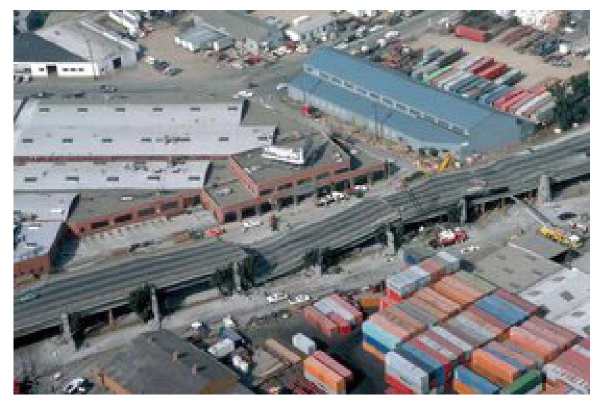
3 | Geologic Hazards

3.1 | Overview

Primary hazards Most, though not all, of the geologic hazards that present the threat of devastation to life and property are the direct or indirect result of ground movement due to earthquakes (see below). The primary, or direct, earthquake hazards are surface-fault rupture and ground shaking. Secondary hazards, associated with ground shaking, include several forms of ground failure and inundation. (Inundation hazards, which may or may not be associated with earthquakes, are discussed in Chapter 6, "Flooding Hazards.") Ground failure is the permanent deformation of the ground due to its loss of strength or failure of the underlying materials during earthquake shaking, and includes liquefaction, landslides, mudslides, differential settlement and subsidence. The likelihood of occurrence of these secondary earthquake effects (with the exception of inundation) is generally high.



The main geologic hazards include:

- Fault rupture or displacement: a sudden shifting of the ground along the trace of an earthquake fault; usually, but not always, occurs at the time of an earthquake, and is associated with stronger quakes.

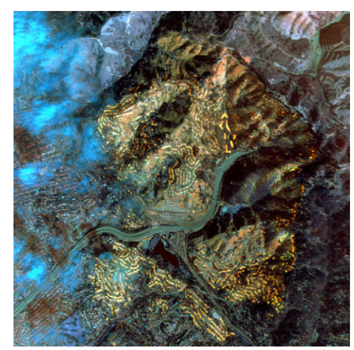
- Ground shaking: movement of the ground caused by the passage of seismic waves through the earth's outer crust during an earthquake; it typically is strongest near the earthquake fault. Ground shaking is the most noticeable phenomenon of seismic activity and the one people associate most closely with earthquakes; it also represents the major hazard from an earthquake, in the form of damage to structures. The intensity of ground shaking at a particular site is affected by the characteristics of the earthquake, distance from the fault, and the characteristics of the underlying soil.
- Liquefaction: the rapid transformation of sediment from a solid state into a fluid state, which causes the soil to lose cohesiveness and become incapable of carrying significant loads; it causes sediment to behave as quicksand, and results in structures settling, tipping or—in the case of underground tanks, for example—rising buoyantly. Its potential to occur is a function of the intensity of the ground shaking and the underlying geologic conditions. In general, liquefaction is less destructive than ground shaking; however, in certain areas, it has occasionally resulted in substantial damage to property from the failure of structural foundations.
- Landsliding: the rapid down-slope movement of soil, rock and rock debris. Most slides are natural occurrences, though they can be triggered by improper construction activities. The main causes of landslides are earthquake-induced ground shaking, heavy rains and poorly engineered grading and drainage projects. (Improper grading may alter natural drainage patterns and allow water to collect and loosen soils.) Factors that determine the extent and severity of a landslide include the steepness of slope, the presence of weak or poorly consolidated soils, the soil's water-content level and the existing grading and drainage patterns.

Less common or less destructive geologic hazards include tectonic creep (slight and gradual slippage of the ground along seismically active faults, usually in a lateral direction), subsidence or differential settlement (downward movement of poorly compacted, non-uniform soil, often as a result of prolonged pumping of groundwater), lateral spreading or lurching (sideways movement of soil, usually where open banks and unsupported cut slopes provide a free face, or where artificial fill overlies bay mud), and soil creep (downslope movement that occurs over years when soil shrinks and swells). The main geologic hazard not associated with earthquakes is erosion, the wearing away of the soil mantle by wind, running water or geologic forces.

Earthquakes are the most pervasive safety hazard in Oakland. Unlike fires or floods—the paths of which can, to some extent, be measured, predicted and contained—earthquakes are, at present, impossible to predict or contain. Although it is not possible to eliminate all the risks associated with earthquakes, it is the intent of the safety element to use available tools, such as geotechnical studies, appropriate land-use decisions and adequate building codes, to reduce the risks. Because earthquakes rarely destroy an entire neighborhood or even city block, the prohibition of construction in a particular area—with the exception of earthquake fault zones—is a less-effective mitigation measure than improved building design.

Local geology The landform of Oakland and the rest of the Bay Area is, in geologic terms, relatively young. The region sits at the intersection of two of the plates that make up the earth's crust, which also makes the area geologically very dynamic. The movement of these plates over time has shaped the valleys and ridges of the East Bay hills, while erosion and sedimentation from the San Joaquin/Sacramento Delta have created the broad alluvial plain on which most of Oakland lies. The area's predominant rock group was deposited approximately 100-150 million years ago; known as the Franciscan formation, it comprises the region's bedrock. As recently as 10 million years ago, however, the Oakland Hills still did not exist and the city's landform was part of a broad lowland that drained east to an inland arm of the sea. Within only the last five million years, the faulting and folding of earthquake plates uplifted the present Oakland Hills and created the trough that is now San Francisco Bay. Volume One of the technical report for Oakland's "Open Space, Conservation and Recreation (OSCAR) Element" contains a map showing the city's main geologic deposit units; see Figure 1-3 of that document.

Local topography Oakland consists of two generally distinct geologic and topographic zones, separated by the northwest-trending Hayward fault: the lowlands and the hills (or uplands). The lowlands, to the south and west of the fault, correspond to the nearly flat coastal landforms that surround the bay, the adjoining tidal flats, and the gently sloping, rolling terrain further inland. Most of Oakland's development lies on this coastal shelf, which varies in width from two to four miles, approximately. Along the city's western and southwestern edges, the natural shoreline has been extended by up to two miles with landfill. The location of the original shoreline is not apparent, and the filled areas appear to be a natural continuation of the urbanized plain (see Figure 3.1). The areas around the Bay Bridge approach, the former Oakland Army Base and the seaport shipping terminals were formerly open water, while lands along the Oakland Estuary and around San Leandro Bay were formerly marshes and mudflats.



The coastal shelf rises gradually to elevations of between 100 and 200 feet. Beyond these elevations, the land rises abruptly into the Oakland Hills, reaching just over 1,760 feet at Grizzly Peak, northwest of the Caldecott Tunnel. Most of the area above Highway 13, north of Joaquin Miller Park, is at elevations greater than 600 feet; south of the park, the hills are significantly lower, with much of the land at only 100-600 feet of elevation. Since 1960, most the land developed in Oakland has been in the hills, and the hills still contain most of the city's remaining vacant land. However, the remaining sites tend to have severe slope, geologic and access constraints.

Local soils The three primary soil types in Oakland are the bay muds located along the shoreline and in the landfilled areas; the alluvium and dune-sand deposits in the flatland and lower hill areas; and the sandstones and shale fragments of the upper hill areas. Bay mud consists of fine-grained, unconsolidated sand, silt and clay with abundant organic material; over time, bay muds near the original shoreline have been overlain with artificial fill, typically consisting of heterogeneous material such as rock and other debris. Soils in the flatlands have been formed by thousands of years of hillside erosion, and are characterized by high corrosivity and low erosion potential. Finally, soils in the upper hills are composed of sandstone and shale materials, while soils in the lower hills consist of variable soils deposited through erosion, landsliding and artifical cutting and filling. Volume One of the OSCAR element's technical report contains a map of the city's main soil types; see Figure 1-8 of that document.

