: GRAPHIC FROM THE USGS



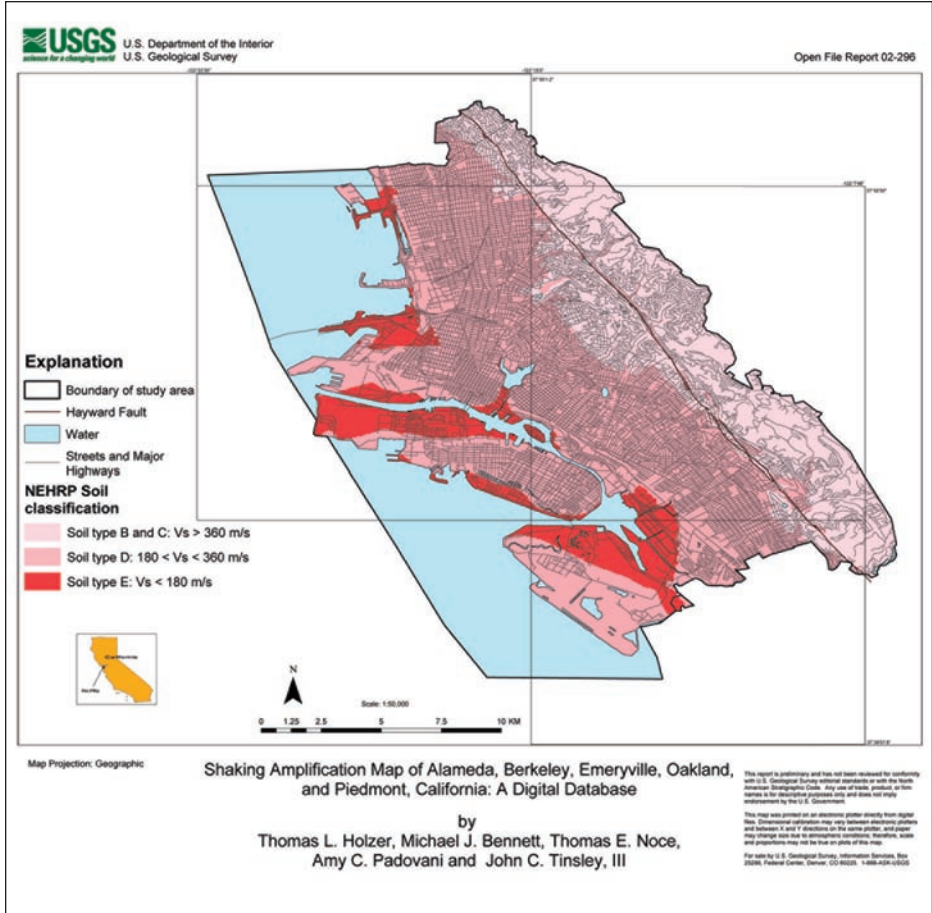


Figure 3-15: USGS Shaking Amplification Map of Alameda, Berkeley, Emeryville, Oakland and Piedmont, California. SOURCE: USGS (HOLZER ET AL.)

potential for amplification, and type A soils have the least. These soil types are recognized in many local building codes. Records from many earthquakes show that ground conditions immediately beneath a structure affect how hard the structure shakes. For example, sites underlain by soft clayey soils tend to shake more violently than those underlain by rock. The map depicts the amplification potential at a regional scale, and it should not be used for site-specific design. Subsurface conditions can vary abruptly, and borings are required to estimate amplification at a given location.”

