SECTION 6: EARTHQUAKES

Table of Contents

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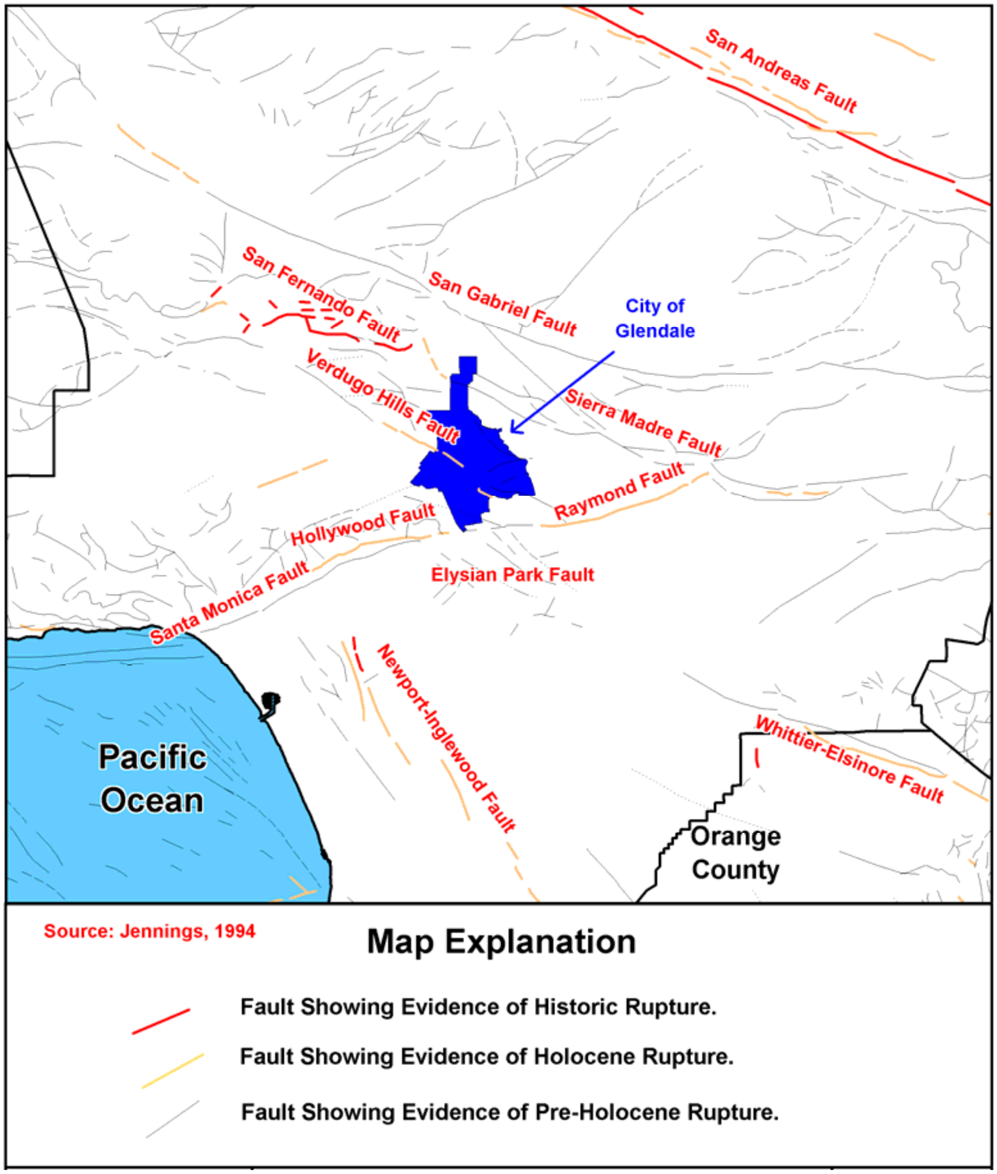
Why Are Earthquakes a Threat to the City of Glendale?

While Glendale is at risk from many natural and man-made hazards, an earthquake is the event with the greatest potential for far-reaching loss of life or property, and economic damage. This is true for most of southern California, since damaging earthquakes are frequent, affect widespread areas, trigger many secondary effects, and can overwhelm the ability of local jurisdictions to respond. Earthquake-triggered geologic effects include ground shaking, surface fault rupture, landslides, liquefaction, subsidence, and seiches. Earthquakes can also cause human-made hazards such as urban fires, dam failures, and toxic chemical releases.

In California, recent earthquakes in or near urban environments have caused relatively few casualties. This is due more to luck than design. For example, when a portion of the Nimitz Freeway in Oakland collapsed at rush hour during the 1989, M_W 7.1 Loma Prieta earthquake, it was uncommonly empty because so many were watching the World Series. The 1994, M_W 6.7 Northridge earthquake occurred before dawn, when most people were home safely in bed. Despite such good luck, California's urban earthquakes have resulted in significant losses. The moderate-sized Northridge earthquake caused 54 deaths, more than 1,500 injuries and nearly $30 billion in damage. For days afterward, thousands of homes and businesses were without electricity; tens of thousands had no gas; and nearly 50,000 had little or no water. Approximately 15,000 structures were moderately to severely damaged, which left thousands of people temporarily homeless. Several collapsed bridges and overpasses created commuter havoc on the freeway system. Extensive damage was caused by ground shaking, with shaking-induced liquefaction and dozens of fires after the earthquake causing additional severe damage. This moderately sized earthquake resulted in record economic losses, and yet Glendale is at risk from earthquakes that could release more than ten times the seismic energy of the Northridge earthquake.

Historical and geological records show that California has a long history of seismic events. Southern California is probably best known for the San Andreas fault, a 750-mile long fault running from the Mexican border to a point offshore west of San Francisco. Geologic studies show that over the past 1,400 to 1,500 years, large earthquakes have occurred on the southern San Andreas fault at about 130-year intervals. As the last large earthquake on the southern San Andreas occurred in 1857, that section of the fault is considered a likely location for an earthquake within the next few decades. The San Andreas fault, however, is only one of dozens of known faults that criss-cross southern California. Some of the better-known faults include the Sierra Madre, Newport-Inglewood, Whittier, Elsinore, Hollywood, and Palos Verdes faults. Of these, the Sierra Madre and Hollywood faults extend through the northern and southwestern portions, respectively, of Glendale, whereas the lesser-known, but active Verdugo and Raymond faults extend through the central and southeastern portions of Glendale (see Map 6.1). Beyond these known faults, there are several "blind" faults that underlie southern California. [“Blind” faults do not break the surface, but rather occur thousands of feet below the ground. They are not less of a seismic hazard, though]. One such blind fault ruptured causing the Whittier Narrows earthquake in October 1987. Each of these faults is capable of producing, at a minimum, a moderate-sized earthquake that has the potential to inflict great damage on the urban core of the Los Angeles basin. For example, seismologists believe that a 6.0 to 6.5 earthquake on the Newport-Inglewood fault would result in far more death and destruction than a "great" quake on the San Andreas fault, because the San Andreas is relatively remote from the urban centers of southern California.

Map 6.1: Faults In and Near Glendale



Although great advances in earthquake engineering have been made in the last decade, in great part as a result of the 1994 Northridge, California, 1995 Kobe, Japan, 1999 Izmit, Turkey and 1999 Chi-Chi, Taiwan earthquakes, the majority of California communities remain unprepared because there is a general lack of understanding regarding earthquake hazards among Californians. It is not possible to prevent earthquakes, but their destructive effects can be minimized. Comprehensive hazard mitigation programs that include the identification and mapping of hazards, prudent planning, public education, emergency exercises, enforcement of building codes, and expedient retrofitting and rehabilitation of weak structures can significantly reduce the scope of an earthquake's effects and avoid disaster. Local government, emergency relief organizations, and residents must take action to develop and implement policies and programs to reduce the effects of earthquakes.

Earthquake Basics - Definitions

The outer 10 - 70 kilometers of the Earth consist of enormous blocks of moving rock, called **plates**. There are about a dozen major plates, which slowly collide, separate, and grind past each other. In the uppermost plates, friction locks the plate edges together, while movement continues at depth. Consequently, the near-surface rocks bend and deform near plate boundaries, storing strain energy. Eventually, the frictional forces are overcome and the locked portions of the plates move. The stored strain energy is released in waves.

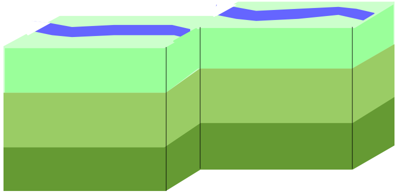
By definition, the break or fracture between moving blocks of rock is called a **fault**, and such differential movement produces a **fault rupture**. The place where the fault first ruptures is called the **focus** (or **hypocenter**). The released energy waves radiate out in all directions from the rupture surface, making the earth vibrate and shake as the waves travel through. This shaking is what we feel in an **earthquake**.

Although faults exist everywhere, most earthquakes occur on or near plate boundaries. Thus, southern California has many earthquakes, because it straddles the boundary between the North American and Pacific plates, and fault rupture accommodates their motion. The Pacific Plate is moving northwesterly, relative to the North American Plate, at about 50 mm/yr. This is about the rate at which fingernails grow, and seems unimpressive. However, it is enough to accumulate enormous amounts of strain energy over dozens to thousands of years. Despite being locked in place most of the time, in another 15 million years (a short time in the context of the Earth's history), due to plate movements, Glendale will be hundreds of kilometers north of San Francisco.

Although the San Andreas fault marks the actual separation between the Pacific and North American plates, only about 70 percent of the plate motion occurs on the San Andreas fault itself. The rest is distributed among other faults of the San Andreas system, including the San Jacinto, Whittier-Elsinore, Newport-Inglewood, Palos Verdes, plus several offshore faults; and among faults of the Eastern Mojave Shear Zone, a series of faults east of the San Andreas, responsible for the 1992 Landers and 1999 Hector Mine earthquakes. (M_W stands for moment magnitude, a measure of earthquake energy release, discussed below.) Thus, the zone of plate-boundary earthquakes and ground deformation covers an area that stretches from the Pacific Ocean to Nevada.

Because the Pacific and North American plates are sliding past each other, with relative motions to the northwest and southeast, respectively, all of the faults mentioned above are aligned northwest-southeast, and are **strike-slip faults**. On average, strike-slip faults are nearly vertical breaks in the rock, and when a strike-slip fault ruptures, the rocks on either side of the fault slide horizontally past each other.

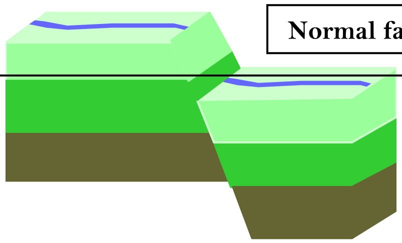
However, about 75 miles northeast of Glendale, there is a kink in the San Andreas fault, commonly referred to as the "Big Bend." Near the Big Bend, the two plates do not slide past each other. Instead, they collide, causing localized compression, resulting in folding and **thrust faulting**. Thrust faults meet the surface of the Earth at a low angle, dipping 25 – 45 degrees from the horizontal. Thrusts are a type of **dip-slip fault**, where rocks on opposite sides of the fault move up or down relative to each other. When a thrust fault ruptures, the top block of rock moves up and over the rock on the other side of the fault.

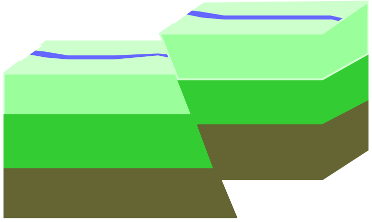


Strike-slip faults are vertical or almost vertical rifts where the earth's plates move mostly horizontally. From the observer's perspective, if the opposite block looking across the fault moves to the right, the slip style is called a right- lateral fault; if the block moves left, the shift is called a left-lateral fault.

Normal fault

Reverse fault





Dip-slip faults are slanted fractures where the blocks mostly shift vertically. If the earth above an inclined fault moves down, the fault is called a normal fault, but when the rock above the fault moves up, the fault is called a reverse fault. Thrust faults are reverse faults with a dip of 45 ° or less.

Few faults are simple, planar breaks in the Earth. They more often consist of smaller **strands**, with a similar orientation and sense of movement. Sometimes geologists group strands into **segments**, which are believed capable of rupturing together during a single earthquake. The more extensive the fault, the bigger the earthquake it can produce. Therefore, multi-strand fault ruptures produce larger earthquakes.

The bigger and closer the earthquake, the greater the likelihood of damage. Thus fault dimensions and proximity to urban centers are key parameters in any hazard assessment. In addition, it is important to know a fault's style of movement (i.e. is it dip-slip or strike-slip), the age of its most recent activity, its total displacement, and its slip rate (all discussed below). These values indicate how often a fault produces damaging earthquakes, and how big an earthquake should be expected the next time the fault ruptures.

Total displacement is the length, measured in kilometers (km), of the total movement that has occurred along the fault over as long a time as the geologic record reveals. It is usually estimated by measuring distances between geologic features that have been split apart and separated (**offset**) by the cumulative movement of the fault over many earthquakes. **Slip rate** is a speed, expressed in millimeters per year (mm/yr). Slip rate is estimated by measuring an amount of offset accrued during a known amount of time, obtained by dating the ages of geologic features. Slip rate data also are used to estimate a fault's **earthquake recurrence interval**. Sometimes referred to as "repeat time" or "return interval", the recurrence interval represents the average amount of time that elapses between major earthquakes on a fault. The most specific way to derive recurrence interval is to excavate a trench across a fault to obtain **paleoseismic** evidence of earthquakes that have occurred during prehistoric time.

In southern California, ruptures along thrust faults have built the Transverse Ranges geologic province, a region with an east-west trend to its landforms and underlying geologic structures. This orientation is anomalous, virtually unique in the western United States, and a direct consequence of the plates colliding at the Big Bend. Many of southern California's most recent damaging earthquakes have occurred on thrust faults that are uplifting the Transverse Ranges, including the 1971 San Fernando, the 1987 Whittier Narrows, the 1991 Sierra Madre, and the 1994 Northridge earthquakes. Thrust faults can be particularly hazardous because many are **blind thrust faults**, that is, they do not extend to the surface of the Earth. These faults are extremely difficult to detect before they rupture. Some of the most recent earthquakes, like the 1987 Whittier Narrows earthquake, and the 1994 Northridge earthquake, occurred on blind thrust faults.

When comparing the sizes of earthquakes, the most meaningful feature is the amount of energy released. Thus scientists most often consider **seismic moment**, a measure of the energy released when a fault ruptures. We are more familiar, however, with scales of **magnitude,** which measure amplitude of ground motion. Magnitude scales are logarithmic. Each one-point increase in magnitude represents a ten-fold increase in amplitude of the waves as measured at a specific location, and a 32-fold increase in energy. That is, a magnitude 7 earthquake produces 100 times (10 x 10) the ground motion amplitude of a magnitude 5 earthquake. Similarly, a magnitude 7 earthquake releases approximately 1,000 times more energy (32 x 32) than a magnitude 5 earthquake. Recently, scientists have developed the **moment magnitude (M_w)** scale to relate energy release to magnitude. [The moment magnitude scale has replaced the Richter scale, which is no longer being used.]

An early measure of earthquake size still used today is the seismic **intensity scale**, which is a qualitative assessment of an earthquake's effects at a given location. Although it has limited scientific application, intensity is still widely used because it is intuitively clear and quick to determine. The most commonly used measure of seismic intensity is called the Modified Mercalli Intensity (MMI) scale, which has 12 damage levels (Table 6.1).

A given earthquake will have one moment and, in principle, one magnitude, although there are several methods of calculating magnitude, which give slightly different results. However, one earthquake will produce many intensities because intensity effects vary with the location and perceptions of the observer.

Table 6-1: Abridged Modified Mercalli Intensity Scale

Intensity Value and Description		Average Peak Velocity (cm/sec)	Average Peak Acceleration (g = gravity)
I.	Not felt except by a very few under especially favorable circumstances (I Rossi-Forel scale). Damage potential: None.	<0.1	<0.0017
II.	Felt only by a few persons at rest, especially on upper floors of high-rise buildings. Delicately suspended objects may swing. (I to II Rossi-Forel scale). Damage potential: None.	0.1 – 1.1	0.0017 – 0.014
III.	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel scale). Damage potential: None.		
IV.	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like a heavy truck striking building. Standing automobiles rocked noticeably. (IV to V Rossi-Forel scale). Damage potential: None. Perceived shaking: Light.	1.1 – 3.4	0.014 - 0.039
V.	Felt by nearly everyone; many awakened. Some dishes, windows, and so on broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel scale). Damage potential: Very light. Perceived shaking: Moderate.	3.4 – 8.1	0.039-0.092
VI.	Felt by all; many frightened and run outdoors. Some heavy furniture moved, few instances of fallen plaster and damaged chimneys. Damage slight. (VI to VII Rossi-Forel scale). Damage potential: Light. Perceived shaking: Strong.	8.1 - 16	0.092 -0.18
VII.	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars. (VIII Rossi-Forel scale). Damage potential: Moderate. Perceived shaking: Very strong.	16 - 31	0.18 - 0.34
VIII.	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, and walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed. (VIII+ to IX Rossi-Forel scale). Damage potential: Moderate to heavy. Perceived shaking: Severe.	31 - 60	0.34 - 0.65
IX.	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel scale). Damage potential: Heavy. Perceived shaking: Violent.	60 - 116	0.65 – 1.24
X.	Some well-built wooden structures destroyed; most masonry and frame structures destroyed; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks. (X Rossi-Forel scale). Damage potential: Very heavy. Perceived shaking: Extreme.	> 116	> 1.24
XI.	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.		
XII.	Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into air.		

Modified from Bolt (1999); Wald et al. (1999).

Causes of Earthquake Damage

Causes of earthquake damage can be categorized into three general areas: strong shaking, various types of ground failure that are a result of shaking, and ground displacement along the rupturing fault.

Ground shaking is the motion felt on the earth's surface caused by seismic waves generated by the earthquake. It is the primary cause of earthquake damage, and is typically reported as the peak horizontal ground acceleration estimated as a percentage of **g**, the acceleration of gravity. Full characterization of shaking potential, though, requires estimates of peak (maximum) ground displacement and velocity, the duration of strong shaking, and the periods (lengths) of waves that will control each of these factors at a given location. The strength of ground shaking also depends on the source, path, and site effects. Estimates of the ground shaking possible at different locations in California have been mapped, as shown on Map 6.2.

- **Source effects** include earthquake size, location, and distance, plus directivity of the seismic waves (for example, the 1995, M_W 6.9, Kobe, Japan earthquake was not much bigger than the 1994, M_W 6.7 Northridge, California earthquake, but Kobe caused much worse damage. During the Kobe earthquake, the fault's orientation and movement directed seismic waves into the city. During the Northridge earthquake, the fault's motion directed waves away from populous areas).

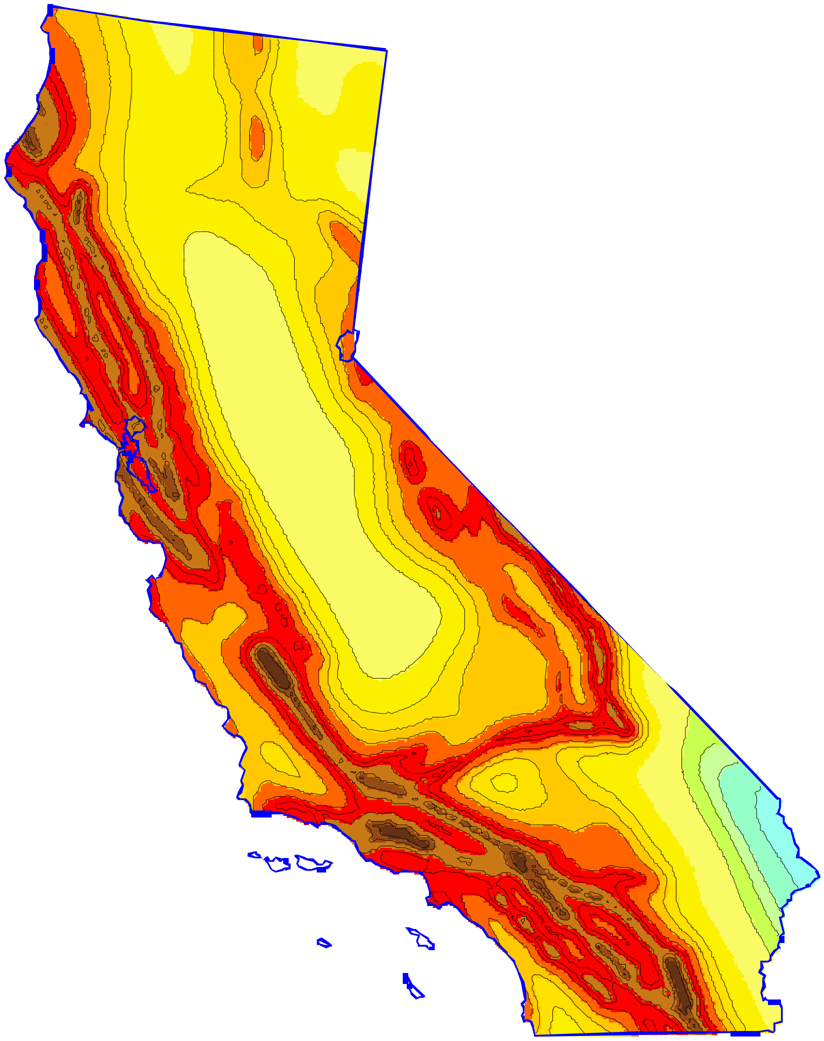
- **Path effects** refers to how the seismic waves change direction as they travel through the Earth's contrasting layers, just as light bounces (reflects) and bends (refracts) as it moves from air to water. Sometimes seismic energy gets focussed into one location and causes damage in unexpected areas (focussing of 1989's M_W 7.1 Loma Prieta earthquake waves caused damage in San Francisco's Marina district, some 100 km distant from the rupturing fault).

- **Site effects** refer to how seismic waves interact with the ground surface; seismic waves slow down in the loose sediments and weathered rock at the Earth's surface. As they slow, their energy converts from speed to amplitude, which heightens shaking (amplification). Therefore, buildings on poorly consolidated and thick soils will typically see more damage than buildings on consolidated soils and bedrock. Amplification can also occur in areas on deep, sediment-filled basins and on ridge tops. Seismic waves can also get trapped at the surface and reverberate (resonate). Whether resonance will occur depends on the period (the length) of the incoming waves. Long-period seismic waves, which are created by large earthquakes, are most likely to reverberate and cause damage in long-period structures, like bridges and high-rises. ("Long-period structures" are those that respond to long-period waves.) Shorter-period seismic waves, which tend to die out quickly, will most often cause damage fairly near the fault, and they will cause most damage in shorter-period structures such as one- to three-story buildings. Very short-period waves are most likely to cause near-fault, interior damage, such as to equipment.