Local seismology The tectonic plates that make up the earth's crust are in continual movement. This movement causes strain to build at the plate boundaries, or faults. Strain accumulates until the plates can no longer sustain it, at which point there is an energy release. This energy release expresses itself as tectonic creep, fault ruptures, ground shaking and, more generally, earthquakes. Once the release occurs, the process of gradual strain build-up begins anew. Major earthquakes result when collisions of the plates occur at shallow depths or involve larger plates or longer faults, and usually have their epicenters on or near a fault. Earthquakes are common in California because the state's coastline is at the boundary of two tectonic plates. The coastline is part of the Circum-Pacific seismic belt, which extends the length of the western edge of the Western hemisphere, and is where over 80 percent of the world's earthquakes occur.

The City of Oakland lies within the San Andreas fault system, the largest one in California and the one with potential for the strongest earthquakes. More specifically, the city straddles the Hayward fault, a "branch" fault of the larger system. The Hayward fault runs along the southwestern base of the East Bay hills and parallels Highway 13, making it an approximate physical boundary between the low-lying, urbanized portions of Oakland to the west and the less developed, upland areas to the east. The fault's two segments, each approximately 30 miles long, extend from the Warm Springs district of Fremont to Oakland, and from Oakland to Point Pinole. The Hayward fault is believed to accumulate strain at one of the highest rates in the Bay Area, suggesting that it is one of the faults in the region most likely to generate a large earthquake. In fact, the fault is one of the most hazardous in the world because of its high "slip rate;" its demonstrated ability to generate large, surface-rupturing earthquakes; and, most importantly, its location through a heavily urbanized area. The last major quake on the Hayward fault occurred in 1868 (see below). A far less active fault, the Calaveras fault, runs down the San Ramon Vally, parallel to and approximately ten miles east of the Oakland hills crest.

Historic local earthquakes Earthquakes occur very frequently in the Bay Area, although most are so weak that they can be detected only by seismographs. However, the Bay Area has been impacted by about a dozen great earthquakes during historic time and Oakland has been shaken by moderate-to-major earthquakes approximately 60 times in the recorded history of the area. (Commonly accepted descriptive names for earthquake are "minor," "small," "moderate," "major" and "great.") The strongest quakes in the Bay Area during recent history occurred as follows:

- In 1836, on the Hayward fault and in 1838, on the San Andreas fault; historical data are meager for these quakes.
- In 1868, on the Hayward fault, and estimated to have measured 6.8 on the Richter scale. It caused extensive damage to the then-town of Hayward. Fault ruptures extended for 30 miles, with horizontal ground displacement of up to three feet.
- The great San Francisco earthquake of 1906, on the San Andreas fault, with a magnitude of 8.3 on the Richter scale. It is the deadliest quake in the history of the Bay Area, with a human toll of 700 people. Surface fault ruptures extended for 267 miles, with displacement of up to seven yards (in Marin).
- The Loma Prieta earthquake of October 17, 1989, along the San Andreas fault, and measuring 7.1 on the Richter scale. It caused 62 deaths (including 41 in Oakland), injured almost 4,000 people, left more than 12,000 homeless, and damaged more than 18,000 homes and 2,500 businesses. Total property loss is estimated at over $6 billion; fiscal impacts to the City of Oakland were estimated at $140 million.

Structural hazards Geologic conditions must be taken into account in the development of land, as the danger to life and property increases if structures are

Earthquake magnitude—the amount of energy released at the quake's epicenter—is now generally reported using the moment magnitude scale, the symbol for which is "MW." This has functionally replaced the local magnitude scale (ML), popularly known as the Richter scale.

constructed in ways that are unsuitable. The primary structural hazards are related to earthquakes, and involve partial or total collapse of a building, falling debris or internal contents (including elevators, mechanical equipment, heavy furniture and storage racks), fire or explosion, and disruption of lifelines (transportation, water, sewer, gas, electricity and telephone). All structures are susceptible to ground shaking, and most earthquake-related deaths result from structural failure due to ground shaking. The potential for structural hazards depends on the intensity of the ground shaking and a structure's design and construction type.

Generally, structures most vulnerable to damage are those constructed prior to the adoption and enforcement of building codes requiring seismic- safety measures and earthquake-resistant design (in general, buildings constructed prior to 1965); structures that have suffered undetected damage from previous earthquakes; and structures that were inadequately designed and constructed, and that have been inadequately maintained. More specifically, hazardous structures and construction types include unreinforced masonry buildings (URMs), concrete tilt-up slab buildings, inadequately braced and non-anchored wood-frame construction, "soft-story" buildings (most commonly two- or three-story buildings with apartments or offices over ground-level parking) and buildings with parapets or exterior ornamentation (which could fall on pedestrians). At the other extreme, modern, single-story wood-frame homes are the most earthquake-resistant structures; in addition, structures built on bedrock can be expected to sustain less damage. Every major earthquake has provided valuable data for evaluating and improving upon existing construction techniques. The Long Beach earthquake of 1933, for example, demonstrated the vulnerability of URM buildings and the hazards of parapets and unanchored façade decorations; one of the surprises from the Northridge earthquake of 1993 is that many steel-frame buildings, believed before the quake to be among the safest structures, suffered welding joint damage.

3.2 | INSTITUTIONAL FRAMEWORK

U.S. Geological Survey (USGS) The USGS, an agency of the federal government, provides scientific information about the Earth, its biological and mineral resources, and natural hazards. USGS scientists assess areas of potential natural hazards and the potential risks to residents of those areas. More specifically, and of particular relevance, the USGS has identified and mapped areas subject to damaging earthquakes and landslides, and assessed the probability of occurrence and the potential consequences of those events.

California Geological Survey (CGS) Previously known as the Division of Mines and Geology, CGS develops and disseminates technical information and advice on the state's geology, geologic hazards and mineral resources. Following damaging earthquakes and landslides in the 1970's and 1980's, legislation was passed that focused CGS's authority on several fronts, including:

- establishing a "strong-motion instrumentation program," to record the response of rock, soil and structures to ground motion caused by earthquakes;
- enacting the Alquist-Priolo Earthquake Fault Zoning Act, which mandates the delineation of zones along traces of hazardous faults;
- enacting the Seismic Hazards Mapping Act, which established a program to identify and map seismic hazard zones; and
- the identification and mapping of geologic hazards and estimates of potential consequences and likelihood of occurrence.

Alquist-Priolo Earthquake Fault Zoning Act This law, passed in 1972 and previously known as the Alquist-Priolo Special Studies Zones Act, seeks to mitigate the hazard of surface faulting. The act requires the State Geologist, who also serves as the chief of CGS (see above), to establish regulatory zones known as "earthquake fault zones" (EFZs) around the surface traces of potentially or recently active faults and to prepare and distribute maps of these zones. Cities and counties are required to withhold approval of most kinds of development projects in EFZs until an investigation is conducted by a licensed geologist determining the precise location of active-fault traces and assessing the hazard of surface fault rupture in the area. The act prohibits the construction of most types of structures for human occupancy within 50 feet, generally, of any active fault.

The Alquist-Priolo Earthquake Fault Zoning Act is found in Sections 2621-2630 of the California Public Resources Code. The entire act and a full report on the state program implementing this act are contained in CGS Special Publication 42, which may be downloaded from the CGS website, at www.conservation.ca.gov.cgs.