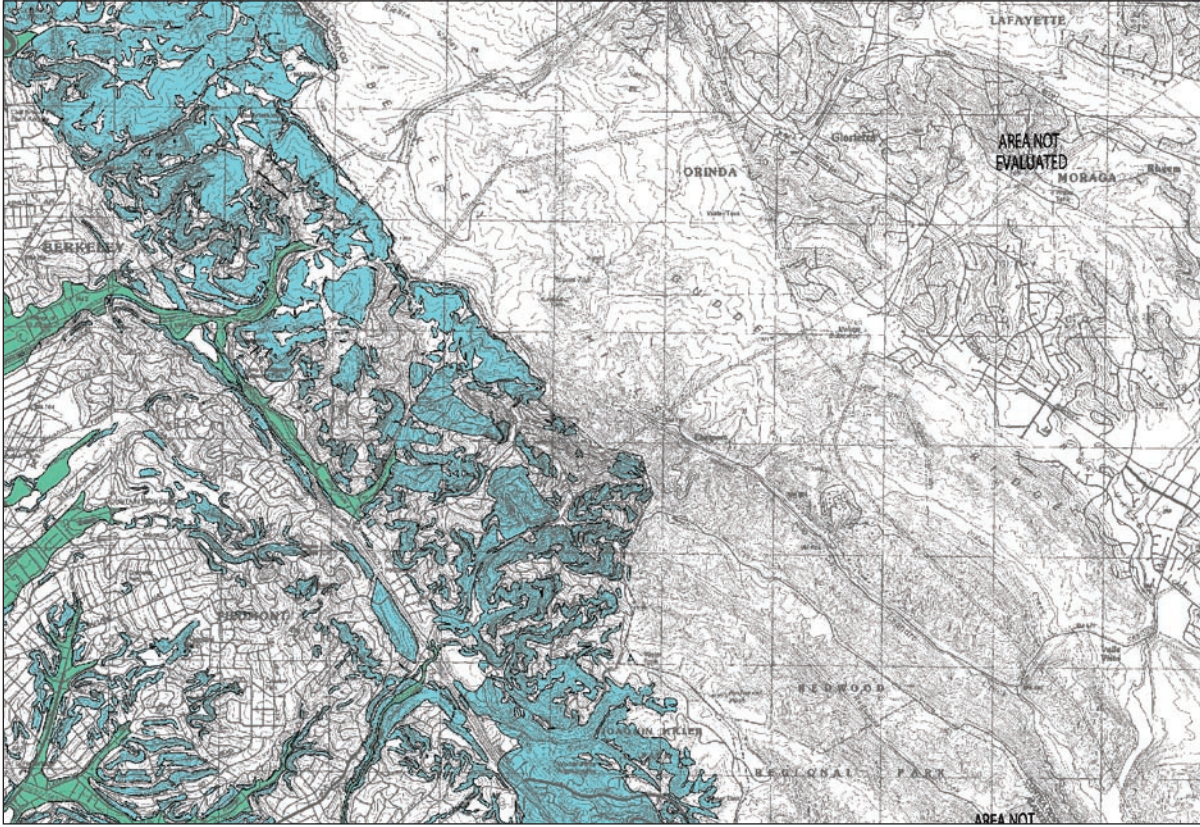


Figure 3-16: Landside Hazard Zones for Berkeley and Oakland, California. Blue areas are those that are susceptible to earthquake-caused landslides.

SOURCE: CGS

### 3.6.4 Ground Failure, Debris Flows, and Land Slides

Potential for ground failure and landslides is determined by soil type, water content (degree of saturation), gradient (slope angle) and triggering events (an earthquake, excavation that upsets the site equilibrium, increase in water content resulting from irrigation or storm run-off). Geotechnical investigations of the site and surrounding terrain are critical in determining site vulnerability.

- **Landslide Hazard Maps**

The USGS and CGS have prepared Landslide Hazard Zone Maps for parts of northern and southern California (Figure 3-16). The map de-