Earthquake damage also depends on the characteristics of human-made structures. The interaction of ground motion with the built environment is complex. Governing factors include a structure's height, construction, and stiffness, architectural design, condition, and age of the structure.

Map 6.2: Ground Shaking Zones in California

(map shows areas of ground shaking with a 10 percent chance of exceedance in 50 years – the darker zones can experience higher ground shaking because they are closer to active faults, and are underlain by sediments that may amplify the effects of shaking)



Liquefaction typically occurs within the upper 50 feet of the surface, when saturated, loose, fine- to medium-grained soils (sand and silt) are present. Earthquake shaking suddenly increases pressure in the water that fills the pores between soil grains, causing the soil to lose strength and behave as a liquid. This process can be observed at the beach by standing on the wet sand near the surf zone. Standing still, the sand will support your weight. However, when you tap the sand with your feet, water comes to the surface, the sand liquefies, and your feet sink.

Liquefaction-related effects include loss of bearing strength, ground oscillations, lateral spreading and flow failures or slumping. The excess water pressure is relieved by the ejection of material upward through fissures and cracks. When soils liquefy, the structures built on them can sink, tilt, and suffer significant structural damage. Buildings and their occupants are at risk when the ground can no longer support the buildings.

Earthquake-induced landslides and rockfalls are secondary earthquake hazards that occur from ground shaking. Gravity inexorably pulls hillsides down, and earthquake shaking enhances this on-going process. Landslides and rockfalls can destroy the roads, buildings, utilities, and other critical facilities necessary to respond and recover from an earthquake. Many communities in southern California with steep slopes have a high likelihood of being impacted by landslides.

Primary Ground Rupture Due to Fault Movement typically results in a relatively small percentage of the total damage in an earthquake, yet being too close to a rupturing fault can result in extensive damage. It is difficult to safely reduce the effects of this hazard through building and foundation design. Therefore, the primary mitigation measure is to avoid active faults by setting structures back from the fault zone. Application of this measure is subject to requirements of the Alquist-Priolo Earthquake Fault Zoning Act and guidelines prepared by the California Geological Survey – previously known as the California Division of Mines and Geology.

History of Earthquake Events in Southern California

To better understand earthquake hazards, scientists study past earthquakes by looking at their records, or by studying the effects that past earthquakes had on the ground surface and the built environment. Historical earthquake records are either from the instrumental period (since about 1932, when the first seismographs were deployed), or pre-instrumental. In the absence of instrumentation, the detection and record of earthquakes are based on observations and felt reports, and are dependent upon population density and distribution. Since California was sparsely populated in the 1800s, our record of pre-instrumental earthquakes is relatively incomplete. However, two very large earthquakes, the Fort Tejon in 1857 (M7.9) and the Owens Valley in 1872 (M7.6) are evidence of the tremendously damaging potential of earthquakes in southern California. More recently, two M7.3 earthquakes struck southern California, in Kern County (1952) and Landers (1992), and a M7.1 earthquake struck the Mojave Desert (Hector Mine, in 1999). The damage from these five large earthquakes was limited because they occurred in sparsely populated areas. A similarly sized earthquake closer to southern California's population centers has the potential to place millions of people at risk.

Since seismologists started recording and measuring earthquakes, there have been tens of thousands of recorded earthquakes in southern California, most with a magnitude below 3.0. Plate H-3 (in Appendix H) shows the historical seismicity in the immediate vicinity of Glendale. The map shows that small earthquakes, of magnitude between 1 and 3, have occurred historically in the area, but that no moderate to large earthquakes have occurred beneath Glendale in historical times. Nevertheless, these recordings show that only the easternmost portion of southern California may be beyond the reach of a damaging earthquake. Table 6-2 lists the moderate to large historical earthquake events that have affected southern California. The most significant of these events based on their felt effects in Glendale are summarized in the next pages.

Table 6-2: Historical Earthquakes in the Southern California Region with Magnitude > 5

1769 Los Angeles Basin	1916 Tejon Pass Region
1800 San Diego Region	1918 San Jacinto
1812 Wrightwood	1923 San Bernardino Region
1812 Santa Barbara Channel	1925 Santa Barbara
1827 Los Angeles Region	1933 Long Beach
1855 Los Angeles Region	1941 Carpinteria
1857 Great Fort Tejon Earthquake	1952 Kern County
1858 San Bernardino Region	1954 West of Wheeler Ridge
1862 San Diego Region	1971 San Fernando
1892 San Jacinto or Elsinore Fault	1973 Point Mugu
1893 Pico Canyon	1986 North Palm Springs
1894 Lytle Creek Region	1987 Whittier Narrows
1894 San Diego Region	1992 Landers
1899 Lytle Creek region	1992 Big Bear
1899 San Jacinto and Hemet	1994 Northridge
1907 San Bernardino region	1999 Hector Mine
1910 Glen Ivy Hot Springs	

Long Beach Earthquake of 1933

This M_w 6.4 earthquake occurred on March 10, 1933, at 5:54 in the afternoon. The location of the earthquake's epicenter has been re-evaluated, and determined to have occurred approximately 3 miles south of present-day Huntington Beach. However, it caused extensive damage in Long Beach, hence its name. The earthquake occurred on the Newport-Inglewood fault, a right-lateral strike slip fault that extends across the western portion of the Los Angeles basin. The Newport-Inglewood fault did not rupture the surface during this earthquake, but substantial liquefaction-induced damage was reported. The earthquake caused 120 deaths, and over $50 million in property damage (Wood, 1933).

Most of the damaged buildings were of unreinforced masonry, and many school buildings were destroyed. Fortunately, children were not present in the classrooms at that time, otherwise, the death toll would have been much higher. This earthquake led to the passage of the Field Act, which gave the Division of the State Architect authority and responsibility for approving design and supervising construction of public schools. Building codes were also improved.

San Fernando (Sylmar) Earthquake of 1971

This M_w 6.6 earthquake occurred on the San Fernando fault zone, the western-most segment of the Sierra Madre fault, on February 9, 1971, at 6:00 in the morning. The surface rupture caused by this earthquake was nearly 12 miles long, and occurred in the Sylmar-San Fernando area, just a few miles northwest of Glendale. The maximum slip measured at the surface was nearly 6 feet.

The earthquake caused over $500 million in property damage and 65 deaths. Most of the deaths occurred when the Veteran's Administration Hospital collapsed. Several other hospitals, including the Olive View Community Hospital in Sylmar suffered severe damage. Newly constructed freeway overpasses also collapsed, in damage scenes similar to those that occurred 23 years later in the 1994 Northridge earthquake. Loss of life could have been much greater had the earthquake struck at a busier time of day. Thirty-one buildings in Glendale were so severely damaged that they had to be demolished, and approximately 3,250 masonry chimneys in the City collapsed. The total building loss in Glendale as a result of this earthquake was estimated at more than $2 million (Oakeshott, 1975). As with the Long Beach earthquake, legislation was passed in response to the damage caused by the 1971 earthquake. In this case, the building codes were strengthened and the Alquist Priolo Special Studies (now Earthquake Fault) Zone) Act was passed in 1972.

Whittier Narrows Earthquake of 1987

The Whittier Narrows earthquake occurred on October 1, 1987, at 7:42 in the morning, with its epicenter located approximately 12 miles southwest of Glendale (Hauksson and Jones, 1989). The M_L 5.9 earthquake occurred on a previously unknown, north-dipping concealed thrust fault (blind thrust) now called the Puente Hills fault (Shaw, and Shearer, 1999). The earthquake caused eight fatalities, over 900 injured, and $358 million in property damage. Severe damage was confined mainly to communities east of Los Angeles and near the epicenter. Areas with high concentrations of URMs, such as the "Uptown" district of Whittier, the old downtown section of Alhambra, and the "Old Town" section of Pasadena, were severely impacted. Several tilt-up buildings partially collapsed, including tilt-up buildings built after 1971, that were built to improved building standards but were of irregular configuration, revealing seismic vulnerabilities not previously recognized. Residences that sustained damage usually were constructed of masonry, were not fully anchored to foundations, or were houses built over garages with large door openings. Many chimneys collapsed and in some cases, fell through roofs. Wood-frame residences, in contrast, sustained relatively little damage, and no severe structural damage to high-rise structures in downtown Los Angeles was reported.

Pasadena Earthquake of 1988

The Pasadena earthquake occurred at 3:38 in the morning on December 3, 1988, directly underneath the city of Pasadena. The M_L5.0 earthquake occurred on the Raymond fault (Hauksson and Jones, 1991), and helped determine that the Raymond fault is a left-lateral strike-slip fault (prior to this earthquake, the geological community was divided on this issue – the fault forms a well-defined scarp that many attributed to reverse faulting). This earthquake was also notable because it was followed by an unusually small number of aftershocks, and these were of small size (the largest was only a magnitude 2.4).

Sierra Madre Earthquake of 1991

The Sierra Madre earthquake occurred on June 28, 1991 at 7:43 in the morning approximately 18 miles northeast of Glendale. The M_w 5.8 earthquake probably occurred on the Clamshell-Sawpit Canyon fault, an offshoot of the Sierra Madre fault zone in the San Gabriel Mountains (Haukson, 1994). Because of its depth and moderate size, it caused no surface rupture, but it did trigger rockslides that blocked some of the local mountain roads. Roughly $40 million in property damage occurred in the San Gabriel Valley; URM buildings were hardest hit, and many brick chimneys collapsed. Two deaths resulted from this earthquake -- one person was killed in Arcadia, and one person in Pasadena died from a heart attack. In all, at least 100 others were injured, though the injuries were mostly minor.

Landers and Big Bear Earthquakes of 1992

On the morning of June 28, 1992, most people in southern California were awakened at 4:57 by the largest earthquake to strike California in 40 years. Named "Landers" after a small desert community near its epicenter, the earthquake had a magnitude of 7.3. More than 50 miles of surface rupture associated with five or more faults occurred as a result of this earthquake. The average right-lateral strike-slip displacement was about 10 to 15 feet, but a maximum of 18 feet of slip was observed. Centered in the Mojave Desert, approximately 120 miles from Los Angeles, the earthquake caused relatively little damage for its size (Brewer, 1992). It released about four times as much energy as the very destructive Loma Prieta earthquake of 1989, but fortunately, it did not claim as many lives (one child died when a chimney collapsed). The power of the earthquake was illustrated by the length of the ground rupture it left behind. The earthquake ruptured 5 separate faults: Johnson Valley, Landers, Homestead Valley, Emerson, and Camp Rock faults (Sieh et al., 1993). Nearby faults also experienced triggered slip and minor surface rupture. There are no Modified Mercalli Intensity (MMI) reports for this earthquake in the Glendale area, but in Pasadena three individuals reported MMIs of IV, and in Burbank, MMIs of IV to V were reported (http://pasadena.wr.usgs.gov/shake/ca/).

The magnitude 6.4 Big Bear earthquake struck little more than 3 hours after the Landers earthquake on June 28, 1992 at 8:05:30 A.M. PDT. This earthquake is technically considered an aftershock of the Landers earthquake (indeed, the largest aftershock), although the Big Bear earthquake occurred over 20 miles west of the Landers rupture, on a fault with a different orientation and sense of slip than those involved in the main shock. From its aftershock, the causative fault was determined to be a northeast-trending left-lateral fault. This orientation and slip are considered "conjugate" to the faults that slipped in the Landers rupture. The Big Bear earthquake did not break the ground surface, and, in fact, no surface trace of a fault with the proper orientation has been found in the area. The Big Bear earthquake caused a substantial amount of damage in the Big Bear area, but fortunately, it claimed no lives. However, landslides triggered by the quake blocked roads in the mountainous areas, aggravating the clean-up and rebuilding process (SCEC-DC, 2001).

Northridge Earthquake of 1994

The Northridge Earthquake of January 17, 1994 woke up most of southern California at 4:30 in the morning. The earthquake's epicenter was located 20 miles to the west-northwest of downtown Los Angeles, on a previously unknown blind thrust fault now called the Northridge (or Pico) Thrust. Although moderate in size, this earthquake produced the strongest ground motions ever instrumentally recorded in North America. The M_w 6.7 earthquake is one of the most expensive natural disasters to have impacted the United States. Damage was widespread, sections of major freeways collapsed, parking structures and office buildings collapsed, and numerous apartment buildings suffered irreparable damage. Damage to wood-frame apartment houses was very widespread in the San Fernando Valley and Santa Monica areas, especially to structures with "soft" first floor or lower-level parking garages. The high accelerations, both vertical and horizontal, lifted structures off of their foundations and/or shifted walls laterally. The death toll was 57, and more than 1,500 people were seriously injured.

In the Glendale area, this earthquake caused predominantly Modified Mercalli intensities of VII (http://pasadena.wr.usgs.gov/shake/ca/). High-profile damage in Glendale includes the following cases: A section of the third level above grade in the Glendale City Center parking structure collapsed, sections of the Glendale Galleria parking structure settled 4 to 8 inches due to damage to pedestals, and the Glendale Fashion Center had damage to exterior columns.
Despite the losses, gains made through earthquake hazard mitigation efforts of the last two decades were obvious. Retrofits of masonry building helped reduce the loss of life, hospitals suffered less structural damage than in 1971 San Fernando earthquake, and emergency response was exemplary.

Earthquake Hazard Assessment

Choosing Earthquakes for Planning and Design

It is often useful to create a **deterministic** or **design earthquake scenario** to study the effects of a particular earthquake on a building or a community. Often, such scenarios consider the largest earthquake that is believed possible to occur on a fault or fault segment, referred to as the **maximum magnitude earthquake (M_{max})**. Other scenarios consider the **maximum probable earthquake (M_{PE})** or **design basis earthquake (DBE)** (1997 Uniform Building Code - UBC), the earthquake with a statistical return period of 475 years (with ground motion that has a 10 percent probability of being exceeded in 50 years). For public schools, hospitals, and other critical facilities, the California Building Code (1998) defines the **Upper Bound Earthquake (UBE)**, which has a statistical return period of 949 years and a ground motion with a 10 percent probability of being exceeded in 100 years. As the descriptions above suggest, which earthquake scenario is most appropriate depends on the application, such as the planned use, lifetime or importance of a facility. The more critical the structure, the longer the time period used between earthquakes and the larger the design earthquake should be.

Geologists, seismologists, engineers, emergency response personnel and urban planners typically use maximum magnitude and maximum probable earthquakes to evaluate seismic hazard. The assumption is that if we plan for the worst-case scenario, we establish safety margins. Then smaller earthquakes, that are more likely to occur, can be dealt with effectively.

Seismic design parameters define what kinds of earthquake effects a structure must be able to withstand. These include peak ground acceleration, duration of strong shaking, and the periods of incoming strong motion waves.

As is true for most earthquake-prone regions, many potential earthquake sources pose a threat to Glendale. Thus it is also important to consider the overall likelihood of damage from a plausible suite of earthquakes. This approach is called **probabilistic seismic hazard analysis (PSHA)**, and typically considers the likelihood of exceeding a certain level of damaging ground motion that could be produced by any or all faults within a 100-km radius of the project site, or in this case, the City. PSHA is utilized by the U.S. Geological Survey to produce national seismic hazard maps that are used by the Uniform Building Code (ICBO, 1997).

Regardless of which fault causes a damaging earthquake, there will always be **aftershocks**. By definition, these are smaller earthquakes that happen close to the **mainshock** (the biggest earthquake of the sequence) in time and space. These smaller earthquakes occur as the Earth adjusts to the regional stress changes created by the mainshock. The bigger the mainshock, the greater the number of aftershocks, the larger the aftershocks will be, and the wider the area in which they might occur. On average, the largest aftershock will be 1.2 magnitude units less than the mainshock. This is an average, and there are many cases where the biggest aftershock is larger than the average predicts. The key point is this: any major earthquake will produce aftershocks large enough to cause additional damage, especially to already-weakened structures. Consequently, post-disaster response planning must take damaging aftershocks into account.

Hazard Identification

In California, many agencies are focused on seismic safety issues: the State's Seismic Safety Commission, the Applied Technology Council, Governor's Office of Emergency Services, United States Geological Survey, Cal Tech, the California Geological Survey as well as a number of universities and private foundations. These organizations, in partnership with other State and Federal agencies, have undertaken a rigorous program in California to identify seismic hazards and risks including active fault identification, ground shaking, ground motion amplification, liquefaction, earthquake induced landslides, and for coastal areas, tsunami inundation zones. Seismic hazard maps have been published and are available for many communities in California through the California Geological Survey. Some of the most significant earthquake-induced hazards with the potential to impact the city of Glendale are described below.

Seismic Shaking

Seismic shaking is the seismic hazard that has the greatest potential to severely impact Glendale given the city's proximity to several active seismic sources (faults). To give the City a better understanding of the hazard posed by these faults, we performed a deterministic seismic hazard analysis to estimate the Peak Horizontal Ground Accelerations (PHGA) that can be expected at Glendale's City Center due to earthquakes occurring on any of the known active or potentially active faults within 100 km (62 miles) from the city. We also conducted probabilistic seismic hazard analyses to estimate the median PHGA at twelve different sites throughout the city. Those faults that, based on the ground shaking analyses described above, can cause peak horizontal ground accelerations of about 0.1g or greater (Modified Mercalli Intensities greater than VII) in the Glendale area are listed in Table 6-3. For a map showing most of these faults, refer to Map 6-1. Those faults included in Table 6-3 that pose the greatest impact on the Glendale area, or that are thought to have a higher probability of causing an earthquake, are described in more detail in the following pages.

Table 6-3 shows:

- The closest approximate distance, in miles and kilometers, between Glendale's City Hall and each of the main faults considered in the deterministic and probabilistic analyses;
- the maximum magnitude earthquake (M_{max}) each fault is estimated capable of generating;
- the intensity of ground motion, expressed as a fraction of the acceleration of gravity (g), that could be experienced in the Glendale area if the M_{max} occurs on one of these faults; and
- the Modified Mercalli seismic Intensity (MMI) values estimated to be felt in the City as a result of the M_{max} on each one of these faults.

Table 6-3: Estimated Horizontal Peak Ground Accelerations and Seismic Intensities in the Glendale Area

Fault Name	Distance to Glendale (mi)	Distance to Glendale (km)	Magnitude of M_{max} *	PGA (g) from M_{max}	MMI from M_{max}
Verdugo	<1	<1	6.7	0.61	X
Hollywood	<2	~1	6.4	0.55	X
Raymond	<2	~1	6.5	0.55	X
Sierra Madre	5	9	7.0	0.46+	X
Elysian Park Thrust	6	10	6.7	0.38	IX
Sierra Madre (San Fernando)	9	15	6.7	0.28	IX
Santa Monica	10	16	6.6	0.25	IX
Newport-Inglewood	11	17	6.9	0.24	IX
Compton Thrust	12	19	6.8	0.25	IX
San Gabriel	12	19	7.0	0.23	IX
East Oak Ridge (Northridge)	12	20	6.9	0.26	IX
Clamshell-Sawpit	13	21	6.5	0.20	VIII
Malibu Coast	17	28	6.7	0.18	VIII
Whittier	17	28	6.8	0.16	VIII
Santa Susana	19	30	6.5	0.16	VIII
San Jose	21	33	6.5	0.14	VIII
Palos Verdes	21	34	7.1	0.16	VIII
Holser	24	39	6.5	0.13	VIII
Cucamonga	27	43	7.0	0.15	VIII
Chino-Central Avenue	27	44	6.7	0.13	VIII
Anacapa Dume	28	45	7.3	0.17	VIII
San Andreas (1857 Rupture)	29	46	7.8	0.18	VIII
San Andreas - Mojave	29	46	7.1	0.12	VII
Oakridge (Onshore)	31	49	6.9	0.13	VIII
Simi-Santa Rosa	33	53	6.7	0.11	VII
San Cayetano	36	57	6.8	0.11	VII

* The M_{max} reported herein are based on the fault parameters published by the CGS (CDMG, 1996). However, as described further below, in the text, recent paleoseismic studies suggest that some of these faults, like the Sierra Madre fault, can generate even larger earthquakes than those listed above. These PGAs were calculated using Blake's (2000a) deterministic analysis software. In general, areas closer to a given fault will generally experience higher accelerations than areas farther away, therefore the northern portion of the City, next to the Sierra Madre fault, would experience higher accelerations than those reported herein.

Abbreviations used in Table 6-3:
mi – miles; **km** – kilometers; M_{max} – maximum magnitude earthquake; **PGA** – peak ground acceleration as a percentage of **g**, the acceleration of gravity; **MMI** – Modified Mercalli Intensity.

In general, peak ground accelerations and seismic intensity values decrease with increasing distance away from the causative fault. However, local site conditions, such as the top of ridges, can amplify the seismic waves generated by an earthquake, resulting in localized higher accelerations than those listed here. The strong ground motion values presented here should therefore be considered as average values; higher values may occur locally in response to site-specific conditions.