Seismic Hazards Mapping Act Passed in 1990, this law is similar to the Alquist-Priolo Earthquake Fault Zoning Act but addresses earthquake hazards other than the hazard of surface fault rupture. The law requires the State Geologist to identify and map zones prone to seismically induced liquefaction, ground-shaking, landslides and other forms of ground failure resulting from earthquakes. Prior to approving a development project, affected local governments must require a geotechnical report identifying all

The Seismic Hazards Mapping Act is found in Sections 2690-2699.6 of the California Public Resources Code. The entire act and a full report on the state program implementing this act are contained in CGS Special Publication 117, which may be downloaded from the CGS website, at www.conservation.ca.gov.cgs.

seismic hazards, and may approve projects only after the nature and severity of the hazards have been evaluated and appropriate mitigation measures have been incorporated. Finally, afftected property owners must disclose to prospective buyers the fact that the property is located within a seismic hazard zone.

The California Building Code is published by non-governmental organizations with sole publication and distribution rights, and is not yet available on the Internet. However, it may be examined free of charge at one of many "depository libraries" throughout the state, listed on the website of the California Building Standards Commission, at www.bsc.ca.gov.

California Building Code Title 24 of the California Code of Regulations ("California Building Standards Code") sets forth the fire, life-safety and other building-related regulations applicable to any structure fit for occupancy statewide for which a building permit is sought. Within Title 24, Part 2 is the California Building Code (CBC), which establishes general standards for the design and construction of buildings, including provisions related to seismic safety. The CBC has been revised many times over the years to increase the earthquake resistance of structures, often in response to structural lessons learned from major earthquakes in this country and elsewhere.

The Field Act consists of sections 17280-17317, sections 17365-17374 and sections 81130-81149 of the California Education Code. The Private Schools Building Safety Act is found in sections 17320-17336 of the same code. The regulations concerning "potentially hazardous buildings" are found in Section 8875 of the Government Code.

Other state laws and regulations In addition to the two acts mentioned above, California has passed numerous laws regulating land-use development and building construction with regard to seismic and other geologic hazards. The Field Act, enacted in 1933 (after the Long Beach earthquake of that year), set strict earthquake-resistant structural requirements for new public schools, while amendments to the act require the replacement or retrofitting of pre-existing public schools. The Private Schools Building Safety Act of 1986 seeks to provide a similar level of earthquake safety to private-school students that is afforded by the Field Act to public-school students. The state has also enacted a law requiring localities to identify all "potentially hazardous buildings"—defined as unreinforced masonry buildings constructed prior to the adoption of local building codes requiring earthquake-resistant design—within their jurisdiction; the law also requires localities to create a mitigation program that, at the very least, notifies owners of potentially hazardous buildings of the status of their buildings.

The Alquist Hospital Facilities Seismic Safety Act is found in sections 129675-130070 of the Health and Safety Code (HSC). The Essential Services Buildings Seismic Safety Act is found in sections 16000-16023 of the HSC, while the State Historical Building Code is found in sections 18950-18961.

The Alquist Hospital Facilities Seismic Safety Act of 1983 requires that major health facilities be designed and constructed so as to remain standing and functional following an earthquake. The Essential Services Buildings Seismic Safety Act of 1986 establishes similar requirements for fire and police stations, emergency operations centers, and other buildings expected to provide essential services to the public after a disaster; the act also requires that nonstructural components such as communications systems and emergency backup systems, be given "adequate consideration during the design and construction process" to assure continued operation of the facility after a disaster. The State Historical Building Code provides alternative building regulations and standards for the rehabilitation, preservation and restoration of designated historic structures; the purpose of the code is to preserve a structure's original architectural elements and features while providing for the safety of its occupants.

California Environmental Quality Act (CEQA) The state's CEQA guidelines propose a wide range of environmental impacts that public agencies should consider in their evaluation of development proposals. Considerations related to geologic hazards include the potential for a project to:

- expose people or structures to potential adverse effects, including the risk of loss, injury or death involving rupture of a known earthquake fault, strong seismic ground shaking, seismic-related ground failure (including liquefaction) or landslides;
- result in substantial soil erosion or the loss of topsoil;
- be located on a geologic unit or soil that is unstable, or that would become unstable as a result of the project, and potentially result in on- or off-site landslide, lateral spreading, subsidence, liquefaction or collapse;
- be located on expansive soil, creating substantial risks to life or property;
- substantially alter the existing drainage pattern of the site or area in a manner which would result in substantial erosion or siltation on- or off-site; and
- be subject to inundation by mudflow.

Local regulations The City of Oakland has a number of ordinances aimed at mitigating seismic and other geologic hazards. The city's subdivision ordinance requires developers to file soil reports indicating any soil characteristics which may create hazards, and identifying measures to avoid soil hazards and prevent grading from creating unstable slopes. The ordinance requires that a state-registered civil engineer prepare the soils report and direct all grading work. The city's grading, erosion and sedimentation ordinance sets forth requirements for grading permits and erosion control and sedimentation control plans, and prohibits the discharge or channel concentrated flow of storm water. The unreinforced masonry ordinance implements the state's unreinforced masonry building law (or "potentially hazardous building" law; see above) by, among other things, requiring building owners to retrofit their properties within a specified time. The "earthquake-damaged structures" ordinance establishes regulations and standards governing the alteration, repair, restoration and rehabilitation of earthquake-damaged buildings (other than unreinforced masonry buildings) in a "just, equitable, expedient and practicable" way. The city's "geologic reports" ordinance implements the state's Alquist-Priolo Earthquake Fault Zoning Act (see above). The creek protection, storm water management and discharge control ordinance has among

The city's regulations regarding soil reports are found in Chapter 16.20 of the Oakland Municipal Code. The grading, erosion and sedimentation ordinance is found in section 15.04.780. The unreinforced masonry ordinance is found in Chapter 15.28, the "earthquake-damaged structures" ordinance is found in Chapter 15.24 and the "geologic reports" ordinance is found in Chapter 15.20. The creek protection ordinance is found in chapter 13.16. Local amendments to the California Building Code are found in chapter 15.04.

its purposes to prevent activities that would contribute significantly to erosion or sedimentation. Finally, the city's building construction standards are based on the California Building Standards Code, especially on the CBC (see above); Oakland, like many other localities in California, has amended the CBC to reflect local conditions.

3.3 | ANALYSIS

Earthquake potential Based on the geological record, it can be expected that earthquakes of a certain magnitude will take place in locations where earthquakes of a similar magnitude have previously occurred. This suggests that the San Andreas, Hayward and Calaveras faults will experience major earthquakes in the future. On the basis of research conducted since the 1989 Loma Prieta earthquake, USGS scientists have concluded that there is a 62 percent probability of one or more major earthquakes—defined as having magnitude 6.7 or greater—striking the San Francisco Bay Area between the years 2003 and 2032. (As shown by the 6.7 Northridge quake in 1994 in Southern California, earthquakes of that magnitude can cause widespread damage.) Of the Bay Area faults evaluated by the USGS, the Hayward fault received the highest probability—27 percent—of experiencing such a damaging earthquake, while the San Andreas and Calaveras faults had probabilities of 21 percent and 11 percent respectively. Moreover, previous evaluation by USGS and the State Geologist indicates that the maximum credible earthquake produced by the Hayward, San Andreas and Calaveras faults would have magnitudes of 7.5, 8.4 and 7.3 respectively. The presence of these three faults within 10-15 miles of Oakland creates a high cumulative probability of future earthquakes locally . Of these three faults, the Hayward fault poses the most serious threat by far to Oakland due to its location through the city, the intensity of land uses near the fault zone, and the long interval since the last major quake along the fault (which has resulted in stored potential).