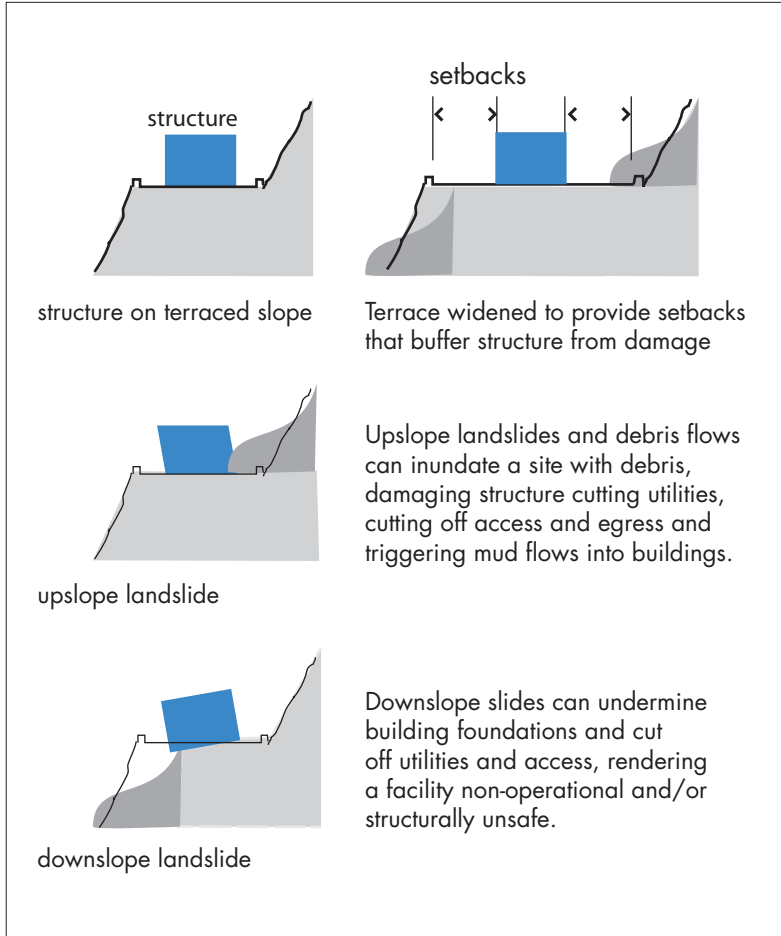


Figure 3-17  
The effect of upslope and downslope landslides.

picts a section of the Oakland-Berkeley East Bay Hills, indicating areas where slope, soil type and seismic risk could trigger landslides. Construction in the Landslide Hazard Zone requires an assessment by a geotechnical engineer.

Downslope slides can undermine building foundations and cut off utilities and access, rendering a facility non-operational and/or structurally unsafe (Figure 3-17). The USGS's *National Landslide Hazards Mitigation Strategy*<sup>14</sup> and the California Geological Survey's *Recommended Procedures for Implementation of DMG Special Publication 117: Guidelines for Analyzing and Mitigating Landslide Hazards in California*<sup>15</sup> offer guidance in determining landslide vulnerability and mitigation options.

## ● Mitigation Options

Foundation systems and structures can be designed to reduce damage from ground failure. The geotechnical engineer can provide recommendations for appropriate foundation design.

### ○ Set-Back

The most failsafe option for mitigation is to locate structures and lifelines in parts of the site that are not at risk to slide damage. Set back structures from both the toe of an upslope and from the lip of a down slope. Allow separation to accommodate catch basins, debris diverters and barriers. Parking lots or storage areas can be designed and located to “buffer” structures from debris.

### ○ Drainage

Since water acts as a lubricant on slope-failure surfaces, it is critical that the site and its surroundings be well drained, that irrigation is limited, and that dewatering systems reduce subsurface hydrostatic (water pressure) pressures. Dewatering systems can either be passive (drains into slopes, “French drains,” top-of-slope catch basins) or active, providing pumping of subsurface water from sumps into a drain system. In both cases, continuous maintenance is essential to ensure reliable operation of the system. Emergency power may also be required for active drainage systems. Where storm water runoff must be managed on site, design of parking and landscaped areas should accommodate storage. Facility access procedures will need to address displacement of parking and limitations on access during periods the site is flooded.

### ○ Redundant Infrastructure

Ground failure can severely disrupt utility and lifeline connections to a site. Where continued operations are essential to a client, connections to utility and transportation networks should be redundant, providing more than one means of connection, access, and egress. For telecommunications, redundancy would include dedicated connections to two different switching offices, planned to follow two different routes to the site. Multiple access and egress paths should also be provided. For facilities dependent on electrical power, multiple, dispersed connections to the grid, co-generation and/or emergency back-up power generation should be planned.