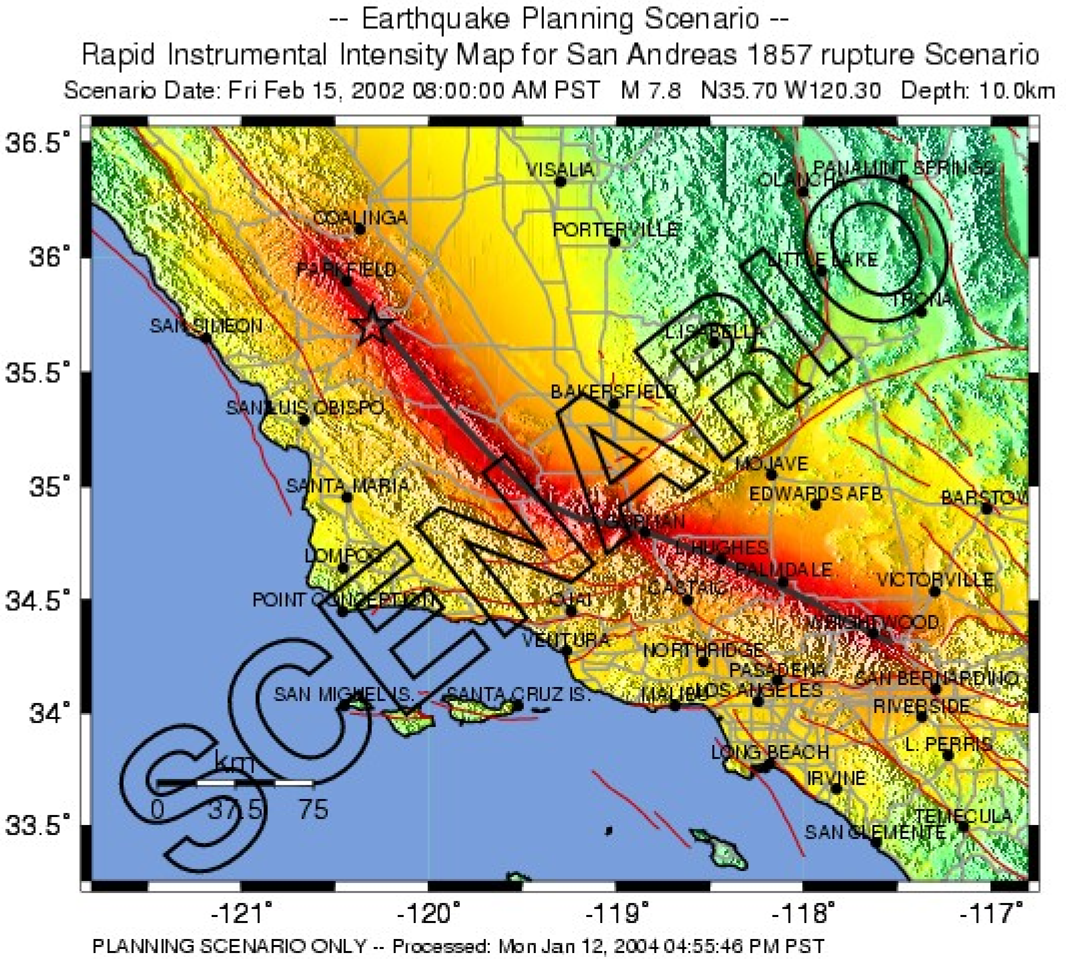
San Andreas Fault Zone: As discussed previously, the San Andreas fault is the principal boundary between the Pacific and North American plates, and as such, it is considered the "Master Fault" because it has frequent (geologically speaking), large, earthquakes, and it controls the seismic hazard in southern California. The fault extends over 750 miles (1,200 kilometers), from near Cape Mendocino in northern California to the Salton Sea region in southern California. At its closest approach, the San Andreas fault is approximately 24 miles (38 km) north of Glendale.

Large faults, such as the San Andreas fault, are generally divided into segments in order to evaluate their future earthquake potential. The segments are generally defined at discontinuities along the fault that may affect the rupture length. In central and southern California, the San Andreas fault zone is divided into five segments named, from north to south, the Cholame, Carrizo, Mojave, San Bernardino Mountains, and Coachella Valley segments (Working Group on California Earthquake Probabilities - WGCEP, 1995). Each segment is assumed to have a characteristic slip rate (rate of movement averaged over time), recurrence interval (time between moderate to large earthquakes), and displacement (amount of offset during an earthquake). While this methodology has some value in predicting earthquakes, historical records and studies of prehistoric earthquakes show that it is possible for more than one segment to rupture during a large quake or for ruptures to overlap into adjacent segments.

The last major earthquake on the southern portion of the San Andreas fault was the 1857 Fort Tejon (Mw 7.8) event. This is the largest earthquake reported in California. The 1857 surface rupture broke the Cholame, Carrizo, and Mojave segments, resulting in displacements of as much as 27 feet (9 meters) along the rupture zone. Peak ground accelerations in the Glendale area as a result of the 1857 earthquake are estimated to have been as high as 0.18g. Rupture of these fault segments as a group, during a single earthquake, is thought to occur with a recurrence interval of between 104 and 296 years. Map 6.3 shows the seismic intensities that would be expected in the southern California areas if a repeat of the 1857 earthquake occurred.

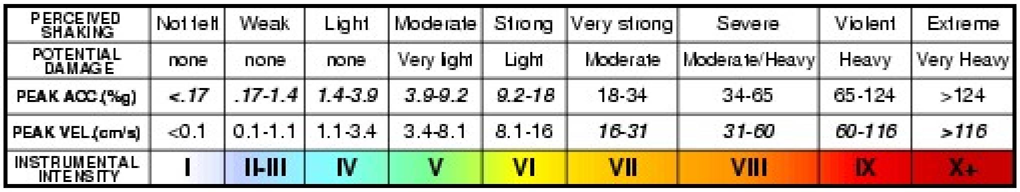
The closest segment of the San Andreas fault to Glendale is the **Mojave segment,** located approximately 29 miles to the northeast of the City Center area. This segment is 83 miles (133 km) long, extending from approximately Three Points southward to just northwest of Cajon Creek, at the southern limit of the 1857 rupture (WGCEP, 1995). Using a slip rate of 30±8 millimeters per year (mm/yr) and a characteristic displacement of 4.5±1.5 meters (m), the Working Group on California Earthquake Probabilities (WGCEP, 1995) derived a recurrence interval of 150 years for this segment. The Mojave segment is estimated to be capable of producing a magnitude 7.1 earthquake, which could result in peak ground accelerations in the Glendale area of about 0.13g. The WGCEP (1995) calculated that this segment has a 26 percent probability of rupturing sometime between 1994 and 2024.

Map 6.3: Earthquake Scenario for the 1857 San Andreas Rupture Showing Estimated Intensity Values in the Region Resulting from this Event



-- Earthquake Planning Scenario --
Rapid Instrumental Intensity Map for San Andreas 1857 rupture Scenario
Scenario Date: Fri Feb 15, 2002 08:00:00 AM PST M 7.8 N35.70 W120.30 Depth: 10.0km

PLANNING SCENARIO ONLY -- Processed: Mon Jan 12, 2004 04:55:46 PM PST



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

The next closest segment of the San Andreas fault to the City of Glendale is the **Carrizo segment**, located approximately 41 miles from downtown**.** This fault segment, which is about 75 miles (121 km) long, also ruptured during the 1857 earthquake. Slip on this segment of the San Andreas fault was greater than on either of the two other segments, averaging 6 to 7 m, and locally displaying offsets of as much as 8 to 10 m. Several paleoseismological studies have been conducted on this segment of the San Andreas fault. This would suggest that this segment is well understood, but the data are often conflicting or inconclusive. Past earthquakes have been resolved in some trench exposures but not in others only a few miles away, and the slip estimates for past earthquakes as determined from these exposures also vary. To account for and resolve these discrepancies, the 1995 WGCEP used a slip rate of 34±3 mm/yr, and a slip per event of 7±4 m. The error bars on the slip-per-event data reflect the varying measurements that have been made along the fault length for the 1857 event. These values resolve into a recurrence interval of 206 (+149, -125 years). This segment is thought capable of producing a magnitude 7.2 earthquake, which could result in peak ground accelerations in the Glendale area of about 0.10g. The WGCEP (1995) also calculated an 18 percent probability that this fault segment will generate an earthquake sometime between 1994 and 2024.

The **San Bernardino Mountains segment**, located about 43 miles from downtown Glendale, is approximately 49 miles (78 km) long, and extends from Cajon Creek to the San Gorgonio Pass. This segment is a structurally complex zone that is poorly understood, and for which there are scant data on fault behavior. Using a slip rate of 24±5 mm/yr and a characteristic displacement of 3.5±1.0 m, the WGCEP (1995) derived a recurrence interval on this fault of 146 years. This fault segment is estimated capable of producing a magnitude 7.3 earthquake, which could result in peak ground accelerations in Glendale of about 0.1g. If this fault segment ruptures together with the Mojave and Coachella Valley segments, higher ground motions would be expected. In 1994, the WGCEP (1995) calculated that this fault segment had a 28 percent probability of rupturing sometime in the next 30 years. Since the fault has not ruptured yet, the probability that it will before the year 2024 has increased.

Sierra Madre Fault: The Sierra Madre fault zone is a north-dipping reverse fault zone approximately 47 miles (75 km) long that extends along the southern flank of the San Gabriel Mountains from San Fernando to San Antonio Canyon, where it continues southeastward as the Cucamonga fault. The Sierra Madre fault has been divided into five segments, and each segment seems to have a different rate of activity.

The northwestern-most segment of the Sierra Madre fault (the San Fernando segment) ruptured in 1971, causing the M_w 6.7 San Fernando (or Sylmar) earthquake. As a result of this earthquake, the Sierra Madre fault has been known to be active. In the 1980s, Crook and others (1987) studied the Transverse Ranges using general geologic and geomorphic mapping, coupled with a few trenching locations, and suggested that the segments of the Sierra Madre fault east of the San Fernando segment have not generated major earthquakes in several thousands of years, and possibly as long as 11,000 years. By California's definitions of active faulting, most of the Sierra Madre fault would therefore be classified as not active. Then, in the mid 1990s, Rubin et al. (1998) trenched a section of the Sierra Madre fault in Altadena, at the Loma Alta Park, and determined that this segment has ruptured at least twice in the last 15,000 years, causing magnitude 7.2 to 7.6 earthquakes. This suggests that the Los Angeles area is susceptible to infrequent, but large near-field earthquakes on the Sierra Madre fault. Rubin et al.'s (1998) trenching data show that during the last earthquake, this fault trace shifted as much as 13 feet (4 meters) at the surface, and that total displacement in the last two events adds to more than 34 feet (10.5 meters)!

Although the fault seems to slip at a rate of only between 0.5 and 1 mm/yr (Walls et al., 1998), over time, it can accumulate a significant amount of strain. The paleoseismic data obtained at the Loma Alta Park site were insufficient to estimate the recurrence interval and the age of the last surface-rupturing event on this segment of the fault. However, Tucker and Dolan (2001) trenched the east Sierra Madre fault at Horsethief Canyon and obtained data consistent with Rubin et al.'s (1998) findings. At Horsethief Canyon, the Sierra Madre fault last ruptured about 8,000 to 9,000 years ago. Using a slip rate of 0.6 mm/yr and a slip per event of 5 meters, resolves into a recurrence interval of about 8,000 years. If the last event occurred more than 8,000 years ago, it is possible that these segments of the Sierra Madre fault are near the end of their cycle, and therefore likely to generate an earthquake in the not too distant future.

Given the data presented above, and since the Sierra Madre fault extends across the northern reaches of the Glendale area, this fault poses a significant hazard to the City. The deterministic analysis for the Glendale City Center area estimates peak ground accelerations of about 0.46g, based on a magnitude 7.0 earthquake on the segment of the Sierra Madre fault that extends through the City of Glendale. A larger earthquake on this fault, of magnitude between 7.2 and 7.6, could generate significantly stronger peak ground accelerations, especially in the northern portion of the City. Specific losses in Glendale as a result of an earthquake on the Sierra Madre fault are discussed in detail in Section 1.9, below. If the San Fernando segment of the Sierra Madre fault ruptured, causing a magnitude 6.7 earthquake, peak ground accelerations of about 0.28g are anticipated in the southern portion of Glendale, near City Hall. As before, stronger ground accelerations would be expected in the northern reaches of the City, closer to the fault.

Elysian Park Fault: The Whittier Narrows earthquake of October 1, 1987 occurred on a previously unknown blind thrust fault underneath the eastern part of the Los Angeles basin. Davis et al. (1989) used oil field data to construct cross-sections showing the subsurface geology of the basin, and concluded that the Whittier Narrows earthquake occurred on a thrust ramp they called the Elysian Park thrust fault. They modeled the Elysian Park as a shallow-angle, reverse-motion fault 6 to 10 miles below the ground surface generally located between the Whittier fault to the southeast, and the Hollywood fault to the west-northwest. Although blind thrusts do not extend to the Earth's surface, they are typically expressed at the surface by a series of hills or mountains. Davis et al. (1989) indicated that the Elysian Park thrust ramp is expressed at the surface by the Santa Monica Mountains, and the Elysian, Repetto, Montebello and Puente Hills.

Davis et al. (1989) estimated a long-term slip rate on the Elysian Park of between 2.5 and 5.2 mm/yr. Dolan et al. (1995) used a different approach to estimate a slip rate on the Elysian Park fault of about 1.7 mm/yr with a recurrence interval of about 1,475 years. Then, in 1996, Shaw and Suppe re-interpreted the subsurface geology of the Los Angeles basin, proposed a new model for what they call the Elysian Park trend, and estimated a slip rate on the thrust ramp beneath the Elysian Park trend of 1.7±0.4 mm/yr. More recently, Shaw and Shearer (1999) relocated the main shock and aftershocks of the 1987 Whittier Narrows earthquake, and showed that the earthquake sequence occurred on an east-west trending buried thrust they called the Puente Hills thrust (rather than the northwest-trending Elysian Park thrust).

Given the enormous amount of research currently underway to better characterize the blind thrust faults that underlie the Los Angeles basin, the Elysian Park thrust fault will most likely undergo additional significant re-interpretations. In fact, Shaw and Shearer (1999) suggest that the Elysian Park thrust fault is no longer active. However, since this statement is under consideration, and the Elysian Park thrust is still part of the active fault database for southern California (CGS, previously CDMG, 1996), we have considered this fault as a potential seismic source in Glendale. If this fault caused a magnitude 6.7 earthquake, it is estimated that Glendale would experience peak ground accelerations of about 0.38g.

Verdugo Fault: The Verdugo fault is a 13 to 19-mile (21 to 30 km) long, southeast-striking fault that that extends along the northeastern edge of the San Fernando Valley, and at or near the southern flank of the Verdugo Mountains, through the cities of Glendale and Burbank. Weber et al. (1980) first reported southwest-facing scarps 2 to 3 meters high in the alluvial fan deposits in the Burbank and west Glendale areas, and other subsurface features indicative of faulting. Weber et al. (1980) relied on these scarps, on offset alluvial deposits at two localities, and on a subsurface groundwater cascade beneath Verdugo Wash to suggest that movement on this fault is youthful, but no age estimates were provided. Weber et al. (1980) further suggested that this fault is a shallow, north-dipping reverse fault responsible for uplift of the Verdugo Mountains, and proposed that the fault zone is approximately 1 km wide. For nearly 20 years since Weber et al.'s (1980) report, the Verdugo fault was not studied, but in the last few years, recognizing the potential threat that this fault poses to the Los Angeles metropolitan region, several researchers have started to investigate this fault.

Some researchers have relied on deep subsurface data, primarily oil well records and geophysical data to review the subsurface geology of the San Fernando Valley area, including the characteristics of the Verdugo fault (Tsutsumi and Yeats, 1999; Langenheim et al., 2000; Pujol et al., 2001). Results of these studies suggest that the Verdugo fault changes in character from a reverse fault adjacent to the Pacoima Hills, near its northwestern terminus, to a normal fault at the southwest edge of the Verdugo Mountains. To the north, the Verdugo fault appears to merge with both the Mission Hills and Northridge Hills faults. To the south, the fault is on trend with the Eagle Rock fault, but it is still unclear whether these faults are connected. Vertical separation on the Verdugo fault is at least 1,000 meters (3,300 feet), based on the structural relief between the valley floor and the crest of the Verdugo Mountains and other indicators (Tsutsumi and Yeats, 1999). Even though some of the data suggest that the Verdugo fault is a reverse fault, there are several researchers who now propose that the Verdugo fault is a left-lateral strike-slip fault (Walls et al., 1998; Dolan, personal communication, 2002).

Other investigators have taken a more direct, hands-on approach to study this fault, but finding locations suitable for trenching has been difficult in the extensively developed San Fernando Valley. Dolan and Tucker (1999) tried to better define the location and recency of activity of the Verdugo fault by conducting geological and geophysical studies across the inferred trace of the fault in Brand Park. They used closely spaced boreholes drilled in a line perpendicular to the trend of the fault, and ground penetrating radar to look for stratigraphic anomalies that could be suggestive of faulting. They identified one possible anomaly that could be the Verdugo fault and excavated a trench across the suspect area. However, the sediments exposed in the trench were too friable to maintain the trench open long enough to conduct their study. Dolan and Tucker believe that they did locate a fault, but they are uncertain about whether or not the fault is a recent strand of the Verdugo fault. Realizing that the Brand Park site may not yield any additional, useful information, Dolan and Tucker (1999) shifted their attention to another potential trenching site, at Palm Park in Burbank. Unfortunately, their studies at Palm Park were equally unsuccessful at locating and characterizing this fault (Dolan, personal communication, 2002).

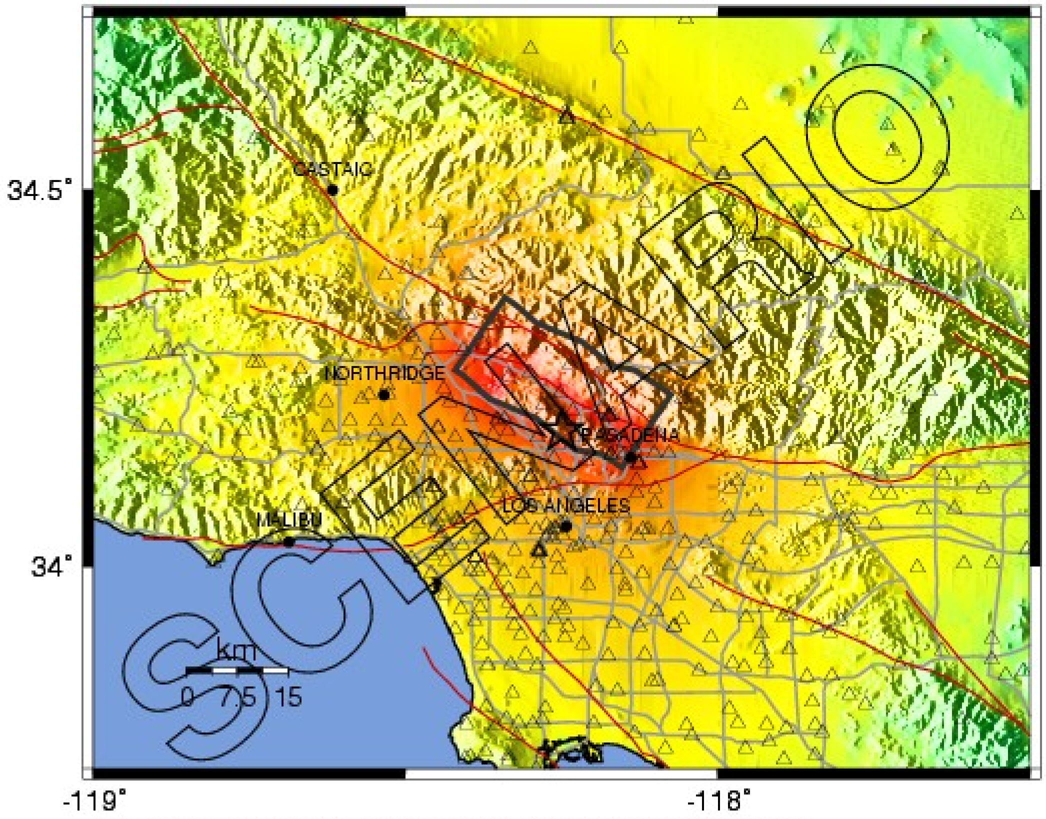
Slip rate on the Verdugo fault is poorly constrained, and currently estimated at about 0.5 mm/yr (CDMG, 1996). The fault's recurrence interval is unknown; however, the fault's southern segment is thought to have ruptured during the Holocene, and the fault is therefore considered active (Jennings, 1994). Based on its length, the Verdugo fault is thought capable of generating magnitude 6.0 to 6.8 earthquakes. A magnitude 6.7 earthquake on this fault would generate peak ground accelerations in the Glendale area of about 0.6g to 0.7g, with intensities as high as X (see Map 6.4). Higher accelerations can be expected locally. Given the high accelerations that this fault is estimated capable of generating in Glendale, an earthquake scenario on this fault was modeled for loss estimation purposes.

**Map 6.4: Scenario for a M6.7 Earthquake on the Verdugo Fault
Showing Estimated Intensity Values in the Region Resulting from this Event**

-- Earthquake Planning Scenario --

Rapid Instrumental Intensity Map for Verdugo Fault M6.7 Scenario

Scenario Date: Tue Oct 30, 2001 04:00:00 AM PST M 6.7 N34.18 W118.25 Depth: 6.0km



PLANNING SCENARIO ONLY -- Processed: Wed Jul 7, 2004 11:01:41 PM PDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Hollywood Fault: The Hollywood fault is the eastern 9-mile (14 km) long segment of the Santa Monica – Hollywood fault system that forms the southern margin of the Santa Monica Mountains (locally known as the Hollywood Hills). It has also been considered the westward extension of the Raymond fault. From east to west, the fault traverses the Hollywood section of Los Angeles, and the cities of West Hollywood and Beverly Hills. Its eastern end is mapped immediately south of Glendale's southern boundary (see Map 6-1 and Plate H-4). Movement on the Hollywood fault over geologic time is thought responsible for the growth of the Hollywood Hills, which is why earlier researchers characterized this fault as a northward-dipping reverse fault. However, recent studies by Dolan et al. (1997, 2000a) and Tsutsumi et al. (2001) show that the Hollywood fault is primarily a left-lateral strike-slip fault. A lateral component of movement on this fault is consistent with its linear trace and steep, 80- to 90-degree dips (reverse faults typically have irregular, arcuate traces and shallow dips).

The Santa Monica – Hollywood fault system has not produced any damaging historical earthquakes, and it has had only relatively minor microseismic activity. Subsurface studies by Dolan et al. (2000a) suggest that the Hollywood fault moves infrequently. The most recent surface-rupturing earthquake on this fault appears to have occurred 7,000 to 9,500 years ago, and another earthquake appears to have occurred in the last 10,000 to 22,000 years (Dolan et al., 2000a). These data suggest that the fault either has a slow rate of slip (of between 0.33 and 0.75 mm/yr), or that it breaks in large-magnitude events. Interestingly, the recent past history of earthquakes on the Hollywood fault is remarkably similar to that of the Sierra Madre fault. Paleoseismologists are currently researching the possibility that earthquakes on the Sierra Madre fault trigger rupture of the Santa Monica – Hollywood fault system. If this is the case, then large earthquakes in the Los Angeles region may cluster in time, releasing a significant amount of strain over a geologically short time period, followed by lengthy periods of seismic quiescence.