The degree of damage caused by an earthquake depends on an area's geologic composition, the number of people and the designated land uses, the prevailing construction standards, the efficiency of the emergency-response system and even the time of day and day of the week. (The greatest damage would be caused by an earthquake occurring in the middle of the day or during the commute period, due to mass panic, widespread confusion and attempts by individuals to contact family members, which would overwhelm transportation and communication systems.) A major earthquake along the Hayward fault—together with landslides, fires and floods triggered by the quake—could have a catastrophic effect on Oakland. It could cause a large number of deaths and injuries and extensive property damage reaching into the hundreds of millions, or into the billions, of dollars; buildings and freeways could collapse, or be required to be demolished later; and the city's lifelines—drinking and waste water, power, telecommunications and transportation systems—could become severely disrupted. Such a disaster could easily exceed the combined response capability of the city and state, requiring relief support from the federal government and nonprofit organizations. The emergency-response phase could last as long as several days, and could involve search-and-rescue operations to find and assist missing and trapped persons; the provision of emergency medical care, food and temporary shelter; the identification and burial of dead persons; the control of disease outbreaks; the removal of debris and stabilization of imminently unsafe structures; and the re-establishment of public services and utilities, including the clearance of roads. The recovery phase could stretch into many years.

Fault displacement Buildings, roads and utility lines usually suffer heavy damage from any degree of sudden fault rupture or of relatively slow tectonic creep—even of as little as one inch; well-engineered structures, however, may withstand collapse and provide for the life safety of occupants. Because fault displacement involves forces of such great energy, it is generally not economically feasible to accommodate this phenomenon, and the only way to prevent damage to structures and infrastructure is to employ suitable setbacks from active fault traces. Geologic records show that fault displacement usually happens in areas where displacement has previously occurred. For this reason, the ground-displacement hazard is normally confined to a narrow zone along the traces of earthquake faults considered to be active or potentially active. These zones have been legally defined by the State Geologist as earthquake fault zones (EFZs; see previous section). The only EFZ found in Oakland occurs through the Oakland hills, along both sides of the Hayward fault (see Figure 3.1). Tectonic creep along the Hayward fault has cracked and offset curbs, streets, fences, railroads, pipelines and buildings at several locations in the East Bay. More seriously, a high-magnitude earthquake along the Hayward fault can be expected to produce horizontal ground displacement of up to several feet, which would have a catastrophic effect on any structures, roads and utility lines that were built atop or across the fault before the

An active fault is defined as one that has experienced displacement during the last 10,000 years, approximately. A potentially active fault is one showing evidence of surface displacement between 10,000 and 1.8 million years ago, approximately. In addition to faults classified as active or potentially active, there are faults for which displacement activity has not been clearly established.

establishment of earthquake fault zones. Much of the land near the Hayward fault is public open space or is intended for such use in the future.

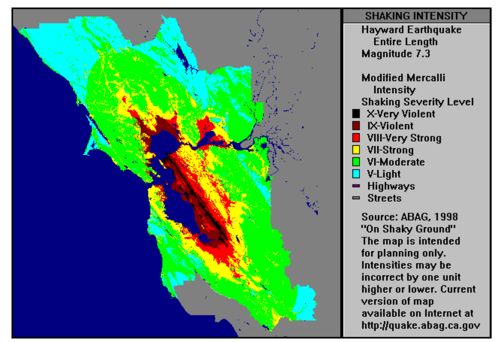
Ground shaking Typically, ground shaking causes most of the structural damage—and indirectly, loss of life—resulting from earthquakes. Violent ground-shaking can cause brick and wood-frame buildings to collapse, streets to crack, and utility lines to rupture. The intensity of ground shaking and its effects on a structure are a function of the duration and intensity of the earthquake, the distance to the fault, the properties of the underlying geologic materials (including cohesion and density of sediments, and the depth to bedrock) and the building's design and construction characteristics. Research has shown that geologic and soil conditions can either amplify or dampen the effects of ground shaking. Unconsolidated recent alluvium or artificial fill (like those found along the bay) can amplify the strength and duration of ground shaking, for example, increasing the risk of structural damage. (Considerable differences were noted in the amount of ground shaking in San Francisco during the great earthquake of 1906 between areas underlain by fill and areas underlain by bedrock.) While ground shaking can extend over a wide area, attenuation occurs with distance from the epicenter of an earthquake; however, little attenuation is observed within about 15 miles of a fault during a major earthquake.

The state's Seismic Hazards Mapping Act (see previous section) requires the State Geologist to compile maps identifying zones subject to seismic hazards such as strong ground shaking, liquefaction and landslides. Areas with liquefaction and landslide potential have already been mapped for many parts of the state (see below). However, the committee created to advise on implementation of the mapping act has determined that, given the current understanding of the effects of geologic material and structure on earthquake ground motions, there would be no benefit in establishing "amplified shaking hazard zones" for purposes of design and construction. The committee's opinion was that "[b]uilding codes are currently the primary means of mitigating the effects of strong earthquake shaking on buildings" and that the need for "special provisions, beyond those contained in the [Uniform Building Code]…to ensure public safety…has not been recognized for the hazard of ground shaking."

The California Geologic Survey has, however, developed a "probabilistic" map of the relative intensity of ground shaking and damage in California from future earthquakes. (It is probabilistic in the sense that the analysis considers the uncertainties in the size and location of earthquakes and the resulting ground motions that can affect a particular site.) The map classifies the entire state according to nine levels of relative intensity, ranging from areas "distant from known, active faults [where] in most earthquakes, only weaker, masonry buildings would be damaged" to areas "near major, active faults [that] will experience stronger earthquake shaking more frequently [and where] this intense shaking can damage even strong, modern buildings." Most of Oakland is found within the three levels of greatest intensity of ground shaking and damage. (The map may be viewed at www.conservation.ca.gov/CGS/rghm/pshamap/pshamain.html.)

In addition, the USGS has created a digital map of areas in Oakland and surrounding cities with the potential to amplify ground shaking from earthquakes. (The map depicts the hazard at a regional scale and should not be used for site-specific purposes.) The map is based in part on 210 newly acquired cone-penetration-test (CPT) soundings, which make Oakland one of the most densely instrumented cities in the country—if not *the* most—for purposes of earthquake-related ground shaking (and also liquefaction). The ground shaking amplification map is available at geopubs.wr.usgs.gov/open-file/of02-296, as is a map showing the location of the CPT soundings.

Also, the Association of Bay Area Governments (ABAG), the regional land-use planning agency, has developed maps for all cities in the Bay Area depicting the shaking intensity likely to result during a "characteristic" earthquake along any of the Bay Area's earthquake faults. In general—and with the notable exception of ground shaking resulting from earthquakes on the Hayward fault (as discussed below)—the maps for Oakland show that shaking intensities can be expected to be lowest in the hills, which are underlain by bedrock, and highest on the bay's edge, which are underlain by poorly consolidated sediments. Not surprisingly, the strongest ground shaking in Oakland is expected to occur as a result of earthquakes on the Hayward fault, while earthquakes originating in more distant faults will produce less intense shaking. According to ABAG's maps, a representative earthquake of magnitude 6.9 on the north and south segments of the Hayward fault would produce "very violent" ground shaking throughout the Hayward fault EFZ, along Lake Merritt Channel and on the margins of San Leandro Bay; most of the rest of the city would experience "violent" shaking, with a smaller area experiencing "very strong" shaking. (The maps are found at www.abag.ca.gov/bayarea/eqmaps/pickcity.html). ABAG has also produced maps for all cities in the Bay Area showing the expected ground shaking amplification based on an area's underlying geologic materials. The maps classify areas according to eight levels of relative amplification, from "very low" to "extremely high." In Oakland, predictably, the closer an area is to the shoreline, the higher is its degree of shaking amplification. (The maps may be viewed at www.abag.ca.gov/bayarea/eqmaps/mate.html .)