Where continuous operation is not essential, emergency back-up power should be provided to ensure safety, security and operation of environmental protection systems (such as heating and ventilating systems [HVAC], water pumps, security systems, evacuation and lighting systems, computer operations and data security. Emergency power generation capacity should exceed minimum requirements to ensure adequate power for projected needs of essential systems. For facilities where a consistent quality-controlled supply of water is essential for operations, on-site storage and purification should be provided to meet operational needs until alternative sources can be secured.

### **3.7 OFF-SITE ISSUES THAT AFFECT SITE SELECTION**

As noted previously, for facilities designed to performance-based criteria, including minimum disruption and continued operation, the location of the site within the region may play a critical role in mitigation options. A vulnerability assessment should address issues of access to and egress from the site to regional transportation and communication systems, the robustness of utilities that support the site, and regional earthquake impacts that would affect site operations.

#### **3.7.1 Access and Egress**

For manufacturing and essential facilities where access and egress are essential for continued operations, siting decisions should address the vulnerability of access roads, freeways, public and private transit and transportation structures upon which business operations will depend. Selection of a site that provides multiple or redundant access and egress is a good idea. This approach will also be essential if facility operations or production is dependant on access by employees, raw materials, and delivery of products, be they manufactured goods or information, to markets. For example, a number of manufacturing firms have relocated their manufacturing from California to other states where product manufacture and delivery would not be disrupted by earthquake damage to buildings, freeway structures, telecommunications, and the dislocation of employees.

#### **3.7.2 Infrastructure**

We have become more dependent on infrastructure, particularly high-speed telephony for day-to-day business operations. Most businesses are also totally dependent on electrical power from a regional grid, and

water and waste-water disposal from offsite utilities. In assessing the vulnerability of a facility expected to be operational immediately after a disaster, the client and designer should assess the reliability of these infrastructure systems and provide for redundancy and back-up systems. For a critical system such as telephony, data telemetry or just Internet access, redundancy should include multiple access or paths to primary utilities. For example, for critical telephony, redundancy would provide multiple paths to different telephone switching offices and satellite communications capability. For electric power, back-up generators and fuel storage (and contracts with suppliers to provide refueling until utility power is restored) to provide for continued operations would be essential. On-site storage for wastewater would provide redundancy to a sewer system that may be damaged by power loss, earthquake damage or flood.

### **3.7.3 Adjacency**

Adjacent land uses may pose a threat to the continued operation of the proposed facility. Collapse-hazard structures can spill debris onto the site, damaging structures or blocking access and egress. Hazardous materials released upwind of the site may force evacuation and shut down of operations. Setbacks from adjacent land uses and separation from adjacent structures should be used to protect structures, access and areas of refuge and to protect against pounding. In addition, HVAC systems may require enhanced design to protect building occupants from hazardous materials plumes.

## **3.8 EARTHQUAKE AND TSUNAMI HAZARDS**

A tsunami is a rapid rise in coastal sea level caused by offshore earthquakes that displace the ocean bottom, earthquake-triggered or natural submarine landslides and slumps, volcanic eruptions, or very infrequently by meteor strikes. Tsunami waves have a very long wavelength and travel at approximately 500 miles per hour in the open ocean. As they approach shallow waters, their speed and wavelength decreases, and their height increases dramatically.

While coastal storm surge is well documented and understood, the impacts of tsunamis are not as commonly understood. Storm surge produces higher tides and pounding waves over a period of hours. Tsunamis, generated by distant earthquakes on the Pacific Rim, volcanic

eruptions or undersea landslides on near-coast continental shelves, or by near-shore earthquakes, can typically cause unpredictable, high and rapidly changing tidal-like inundation from 1 to 30 feet in height above the tide, carrying flood waters and debris inland in, cases up to 100 feet. Tsunami wave arrival is usually, but not always, preceded by extreme tidal recession. The initial wave is usually followed by secondary tsunami waves for periods lasting up to eight hours. These secondary waves can be higher and carry debris from initial inundation, creating a lethal combination of inundation and battering.