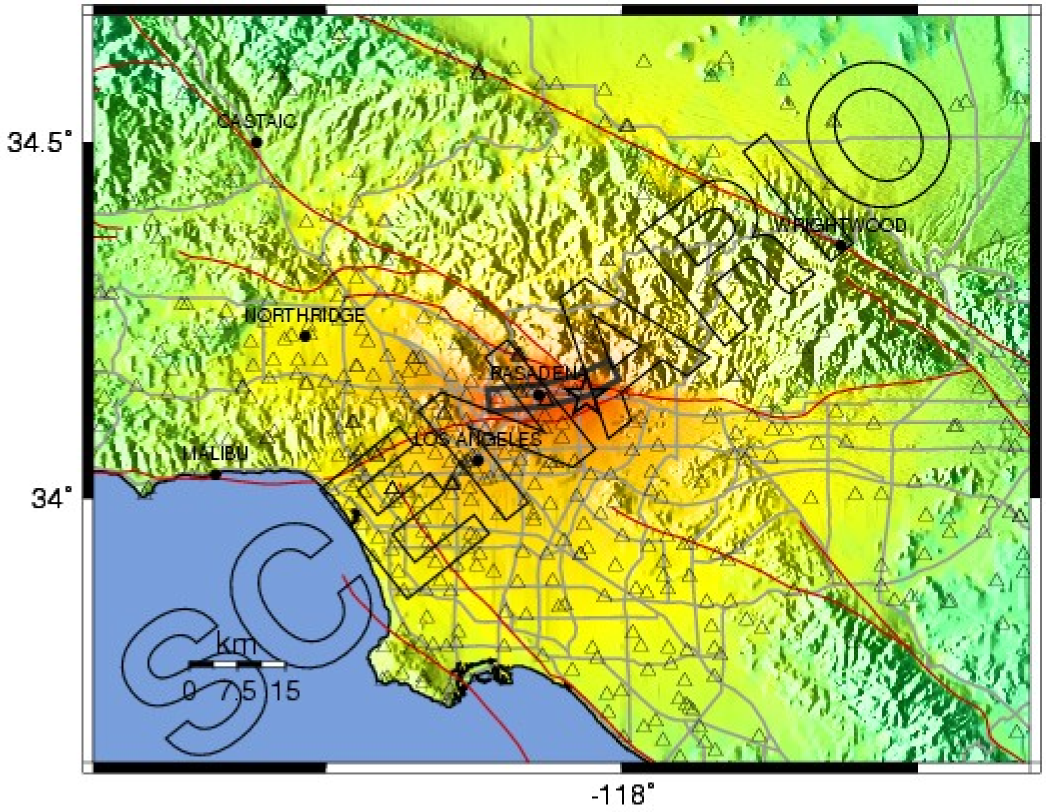
Based on its length, the Hollywood fault is thought capable of generating a Mw ~6.4 to 6.6 earthquake. A conservative magnitude 6.4 earthquake on the Hollywood fault is thought capable of generating peak ground accelerations of about 0.55g in Glendale, near City Hall. Even higher accelerations, of as much as 0.7g can be expected along the southernmost portion of the City, near the eastern end of the fault.

Raymond Fault: The Raymond (or Raymond Hills) fault is a left-lateral, strike-slip fault about 13 miles (20 km) long that extends across the San Gabriel Valley, along the eastern and southern margins of Pasadena, and through the northern reaches of Arcadia, San Marino and South Pasadena. The westernmost portion of the Raymond fault is mapped just south of the City of Glendale (see Map 6.1 and Plate H-4). The fault produces a very obvious south-facing scarp along much of its length, which led many geologists to favor reverse-slip as the predominant sense of fault motion. However, left-deflected channels, shutter-ridges, sag ponds, and pressure ridges indicate that the Raymond fault is predominantly a left-lateral strike-slip fault. This sense of motion is confirmed by the seismological record, especially by the mainshock and aftershock sequence to the 1988 Pasadena earthquake of local magnitude (M_L) 5.0 that probably occurred on this fault (Jones et al., 1990; Hauksson and Jones, 1991). Investigators have suggested that the Raymond fault transfers slip southward from the Sierra Madre fault zone to other fault systems (Walls et al., 1998).

The Raymond fault was recently trenched in San Marino, at the Los Angeles Arboretum in Arcadia (Weaver and Dolan, 2000), and in eastern Pasadena (Dolan et al., 2000b) where significant data on the recent history of this fault were collected. These studies indicate that the most recent surface-rupturing earthquake on this fault occurred 1,000 to 2,000 years ago, and that between three and five earthquakes occurred on this fault between 41,500 and 31,500 years ago. This suggests that the fault either breaks in cluster earthquakes, or that several more surface-rupturing earthquakes have occurred on this fault that were not detected in the trenches. Proposed slip rates on the fault vary from a minimum of 1.5 mm/yr (Weaver and Dolan, 2000) to 4 (+1, -0.5) mm/yr (Marin et al., 2000; Dolan et al., in review). Weaver and Dolan (2000) also suggest an average recurrence interval for this fault of about 3,000 years.

Map 6.5: Earthquake Scenario for a M6.5 Earthquake on the Raymond Fault Showing Estimated Intensity Values in the Region Resulting from this Event

-- Earthquake Planning Scenario --
Rapid Instrumental Intensity Map for Raymond Fault M6.5 Scenario
Scenario Date: Thu Apr 4, 2002 09:15:00 AM PST M 6.5 N34.14 W118.06 Depth: 13.0km



PLANNING SCENARIO ONLY -- Processed: Wed Jul 7, 2004 10:51:50 PM PDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

A conservative magnitude 6.5 earthquake on the Raymond fault would generate peak ground accelerations in the Glendale area of about 0.55g and seismic intensities in the VII to X range (see Table 6-3 and Map 6.5). However, the paleoseismic data suggest that this fault is capable of generating larger earthquakes, in the 7.0 magnitude range (Dolan et al., 2000b). If this is the case, stronger ground shaking as a result of an earthquake on this fault could be experienced in Glendale.

Primary Fault Rupture

Primary fault rupture refers to fissuring and offset of the ground surface along a rupturing fault during an earthquake. Primary ground rupture typically results in a relatively small percentage of the total damage in an earthquake, but being too close to a rupturing fault can cause severe damage to structures. Development constraints within active fault zones were implemented in 1972 with passage of the California Alquist-Priolo Earthquake Fault Zoning Act. This law prohibits the construction of new habitable structures astride an active fault and requires special geologic studies to locate, and evaluate whether a fault has ruptured the ground surface in the last about 11,000 years. If an active fault is encountered, structural setbacks from the fault are defined.

In the Glendale vicinity, the CGS has identified the Rowley fault (a section of the Sierra Madre fault) and the Raymond fault as sufficiently active and well defined to require zoning under the guidelines of the Alquist-Priolo Earthquake Fault Zoning Act. The Alquist-Priolo zones designated by the CGS for these faults are shown on Plate H-4 in Appendix H. Only the Rowley fault zone extends into the city of Glendale proper, so the Raymond fault is not discussed further below. Other faults that have been mapped in Glendale but have not been zoned by the California Geological Survey are discussed in more detail below.

The **Rowley fault** is the first segment of the **Sierra Madre fault** to the east of the fault traces that ruptured the ground surface during the 1971 Sylmar earthquake (see Plate H-4; the Lakeview fault is the easternmost fault that ruptured the surface in 1971. The Sunland fault to the north did not break, but extensive landsliding occurred in the Sunland fault area in response to movement on the Lakeview fault). Where the Rowley fault has been mapped in the town of Tujunga, it consists of at least three fault planes in a zone of brecciated granodiorite that is thrust over very coarse conglomerate and basalt flows. In Glendale, the Rowley fault has been mapped as a single strand that bifurcates at its eastern end, near Ward Canyon (see Plate H-4). The fault has been well located as evidenced by a single solid line on the map. Farther to the east, the fault is not as well defined and is therefore not currently zoned under the Alquist-Priolo Act criteria.

Geologic studies conducted soon after the 1971 earthquake suggested that the last rupture on the San Fernando segment of the Sierra Madre fault prior to 1971 had occurred less than 200 years before (Bonilla, 1973). However, a more recent trenching study in the immediate vicinity of Bonilla's trench suggests that this fault has only broken twice in the last 3,500 to 4,000 years, including the 1971 rupture (Fumal et al., 1995), which suggests this fault has a recurrence interval of about 2,000 years rather than 200 years. Nevertheless, the San Fernando segment appears to be more active than other segments of the Sierra Madre fault, as first suggested by Crook et al. (1987), who proposed that the rest of the fault zone has not moved in many thousands of years, possibly since before the Holocene. Relatively recent trenching studies by Rubin et al. (1998) in Altadena, approximately 6 miles to the southeast of Glendale, have shown that the segment of the Sierra Madre fault through Altadena, and possibly through Glendale, has a long recurrence interval, but that it has moved in the Holocene and is therefore active. The segment of fault that Rubin et al. (1998) trenched has ruptured the ground surface twice in the last about 15,000 years, with the most recent earthquake having occurred probably 8,000 to 9,000 years ago. Other studies farther to the southeast, at Horsethief Canyon in the San Dimas area, also showed that this section of the Sierra Madre fault has not broken in the last 8,000 years, but that the fault has slipped as much as 46 feet (14 m) between 8,000 and 24,000 years ago (Tucker and Dolan, 2001). These two studies suggest that the central segments of the Sierra Madre fault, between the San Fernando segment on the north and the Cucamonga fault on the south, ruptures at the same time in infrequent but large magnitude (M>7) events.

Based on the data presented above, the section of the Rowley fault not currently zoned by the State should nevertheless be considered active. A fault hazard management zone that includes and extends beyond the inferred traces of the fault is proposed in the City's Safety Element of the General Plan. Geologic studies similar in scope to those required by the CGS in Alquist-Priolo Earthquake Fault Zones should be conducted if new development or redevelopment is proposed in the fault hazard management zone. As detailed geological investigations are conducted, the location and activity status (some of the splays may be proven to have not moved within the last 11,000 years) of the faults shown on Plate H-4 may be refined or modified. The map should be amended as new data become available and are validated.

The **Mt. Lukens fault** is a west- to northwest-trending thrust fault that extends across the south flank of the San Gabriel Mountains, between Haynes Canyon on the northwest, and the Los Angeles Crest Highway on the southeast. In the Glendale area, the fault is mapped about 1,500 feet to the north of the Sierra Madre fault. Because of its closeness to the Sierra Madre fault, Smith (1978) previously mapped this fault as part of the Sierra Madre fault system. The fault was mapped more recently by Crook et al. (1987), and Dibblee (1991a, 1991b, 2002). Although the Mt. Lukens thrust fault appears to be a separate fault system, in the Glendale area this fault is so close to the Sierra Madre fault that if the Sierra Madre fault ruptured, it could trigger co-seismic movement on the Mt. Lukens thrust fault. Therefore, a fault hazard management zone for critical facilities is herein proposed for the Mt. Lukens fault.

The **Verdugo Canyon – La Tuna Canyon fault** is oriented in a northwesterly direction through Glendale, where it inferred at the base of the northeast flank of the Verdugo Mountains, but changes to a more westerly orientation in the La Tuna Canyon, where the fault reportedly controls the location of the drainage. This fault was proposed by geologists from the Metropolitan Water District (as mentioned in Envicom, 1975), who indicated that the fault is north-dipping in the La Tuna Canyon, and south-dipping farther east. The fault was also inferred under the Verdugo Wash, where a deep, northwest-trending depression in the basement rocks has been reported (California State Water Rights Board, 1962 as discussed in Envicom, 1975). The sections of the fault described above are not recognized by Dibblee (1991a, 1991b) in his geologic maps of the area, but farther to the east, in the San Rafael Hills, Dibblee maps a fault that is consistent with Byer's (1968) mapping. Farther to the east, the fault appears to swing to the east, where it may join the Sycamore Canyon fault (see Plate H-4). There are no data available to suggest that this fault is active; Envicom (1975) indicate that the fault is not a barrier to groundwater flow in the Verdugo Wash area, and should therefore be considered inactive.

The **Sycamore Canyon fault** zone consists of a series of discontinuous faults that trend northeasterly in the vicinity of Sycamore Canyon, in the western part of the San Rafael Hills. Byer (1968) extended this fault zone westward across and along the north side of Sycamore Canyon, but more recent geologic maps of the area (Dibblee, 1989b) do not show this trace (see Plate 1-2). Although the presence of sheared clays along a portion of the fault, in the eastern San Rafael Hills, has contributed to some slope instability problems, Weber (1980) reported that no evidence that the fault zone is active has been found. Weber (1980) also suggested that topographic lineaments observed in the northeastern San Rafael Hills (within Pasadena) might be an extension of the Sycamore Canyon fault. This connection has not been proven out by field evidence. However, Weber's (1980) lineaments coincide with lineaments in the younger alluvial fan deposits in the Pasadena area mapped by Rubin (1992) that may be the surface expression of the most recently active traces of the Sierra Madre fault. Therefore, in the Pasadena area, the Sycamore Canyon fault has been zoned, with geological studies required in this zone if the proposed development is a critical facility. A similar approach is recommended for the southwest-trending section of the Sycamore Canyon fault that extends through the San Rafael Hills in the Glendale area. Even if the fault is not active, the sheared clays that have been reported along the fault zone may be highly expansive. If a structure is built across the surface trace of these clays, and these clays swell when wetted, the structure could experience some structural damage. Engineered mitigation measures such as deep removals along the clay zone and replacement with non-expansive materials may be warranted.

The **Verdugo fault** strikes southeasterly across the southern edge of the Verdugo Mountains, through the central portion of Glendale, and across the foot of the San Rafael Hills, where it seems to merge with the Eagle Rock fault. The Verdugo fault separates the plutonic and metamorphic rocks that crop out in the Verdugo Mountains from the alluvial fan deposits to the southwest. The fault is probably coincident with the sharp break in slope along the southwestern edge of the Verdugo Mountains, where many of the alluvial fans that emanate from the mountains merge together to form the gently southwest-facing alluvial surface between the mountains and the Los Angeles River. In older aerial photographs of the area, Dolan and Tucker (1999) interpreted several small scarps that could represent the last surface rupturing event on this fault, but these scarps have all been obliterated by development. In fact, the inferred trace of the Verdugo fault is covered with buildings and roads along almost its entire length, which makes it difficult to find suitable field study areas where the fault can be exposed and studied.

To date, there has been only one study in Glendale that attempted to locate and date the most recent surface rupturing events on this fault. This study, conducted in Brand Park (Dolan and Tucker, 1999) may have constrained the location of the fault zone in the area, but the actual fault trace could not be identified due to the discontinuous nature of the alluvial fan deposits that they encountered, and because the trench excavated was too unstable to be entered safely. Dolan and Tucker (1999) proposed that the trace of the Verdugo fault in this area is approximately 300 feet (90 m) farther to the north of where it is inferred by Dibblee (1991), extending in a southeasterly direction through the area between the Tea House and the Dr.'s House at Brand Park. Unfortunately, Dolan and Tucker (1999) could not confirm the fault location elsewhere due to landscaping and previous ground surface modifications at the park (for parking lots and playing fields) that precluded the possibility of excavating another trench.

Previous investigators (Byer, 1968) also identified a wide zone of faulting farther to the north that consists of laterally discontinuous fault planes that generally dip to the northeast. Locally, they observed minor shearing of the terrace deposits, which suggested to them relatively youthful movement on the fault. This zone of faulting is identified in Plate H-4 with cross-hatchures. This zone of faulting may not be the most recent fault trace, but there are insufficient data to determine whether or not these faults are active. Therefore, this fault zone should be investigated in the future if development is proposed in the area.

Although the most recently active traces of the Verdugo fault are not well located, most investigators agree that the Verdugo fault is active and therefore has the potential to generate future surface-rupturing earthquakes. Earlier investigators suggested that this fault is primarily a thrust fault, responsible for uplift of the Verdugo Mountains (R.T. Frankian & Associates, 1968; Weber et al., 1980; Weber, 1980), but more recently, it is thought that the fault displays primarily left-lateral strike-slip movement (Walls et al., 1998; Dolan, personal communication, 2002). A fault hazard management zone that includes the inferred trace of the fault as mapped by Dibblee (1991), but is wider to the north, to include the break in slope and the zone of faulting mapped by Byer (1968) is proposed. As with the fault hazard management zone for the Rowley fault, geological studies should be conducted for sites within the Verdugo fault hazard management zone if new development or significant redevelopment is proposed.

The **Eagle Rock fault** crosses the southwestern part of Pasadena and the northernmost portion of Los Angeles, including along a 2-mile stretch of the Ventura (134) Freeway, where it separates crystalline bedrock on the north from sedimentary rock on the south (see Plates H-2 and H-4). The portion of the Eagle Rock fault east of the San Rafael Hills was originally termed the "San Rafael fault" by Weber (1980), who suggested the fault was active in late Quaternary time. This conclusion was based on the presence of linear topographic features across the Pleistocene alluvial fan surface east of the San Rafael Hills. Farther to the southeast, the fault appears to join the Raymond fault, however the exact location of the eastern terminus of the Eagle Rock fault is not well defined, and its geomorphology in this area is much more subdued than that of the Raymond fault. Consequently, Weaver and Dolan (2000) concluded that a connection with the Raymond fault could not be established with certainty. To the west, the Eagle Rock fault lies on trend with the Verdugo fault, although in the subsurface, based on gravity data, Weber (1980) suggests that there may be a step or bend between the two fault zones. Although very little is known about the Eagle Rock fault, given that it appears to be related to active faults in the area, such as the Verdugo fault, it should be considered potentially active, subject to further study. For example, although the Eagle Rock fault may not be capable of generating an earthquake, it may break co-seismically with movement on the Verdugo fault. A fault hazard management zone for this fault has been recommended in the Pasadena area, similar to that for the Sierra Madre and Verdugo faults. Extension of this zone between Pasadena and Glendale is recommended, but the limits of this zone are predominantly outside the City of Glendale.

The **Scholl Canyon faults** were mapped by Byer (1968), and Envicom (1975) suggested that this fault zone connects the Verdugo fault in the west to the Eagle Rock fault in the east. However, more recent mapping by Dibblee (1989b) does not even show these faults, and there are no data available to indicate that these fault traces, if even present, are active.

The **York Boulevard fault** is a short, northeast trending fault first mapped by Lamar (1970), and more recently by Dibblee (1989a, 1989b) in the Adams Hill area of southern Glendale. According to Lamar (1970) the fault does not offset older, Pleistocene-age deposits, and is therefore not active. However, the York Boulevard fault does appear to separate the Raymond fault from the Hollywood fault, in an area where according to Weber (1980) there is step or bend in the fault zones at depth. Alternatively, the York Boulevard fault may be the eastern extension of the Hollywood fault. Based on these relationships, and given that both the Raymond and Hollywood faults are active, Envicom (1975) suggested that the York Boulevard fault may be active also. Given its length, the York Boulevard fault is not likely to generate an earthquake, but it may move co-seismically with an earthquake on the Hollywood fault. Therefore, a hazard management zone for this fault is proposed, where geological studies to locate and characterize the fault would be required prior to development of a critical facility.

The eastern terminus of the **Hollywood fault** has been mapped along the southwesternmost corner of the City of Glendale (see Map 6.1 and Plate H-4). This fault has been shown to be active in the Los Angeles and West Hollywood areas, where recently obtained data indicate that this fault breaks in infrequent, but large magnitude earthquakes. In the West Hollywood area, the inferred location of the fault along Sunset Boulevard has been proven to be incorrect; the fault is farther south, in the valley. However, in the Los Angeles area, the fault does appear to be at the mountain front. The fault has been well located in the Hollywood Hills, just to the west of Glendale, by Yerkes (1967) and Dibblee (1991b), but as it extends across the Los Angeles River and into the Glendale area, its location is less well defined. Given that this fault is considered active, the inferred location of the fault in Glendale is herein included in a fault hazard management zone. Because of its location in the floodplain of the Los Angeles River, where shallow ground water and deep Holocene sediments are anticipated, geologic studies to locate this fault may prove to be difficult and expensive, requiring the use of deep boreholes rather than trenching.

A few other minor, **unnamed faults** have been mapped both in the San Rafael Hills and in the Verdugo Mountains (see Plate H-4). These faults appear to be confined to the older bedrock units, with no impact on the younger terrace and alluvial deposits, and are therefore not considered active. Fault hazard management zones for these faults are not considered warranted, however, geologists studying these areas should continue to look for evidence of Holocene movement on these faults. As new data are developed and verified by third-party reviewers, Plate H-4 should be amended to reflect any changes in the location, recency of activity and need for future studies on these faults.

Liquefaction and Related Ground Failure

Liquefaction is a geologic process that causes various types of ground failure. Liquefaction typically occurs in loose, saturated sediments primarily of sandy composition, in the presence of ground accelerations over 0.2g (Borchardt and Kennedy, 1979; Tinsley and Fumal, 1985). When liquefaction occurs, the sediments involved have a total or substantial loss of shear strength, and behave like a liquid or semi-viscous substance. Liquefaction can cause structural distress or failure due to ground settlement, a loss of bearing capacity in the foundation soils, and the buoyant rise of buried structures. The excess hydrostatic pressure generated by ground shaking can result in the formation of sand boils or mud spouts, and/or seepage of water through ground cracks.

As indicated above, there are three general conditions that need to be met for liquefaction to occur. The first of these – strong ground shaking of relatively long duration - can be expected to occur in the Glendale area as a result of an earthquake on any of several active faults in the region. The second condition - loose, or unconsolidated, recently deposited sediments consisting primarily of silty sand and sand - occurs along the Verdugo Wash and the lower reaches of its tributaries, and in the alluvial plain south of the Verdugo Mountains and the San Rafael Hills. Young alluvial sediments have also been mapped in the area between the San Gabriel and Verdugo Mountains, in the northern portion of the city, but close to the San Gabriel Mountains these sediments are coarser grained and may therefore not be susceptible to liquefaction. Alluvial sediments have also been mapped in the canyons emanating from the San Rafael Hills, such as Scholl and Sycamore canyons. The third condition – water-saturated sediments within about 50 feet of the surface – has been known to occur historically only in the Verdugo Wash north of surface projection of the Verdugo fault, and in the floodplain of the Los Angeles River. Therefore, these are the areas with the potential to experience future liquefaction-induced ground displacements. The areas are shown on Plate H-5, and are discussed further below.

The Verdugo fault appears to cause a step or series of steps in the ground water surface, with groundwater levels consistently lower on the south side of the fault zone. Brown (1975) indicated that these steps in the groundwater surface are due to offsets in the bedrock surface at depth along the fault zone, but that no surface evidence of a fault forming groundwater barrier has been found in the area. Nevertheless, a barrier to groundwater must be present in this area to cause the water on the north side of the fault zone to rise to within 50 feet of the ground surface. Although not mapped, shallow groundwater conditions may occur locally in those sections of the south-flowing canyons emanating from the Verdugo Mountains that are located north of the Verdugo fault zone. Ground water may be perched on top of the bedrock surface, and ponded behind the fault zone. Since the bedrock that forms these mountains weathers to sand-sized particles, some of the canyons may contain sediments susceptible to liquefaction. The potential for these areas to liquefy should be evaluated on a case-by-case basis.