Liquefaction The hazard from liquefaction (as with other forms of ground failure) exists mainly on sandy, silty or muddy soils that are geologically young, saturated with water and unconsolidated or poorly consolidated. Such conditions tend to be found in low-lying areas such as marshes, lands adjacent to estuaries and creeks, and areas of artificial fill. Conversely, areas underlain by hard bedrock and with low water tables typically have low liquefaction potential. Liquefaction is of significance to Oakland since much of the city's waterfront is built on natural and artificial bay fill, and has a high water table. Sites prone to liquefaction have limited development potential. However, since liquefaction occurs at shallow depths, it is possible to reduce the liquefaction hazard by using specialized structural-design measures and construction techniques.

Pursuant to the state's Seismic Hazards Mapping Act (see previous section), the California Geological Survey has released official maps showing those areas of the state where historic occurrence of liquefaction or local geological, geotechnical and groundwater conditions indicate the potential for liquefaction. The maps are intended to delineate "zones of required investigation," or those areas encompassing sites for which local jurisdictions must withhold development permits until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures are incorporated into development plans. The seven seismic-hazard-zone maps covering Oakland—for the USGS quadrangles of Briones Valley, Hayward, Hunters Point, Las Trampas Ridge, Oakland East, Oakland West and San Leandro—indicate that most of West Oakland, North Oakland and East Oakland are prone to liquefaction, as are large parts of central Oakland (see Figure 3.1).

In addition, the USGS has created a digital map of areas in Oakland and surrounding cities with the potential to produce surface manifestations of liquefaction such as sand boils, ground cracks and lateral spreading. (The map depicts the hazard at a regional scale and should not be used for site-specific purposes.) The map is based in part on the CPT soundings mentioned earlier. The liquefaction-hazard map is available at geopubs.wr.usgs.gov/open-file/of02-296.

Also, ABAG has created a map of the Bay Area which classifies land according to five liquefaction-susceptibility levels: very low, low, moderate, high and very high. These maps indicate that most of West Oakland, areas surrounding San Leandro Bay and much of the rest of the city's shoreline have a "high" or "very high" susceptibility to liquefaction, while the steep uplands north and east of the Hayward fault zone are classified as having "very low" susceptibility; most of the rest of the city has been assigned a "moderate" or "low" susceptibility-level ranking. (This map may be viewed at gis.abag.ca.gov/website/liq/viewer.htm.) ABAG has also produced maps of the liquefaction *hazard* by combining the level of liquefaction susceptibility (see above) with the probability of earthquake-induced ground shaking that is strong enough to trigger liquefaction. On these maps, land is classified according to four liquefaction-hazard levels: very low, moderately low, moderate and high. These maps show that the liquefaction hazard in Oakland under a representative 7.1 earthquake along the north and south segments of the Hayward fault is considered "high" throughout most of West Oakland, downtown and East Oakland, in parts of North Oakland and Fruitvale, and along the Estuary shoreline; "moderate" in an area centered on the I-580/I-980 interchange; and "moderately low" or "very low" in the rest of the city. (These maps can be found at www.abag.ca.gov/bayarea/eqmaps/liquefac/pickcityliq.html.)

Subsidence and settlement Subsidence is the gradual settling of land; it occurs primarily as a result of the prolonged and excessive withdrawal of groundwater, which lowers the water table and causes the ground to sink. Subsidence is of little concern in Oakland, where water is drawn mostly from reservoirs rather than from wells. Settlement is the gradual downward movement of land and engineered structures due to the compaction of unconsolidated material underneath. Settlement can occur from natural soil consolidation, from seismically innduced soil compaction and from excessive structural loads. Since it usually occurs in areas of poorly consolidated soils, it generally affects those same areas that are subject to moderate or high liquefaction potential. Artificial fill—which settles over time, regardless of the quality of the material and previous degree of compaction—is especially susceptible to settlement. The degree of settlement depends on the compressibility, depth and density of the soil.

Settlement of a building can occur uniformly or differentially. Uniform settlement can cause a building to sink, leading to poor drainage and the potential failure of utility connections. Differential settlement—from variations in soil thickness and compaction rates—can cause a building to tilt, creating structural and mechanical problems. Settlement also has the potential to crack roads and utility systems and should be a consideration in development proposed on landfilled areas especially, and in hillside areas where slopes have been filled to reduce their gradient. Because of the gradual, long-term nature of subsidence and settlement, these phenomena do not pose a life-safety hazard do result in property losses.

Slope instability Most sloping land has some landslide potential. The risks tend to be greatest where a number of contributing factors are present, including slopes over 15 percent, weak, unconsolidated or shallow soils, water saturation, a history of landslides, active earthquake faults, extensive grading and vegetation removal (from fires or development activity). The slide itself is usually triggered by an earthquake, heavy rain or misdirected runoff. Landslides are a relatively common hazard in the East Bay hills, especially during and soon after heavy rainstorms, when the ground is saturated. Mudslides—fast, shallow movements of water-saturated earth that flow as muddly slurries, typically following water courses—are the most common type of landslides in Oakland; they are also known as debris flows or soil slumps.

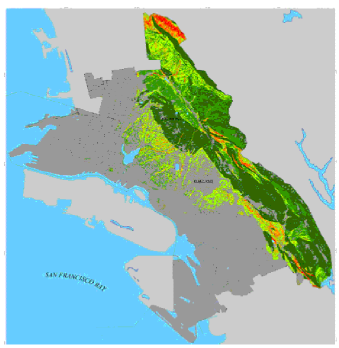
More than half of Oakland's area, including most of its vacant land, consists of gently sloping or hilly land. Moreover, approximately one-quarter of the city, including all of the Oakland Hills, contains slopes greater than 15 percent. Slopes of 15-30 percent are considered developable but are likely to require site modification or special grading or foundation design to reduce the potential for slope instability. Slopes of that degree are found in Oakland throughout the southern Oakland Hills, in the roughly triangular area formed by I-580 and highways 13 and 24, in the vicinity of Mills College and Eastmont, and on some of the hills around Lake Merritt. Development on slopes exceeding 30 percent is considered difficult and potentially hazardous. Such slopes are concentrated throughout the Oakland Hills (especially in the northern hills) and within two miles south of Highway 13. In these areas there exist isolated slopes as steep as 75 percent.

Landslides in Oakland have usually been triggered not by seismic activity but by heavy rains, the modification of creek channels, or improper grading and development activity. Over twenty significant landslides have occurred in Oakland during the last seven decades or so, generally within a mile-wide band along the Hayward fault (see Figure 3.1). Clusters of slide activity exist in the Eastmont Ridge around King Estates, in Redwood Heights, in Shepherd and Snake canyons, and in Dimond Canyon and further downstream on Sausal Creek. Landslides have cracked foundations, structures and retaining walls, and have damaged roads, sidewalks and trails; also, debris and mud from landslides have blocked roads, clogged drainage channels and dammed streams and creeks. A slide near McKillop Road, near the Central reservoir, in the 1930s, swallowed half a city block; the slide area was subsequently dedicated as Wood Park. Land stability is a concern in the area of the 1991 firestorm, which burned off much of the surface vegetation, leaving loose soil, ash and debris. Although interim erosion-control measures were taken after the fire, there is still a concern about shallow and deep-seated landslides that could occur under heavy rainfall.