Tsunamis are not limited to the Pacific Coast, Hawaii and Alaska. Earthquakes and volcanic eruptions can generate tsunamis along the US southeast and gulf coasts and the Caribbean, with a remote possibility of volcanic and submarine landslides generating a tsunami that could affect the entire Atlantic coastline.

### **3.8.1 Special Considerations for Coastal Area Site Assessment**

Coastlines are dynamic. Beaches erode and migrate, and bluffs collapse as part of the natural process in the coastal zone. Earthquakes can accelerate this process. Site plans must address the dynamic nature of the beach-ocean interface, providing setbacks adequate to accommodate inevitable change. Dramatic changes in short periods of time frequently occur as a result of earthquakes, storms and tsunamis. Designing structures to resist coastal forces of wind, flood, storm surge, earthquake, tsunami inundation and battering is a complex problem.

#### **● Mitigating Tsunami and Coastal Surge Hazards**

FEMA's Coastal Construction Manual (CCM) identifies a process for evaluation of flood hazards in coastal areas that is applicable to earthquake and tsunami forces as well. Alternatives include locating development above the coastal flood zone, orientating structures to reduce the profile presented to wave action, site-planning options for locating structures, parking and landscaping, altering the site and construction of flood protective structures.<sup>16</sup> FEMA suggests the following critical "Do's and Don't's, edited, abridged and adapted from the California Coastal Commission:

- DO avoid areas that require extensive grading.
- DON'T rely on engineering solutions to correct poor design and planning.
- DO identify and avoid or set back from all sensitive, unstable, and prominent land features.
- DON'T overlook the effects of infrastructure location on the hazard vulnerability of building sites.
- DO account for all types of erosion (long-term, storm-induced, stream, and inlets).
- DO incorporate setbacks from identified high-hazard areas.
- DON'T forget to consider future site and hazard conditions.
- DO use a multi-hazard approach to planning and design.
- DON'T assume that engineering and architectural practices can mitigate all hazards.
- DO involve a team of experts with local knowledge and a variety of expertise in site evaluation and assessment.

- **Specific CCM Recommendations for Site Planning**

- Set back structures beyond the code or zoning minimums to provide an extra margin of safety. It is better to be conservative than to have to relocate a structure in the future. If a structure must be located at the minimum setback, it should be designed to be relocated.
- Set back structures from the lip of coastal bluffs. See the CCM for recommendations.
- Be aware of multiple hazards. In many coastal states, coastal structures are subjected to potential storm surge, tsunami, coastal erosion, debris flows, fires and earthquakes!
- Provide setbacks between buildings and erosion or flood control structures to permit maintenance, strengthening and subsequent augmentation.

In site planning, be aware that vegetation and buildings can become “dislodged” and be driven by wind and wave action into structures. Vegetation may serve to stabilize beach areas, but it may not be able to resist

tsunamis. Also beware of land forms that may channel inundation into structures.

### ● Tsunami-Specific Mitigation

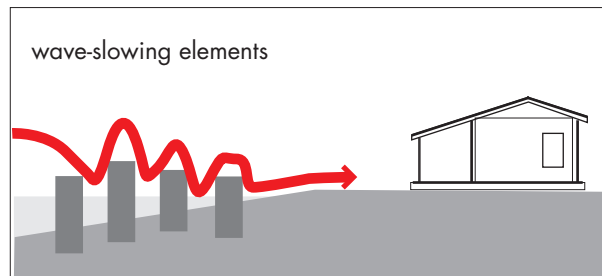
In many coastal communities, tsunami inundation is included in the National Flood Insurance Program. Information concerning the potential for tsunami inundation and maps can be obtained from the local or state emergency management office, FEMA or from NOAA. Detailed inundation projections are being prepared for the coastlines of California, Oregon, Washington, Alaska and Hawaii. The potential for tsunami inundation may also exist for some areas in Puerto Rico and the Gulf and southern Atlantic coast states. Unfortunately, the history of tsunami events in the coastal United States is incomplete. The simplest solution is to avoid new construction in areas subject to tsunami inundation (as a surrogate, maps of areas that have historically been inundated by storm surge may be used). For example, the range of projected tsunami inundation for California's open coast is from 33 to 49 feet (10 to 15 meters), with variation in estuaries and bays. In Oregon, Washington, Alaska and Hawaii, wave heights can be greater. The recommendations of the CCM should be followed for construction in areas where erosion, flooding, hurricanes and seismic hazards exist. In developing a site plan in an area with inundation potential, cluster structures in areas with the lowest risk - generally the highest section of the site.