The San Fernando Valley narrows to essentially a point in the area of Glendale between the Verdugo Mountains to the north, and the Hollywood Hills to the south, in the area where the Los Angeles River veers to the south. Due to this constriction, or reduction in the cross-sectional area of the water-bearing section of the valley, the ground water rises. Historically the ground water in this area has risen to within less than 50 feet of the ground surface. As a result, this portion of the basin, which is underlain by unconsolidated, young sediments, is susceptible to liquefaction. Plate H-5 shows those areas of Glendale that the California Geological Survey (CDMG, 1999) has identified as susceptible to liquefaction based on an extensive database of boreholes and groundwater levels measured in wells. Areas near existing stream channels, such as Verdugo Wash and the Los Angeles River, are thought to be especially vulnerable to liquefaction as indicated by previous events: Much of the liquefaction-related ground failure in the city of Simi Valley during the Northridge earthquake was concentrated near the Arroyo Simi. A study by the CGS found that most of the property damage occurred in poorly engineered fills placed over the natural, pre-development channels of the Arroyo Simi, where ground water is very shallow (Barrows et al., 1994).

The types of ground failure typically associated with liquefaction are explained below.

Lateral Spreading - Lateral displacement of surficial blocks of soil as the result of liquefaction in a subsurface layer is called lateral spreading. Even a very thin liquefied layer can act as a hazardous slip plane if it is continuous over a large enough area. Once liquefaction transforms the subsurface layer into a fluid-like mass, gravity plus inertial forces caused by the earthquake may move the mass downslope towards a cut slope or free face (such as a river channel or a canal). Lateral spreading most commonly occurs on gentle slopes that range between 0.3° and 3°, and can displace the ground surface by several meters to tens of meters. Such movement damages pipelines, utilities, bridges, roads, and other structures. During the 1906 San Francisco earthquake, lateral spreads with displacements of only a few feet damaged every major pipeline. Thus, liquefaction compromised San Francisco's ability to fight the fires that caused about 85 percent of the damage (Tinsley et al., 1985).

Flow Failure - The most catastrophic mode of ground failure caused by liquefaction is flow failure. Flow failure usually occurs on slopes greater than 3°. Flows are principally liquefied soil or blocks of intact material riding on a liquefied subsurface. Displacements are often in the tens of meters, but in favorable circumstances, soils can be displaced for tens of miles, at velocities of tens of miles per hour. For example, the extensive damage to Seward and Valdez, Alaska, during the 1964 Great Alaskan earthquake was caused by submarine flow failures (Tinsley et al., 1985).

Ground Oscillation - When liquefaction occurs at depth but the slope is too gentle to permit lateral displacement, the soil blocks that are not liquefied may separate from one another and oscillate on the liquefied zone. The resulting ground oscillation may be accompanied by the opening and closing of fissures (cracks) and sand boils, potentially damaging structures and underground utilities (Tinsley et al., 1985).

Loss of Bearing Strength - When a soil liquefies, loss of bearing strength may occur beneath a structure, possibly causing the building to settle and tip. If the structure is buoyant, it may float upward. During the 1964 Niigata, Japan earthquake, buried septic tanks rose as much as 3 feet, and structures in the Kwangishicho apartment complex tilted as much as 60° (Tinsley et al., 1985).

Ground Lurching - Soft, saturated soils have been observed to move in a wave-like manner in response to intense seismic ground shaking, forming ridges or cracks on the ground surface. At present, the potential for ground lurching to occur at a given site can be predicted only generally. Areas underlain by thick accumulation of colluvium and alluvium appear to be the most susceptible to ground lurching. Under strong ground motion conditions, lurching can be expected in loose, cohesionless soils, or in clay-rich soils with high moisture content. In some cases, the deformation remains after the shaking stops (Barrows et al., 1994).

Seismically Induced Slope Failure

Strong ground motions can worsen existing unstable slope conditions, particularly if coupled with saturated ground conditions. Seismically induced landslides can overrun structures, people or property, sever utility lines, and block roads, thereby hindering rescue operations after an earthquake. Over 11,000 landslides were mapped shortly after the Northridge earthquake, all within a 45-mile radius of the epicenter (Harp and Jibson, 1996). Although numerous types of earthquake-induced landslides have been identified, the most widespread type generally consists of shallow failures involving surficial soils and the uppermost weathered bedrock in moderate to steep hillside terrain (these are also called disrupted soil slides). Rock falls and rockslides on very steep slopes are also common. The 1989 Loma Prieta and Northridge earthquakes showed that reactivation of existing deep-seated landslides also occurs (Spittler et al., 1990; Barrows et al., 1995).

A combination of geologic conditions leads to landslide vulnerability. These include high seismic potential; rapid uplift and erosion resulting in steep slopes and deeply incised canyons; highly fractured and folded rock; and rock with inherently weak components, such as silt or clay layers. The orientation of the slope with respect to the direction of the seismic waves (which can affect the shaking intensity) can also control the occurrence of landslides.

Several areas in Glendale have been identified as vulnerable to seismically induced slope failure (see Plate H-5). The mountainous region along the northern reaches of the city (the San Gabriel Mountains) is susceptible to slope failure due to the steep terrain. The crystalline bedrock that crops out in the northern and central portions of the San Rafael Hills is locally highly fractured and weathered. In steep areas, strong ground shaking can cause slides or rockfalls in this material. Slope failures can also occur in the western and central portions of the city, in the Verdugo Mountains, where locally steep terrain is combined with fractured igneous and metamorphic rock units. Numerous small landslides can be expected to occur in these areas in response to an earthquake on the Sierra Madre, the Verdugo or other nearby faults. For a more detailed assessment of potential slope instability in the Glendale area, refer to Section 9 of this report.

Ridgetop Fissuring and Shattering

Linear, fault-like fissures occurred on ridge crests in a relatively concentrated area of rugged terrain in the Santa Cruz Mountains during the Loma Prieta earthquake. Shattering of the surface soils on the crests of steep, narrow ridgelines occurred locally in the 1971 San Fernando earthquake, but was widespread in the 1994 Northridge earthquake. Ridgetop shattering (which leaves the surface looking as if it was plowed) by the Northridge earthquake was observed as far as 22 miles away from the epicenter. In the Sherman Oaks area, severe damage occurred locally to structures located at the tops of relatively high (greater than 100 feet), narrow (typically less than 300 feet wide) ridges flanked by slopes steeper than about 2.5:1 (horizontal:vertical). It is generally accepted that ridgetop fissuring and shattering is a result of intense amplification or focusing of seismic energy due to local topographic effects (Barrows et al., 1995).

Ridgetop shattering can be expected to occur in the topographically steep portions of the San Gabriel Mountains north of Glendale, in the Verdugo Mountains, and locally in the San Rafael Hills. These areas are for the most part undeveloped, so the hazard associated with ridgetop shattering is relatively low. However, above ground storage tanks, reservoirs and utility towers are often located on top of ridges, and during strong ground shaking, these can fail or topple over, with the potential to cause widespread damage to development downslope (storage tanks and reservoirs), or disruptions to the lifeline systems (utility towers).

Vulnerability Assessment

The effects of earthquakes span a large area, and large earthquakes occurring in the southern California area would be felt throughout the region. However, the degree to which earthquakes are felt, and the damages associated with them may vary. At risk from earthquake damage are large stocks of old buildings and bridges; many hazardous materials facilities; extensive sewer, water, and natural gas pipelines; earthen dams; petroleum pipelines; and other critical facilities, not to mention private property and businesses. Secondary earthquake hazards, such as liquefaction and earthquake-induced landslides, can be just as devastating as the ground shaking.

Damage to the extensive building stock in the area is expected to vary. Older, pre-1945 steel frame structures may have unreinforced masonry such as bricks, clay tiles and terra cotta tiles as cladding or infilling. Cladding in newer buildings may be glass, infill panels or pre-cast panels that may fail and generate a band of debris around the building exterior (with considerable threat to pedestrians in the streets below). Structural damage may occur if the structural members are subject to plastic deformation which can cause permanent displacements. If some walls fail while others remain intact, torsion or soft-story problems may result. Overall, modern steel frame buildings have been expected to perform well in earthquakes, but the 1994 Northridge earthquake broke many welds in these buildings, a previously unanticipated problem.

Buildings are often a combination of steel, concrete, reinforced masonry and wood, with different structural systems on different floors or different sections of the building. Combination types that are potentially hazardous include: concrete frame buildings without special reinforcing, precast concrete and precast-composite buildings, steel frame or concrete frame buildings with unreinforced masonry walls, reinforced concrete wall buildings with no special detailing or reinforcement, large capacity buildings with long-span roof structures (such as theaters and auditoriums), large unengineered wood-frame buildings, buildings with inadequately anchored exterior cladding and glazing, and buildings with poorly anchored parapets and appendages (FEMA, 1985). Additional types of potentially hazardous buildings may be recognized after future earthquakes.

Mobile homes are prefabricated housing units that are placed on isolated piers, jackstands, or masonry block foundations (usually without any positive anchorage). Floors and roofs of mobile homes are usually plywood, and outside surfaces are covered with sheet metal. Mobile homes typically do not perform well in earthquakes. Severe damage occurs when they fall off their supports, severing utility lines and piercing the floor with jackstands.

In addition to building types, there are other factors associated with the design and construction of the buildings that also have an impact on the structures' vulnerability to strong ground shaking. Some of these conditions are discussed below:

- **Building Shape** - A building's vertical and/or horizontal shape can be important. Simple, symmetric buildings generally perform better than non-symmetric buildings. During an earthquake, non-symmetric buildings tend to twist as well as shake. Wings on a building tend to act independently during an earthquake, resulting in differential movements and cracking. The geometry of the lateral load-resisting systems also matters. For example, buildings with one or two walls made mostly of glass, while the remaining walls are made of concrete or brick, are at risk. Asymmetry in the placement of bracing systems that provide a building with earthquake resistance, can result in twisting or differential motions.

- **Pounding -** Site-related seismic hazards may include the potential for neighboring buildings to "pound," or for one building to collapse onto a neighbor. Pounding occurs when there is little clearance between adjacent buildings, and the buildings "pound" against each other as they deflect during an earthquake. The effects of pounding can be especially damaging if the floors of the buildings are at different elevations, so that, for example, the floor of one building hits a supporting column of the other. Damage to a supporting column can result in partial or total building collapse.

Damage to the region's critical facilities and infrastructure need to be considered and planned for. **Critical facilities** are those parts of a community's infrastructure that must remain operational after an earthquake. Critical facilities include schools, hospitals, fire and police stations, emergency operation centers, and communication centers. Plate H-12 shows the locations of the City's fire stations, police stations, schools, and other critical facilities. A vulnerability assessment for these facilities involves comparing the locations of these facilities to the hazardous areas identified in the

City, including active and potentially active faults (Plate H-4), liquefaction-susceptible areas (Plate H-5), unstable slope areas (Plates H-5 and H-11), potential dam failure inundation areas (Plate H-10), fire hazard zones (Plate H-7), and sites that generate hazardous materials.

High-risk facilities, if severely damaged, may result in a disaster far beyond the facilities themselves. Examples include power plants, dams and flood control structures, freeway interchanges, bridges, and industrial plants that use or store explosives, toxic materials or petroleum products.

High-occupancy facilities have the potential of resulting in a large number of casualties or crowd-control problems. This category includes high-rise buildings, large assembly facilities, and large multifamily residential complexes.

Dependent-care facilities, such as preschools and schools, rehabilitation centers, prisons, group care homes, and nursing homes, house populations with special evacuation considerations.

Economic facilities, such as banks, archiving and vital record-keeping facilities, airports, and large industrial or commercial centers, are those facilities that should remain operational to avoid severe economic impacts.

It is crucial that critical facilities have no structural weaknesses that can lead to collapse. For example, the Federal Emergency Management Agency (FEMA, 1985) has suggested the following seismic performance goals for **health care facilities**:

- The damage to the facilities should be limited to what might be reasonably expected after a destructive earthquake and should be repairable and not be life-threatening.
- Patients, visitors, and medical, nursing, technical and support staff within and immediately outside the facility should be protected during an earthquake.
- Emergency utility systems in the facility should remain operational after an earthquake.
- Occupants should be able to evacuate the facility safely after an earthquake.
- Rescue and emergency workers should be able to enter the facility immediately after an earthquake and should encounter only minimum interference and danger.
- The facility should be available for its planned disaster response role after an earthquake.

Lifelines are those services that are critical to the health, safety and functioning of the community. They are particularly essential for emergency response and recovery after an earthquake. Furthermore, certain critical facilities designed to remain functional during and immediately after an earthquake may be able to provide only limited services if the lifelines they depend on are disrupted. Lifeline systems include water, sewage, electrical power, communication, transportation (highways, bridges, railroads, and airports), natural gas, and liquid fuel systems. The improved performance of lifelines in the 1994 Northridge earthquake, relative to the 1971 San Fernando earthquake, shows that the seismic codes upgraded and implemented after 1971 have been effective. Nevertheless, the impact of the Northridge quake on lifeline systems was widespread and illustrates the continued need to study earthquake impacts, to upgrade substandard elements in the systems, to provide redundancy in systems, to improve emergency response plans, and to provide adequate planning, budgeting and financing for seismic safety.

Some of the observations and lessons learned from the Northridge earthquake are summarized below (from Savage, 1995; Lund, 1996).

- Several electrical transmission towers were damaged or totally collapsed. Collapse was generally due to foundation distress in towers that were located near ridge tops where amplification of ground motion may have occurred. One collapse was the result of a seismically induced slope failure at the base of the tower.
- Damage to above ground water tanks typically occurred where piping and joints were rigidly connected to the tank, due to differential movement between the tank and the piping. Older steel tanks not seismically designed under current standards buckled at the bottom (called "elephant's foot"), in the shell, and on the roof. Modern steel and concrete tanks generally performed well.
- The most vulnerable components of pipeline distribution systems were older threaded joints, cast iron valves, cast iron pipes with rigid joints, and older steel pipes weakened by corrosion. In the case of broken water lines, the loss of fire suppression water forced fire departments to utilize water from swimming pools and tanker trucks.
- Significant damage occurred in water treatment plants due to sloshing in large water basins.
- A number of facilities did not have an emergency power supply or did not have enough power supply capacity to provide their essential services.
- Lifelines within critical structures, such as hospitals and fire stations, may be vulnerable. For instance, rooftop mechanical and electrical equipment is not generally designed for seismic forces. During the Northridge quake, rooftop equipment failed causing malfunctions in other systems.
- A 70-year old crude oil pipeline leaked from a cracked weld, spreading oil for 12 miles down the Santa Clara River.
- A freight train carrying sulfuric acid was derailed causing an 8,000-gallon acid spill and a 2,000-gallon diesel spill from the locomotive.

The above list is by no means a complete summary of the earthquake damage, but it does highlight some of the issues pertinent to the Glendale area. All lifeline providers should make an evaluation of the seismic vulnerability within their systems a priority. The evaluation should include a plan to fund and schedule the needed seismic mitigation.

Risk Analysis

Risk analysis is the third phase of a hazard assessment. Risk analysis involves estimating the damage and costs likely to be experienced in a geographic area over a period of time. Factors included in assessing earthquake risk include population and property distribution in the hazard area, the frequency of earthquake events, landslide susceptibility, buildings, infrastructure, and disaster preparedness of the region. This type of analysis can generate estimates of the damages to the region due to an earthquake event in a specific location. FEMA's software program, HAZUS, uses mathematical formulas and information about building stock, local geology and the location and size of potential earthquakes, economic data, and other information to estimate losses from a potential earthquake. A HAZUS loss estimation was conducted for the city of Glendale as part of its Safety Element of the General Plan. That section of the Safety Element is reproduced in the following pages.

HAZUS-99™ is a standardized methodology for earthquake loss estimation based on a geographic information system (GIS). A project of the National Institute of Building Sciences, funded by the Federal Emergency Management Agency (FEMA), it is a powerful advance in mitigation strategies. The HAZUS project developed guidelines and procedures to make standardized earthquake loss estimates at a regional scale. With standardization, estimates can be compared from region to region. HAZUS is designed for use by state, regional and local governments in planning for earthquake loss mitigation, emergency preparedness, response and recovery. HAZUS addresses nearly all aspects of the built environment, and many different types of losses. The methodology has been tested against the experience of several past earthquakes, and against the judgment of experts. Subject to several limitations noted below, HAZUS can produce results that are valid for the intended purposes.

Loss estimation is an invaluable tool, but must be used with discretion. Loss estimation analyzes casualties, damage and economic loss in great detail. It produces seemingly precise numbers that can be easily misinterpreted. Loss estimation's results, for example, may cite 4,054 left homeless by a scenario earthquake. This is best interpreted by its magnitude. That is, an event that leaves 4,000 people homeless is clearly more manageable than an event causing 40,000 homeless people; and an event that leaves 400,000 homeless would overwhelm a community's resources. However, another loss estimation that predicts 7,000 people homeless should probably be considered equivalent to the 4,054 result. Because HAZUS results make use of a great number of parameters and data of varying accuracy and completeness, it is not possible to assign quantitative error bars. Although the numbers should not be taken at face value, they are not rounded or edited because detailed evaluation of individual components of the disaster can help mitigation agencies ensure that they have considered all the important options.

The more community-specific the data that are input to HAZUS, the more reliable the loss estimation. HAZUS provides defaults for all required information. These are based on best-available scientific, engineering, census and economic knowledge. The loss estimations in this report have been tailored to Glendale by using a map of soil types for the City. HAZUS relies on 1990 Census data, but for the purposes of this study, we replaced the population by census tract data that came with the software with the 2000 Census data. Other modifications made to the data set before running the analyses include:

- updated the database of critical facilities, including the number and location of the fire and police stations in the City,
- revised the number of beds available in the three major hospitals in Glendale to better represent their current patient capacity, and

- upgraded the construction level for most unreinforced masonry buildings in the City to better represent the City's retrofitting efforts of the last decade.

As useful as HAZUS seems to be, the loss estimation methodology has some inherent uncertainties. These arise in part from incomplete scientific knowledge concerning earthquakes and their effect upon buildings and facilities, and in part from the approximations and simplifications necessary for comprehensive analyses.

Users should be aware of the following specific limitations:

- HAZUS is driven by statistics, and thus is most accurate when applied to a region, or a class of buildings or facilities. It is least accurate when considering a particular site, building or facility.
- Losses estimated for lifelines may be less than losses estimated for the general building stock.
- Losses from smaller (less than M 6.0) damaging earthquakes may be overestimated.
- Pilot and calibration studies have not yet provided an adequate test concerning the possible extent and effects of landsliding.
- The indirect economic loss module is new and experimental. While output from pilot studies has generally been credible, this module requires further testing.
- The databases that HAZUS draws from to make its estimates are often incomplete or outdated (as discussed above, efforts were made to improve some of the datasets used for the analysis, but for some estimates, the software still relies on 1990 census tracts data and 1994 DNB economic reports). This is another reason the loss estimates should not be taken at face value.

Essential facilities and lifeline inventory are located by latitude and longitude. However, the HAZUS inventory data for lifelines and utilities were developed at a national level and where specific data are lacking, statistical estimations are utilized. Specifics about the site-specific inventory data used in the models are discussed further in the paragraphs below. Other site-specific data used include soil types and liquefaction susceptible zones. The user then defines the earthquake scenario to be modeled, including the magnitude of the earthquake, and the location of the epicenter. Once all these data are input, the software calculates the loss estimates for each scenario.

The loss estimates include physical damage to buildings of different construction and occupancy types, damage to essential facilities and lifelines, number of after-earthquake fires and damage due to fire, and the amount of debris that is expected. The model also estimates the direct economic and social losses, including casualties and fatalities for three different times of the day, the number of people left homeless and number of people that will require shelter, number of hospital beds available, and the economic losses due to damage to the places of businesses, loss of inventory, and (to some degree) loss of jobs. The indirect economic losses component is still experimental; the calculations in the software are checked against actual past earthquakes, such as the 1989 Loma Prieta and 1994 Northridge earthquake, but indirect losses are hard to measure, and it typically takes years before these monetary losses can be quantified with any degree of accuracy. Therefore, this component of HAZUS is still considered experimental.

HAZUS breaks **critical facilities** into two groups: essential facilities and high potential loss (HPL) facilities. Essential facilities provide services to the community and should be functional after an earthquake. Essential facilities include hospitals, medical clinics, schools, fire stations, police stations and emergency operations facilities. The essential facility module in HAZUS determines the expected loss of functionality for these facilities. The damage probabilities for essential facilities are determined on a site-specific basis (i.e., at each facility). Economic losses associated with these facilities are computed as part of the analysis of the general building stock. Data required for the analysis include occupancy classes (current building use) and building structural type, or a combination of essential facilities building type, design level and construction quality factor. High potential loss facilities include dams, levees, military installations, nuclear power plants and hazardous material sites.

HAZUS divides the **lifeline** inventory into two systems: transportation and utility lifelines. The transportation system includes seven components: highways, railways, light rail, bus, ports, ferry and airports. The utility lifelines include potable water, wastewater, natural gas, crude and refined oil, electric power and communications. If site-specific lifeline utility data are not provided for these analyses, HAZUS performs a statistical calculation based on the population served.

General Building Stock Type and Classification: HAZUS provides damage data for buildings based on these structural types:

- Concrete
- Mobile Home
- Precast Concrete
- Reinforced Masonry Bearing Walls
- Steel
- Unreinforced Masonry Bearing Walls
- Wood Frame

and based on these occupancy (usage) classifications:

- Residential
- Commercial
- Industrial
- Agriculture
- Religion
- Government and
- Education

Loss estimation for the general **building stock** is averaged for each census tract. Building damage classifications range from slight to complete. As an example, the building damage classification for wood frame buildings is provided below. Wood-frame structures comprise the city's most numerous building type.

Wood, Light Frame:

- *Slight Structural Damage*: Small plaster or gypsum-board cracks at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneer.
- *Moderate Structural Damage*: Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.
- *Extensive Structural Damage*: Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations; partial collapse of "room-over-garage" or other "soft-story" configurations; small foundations cracks.
- *Complete Structural Damage*: Structure may have large permanent lateral displacement, may collapse, or be in imminent danger of collapse due to cripple wall failure or failure of the lateral load resisting system; some structures may slip and fall off the foundations; large foundation cracks.

Estimates of building damage are provided for "High", "Moderate" and "Low" seismic design criteria. Buildings of newer construction (e.g., post-1973) are best designated by "High." Buildings built after 1940, but before 1973, are best represented by "Moderate." If built before about 1940 (i.e., before significant seismic codes were implemented), "Low" is most appropriate. A large percentage of buildings in the City of Glendale fall in the "Moderate" and "High" seismic design criteria.