The landslide hazard in the Oakland Hills is exacerbated by the fact that the area is crossed by the Hayward fault. During a major earthquake on that fault, landsliding, widespread failure of steep slopes and the collapse of natural stream banks could be expected in the hills in response to strong ground movements anticipated to occur in the area. Landslides could block roads, which would hamper evacuation, firefighting and relief operations within the area. Nevertheless, landslides are not expected to produce a large-scale disaster; rather, they present a persistent risk of damage to buildings and infrastructure in areas of potentially unstable slopes. Landslides would affect only scattered structures located in the direct path, but could result in some loss of life, from the collapse of structures and tumbling earth, rocks and debris. Although the landslide hazard cannot be completely eliminated, damage can be minimized by following proper development practices or by steering development away from areas of unstable slopes. Sound practices and techniques include drainage provisions to avoid oversaturation of the soil, setbacks between structures and filled slope areas, retaining walls, and the use of detailed soil investigations. While efforts have been taken by the city through the development process to minimize landslide potential, most hillside development predates the imposition of grading and related requirements. For this reason, older hillside homes and subdivisions are the most susceptible to damage from landslides. In addition, development continues to occur on slopes greater than 30 percent, and the city's general-plan and zoning designations do not reflect slope differentials. In fact, there are areas in the city with slopes greater than 50 percent that are still zoned for residential use.

Pursuant to the state's Seismic Hazards Mapping Act (see paragraphs on liquefaction, above, and also previous section), the California Geological Survey has produced official maps showing those areas of Oakland (and of other parts of the state) where previous occurrence of landslides, or local topographic, geological, geotechnical and subsurface-water conditions, indicate the potential for earthquake-induce landslides. As for the liquefaction hazard, mentioned above, these maps are intended to delineate "zones of required investigation," or those areas encompassing sites for which local jurisdictions must withhold development permits until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures are incorporated into development plans. The state's seismic hazard zone maps indicate that most of the upper Oakland Hills, and also scattered areas of the lower hills, are susceptible to earthquake-induced landslides (see Figure 3.1).

In addition, USGS has produced a map describing the landslide hazard in Oakland and Piedmont resulting from an earthquake of magnitude 7.1 on the Hayward fault. The magnitude of this scenario is associated with complete rupture of the northern and southern segments of the Hayward fault, an event that has an estimated return period of approximately 500 years. Also, the modeled hazard corresponds to completely saturated groundwater conditions resulting from an extreme storm event. Needless to say, this scenario represents a particularly severe hazard state; the overall hazard would be less for dry groundwater conditions, though relative patterns of hazard are likely to change. The map includes six levels of hazard (which should be interpreted on a relative basis): low, moderately low, moderate, moderately high, high and very high. Most areas of highest hazard are associated with relatively weak bedrock units east of the Hayward fault, but some areas of "moderate" to "very high" hazard also exist west of the fault. (This map can be found at geopubs.wr.usgs.gov/map-mf/mf2379 .)



In advance of major storms anticipated from the 1997-1998 El Niño event, USGS also created maps delineating the distribution of past landslides throughout the San Francisco Bay Area (since the best available predictor of future landslides is previous occurrences). Past landslides are evident in the landscape from their distinctive topographic shapes (which can persist for thousands of years), and can be recognized through aerial photography. The maps classify land under four categories: "mostly landslide," "many landslides," "few landslides" and "flat land" (areas of gentle slope at low elevation that have little or no potential for slope failure). Predictably, the areas in Oakland classified as "mostly landslide" or consisting of "many landslides" are concentrated in the upper Oakland Hills, especially north of Joaquin Miller Park. (The Oakland map may be viewed at wrgis.wr.usgs.gov/open-file/of97-745/oakdl.html .) Finally, USGS has also created a map estimating the susceptibility to slope failure by landsliding and earthflow in the metropolitan Oakland area. The model combines four sources of data for the area to arrive at the susceptibility index: the area's varying types of bedrock and geologic units, the topographic shape of the land surface, and inventories of old landslide deposits and of post-1970s landslides that caused damage to the built environment. (This map can be found at geopubs.wr.usgs.gov/map-mf/mf2385 .)

Erosion Erosion is a naturally occurring phenomenon and ordinarily is not hazardous. However, the rate of erosion can be easily aggravated by development, as vegetation is removed and impervious-surface coverage increases. Hillside construction usually requires the movement of earth to ensure that roads, utilities and structures are stabilized, while on steeper sites grading may require major cutting and filling. Excessive erosion from these activities can contribute to landslides, siltation of water bodies, obstruction of storm drains, and the undermining of building foundations. Erosion and sedimentation from development activities can be greatly reduced if soil disturbance and tree removal are kept to a minimum, especially during the rainy season, and if disturbed areas are quickly revegetated. Engineered solutions, such as culverts and retaining walls, can be effective but also might be less desirable than natural solutions due to their visual and environmental impacts.

The U.S. Department of Agriculture has classified Oakland into four categories reflecting erosion potential. The bay plain, or flatlands, where slopes are typically less than five percent, have "low" erosion potential; in these areas, the greatest erosion risk exists along streambanks. Areas with "moderate" potential for erosion include those with slopes between five and 30 percent; in these areas, sheet erosion, gullying, streambank failure, and slumping may occur, and landsliding on artificial slopes is possible, especially where the soil is underlain by weathered or highly fractured bedrock. "High" erosion potential exists in areas with steep terrain, where rainfall averages 25 inches or more, and where the bedrock is deeply weathered or fractured; here, significant gullying occurs where vegetation has been removed, and the landslide hazard is usually present. Finally, areas of "extreme" erosion potential are those underlain by active landslides, with little or no vegetation, and moderate to heavy amounts of rainfall. Additional information on erosion is found in Chapter 6, "Flooding Hazards."

Soils The city's shoreline areas pose significant development constraints. Areas of fill and of weak, compressible soils are susceptible to liquefaction in the event of an earthquake, while settlement in these areas may cause cracking of building foundations and of roads. In addition, shoreline areas are subject to erosion from wave and tidal action. Soils in the bay plain are characterized by low erosion potential and tend to be the best-suited for development. The Oakland Hills are characterized by steep slopes, weak bedrock, rocky soils and local landslide deposits; soils in the area have relatively low structural stability, surface and gully erosion is common, and the potential exists for further landslides in many areas. In general, soils south and west of the Hayward fault are deep, more fine-textured and less well drained than soils north and east of the fault.

The water table is relatively high near the bay and somewhat lower inland; generally, it can be found within just a few feet of the surface. North and east of the Hayward fault, the soils are well drained, are shallow to moderately deep, and have moderate permeability and low-to-moderate water-holding capacity. The groundwater level is relatively high due to the impervious barrier formed by pulverized materials on the fault zone.

In the early 1980s, the U.S. Department of Agriculture evaluated the ability of each soil type in Oakland to support development in the city. Soils were classified as having "low," "moderate" or "severe" limitations for development based on their shrink-swell potential, slope, strength, wetness, depth to bedrock and flooding potential. (Shrink-swell is a cyclic change in volume that occurs in fine-grained sediments due to the expansion and contraction of clay caused by wetting and drying.) Most of the local soils were evaluated as having "severe" limitations in one or more of these categories. In steeper areas of the city, slope was the most severe constraint, occasionally accompanied by shrink-swell potential. In the flatland areas, shrink-swell was the most common severe constraint. The potential for shrink-swell is highest in areas underlain by Bay Mud and in the fine-grained basin deposits which contain high quantities of expansive clay derived from the uplands by erosion. The alluvial deposits in the flatlands may also contain large quantities of expansive clay at the surface. Low soil strength also appears as a common constraint. Because of the relatively minor economic losses resulting from shrink-swell behavior and low soil strength, these phenomena are rarely insurmountable obstacles to development; they do, however, necessitate special design and construction techniques, which increases development costs. Finally, in historically flood-prone areas, wetness and flooding were also rated as severe problems. To some extent, these constraints have been mitigated through development of the city's drainage system (see Chapter 6, "Flooding").