### ● Resources for Tsunami Mitigation

The National Tsunami Hazard Mitigation Program of NOAA has prepared a number of resource documents to assist architects and planners in mitigating tsunami risk. The guide, *Planning for Tsunami: Seven Principles for Planning and Designing for Tsunami*<sup>17</sup>, provides general guidance to local elected officials and those involved in planning, zoning, and building regulation in areas vulnerable to tsunami inundation.

As in other areas where flooding can occur, structures should be elevated above the expected tsunami inundation height. Energy-abating structures, earth berms, and vegetation can dissipate some of the energy of the incoming and receding waves, but they are not a failsafe solution. In areas where inundation is expected to be less than a meter, flood walls may protect structures from both surge and battering from debris (Figure 3-18).

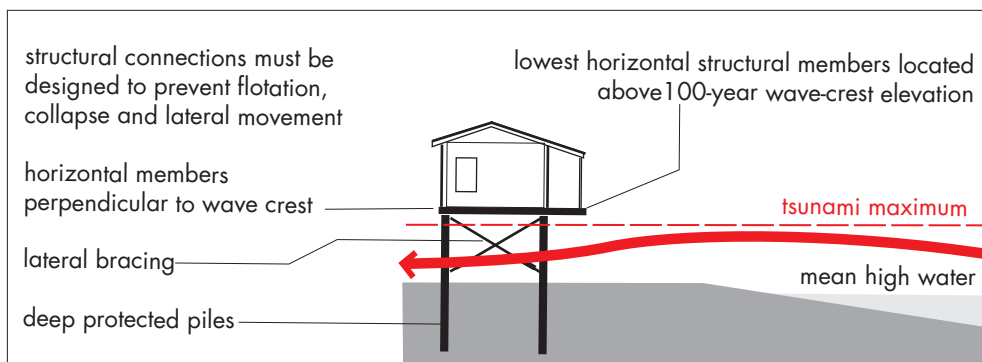
Figure 3-18  
Slowing a tsunami.



Structures in low-lying areas should be designed so that the surge passes under or through the building, by elevation of the structure or by creating “weak non-structural walls,” also known as “break-away walls,” perpendicular to expected waves (Figure 3-19). This would allow the waves and debris to pass through the structure. Buildings should be oriented perpendicular to wave inundation to provide the smallest profile to the wave. However, it is critical in areas that experience both tsunami and earthquakes that foundations and structures be designed to resist earthquake forces and the forces of water velocity, debris battering, and scouring and liquefaction of foundations and piles.

When program requirements such as orientation to view or site limitations necessitate building configurations that are parallel to incoming waves, attention to structural design is critical.

Figure 3-19: Avoiding a tsunami.



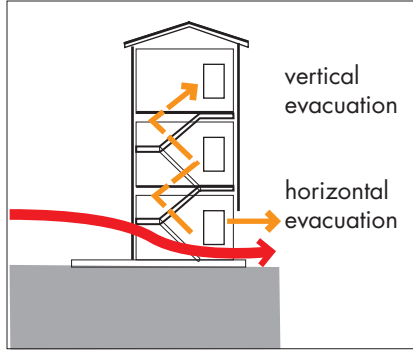


Figure 3-20  
 Designing evacuation options:  
 two options are moving people to  
 higher floors or moving people to  
 higher ground

Construction in coastal zones of California, Oregon, Washington, Alaska, and Hawaii must accommodate both tsunami inundation and earthquake ground motions from large near-coast events.