HAZUS estimates two types of **debris**. The first is debris that falls in large pieces, such as steel members or reinforced concrete elements. These require special treatment to break into smaller pieces before they are hauled away. The second type of debris is smaller and more easily moved with bulldozers and other machinery and tools. This type includes brick, wood, glass, building contents and other materials.

Casualties are estimated based on the assumption that there is a strong correlation between building damage (both structural and non-structural) and the number and severity of casualties. In smaller earthquakes, non-structural damage will most likely control the casualty estimates. In severe earthquakes where there will be a large number of collapses and partial collapses, there will be a proportionately larger number of fatalities. Data regarding earthquake-related injuries are not of the best quality, nor are they available for all building types. Available data often have insufficient information about the type of structure in which the casualties occurred and the casualty-generating mechanism. HAZUS casualty estimates are based on the injury classification scale described in Table 6-4.

Table 6-4: Injury Classification Scale

Injury Severity Level	Injury Description
Severity 1	Injuries requiring basic medical aid without requiring hospitalization.
Severity 2	Injuries requiring a greater degree of medical care and hospitalization, but not expected to progress to a life-threatening status.
Severity 3	Injuries which pose an immediate life-threatening condition if not treated adequately and expeditiously. The majority of these injuries are the result of structural collapse and subsequent entrapment or impairment of the occupants.
Severity 4	Instantaneously killed or mortally injured.

In addition, HAZUS produces casualty estimates for **three times of day**:

- Earthquake striking at 2:00 a.m. (population at home)
- Earthquake striking at 2:00 p.m. (population at work/school)
- Earthquake striking at 5:00 p.m. (commute time).

Displaced Households/Shelter Requirements - Earthquakes can cause loss of function or habitability of buildings that contain housing. Displaced households may need alternative short-term shelter, provided by family, friends, temporary rentals, or public shelters established by the City, County or by relief organizations such as the Red Cross or Salvation Army. Long-term alternative housing may require import of mobile homes, occupancy of vacant units, net emigration from the impacted area, or, eventually, the repair or reconstruction of new public and private housing. The number of people seeking short-term public shelter is of most concern to emergency response organizations. The longer-term impacts on the housing stock are of great concern to local governments, such as cities and counties.

Economic Losses - HAZUS estimates structural and nonstructural repair costs caused by building damage and the associated loss of building contents and business inventory. Building damage can cause additional losses by restricting the building's ability to function properly. Thus, business interruption and rental income losses are estimated. HAZUS divides building losses into two categories: (1) direct building losses and (2) business interruption losses. Direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. Business interruption losses are associated with inability to operate a business because of the damage sustained during the earthquake. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the earthquake.

Earthquakes may produce indirect economic losses in sectors that do not sustain direct damage. All businesses are forward-linked (if they rely on regional customers to purchase their output) or backward-linked (if they rely on regional suppliers to provide their inputs) and are thus potentially vulnerable to interruptions in their operation. Note that indirect losses are not confined to immediate customers or suppliers of damaged enterprises. All of the successive rounds of customers of customers and suppliers of suppliers are affected. In this way, even limited physical earthquake damage causes a chain reaction, or ripple effect, that is transmitted throughout the regional economy.

HAZUS Scenario Earthquakes for the Glendale Area

Five specific scenario earthquakes were modeled using the HAZUS loss estimation software available from FEMA: earthquakes on the San Andreas, Sierra Madre, Verdugo, Raymond and Hollywood faults (see Table 6-5).

Table 6-5: HAZUS Scenario Earthquakes for the City of Glendale

Fault Source	Magnitude	Description
San Andreas - Mojave Segment	7.1	A large earthquake that ruptures the Mojave segment of the San Andreas fault is modeled because of its high probability of occurrence, even though the epicenter would not be too close to the City.
Sierra Madre	7.2	Likely worst-case scenario for the Glendale area. The 7.2 magnitude earthquake modeled is at the lower range of the size of earthquakes that researchers now believe this fault is capable of generating.
Verdugo	6.7	Possible worst-case scenario for Glendale. Although this earthquake is not as large as the one estimated on the Sierra Madre fault, this fault extends through an extensively developed area, and therefore has the potential to cause significant damage to buildings and infrastructure.
Raymond	6.5	Maximum magnitude earthquake on the Raymond fault. This fault near the southern portion of the City could cause significant damage in the southern and eastern portions of Glendale, and in the San Rafael Hills.
Hollywood	6.4	Maximum magnitude earthquake on the Hollywood fault would cause extensive damage in Hollywood, West Hollywood, and in the southwestern portion of Glendale. This fault could break together with the Santa Monica faults, generating a stronger, more damaging earthquake than the one presented herein.

Four of the five earthquake scenarios modeled for this study are discussed in the following sections. An earthquake on the San Andreas fault is discussed because it has the highest probability of occurring in the not too distant future, even though the loses expected from this earthquake are not the worst possible for Glendale. An earthquake on the San Andreas fault has traditionally been considered the "Big One," the implication being that an earthquake on this fault would be devastating to southern California. However, there are several other seismic sources that, given their location closer to the Los Angeles metropolitan area, have the potential to be more devastating to the region, even if the causative earthquake is smaller in magnitude than an earthquake on the San Andreas fault. The 7.1 magnitude San Andreas earthquake modeled for this study would result from the rupture of the Mojave segment of the fault. This segment is thought to have more than a 40 percent probability of rupturing in the next 30 years. A larger-magnitude earthquake on the San Andreas fault would occur if more than one segment of the fault ruptures at the same time. If all three southern segments of the San Andreas fault break together, an earthquake of at least magnitude 7.8 would result.

The Sierra Madre and Verdugo scenarios are also presented here because both of these faults have the potential to cause significant damage in the City. As discussed in Section 1.5.5, the Sierra Madre fault appears to have last ruptured more than 8,000 years ago, and may be near the end of its strain accumulation cycle. Given that recent studies suggest that the Sierra Madre fault can generate earthquakes of magnitude 7.2 to 7.5 (instead of the 7.0 used by the California Geological Survey), a lower-bound 7.2 magnitude earthquake was chosen for the scenario and loss estimation analysis. The earthquake history and recurrence interval of the Verdugo fault are unknown, and as a result, the probability of future earthquakes on this fault cannot be quantified with any degree of certainty. What it is certain is that if, and when this fault breaks, the City of Glendale will be impacted. HAZUS helps to quantify the damage expected.

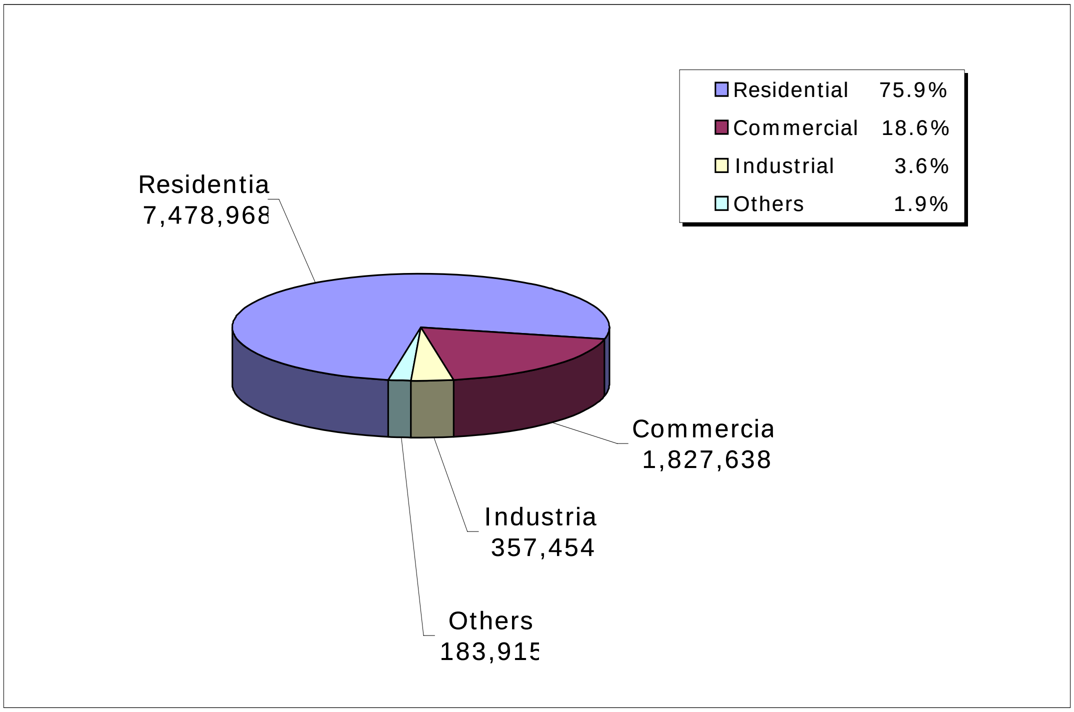
The Raymond and Hollywood faults would both cause about the same amount of damage in Glendale. The Raymond fault appears to break more often than the Hollywood fault, and as a result, one could argue that it has a higher probability of rupturing again in the future. However, since the Hollywood fault appears to have last ruptured several thousand years ago, it may actually be closer to rupture. Since both faults are located immediately south of Glendale, the damage patterns can be expected to be very similar (directivity of fault breakage can have a substantial impact on the damage potential, but the damage analyses conducted for this study are not designed to be sensitive to this issue).

As mentioned previously, the population data used for the Glendale analyses were modified using the recently available 2000 Census data. The general building stock and population inventory data conform to census tract boundaries, and the census tract boundaries generally conform to the City limits, with minor exceptions. The region studied is 30 square miles in area and contains 28 census tracts. There are over 68,000 households (1990 Census Bureau data – the 2000 Census lists 74,000 households) in the region, with a total population of 194,000 (based on 2000 Census Bureau data). There are an estimated 33,000 buildings in the region with a total building replacement value (excluding contents) of $9.85 billion (1994 dollars). Approximately 96 percent of the buildings (and 76 percent of the building value) are associated with residential housing (see Figure 6-1). In terms of building construction types found in the region, wood-frame construction makes up 94 percent of the building inventory. The remaining percentage is distributed between the other general building types. The replacement value of the transportation and utility lifeline systems in the City of Glendale is estimated to be nearly $3.26 billion and $245 million (1994 dollars), respectively.

The HAZUS inventory of unreinforced masonry (URM) buildings includes more URMs than those now present in the City, since many URMs have been demolished since 1994. Therefore, the URM numbers in the HAZUS output are somewhat overstated. However, far more URMs in Glendale have been retrofitted than demolished, and the database used for the HAZUS analyses accounts for this: the seismic design criteria for most URMs in the City were upgraded from low to moderate to reflect the retrofitting efforts that have been accomplished in the late 1990s and early 2000s. It is important to note, however, that retrofitting is typically designed to keep buildings from collapsing, but that structural damage to the building is still possible and expected.

Changes were made to the HAZUS hospital inventory for Glendale, specifically, to the number of beds available. In all cases, the number of beds at all hospitals has increased since 1990, based on recent bed counts published by each of the three main hospitals in the City: Glendale Adventist Medical Center has 450 beds, Glendale Memorial Hospital and Health Center has 334 beds, and Verdugo Hills Hospital has 158 beds, for a total hospital capacity of 942 beds. At least one of these hospitals (Glendale Memorial) is currently enlarging its facilities to serve an even larger number of patients. The new hospital wing is being built to the seismic standards of the Office of the State Architect in accordance with State law.

Figure 6-1
Building Inventory, by Occupancy Type, in the Glendale Area
(values shown are in millions of dollars)



Regarding critical facilities, the HAZUS database for Glendale includes 70 schools or school facilities, including school district offices, private schools, and community colleges. The City's emergency operations center in the basement of City Hall is also included. The database was modified to include the two police stations and nine fire stations that serve the City. The locations of these facilities are shown on Plate H-12.

HAZUS loss estimations for the City of Glendale based on four of the earthquake scenarios modeled are presented concurrently below. These scenarios include earthquakes on the San Andreas, Sierra Madre, Verdugo and Raymond faults. Of the five earthquake scenarios modeled for the city, the results indicate that the San Andreas fault earthquake will pose the least damage to the Glendale, although this fault may have the highest probability of rupturing in the near-future.

The Sierra Madre and Verdugo earthquake scenarios are the worst-case scenarios for the City. The losses are similar, but the damaged areas will be different, as the faults transect different sections of the City. Since the Sierra Madre fault is a reverse fault, it has the potential to generate stronger ground accelerations than the predominantly left-lateral strike slip Verdugo fault (reverse faults typically generate stronger ground accelerations, distributed over a broader geographic area than strike-slip faults). However, the stronger seismic shaking will be experienced north of the fault, in the sparsely populated San Gabriel Mountains. Landsliding and rock collapse can be expected to result in road closures in the mountains, and some damage to the dams north of the area can be anticipated. The areas adjacent to and immediately south of the Sierra Madre fault will also experience damage.

The losses anticipated as a result of either the Raymond or Hollywood fault causing an earthquake are also similar. These events would pose the next worst-case scenario for Glendale. Directivity of the seismic waves, as discussed earlier in this chapter, will determine, at least to some extent, where and how much damage will be experienced in the area as a result of earthquakes on either the Hollywood or Raymond faults. However, seismologists still do not have the tools to predict where, when, and how a fault will break, and HAZUS does not consider these issues in the loss estimation analysis.

Building Damage - HAZUS estimates that between approximately 350 and 5,000 buildings will be at least moderately damaged in response to the earthquake scenarios presented herein, with the lower number representative of damage as a result of an earthquake on the San Andreas fault, and the higher number representing damage as a result of an earthquake on either the Verdugo or Sierra Madre fault. These figures represent about 1 to 15 percent of the total number of buildings in the study area. An estimated 0 to 55 buildings will be completely destroyed. Table 6-6 summarizes the expected damage to buildings by general occupancy type, while Table 6-7 summarizes the expected damage to buildings in Glendale, classified by construction type.

The data presented in Tables 6-6 and 6-7 show that most of the buildings damaged will be residential, with wood-frame structures experiencing mostly slight to moderate damage. The Verdugo and Sierra Madre fault earthquake scenarios both have the potential to cause at least slight damage to more than 50 percent of the residential structures in Glendale, and moderate to complete damage to as much as 16 percent of the residential stock. The distribution and severity of the damage caused by these earthquakes to the residential buildings in the city is illustrated in Map 6.6. As mentioned before, an earthquake on the Sierra Madre fault would cause more damage in the northern section of the city than an earthquake on either the Verdugo or Raymond faults. The Raymond (and Hollywood) faults have the potential to cause significant damage to the residential stock of Glendale, but the damage would not be as severe as that caused by either the Sierra Madre or Verdugo faults. The San Andreas fault scenario is anticipated to cause slight to moderate damage to about 10 percent of the residential buildings in the city.

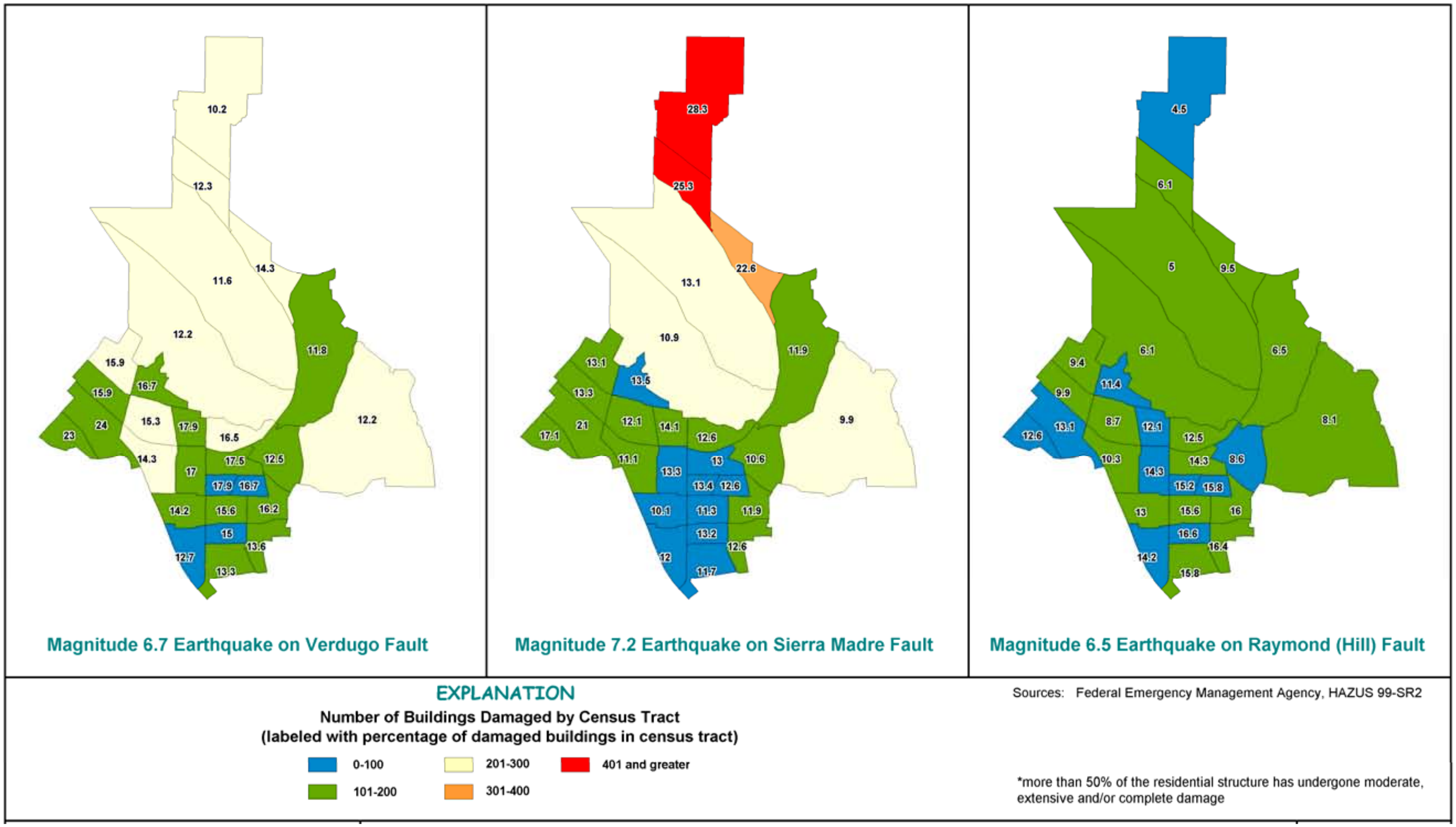
Table 6-6: Number of Buildings Damaged, by Occupancy Type

Scenario	Occupancy Type	Slight	Moderate	Extensive	Complete	Total
San Andreas	Residential	2,859	308	0	0	3,167
	Commercial	86	25	0	0	111
	Industrial	23	10	1	0	34
	Agriculture	0	0	0	0	0
	Religion	3	0	0	0	3
	Government	0	0	0	0	0
	Education	0	0	0	0	0
	Total	2,971	343	1	0	**3,315**
Sierra Madre	Residential	11,362	4,166	387	51	15,966
	Commercial	276	257	68	2	603
	Industrial	65	71	24	2	162
	Agriculture	2	2	0	0	4
	Religion	18	14	2	0	34
	Government	1	0	0	0	1
	Education	5	2	0	0	7
	Total	11,729	4,512	481	55	**16,777**
Verdugo	Residential	11,656	4,153	330	20	16,159
	Commercial	285	272	82	5	644
	Industrial	66	73	24	2	165
	Agriculture	2	1	0	0	3
	Religion	18	15	2	0	35
	Government	1	0	0	0	1
	Education	5	1	0	0	6
	Total	12,033	4,515	438	27	**17,013**
Raymond	Residential	10,026	2,949	186	4	13,165
	Commercial	271	224	50	0	545
	Industrial	62	60	16	2	140
	Agriculture	2	0	0	0	2
	Religion	17	11	1	0	29
	Government	1	0	0	0	1
	Education	4	1	0	0	5
	Total	10,383	3,245	253	6	**13,887**

Although the numbers presented in Table 6-6 only hint at it, the commercial and industrial structures will also be impacted. The Sierra Madre and Verdugo earthquakes have the potential to damage about 10 percent and 14 percent of the commercial and industrial buildings, respectively, in the City. The distribution and severity of damage to the commercial structures in the City as a result of earthquakes on the Verdugo, Sierra Madre and Raymond faults is illustrated in Map 6.7. All three earthquakes shown on Map 6.7 are anticipated to cause damage in the commercial district of the City, but an earthquake on the Verdugo fault would be the most severe, given the fault's location through the heart of Glendale.