Structural hazards The extent of damage to structures resulting from an earthquake depends on the magnitude of the event, the distance from the epicenter, the response of the underlying geologic materials, and the strength and construction quality of the buildings. It has been shown that weak soil and geologic conditions are a greater seismic hazard than proximity to an earthquake's fault and epicenter. Because ground motion on water-saturated materials is amplified and lasts longer, and also because of the tendency for unconsolidated materials to deform to a greater degree, structures located on these materials suffer far greater damage than those built on solid rock. During an earthquake, buildings constructed on bay mud may experience differential settlement while those built on landfill may collapse as the soil gives out under them. High-rise buildings on "poor," or unstable, soils could experience violent shaking but should not suffer major damage if built on pile foundations. In areas of high landslide potential, structural damage could occur from inundation by debris from above or from the loss of ground support from under a building. Structural damage and collapse could also occur due to lateral spreading of soils (on stream banks, for example) or due to lurch cracking (if cracks in ground materials spread into building foundations).

In general, the older the building, the less likely it is to meet provisions in the current Uniform Building Code (UBC) relating to earthquake impacts and the more likely it is to suffer damage during an earthquake. (Increasingly stringent earthquake standards have been included in updates to the UBC since the 1933 Long Beach earthquake.) In Oakland, older buildings are concentrated downtown and in other older parts of the city, and many of those buildings are constructed of unreinforced stone, brick, block and other types of masonry. These unreinforced masonry (URM) buildings are the structures most prone to collapse from strong ground shaking (or to require demolition afterward), and have the highest potential to result in death and injury, from collapsing walls, floors, roofs and parapets. Recognizing this hazard, the state in 1986 passed SB 547, a law requiring cities and counties to prepare an inventory of potentially hazardous masonry buildings and adopt ordinances to improve or replace these structures. Oakland's survey was conducted in 1989. Soon after, owners of such buildings were notified of the hazard and have since been required, with certain exceptions, to retrofit their buildings or otherwise reduce the risk of death and injury from their collapse during an earthquake. There are approximately 870 buildings on the city's list of potentially hazardous URM buildings, the majority of which are located downtown and were built during the first half of the twentieth century. In addition to those URM buildings, there are thousands of existing buildings that were constructed before the UBC was in effect.

Other types of buildings that may suffer serious damage are older steel- and concrete-frame buildings that were not designed to resist earthquake vibrations, and buildings with concrete frames and tilt-up walls constructed before 1974 (when less-strict building codes were in place). On the other hand, newer, small steel-frame buildings generally are the safest non-residential structures, while newer concrete tilt-ups pose a slightly greater risk. Steel-frame buildings generally perform well under strong shaking, and are the preferred type of construction for highrises in seismically active areas. Nonetheless, even on well-designed buildings, non-structural parts such as windows, chimneys, façade panels, ornamental features, light fixtures, mechanical equipment and furniture may break or fall and injure occupants or people outside the building. Industrial facilities present special hazards not only to their occupants but also to the surrounding community because of the potential for the release of hazardous materials used or stored onsite (see more information under Chapter 5, "Hazardous Materials").

The majority of single-family or small multi-unit residential buildings in Oakland are one- or two-story structures of wood-frame construction. These are the structures least likely to collapse from earthquake shaking due to their low-elevation design and the inherent flexibility of wood as a building material; serious damage would be rare, even during strong earthquakes, except where directly affected by ground rupture, landsliding, or extremely high ground acceleration. Nonetheless, damage could result from even moderate shaking to relatively inflexible building elements such as chimneys, porches, stucco and utility lines, and occupants could suffer harm from broken glass and falling furniture. Also, older residences with inadequate foundation-to-frame connections or which have been weakened by rot or termite infestation may slip or break from their footings, rupturing utility connections. In these cases, foundation bolts, shear walls and other strengthening devices would minimize potential property damage.

While it is impossible to prevent earthquakes, the loss and damage resulting from them can be minimized through proper design of structures and land-use development. Given the short supply of developable land in Oakland, it can be expected that future development will increasingly occur in areas with geologic constrains. For this reason, geological investigations and greater oversight of engineering practices and construction techniques will need to become increasingly important elements of the development process. Since major earthquakes will continue to occur in the Bay Area, structures—especially in areas of potential soil instability—must be designed to withstand significant shaking without collapse in order to minimize the loss of life. At the same time, the safety of existing buildings must be upgraded whenever possible. The most common method for doing so is to require improvements when building permits are issued for major additions or repairs. (The UBC requires compliance with all current code provisions if the work being done exceeds 50 percent of the value of the existing structure.) Unfortunately, there is no comprehensive and systematic inventory of "dangerous buildings." Existing generalized sources of information are inadequate for even large-area and general assessments of the location and number of hazardous structures, while sources of information on individual buildings are insufficient for the diagnosis of structural problems. Nevertheless, it is clear that priority for seismic structural-safety programs should be given to critical structures (including high-occupancy buildings and industrial facilities), especially those located in geologically hazardous areas, and also to older structures and other hazardous building types. It is particularly important that emergency-related facilities such as hospitals, fire stations and emergency shelters be designed or strengthened to remain operative following an earthquake. The proper functioning of these facilities after a disaster is essential in preventing additional casualties and damage.

Transportation facilities Roads, railroads and ports play an essential role in emergency response and recovery by allowing for evacuation and the movement of emergency vehicles and supplies. Unfortunately, transportation systems are vulnerable to damage from major earthquakes. Because of their lineal nature, roads and tracks often cross earthquake faults and areas susceptible to ground failure, and can break and buckle or become blocked in the event of landslides. On the other hand, while pavement and road beds might be damaged, at-grade roads (but not tracks) usually remain passable; in any event, emergency routes can often be improvised. Elevated structures such as bridges, trestles and freeway overpasses and interchanges would be affected much more seriously by earthquake-fault rupture, and would be particularly expensive and time-consuming to repair.

In the event of strong ground motion, bay mud, fill and other weak soils underlying much of the Eastshore Freeway, approaches to the Bay Bridge and the I-80/I-580/I-880 "maze" could be subject to settlement and subsidence. Damage to I-580 south of Mills College and to Highway 13, which are built over or near the Hayward fault, could be extensive under an earthquake centered on that fault; at the same time, those thoroughfares could become blocked from landslides as natural and cut slopes above fail in response to strong ground motion. A number of grade-separated structures in the area, most importantly the Highway 13/Highway 24 and Highway 13/I-580 interchanges, could be damaged if major surface displacement occurs along the Hayward fault. (Following the experiences of the 1989 Loma Prieta earthquake and the 1991 Northridge earthquake, Caltrans has improved the earthquake performance of those interchanges and of many other highway structures statewide under its jurisdiction.) Following a major earthquake, transportation across Highway 13/I-580 could be disrupted, including for emergency vehicles and road closures could make portions of the Oakland Hills isolated and unreachable for many hours if not a few days. Citywide, should the freeway system be so impaired as to prvent access from other areas, supplies could still be delivered through Oakland's airport and seaport. However, those facilities are themselves vulnerable to damage as they are situated on structurally poor ground, namely fill overlying bay mud or marshland. Finally, the Bay Area Rapid Transit (BART) system was designed and built with earthquake impacts in mind, as shown by its ability to withstand the Loma Prieta earthquake. Nevertheless, in Oakland, BART's tracks and overhead structures cross structurally poor soils, so track distortion can be expected from even a moderately intense earthquake. To minimize the potential for train derailment, BART has installed seismic-motion sensors along the system, and has developed procedures to restrict train movement until tracks have been inspected and any damage has been corrected.

Utility systems Modern life is made possible by a pervasive network of utility systems that includes water-transmission and distribution mains, reservoirs and water tanks, sewer mains, water-treatment and sewage-treatment plants, pipelines, telecommunications lines and transmission facilities, and gas and electric lines and substations. As could be expected, these systems are vulnerable to damage from fault rupture, landsliding, and major ground subsidence and liquefaction induced by ground shaking. Underground components may break or rupture during major earthquakes; aboveground elements are also vulnerable, but are usually easier and cheaper to restore.