Site planning in areas of flood, coastal surge, and tsunami must provide for rapid evacuation of occupants to high ground, or structures must be designed for vertical evacuation to floors above forecast flood levels (Figure 3-20). This requires careful engineering because there is currently no guidance available for determining loads. For communities subject to both flood and earthquake hazards, structures intended for vertical evacuation should be designed to seismic standards higher than “life safety” so they will be available after the earthquake to accommodate tsunami evacuees.

### 3.9 CONCLUSION

The success of a project in meeting the client’s expectations begins with the right team of architects and geotechnical, civil, and structural engineers. Understanding the seismic hazards in all of their direct and indirect manifestations is critical to success. Good engineering is not an excuse or a remedy for an inadequate evaluation of the site and design that does not mitigate the earthquake risk. As can be seen in the remainder of this publication, successful design is a team effort, and starts at the site.

## NOTES

- <sup>1</sup> FEMA National Flood Insurance Program. Information available at [www.fema.gov/fima/](http://www.fema.gov/fima/)
- <sup>2</sup> CGS 2002, *Guidelines for Evaluating and Mitigating Seismic hazards in California, Special Publication 117*, California Geological Survey, Seismic Hazard Mapping Program, and State of California. Available at <http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp>
- <sup>3</sup> Southern California Earthquake Center, University of Southern California, Los Angeles. Available at <http://gmw.consrv.ca.gov/shmp/SHMPpgminfo.htm>
- <sup>4</sup> FEMA 386-2 is available on-line at [www.fema.gov](http://www.fema.gov)
- <sup>5</sup> Section 322, Mitigation Planning, of the Robert T. Stafford Disaster Relief and Emergency Assistance Act, enacted by Section 104 of the Disaster Mitigation Act of 2000 (Public Law 106-390)
- <sup>6</sup> §201.6(C)(2), 44 CFR PART 201, State and Local Plan Interim Criteria Under the Disaster Mitigation Act of 2000
- <sup>7</sup> Available at <http://geohazards.cr.usgs.gov/eq/html/wus2002.html>
- <sup>8</sup> Map available from California Seismic Safety Commission, Sacramento, CA
- <sup>9</sup> HAZUS was developed by FEMA through a cooperative agreement with the National Institute of Building Sciences. Information is available at [www.fema.gov/hazus/hz\\_index.shtm](http://www.fema.gov/hazus/hz_index.shtm)
- <sup>10</sup> *California Public Resources Code*, Division 2, Geology, Mines and Mining, Chapter 7.5, Sections 2621-2630, Earthquake Fault Zoning. Available at [www.consrv.ca.gov/cgs/rghm/ap/chp\\_7\\_5.htm#toc](http://www.consrv.ca.gov/cgs/rghm/ap/chp_7_5.htm#toc)
- <sup>11</sup> CGS 1999, *Fault Rupture Hazard Zones in California*, Special Publication 42. Available at <ftp://ftp.consrv.ca.gov/pubs/sp/SP42.PDF>
- <sup>12</sup> *California Public Resources Code*, Division 2. Geology, Mines and Mining, Chapter 7.5 Earthquake Fault Zones, as amended
- <sup>13</sup> G.R. Martin and M.Lew, eds, Southern California Earthquake Center, University of Southern California, 1999
- <sup>14</sup> USGS Open File Report 00-450, 2000
- <sup>15</sup> ASCE and Southern California Earthquake Center, June 2002
- <sup>16</sup> FEMA, *Costal Construction Manual*, 3rd Edition, FEMA 55CD. Available from FEMA at [www.fema.gov](http://www.fema.gov)
- <sup>17</sup> NOAA NTHMP 2001, *Designing for Tsunami: Seven Principles for Planning and Designing for Tsunami Hazards*. Laurence Mintier, ed. Available from <http://www.pmel.noaa.gov/tsunami-hazard/links.html#multi>