Map 6.6: Distribution and Severity of Damaged Residential Buildings in Glendale as a Result of Three Different Earthquake Scenarios

(Damage is defined as more than 50% of the structure has undergone moderate, extensive, and/or complete damage)



Magnitude 6.7 Earthquake on Verdugo Fault

Magnitude 7.2 Earthquake on Sierra Madre Fault

Magnitude 6.5 Earthquake on Raymond (Hill) Fault

EXPLANATION

Number of Buildings Damaged by Census Tract
(labeled with percentage of damaged buildings in census tract)

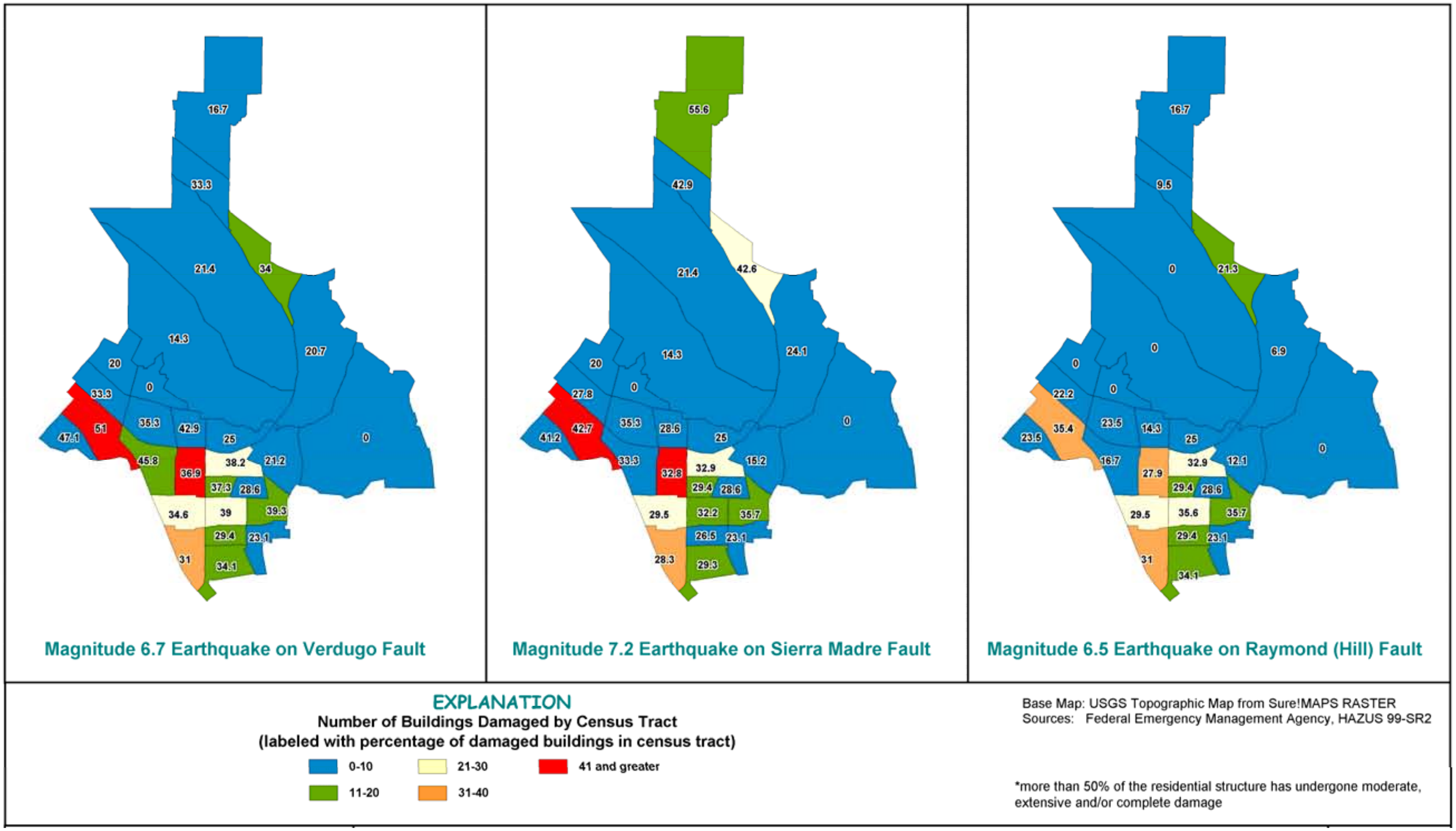
🟦 0-100
🟩 101-200
🟨 201-300
🟧 301-400
🟥 401 and greater

Sources: Federal Emergency Management Agency, HAZUS 99-SR2

*more than 50% of the residential structure has undergone moderate, extensive and/or complete damage

Map 6.7: Distribution and Severity of Damaged Commercial Buildings in Glendale as a Result of Three Different Earthquake Scenarios

(Damage is defined as more than 50% of the structure has undergone moderate, extensive, and/or complete damage)



Base Map: USGS Topographic Map from Sure!MAPS RASTER
Sources: Federal Emergency Management Agency, HAZUS 99-SR2

*more than 50% of the residential structure has undergone moderate, extensive and/or complete damage

Table 6-7: Number of Buildings Damaged, by Construction Type

Scenario	Structure Type	Slight	Moderate	Extensive	Complete	Total
San Andreas	Concrete	26	2	0	0	28
	Mobile Homes	10	5	0	0	15
	Precast Concrete	18	7	0	0	25
	Reinforced Masonry	40	19	0	0	59
	Steel	23	8	0	0	31
	URM	23	5	0	0	28
	Wood	2,831	290	0	0	3,121
	Total	2,971	336	0	0	**3,307**
Sierra Madre	Concrete	103	103	25	0	231
	Mobile Homes	8	25	12	2	47
	Precast Concrete	59	83	22	2	166
	Reinforced Masonry	149	167	57	0	373
	Steel	73	106	34	0	213
	URM	39	50	11	1	101
	Wood	11,298	3,978	315	44	15,635
	Total	11,729	4,512	476	49	**16,766**
Verdugo	Concrete	106	111	31	1	249
	Mobile Homes	11	23	11	0	45
	Precast Concrete	60	91	29	2	182
	Reinforced Masonry	157	185	67	0	409
	Steel	74	106	38	0	218
	URM	39	55	12	1	107
	Wood	11,586	3,944	250	10	15,790
	Total	12,033	4,515	438	14	**17,000**
Raymond	Concrete	103	94	21	0	218
	Mobile Homes	12	20	4	0	36
	Precast Concrete	60	72	20	0	152
	Reinforced Masonry	142	142	45	0	329
	Steel	74	89	24	0	187
	URM	43	43	7	0	93
	Wood	9,949	2,785	126	0	12,860
	Total	10,383	3,245	247	0	**13,875**

The HAZUS output shows that URMs in Glendale will suffer slight to extensive damage, but that very few are likely to be completely destroyed. This is anticipated to reduce the number of casualties significantly. The numbers show that by retrofitting its URMs, Glendale has already reduced significantly its vulnerability to seismic shaking.

Significantly, reinforced masonry, concrete and steel structures are not expected to perform well, with hundreds of these buildings in Glendale experiencing at least moderate damage during an earthquake on the Sierra Madre or Verdugo faults. These types of structures are commonly used for commercial and industrial purposes, and failure of some of these structures explains the casualties anticipated during the middle of the day in the non-residential sector (see Table 6-8). These types of buildings also generate heavy debris that is difficult to cut through to extricate victims.

Casualties - Table 6-8 provides a summary of the casualties estimated for these scenarios. The analysis indicates that the worst time for an earthquake to occur in the City of Glendale is during maximum non-residential occupancy (at 2 o'clock in the afternoon, when most people are in their place of business and schools are in session). The Verdugo fault earthquake scenario is anticipated to cause the largest number of casualties, followed closely by an event on the Sierra Madre fault.

Essential Facility Damage - The loss estimation model calculates the total number of hospital beds in Glendale that will be available after each earthquake scenario.

A maximum magnitude earthquake on the Verdugo fault is expected to impact the local hospitals such that only 38 percent of the hospital beds (358 beds) would be available for use by existing patients and injured persons on the day of the earthquake. One week after the earthquake, about 57 percent of the beds are expected to be back in service. After one month, 82 percent of the beds are expected to be operational.

Similarly, on the day of the Sierra Madre earthquake, the model estimates that only 378 hospital beds (40 percent) will be available for use by patients already in the hospital and those injured by the earthquake. After one week, 59 percent of the beds will be back in service. After thirty days, 83 percent of the beds will be available for use.

An earthquake on the Raymond fault is only expected to be slightly better regarding the availability of hospital beds. The model estimates that only 391 hospital beds (42 percent) will be available on the day of the earthquake. After one week, 60 percent of the hospital beds are expected to be available for use, and after one month, 84 percent of the beds are expected to be operational.

An earthquake on the San Andreas fault is not expected to cause significant damage to the hospitals in Glendale: On the day of the earthquake, the model estimates that 86 percent of the beds will be available for use; after one week, 93 percent of the beds will be available for use; and after 30 days, 98 percent of the beds will be operational.

Given that the models estimate a maximum of about 100 people in the Glendale area will require hospitalization after an earthquake on either the Verdugo or Sierra Madre faults (see Table 6-8), the hospitals in the City, even with the reduced number of beds that the model projects will be available, are anticipated to handle the local demand. However, nearby cities, such as Pasadena, which have limited medical care resources available, are anticipated to have a higher number of casualties. Glendale's hospitals will most likely provide a regional service to other nearby communities, taking in patients that other hospitals outside the City cannot handle because of damage to their own facilities, or due to excess demand for medical care.

Table 6-8: Estimated Casualties

Type and Time of Scenario			Level 1:	Level 2:	Level 3:	Level 4:
			Medical treatment without hospitalization	**Hospitalization but not life threatening**	**Hospitalization and life threatening**	**Fatalities due to scenario event**
	2AM	Residential	15	1	0	0

		Non-Residential	1	0	0	0
		Commute	0	0	0	0
		Total	**16**	**1**	**0**	**0**
	2PM (max educational, industrial, and commercial)	Residential	4	1	0	0
		Non-Residential	24	2	0	0
		Commute	0	0	0	0
		Total	**28**	**3**	**0**	**0**
	5PM (peak commute time)	Residential	4	0	0	0
		Non-Residential	9	1	0	0
		Commute	0	0	0	0
		Total	**13**	**1**	**0**	**0**
Sierra Madre (M7.2)	2AM (maximum residential occupancy)	Residential	165	24	2	4
		Non-Residential	9	2	0	1
		Commute	0	0	0	0
		Total	**175**	**26**	**2**	**4**
	2PM (max educational, industrial, and commercial)	Residential	43	6	1	1
		Non-Residential	337	71	9	19
		Commute	0	0	0	0
		Total	**380**	**78**	**10**	**20**
	5PM (peak commute time)	Residential	51	7	1	1
		Non-Residential	122	26	3	7
		Commute	0	1	1	0
		Total	**173**	**34**	**5**	**8**
Verdugo	2AM (maximum residential occupancy)	Residential	179	27	2	5
		Non-Residential	11	2	1	1
		Commute	0	0	0	0
		Total	**189**	**29**	**3**	**6**
	2PM (max educational, industrial, and commercial)	Residential	47	7	1	1
		Non-Residential	378	82	11	22
		Commute	0	0	0	0
		Total	**425**	**89**	**12**	**23**
	5PM (peak commute time)	Residential	56	8	1	2
		Non-Residential	140	31	4	8
		Commute	1	1	1	0
		Total	**197**	**40**	**6**	**10**
Raymond	2AM (maximum residential occupancy)	Residential	131	17	2	3
		Non-Residential	7	1	0	0
		Commute	0	0	0	0
		Total	**138**	**18**	**2**	**3**
	2PM (max educational, industrial, and commercial)	Residential	35	5	0	1
		Non-Residential	244	47	6	11
		Commute	0	0	0	0
		Total	**279**	**52**	**6**	**12**
	5PM (peak commute time)	Residential	42	5	0	1
		Non-Residential	90	17	2	4
		Commute	0	0	1	0
		Total	**132**	**23**	**3**	**5**

HAZUS also estimates the damage to other critical facilities in the City, including schools, fire and police stations, and the emergency operations center. According to the model, an earthquake on the Mojave segment of the San Andreas fault is not going to damage any of the schools, fire or police stations, or the City's emergency operations center. All of these facilities would be fully functional the day after the earthquake.

An earthquake on the Sierra Madre fault is anticipated to cause at least moderate damage to seven schools in the City, and none of the schools and school district offices in Glendale are expected to be more than 50 percent operational the day after the earthquake. Most of the schools with more than 50 percent moderate damage are located in the northern portion of the City, as illustrated in Map 6.8. The model also indicates that although none of the other critical facilities will experience more than slight damage, none of them would be more than fully operational the day after the earthquake.

An earthquake on the Verdugo fault is anticipated to cause at least moderate damage to one school in the City – Glendale High (see Map 6.8), which according to the HAZUS inventory, also houses the Glendale Cosmetology School. The model indicates that none of the other critical facilities in the City will experience more than slight damage, but with the exception of one hospital, none of the critical facilities (including fire stations and the emergency operations center) will be more than 50 percent functional the day after the earthquake.

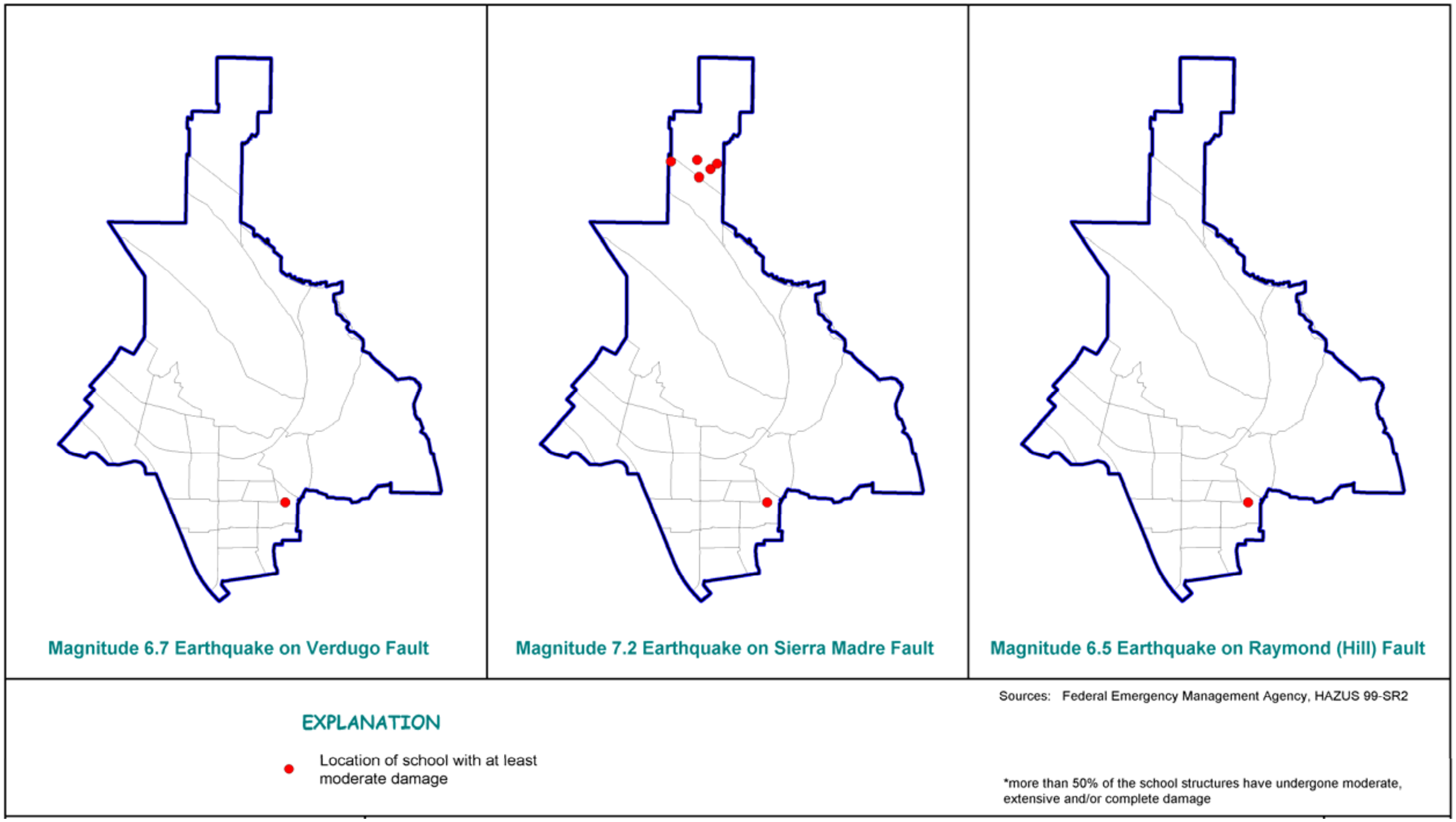
An earthquake on the Raymond fault is expected to also damage Glendale High. Damage to the other critical facilities in the City is expected to be less severe than that caused by earthquakes on either the Sierra Madre or Verdugo faults, but few facilities are expected to be more than 50 percent operational the day after the earthquake.

Economic Losses - The model estimates that total building-related losses in the City of Glendale will range from $83 million for an earthquake on the San Andreas fault, to $853 million for an earthquake on the Verdugo fault. Approximately 20 percent of these estimated losses would be related to business interruption in the city. By far, the largest loss would be sustained by the residential occupancies that make up as much as 60 percent of the total loss. Table 6-9 below provides a summary of the estimated economic losses anticipated as a result of each of the earthquake scenarios considered herein.

Table 6-9: Estimated Economic Losses

Scenario	Property Damage	Business Interruption	Total
San Andreas	$69.8 Million	$13.5 Million	$83.3 Million
Sierra Madre	$639.7 Million	$158.2 Million	$797.8 Million
Verdugo	$680.4 Million	$72.7 Million	$853.0 Million
Raymond	$560.1 Million	$127.6 Million	$687.7 Million

Map 6.8: Distribution and Severity of Damaged Schools in Glendale as a Result of Three Different Earthquake Scenarios
(Damage is defined as more than 50% of the structure has undergone moderate, extensive, and/or complete damage)



Magnitude 6.7 Earthquake on Verdugo Fault

Magnitude 7.2 Earthquake on Sierra Madre Fault

Magnitude 6.5 Earthquake on Raymond (Hill) Fault

Sources: Federal Emergency Management Agency, HAZUS 99-SR2

*more than 50% of the school structures have undergone moderate, extensive and/or complete damage

Shelter Requirement - HAZUS estimates that approximately 1,300 households in Glendale may be displaced due to the Verdugo earthquake modeled for this study (a household contains four people, on average). About 980 people will seek temporary shelter in public shelters. The rest of the displaced individuals are anticipated to seek shelter with family or friends. An earthquake on the Sierra Madre fault is anticipated to displace nearly 1,200 households, with approximately 900 people seeking temporary shelter. An earthquake on the San Andreas fault is not expected to displace any households.

Table 6-10: Estimated Shelter Requirements

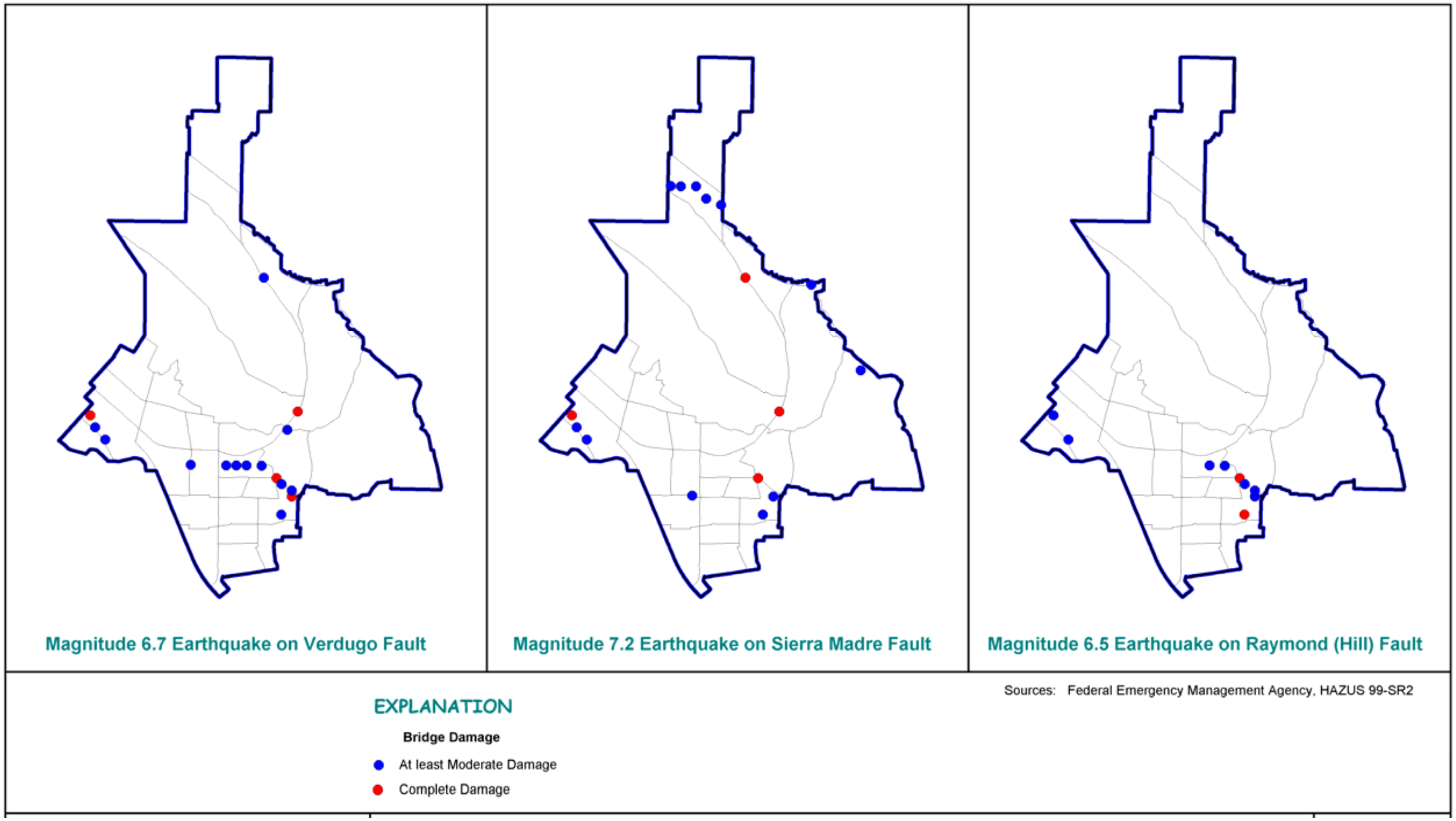
Scenario	Displaced Households	People Needing Short-Term Shelter
San Andreas - Mojave Segment	0	0
Sierra Madre	1,179	886
Verdugo	1,303	980
Raymond	945	738

Transportation Damage – Damage to transportation systems in the city of Glendale is based on a generalized inventory of the region as described in Table 6-11. Road segments are assumed to be damaged by ground failure only; therefore, the numbers presented herein may be low given that, based on damage observed from the Northridge and San Fernando earthquakes, strong ground shaking can cause considerable damage to bridges. Economic losses due to bridge damage are estimated at between $0.8 million (for an earthquake on the San Andreas fault) to $24.4 million for an earthquake on the Sierra Madre fault.

The San Andreas fault earthquake scenario estimates that only 1 of the 143 bridges in the study area will experience at least moderate damage, but this bridge is expected to be more than 50 percent functional by the next day. The San Andreas earthquake scenario indicates that the Burbank airport will experience some economic losses, but that its functionality will not be impaired.

Alternatively, an earthquake on the Sierra Madre fault is expected to damage about 27 bridges in the Glendale area, with 5 of them considered to be completely damaged. Temporary repairs are expected to make all but 2 of the bridge locations more than 50 percent functional one day after the earthquake. Seven days after the earthquake, all bridge locations would be more than 50 percent functional. The Burbank airport is expected to incur losses of about $1.8 million, but the airport will be functional. The Sierra Madre fault earthquake scenario is the worst-case for the transportation system in the city. The damage to bridges as a result of earthquakes on the Sierra Madre, Verdugo and Raymond faults is illustrated in Map 6.9.