Most utility lines in Oakland have been built to withstand some degree of fault displacement without major damage, and are equipped with valves (both manual and automatic) to control or shut off flows at various points, especially near the Hayward fault. However, none of the systems crossing the Hayward fault have been subjected to lateral offsets of more than several inches, and it can be expected that many would fail under a possible offset of several feet. In the event of a major earthquake, damage to utility lines and service disruption of up to several days is possible in areas traversed by the Hayward fault, subject to landsliding or with structurally poor soils. Damage due to liquefaction and subsidence can be expected to utility facilities constructed atop bay mud or other saturated soils, most notably some of the facilities at EBMUD's sewage treatment plant (located at 2020 Wake Avenue) and the interceptors leading to it. Utility-service disruption would be minimal in areas subject only to ground shaking as most utility lines are flexible enough to withstand shaking without significant damage. All utility providers in the Bay Area have implemented or are in the process of implementing seismic improvement programs to strengthen and retrofit critical system facilities; an example is EBMUD's $189 million program begun in 1995 to reinforce its reservoirs and major water lines over a ten-year period. It is worth mentioning that EBMUD has developed water mains on both sides of the Hayward fault to minimize potential service disruption through system redundance, and that it has strengthened and added valves at fault crossings so that flexible lines could be installed quickly if pipes did rupture.

3.4 | Policy Statements Related to Geologic Hazards

Policy GE-1	Develop and continue to enforce and carry out regulations and programs to reduce seismic hazards and hazards from seismically triggered phenomena.

- Action GE-1.1: Continue to enforce the geologic reports ordinance by requiring site-specific geologic reports for development proposals in the Hayward fault Special Studies Zone, and restricting the placement of structures for human occupancy within fifty feet of the trace.

  ▶ **CEDA Building Services Division**

- Action GE-1.2: Enact regulations requiring the preparation of site-specific geologic or geotechnical reports for development proposals in areas subject to earthquake-induced liquefaction, settlement or severe ground shaking, and conditioning project approval on the incorporation of necessary mitigation measures.

  ▶ **CEDA Building Services Division**

- Action GE-1.3: Continue to update the city's geologic-hazard mapping system based on new information from state and federal agencies and site-specific investigations.

  ▶ **CEDA Building Services Division**

Policy GE-2	Continue to enforce ordinances and implement programs that seek specifically to reduce the landslide and erosion hazards.

- ACTION GE-2.1: Continue to enforce provisions under the subdivision ordinance requiring that, under certain conditions, geotechnical reports be filed and soil-hazards investigations be made to prevent grading from creating unstable slopes, and that any necessary corrective actions be taken.

  ▶ **CEDA BUILDING SERVICES DIVISION**

- ACTION GE-2.2: Continue to enforce the grading, erosion and sedimentation ordinance by requiring, under certain conditions, grading permits and plans to control erosion and sedimentation.

  ▶ **CEDA BUILDING SERVICES DIVISION**

- ACTION GE-2.3: Continue to enforce provisions under the creek protection, storm water management and discharge control ordinance designed to control erosion and sedimentation.

  ▶ **PWA ENVIRONMENTAL SERVICES DIVISION**
  ▶ **CEDA BUILDING SERVICES DIVISION**

- ACTION GE-2.4: Consider establishing area-specific interdepartmental task forces, with public participation, to recommend changes to the zoning ordinance to better address hillside development constraints, especially steeply sloping sites and infrastructure availability.

  ▶ **CEDA PLANNING AND ZONING DIVISION**
  ▶ **PWA ENVIRONMENTAL SERVICES DIVISION**

- ACTION GE-2.5: Enact regulations requiring new development projects to employ site-design and source-control techniques to manage peak stormwater runoff flows and impacts from increased runoff volumes.

  ▶ **CEDA BUILDING SERVICES DIVISION**

- ACTION GE-2.6: Design fire-preventive vegetation-management techniques and practices for creeksides and high-slope areas that do not contribute to the landslide and erosion hazard.

  ▶ **OFD SUPPORT SERVICES DIVISION**

POLICY GE-3 Continue, enhance or develop regulations and programs designed to minimize seismically related structural hazards from new and existing buildings.

- Action GE-3.1: Adopt and amend as needed updated versions of the California building code so that optimal earthquake-protection standards are used in construction and renovation projects.
  ▶ **CEDA Building Services Division**

- Action GE-3.2: Continue to enforce the unreinforced masonry ordinance to require that potentially hazardous unreinforced masonry buildings be retrofitted or be otherwise made to reduce the risk of death and injury from their collapse during an earthquake.
  ▶ **CEDA Building Services Division**

- Action GE-3.3: Continue to enforce the earthquake-damaged structures ordinance to ensure that buildings damaged by earthquakes are repaired to the extent practicable.
  ▶ **CEDA Building Services Division**

- Action GE-3.4: Consider developing a program to encourage, assist or provide incentives to owners of single-family homes or small apartment buildings in retrofitting their buildings for seismic safety.
  ▶ **CEDA Building Services Division**

Policy GE-4 Work to reduce potential damage from earthquakes to "lifeline" utility and transportation systems.

- Action GE-4.1: Encourage Caltrans to expedite the retrofit of city- and county-owned highway overpasses in Oakland identified as candidates for seismic strengthening for which Caltrans is the lead agency.
  ▶ **PWA Transportation Services Division**

- Action GE-4.2: As knowledge about the mitigation of geologic hazards increases, encourage public and private utility providers to develop additional measures to further strengthen utility systems against damage from earthquakes, and review and comment on proposed mitigation measures.
  ▶ **PWA Electrical Services Division**

- Action GE-4.3: Encourage BART to prioritize its program for retrofitting the system's aerial structures, stations and Transbay Tube for seismic safety over expansion of the system.
  ▶ **PWA Transportation Services Division**

- ACTION GE-4.4: Continue to designate underground utility districts for the purpose of replacing aboveground electric and phone wires and other structures with underground facilities, and use the planning-approval process to ensure that all new utility lines will be installed underground from the start.

  ▶ **PWA ELECTRICAL SERVICES DIVISION**
  ▶ **CEDA PLANNING AND ZONING DIVISION**

3.5 | RESOURCES

Agencies consulted

- U.S. Geological Survey (www.usgs.gov)
- California Geological Survey (www.conservation.ca.gov/cgs)
- California State Mining and Geology Board (www.conservation.ca.gov/smgb)
- California Seismic Safety Commission (www.seismic.ca.gov)
- California Building Standards Commission (www.bsc.ca.gov)
- Association of Bay Area Governments (www.abag.ca.gov)
- Oakland Public Works Agency (www.oaklandpw.com)
- Oakland Community and Economic Development Agency (www.oaklandnet.com/government/ceda/revised/ceda.html)

Documents consulted

- "Fault-rupture Hazard Zones in California;" California Department of Conservation, California Geological Survey, revised 1997 (ftp.conservation.ca.gov/pub/dmg/pubs/sp/Sp42.pdf).
- "Guidelines for Evaluating and Mitigating Seismic Hazards in California" (Special Publication 117); California Geological Survey, 1997.
- "Recommended Criteria for Delineating Seismic Hazards Zones in California" (Special Publication 118); California Geological Survey, 1999.
- "Earthquake Probabilities in the San Francisco Bay Region;" Working Group on California Earthquake Probabilities, 2003; U.S. Geological Survey open-file report 03-214.

Other resources

- USGS' "Geologic Hazards" (geohazards.cr.usgs.gov)

- U.S. Geological Survey: www.usgs.gov; geologic hazards page: geohazards.cr.usgs.gov; San Francisco Bay region landslide folio: wrgis.wr.usgs.gov/open-file/of97-745
- ABAG earthquake maps and information (quake.abag.ca.gov)

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