Map 6.9: Distribution and Severity of Damaged Bridges in Glendale as a Result of Three Different Earthquake Scenarios



Sources: Federal Emergency Management Agency, HAZUS 99-SR2

A maximum magnitude earthquake on the Verdugo fault is modeled to damage about 25 bridges in the city, with 4 of them considered completely damaged. However, as before, all but 2 of the bridge locations are expected to be functional by the next day. The Raymond and Hollywood fault earthquake scenarios model some damage to the Glendale transportation system, but less than that caused by either the Sierra Madre or Verdugo earthquakes discussed above.

Table 6-11: Expected Damage to Transportation Systems

Scenario	System		Segments in Inventory	Replacement Value for All Segments in Inventory	With At Least Moderate Damage	With Complete Damage	Economic Loss ($M)	>50 percent Functional after 1 Day
San Andreas	Highway	Major Roads	5	$2.8 Billion	0	0	0	5
		Bridges	143	$419 Million	1	0	0.8	143
	Railways	Tracks	2	$19 Million	0	0	0	2
	Airport	Facilities	4	$8 Million	0	0	0.3	4
Sierra Madre	Highway	Major Roads	5	$2.8 Billion	0	0	0	5
		Bridges	143	$419 Million	27	5	24.4	143
	Railways	Tracks	2	$19 Million	0	0	0	2
	Airport	Facilities	4	$8 Million	2	0	1.8	4
Verdugo	Highway	Major Roads	5	$2.8 Billion	0	0	0	5
		Bridges	143	$419 Million	25	4	23.3	141
	Railways	Tracks	2	$19 Million	0	0	0	2
	Airport	Facilities	4	$8 Million	1	0	1.7	4
Raymond	Highway	Major Roads	5	$2.8 Billion	0	0	0	5
		Bridges	143	$419 Million	13	2	12.1	143
	Railways	Tracks	2	$19 Million	0	0	0	2
	Airport	Facilities	4	$8 Million	1	0	1.6	4

Utility Systems Damage - The HAZUS inventory for the Glendale area does not include specifics regarding the various lifeline systems in the city, therefore, the model estimated damage to the potable water and electric power using empirical relationships based on the number of households served in the area. The results of the analyses regarding the functionality of the potable water and electric power systems in the city for the four main earthquakes discussed herein are presented in Table 6-12. According to the models, all of the earthquake scenarios will impact the electric power systems; thousands of households in the city are expected to not have electric power even three days after an earthquake on any of the faults discussed in this report. An earthquake on either the Sierra Madre or Verdugo fault is anticipated to leave as many as 9,000 households without electricity for more than one week.

The potable water system is anticipated to do better, but nearly 8,000 households are expected to be without water for at least 3 days after the earthquake. These results suggest that the city will have to truck in water into some of the residential neighborhoods in the northern portion of the city until the damages to the system are repaired. Residents are advised to have drinking water stored in their earthquake emergency kits, enough to last all members of the household (including pets) for at least 3 days.

Table 6-12: Expected Performance of Potable Water and Electricity Services

Scenario	**Utility**	**Number of Households without Service***				
		Day 1	Day 3	Day 7	Day 30	Day 90
San Andreas	Potable Water	0	0	0	0	0
	Electricity	10,215	1,440	69	0	0
Sierra Madre	Potable Water	16,145	7,933	0	0	0
	Electricity	45,389	26,431	9,695	376	0
Verdugo	Potable Water	11,060	4,189	0	0	0
	Electricity	45,250	26,154	9,449	332	0
Raymond	Potable Water	4,334	52	0	0	0
	Electricity	43,850	24,845	8,868	322	0

*Based on Total Number of Households = 68,186.

Debris Generation - The model estimates that a total of 620 – 1,710 thousand tons of debris will be generated. Of the total amount, brick and wood comprise 28 percent of the total, with the remainder consisting of reinforced concrete and steel. If the debris tonnage is converted to an estimated number of truckloads, it will require 25,000 – 69,000 truckloads (@25 tons/truck) to remove the debris generated by the earthquakes modeled.

Existing Mitigation Activities

Existing mitigation activities include current mitigation programs and activities that are being implemented by county, regional, State, or Federal agencies or organizations.

California Earthquake Mitigation Legislation:

California is painfully aware of the threats it faces from earthquakes. Since the 1800s, Californians have been killed, injured, and lost property as a result of earthquakes. As the State's population continues to grow, and urban areas become even more densely built up, the risk will continue to increase. In response to this concern, for decades now the Legislature has passed laws to strengthen the built environment and protect the citizens. Table 6-13 provides a sampling of some of the 200 plus laws in the State's codes.

Table 6-13: Partial List of the Over 200 California Laws on Earthquake Safety

Government Code Section 8870-8870.95	Creates Seismic Safety Commission.
Government Code Section 8876.1-8876.10	Established the California Center for Earthquake Engineering Research.
Public Resources Code Section 2800-2804.6	Authorized a prototype earthquake prediction system along the cental San Andreas fault near the City of Parkfield.
Public Resources Code Section 2810-2815	Continued the Southern California Earthquake Preparedness Project and the Bay Area Regional Earthquake Preparedness Project.
Health and Safety Code Section 16100-16110	The Seismic Safety Commission and State Architect, will develop a state policy on acceptable levels of earthquake risk for new and existing state-owned buildings.
Government Code Section 8871-8871.5	Established the California Earthquake Hazards Reduction Act of 1986.
Health and Safety Code Section 130000-130025	Defined earthquake performance standards for hospitals.
Public Resources Code Section 2805-2808	Established the California Earthquake Education Project.
Government Code Section 8899.10-8899.16	Established the Earthquake Research Evaluation Conference.
Public Resources Code Section 2621-2630 2621.	Established the Alquist-Priolo Earthquake Fault Zoning Act.
Government Code Section 8878.50-8878.52 8878.50.	Created the Earthquake Safety and Public Buildings Rehabilitation Bond Act of 1990.
Education Code Section 35295-35297 35295.	Established emergency procedure systems in kindergarten through grade 12 in all the public or private schools.
Health and Safety Code Section 19160-19169	Established standards for seismic retrofitting of unreinforced masonry buildings.
Health and Safety Code Section 1596.80-1596.879	Required all child day care facilities to include an Earthquake Preparedness Checklist as an attachment to their disaster plan.

City of Glendale Codes:

Implementation of earthquake mitigation policy most often takes place at the local government level. The City of Glendale Engineering Department, Building and Safety Division enforces building codes pertaining to earthquake hazards. The City has adopted the provisions of the most current version of the California Building Code (CBC), with more restrictive amendments based upon local geographic, topographic or climatic conditions. The City of Glendale, along with 55 other local jurisdictions, have worked together to make these amendments to the California Building Code consistent with the rest of southern California. Currently, Glendale's Building and Safety staff are very active in the code development process and all regional activities to improve the technical provisions of the building code and the understanding of the purpose of the building codes by the public. They participate in the Los Angeles Regional Uniform Code Program, (LARUCP), and promote the adoption of uniform amendments to the CBC by other local jurisdictions.

The City of Glendale Planning Department enforces the zoning and land use regulations relating to earthquake hazards. Generally, these codes and regulations seek to discourage development in areas that could be prone to flooding, landslide, wildfire and / or seismic hazards; and where development is permitted, that the applicable construction standards are met. Developers in hazard-prone areas may be required to retain a qualified professional engineer to evaluate level of risk on the site and recommend appropriate mitigation measures.

Businesses/Private Sector:

Natural hazards have a devastating impact on businesses. In fact, of all businesses which close following a disaster, more than forty-three percent never reopen, and an additional twenty-nine percent close for good within the next two years. The Institute of Business and Home Safety has developed "Open for Business," a disaster planning toolkit to help guide businesses in preparing for and dealing with the adverse affects natural hazards. The kit integrates protection from natural disasters into the company's risk reduction measures to safeguard employees, customers, and the investment itself. The guide helps businesses secure human and physical resources during disasters, and helps to develop strategies to maintain business continuity before, during, and after a disaster occurs.

Hospitals:

"The Alfred E. Alquist Hospital Seismic Safety Act ("Hospital Act") was enacted in 1973 in response to the moderate Magnitude 6.6 Sylmar Earthquake in 1971 when four major hospital campuses were severely damaged and evacuated. Two hospital buildings collapsed killing forty seven people. Three others were killed in another hospital that nearly collapsed.

In approving the Act, the Legislature noted that: "Hospitals, that house patients who have less than the capacity of normally healthy persons to protect themselves, and that must be reasonably capable of providing services to the public after a disaster, shall be designed and constructed to resist, insofar as practical, the forces generated by earthquakes, gravity and winds." (Health and Safety Code Section 129680)

When the Hospital Act was passed in 1973, the State anticipated that, based on the regular and timely replacement of aging hospital facilities, the majority of hospital buildings would be in compliance with the Act's standards within 25 years. However, hospital buildings were not, and are not, being replaced at that anticipated rate. In fact, the great majority of the State's urgent care facilities are now more than 40 years old.

The moderate magnitude 6.7 Northridge Earthquake in 1994 caused $3 billion in hospital-related damage and evacuations. Twelve hospital buildings constructed before the Act were cited (red tagged) as unsafe for occupancy after the earthquake. Those hospitals that had been built in accordance with the 1973 Hospital Act were very successful in resisting structural damage. However, nonstructural damage (for example, plumbing and ceiling systems) was still extensive in those post-1973 buildings.

Senate Bill 1953 ("SB 1953"), enacted in 1994 after the Northridge Earthquake, expanded the scope of the 1973 Hospital Act. Under SB 1953, all hospitals are required, as of January 1, 2008, to survive earthquakes without collapsing or posing the threat of significant loss of life. The 1994 Act further mandates that all existing hospitals be seismically evaluated, and retrofitted, if needed, by 2030, so that they are in substantial compliance with the Act (which requires that the hospital buildings be reasonably capable of providing services to the public after disasters). SB 1953 applies to all urgent care facilities (including those built prior to the 1973 Hospital Act) and affects approximately 2,500 buildings on 475 campuses.

SB 1953 directed the Office of Statewide Health Planning and Development (OSHPD), in consultation with the Hospital Building Safety Board, to develop emergency regulations including "…earthquake performance categories with subgradations for risk to life, structural soundness, building contents, and nonstructural systems that are critical to providing basic services to hospital inpatients and the public after a disaster." (Health and Safety Code Section 130005)

More recently, in 2001, recognizing the continuing need to assess the adequacy of policies and the application of advances in technical knowledge and understanding, the California Seismic Safety Commission created an Ad Hoc Committee to re-examine the compliance with the Alquist Hospital Seismic Safety Act. The formation of the Committee was also prompted by the recent evaluations of hospital buildings reported to OSHPD that revealed that a large percentage (40%) of California's operating hospitals are in the highest category of collapse risk."

Earthquake Education:

Earthquake research and education activities are conducted at several major universities in the Southern California region, including Cal Tech, USC, UCLA, UCSB, UCI, and UCSB.

The local clearinghouse for earthquake information is the Southern California Earthquake Center (SCEC) located at the University of Southern California, Los Angeles, CA 90089, Telephone: (213) 740-5843, Fax: (213) 740-0011, Email: SCEinfo@usc.edu, Website: http://www.scec.org. The Southern California Earthquake Center (SCEC) is a community of scientists and specialists who actively coordinate research on earthquake hazards at nine core institutions, and communicate earthquake information to the public. SCEC is a National Science Foundation (NSF) Science and Technology Center and is co-funded by the United States Geological Survey (USGS).

In addition, Los Angeles County, along with other Southern California counties, sponsors the Emergency Survival Program (ESP), an educational program for learning how to prepare for earthquakes and other disasters. Many school districts have very active emergency preparedness programs that include earthquake drills and periodic disaster response team exercises.

Earthquake Mitigation Action Items

The Earthquake mitigation action items provide guidance on suggesting specific activities that agencies, organizations, and residents in the city of Glendale can undertake to reduce risk and prevent loss from earthquake events. Each action item is followed by ideas for implementation, which can be used by the steering committee and local decision makers in pursuing strategies for implementation.

Short Term - Earthquake # 1:

Action Item: Integrate new earthquake hazard mapping data for the city of Glendale and improve technical analysis of earthquake hazards.

Ideas for Implementation:

- Update the city of Glendale earthquake HAZUS scenarios using City-specific data, such as building inventories, geologic materials and depth to ground water, to improve accuracy of the vulnerability assessment for Glendale.
- Conduct risk analysis incorporating HAZUS data and hazard maps using GIS technology to identify risk sites and further assist in prioritizing mitigation activities and assessing the adequacy of current land use requirements.

Coordinating Organization: Public Works Geographic Information Systems
Timeline: 2 years
Plan Goals Addressed: Partnerships and Implementation, Protect Life and Property
Constraints: Pending Funding and Available Personnel

Short Term – Earthquake # 2:

Action Item: Incorporate the Regional Earthquake Transportation Evacuation Routes developed by the Regional Emergency Managers Group into appropriate planning documents.

Ideas for Implementation:

- Update the transportation routes map in the City of Glendale Natural Hazard Mitigation Plan with the evacuation routes data.
- Integrate the evacuation routes data into the City of Glendale Emergency Operations Plan.

Coordinating Organization: Emergency Services, Police
Timeline: 2 years
Plan Goals Addressed: Emergency Services
Constraints: Pending Funding and Available Personnel

Long Term - Earthquake # 1:

Action Item: Identify funding sources for structural and nonstructural retrofitting of structures that are identified as seismically vulnerable.

Ideas for Implementation:

- Provide information for property owners, small businesses, and organizations on sources of funds (loans, grants, etc.).
- Explore options for including seismic retrofitting in existing programs such as low-income housing, insurance reimbursements, and pre and post disaster repairs.

Coordinating Organization: Hazard Mitigation Advisory Committee
Timeline: Ongoing
Plan Goals Addressed: Partnerships and Implementation, Public Awareness
Constraints: Pending funding and available personnel

Long Term - Earthquake #2:

Action Item: Encourage purchase of earthquake hazard insurance.

Ideas for Implementation:

- Provide earthquake insurance information to Glendale residents.
- Coordinate with insurance companies to produce and distribute earthquake insurance information.

Coordinating Organization: Hazard Mitigation Advisory Committee
Timeline: Ongoing
Plan Goals Addressed: Protect Life and Property, Public Awareness
Constraints: Pending funding and available personnel

Long Term - Earthquake # 3:

Action Item: Encourage seismic strength evaluations of critical facilities in Glendale to identify vulnerabilities for mitigation of schools and universities, public infrastructure, and critical facilities to meet current seismic standards.

Ideas for Implementation:

- Develop an inventory of schools, universities, and critical facilities that do not meet current seismic standards.
- Encourage owners of non-retrofitted structures to upgrade them to meet seismic standards.
- Encourage water providers to replace old cast iron pipes with more ductile iron, and identify partnership opportunities with other agencies for pipe replacement.

Coordinating Organization: Hazard Mitigation Advisory Committee, Building and Safety, Public Works
Timeline: 5 years
Plan Goals Addressed: Protect Life and Property, Emergency Services
Constraints: Pending funding and available personnel

Long Term - Earthquake # 4:

Action Item: Encourage reduction of nonstructural and structural earthquake hazards in homes, schools, businesses, and government offices.

Ideas for Implementation:

- Provide information to government building and school facility managers and teachers on securing bookcases, filing cabinets, light fixtures, and other objects that can cause injuries and block exits.

- Encourage facility managers, business owners, and teachers to refer to FEMA's practical guidebook: "Reducing the Risks Nonstructural Earthquake Damage."

- Encourage homeowners and renters to use "Is Your Home Protected from Earthquake Disaster? A Homeowner's Guide to Earthquake Retrofit" (IBHS) for economic and efficient mitigation techniques.

- Explore partnerships to provide retrofitting classes for homeowners, renters, building professionals, and contractors.

- Target development located in potential fault zones or in unstable soils for intensive education and retrofitting resources.

Coordinating Organization:	Hazard Mitigation Advisory Committee
Timeline:	Ongoing
Plan Goals Addressed:	Protect Life and Property, Public Awareness
Constraints:	Pending funding and available personnel

Earthquake Resource Directory

Local and Regional Resources

Los Angeles County Public Works Department
Level: County Hazard: Multi http://ladpw.org

900 S. Fremont Ave.

Glendale, CA 91803 Ph: 626-458-5100 Fx:

Notes: The Los Angeles County Department of Public Works protects property and promotes public safety through Flood Control, Water Conservation, Road Maintenance, Bridges, Buses and Bicycle Trails, Building and Safety, Land Development, Waterworks, Sewers, Engineering, Capital Projects and Airports

Southern California Earthquake Center (SCEC)
Level: Regional Hazard: Earthquake www.scec.org

3651 Trousdale Parkway Suite 169

Los Angeles, CA 90089-0742 Ph: 213-740-5843 Fx: 213-740-0011

Notes: The Southern California Earthquake Center (SCEC) gathers new information about earthquakes in Southern California, integrates this information into a comprehensive and predictive understanding of earthquake phenomena, and communicates this understanding to end-users and the general public in order to increase earthquake awareness, reduce economic losses, and save lives.

State Resources

California Department of Transportation (CalTrans)
Level: State Hazard: Multi http://www.dot.ca.gov/

120 S. Spring Street

Los Angeles, CA 90012 Ph: 213-897-3656 Fx:

Notes: CalTrans is responsible for the design, construction, maintenance, and operation of the California State Highway System, as well as that portion of the Interstate Highway System within the state's boundaries. Alone and in partnership with Amtrak, CalTrans is also involved in the support of intercity passenger rail service in California.

California Resources Agency
Level: State Hazard: Multi http://resources.ca.gov/

1416 Ninth Street Suite 1311

Sacramento, CA 95814 Ph: 916-653-5656 Fx:

Notes: The California Resources Agency restores, protects and manages the state's natural, historical and cultural resources for current and future generations using solutions based on science, collaboration and respect for all the communities and interests involved.

California Geological Survey
Level: State Hazard: Multi www.consrv.ca.gov/cgs/index.htm

801 K Street MS 12-30

Sacramento, CA 95814 Ph: 916-445-1825 Fx: 916-445-5718

Notes: The California Geological Survey develops and disseminates technical information and advice on California's geology, geologic hazards, and mineral resources.

California Department of Conservation: Southern California Regional Office
Level: State Hazard: Multi www.consrv.ca.gov

655 S. Hope Street #700

Los Angeles, CA 90017-2321 Ph: 213-239-0878 Fx: 213-239-0984

Notes: The Department of Conservation provides services and information that promote environmental health, economic vitality, informed land-use decisions and sound management of our state's natural resources.

California Planning Information Network
Level: State Hazard: Multi www.calpin.ca.gov

Notes: The Governor's Office of Planning and Research (OPR) publishes basic information on local planning agencies, known as the California Planners' Book of Lists. This local planning information is available on-line with new search capabilities and up-to-the- minute updates.

Governor's Office of Emergency Services (OES)
Level: State Hazard: Multi www.oes.ca.gov

P.O. Box 419047

Rancho Cordova, CA 95741-9047 Ph: 916 845- 8911 Fx: 916 845- 8910

Notes: The Governor's Office of Emergency Services coordinates overall state agency response to major disasters in support of local government. The office is responsible for assuring the state's readiness to respond to and recover from natural, manmade, and war-caused emergencies, and for assisting local governments in their emergency preparedness, response and recovery efforts.

Federal and National Resources

Building Seismic Safety Council (BSSC)
Level: National Hazard: Earthquake www.bssconline.org
1090 Vermont Ave., NW Suite 700

Washington, DC 20005 Ph: 202-289-7800 Fx: 202-289-109

Notes: The Building Seismic Safety Council (BSSC) develops and promotes building earthquake risk mitigation regulatory provisions for the nation.

Federal Emergency Management Agency, Region IX
Level: Federal Hazard: Multi www.fema.gov

1111 Broadway Suite 1200

Oakland, CA 94607 Ph: 510-627-7100 Fx: 510-627-7112

Notes: The Federal Emergency Management Agency is tasked with responding to, planning for, recovering from and mitigating against disasters.

Federal Emergency Management Agency, Mitigation Division
Level: Federal Hazard: Multi www.fema.gov/fima/planhowto.shtm

500 C Street, S.W.

Washington, D.C. 20472 Ph: 202-566-1600 Fx:

Notes: The Mitigation Division manages the National Flood Insurance Program and oversees FEMA's mitigation programs. It has a number of programs and activities which provide citizens Protection, with flood insurance; Prevention, with mitigation measures and Partnerships, with communities throughout the country.

United States Geological Survey
Level: Federal Hazard: Multi http://www.usgs.gov/

345 Middlefield Road

Menlo Park, CA 94025 Ph: 650-853-8300 Fx:

Notes: The USGS provides reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect our quality of life.

Western States Seismic Policy Council (WSSPC)
Level: Regional Hazard: Earthquake www.wsspc.org/home.html
125 California Avenue Suite D201, #1

Palo Alto, CA 94306 Ph: 650-330-1101 Fx: 650-326-1769

Notes: WSSPC is a regional earthquake consortium funded mainly by FEMA. Its website is a great resource, with information clearly categorized - from policy to engineering to education.

Institute for Business & Home Safety
Level: National Hazard: Multi http://www.ibhs.org/
4775 E. Fowler Avenue

Tampa, FL 33617 Ph: 813-286-3400 Fx: 813-286-9960

The Institute for Business & Home Safety (IBHS) is a nonprofit association that engages in communication, education, engineering and research. The Institute works to reduce deaths, injuries, property damage, economic losses and human suffering caused by natural disasters.

Publications:

"Land Use Planning for Earthquake Hazard Mitigation: Handbook for Planners" by Wolfe, Myer R. et. al., (1986) University of Colorado, Institute of Behavioral Science, National Science Foundation.

This handbook provides techniques that planners and others can utilize to help mitigate for seismic hazards, It provides information on the effects of earthquakes, sources on risk assessment, and effects of earthquakes on the built environment. The handbook also gives examples on application and implementation of planning techniques to be used by local communities.

Contact: Natural Hazards Research and Applications Information Center
Address: University of Colorado, 482 UCB, Boulder, CO 80309-0482
Phone: (303) 492-6818
Fax: (303) 492-2151
Website: http://www,colorado.edu/UCB/Research/IBS/hazards

"Public Assistance Debris Management Guide", FEMA (July 2000).
The Debris Management Guide was developed to assist local officials in planning, mobilizing, organizing. and controlling large-scale debris clearance, removal, and disposal operations, Debris management is generally associated with post-disaster recovery. While it should be compliant with local and county emergency operations plans, developing strategies to ensure strong debris management is a way to integrate debris management within mitigation activities. The "Public Assistance Debris Management Guide" is available in hard copy or on the FEMA website.