MITIGATION OF PRIMARY FAULT RUPTURE

Paleoseismic studies on the Sierra Madre fault suggest that slip per event on this fault exceeds 13 feet (4 m). Other faults in the area may experience similar amounts of displacement if they break during an earthquake. Most engineered structures are not designed to withstand this amount of movement, so buildings that straddle a fault will most certainly be damaged beyond repair if and when the fault breaks. Since it is impractical to reduce the damage potential to acceptable levels by engineering design, the most appropriate mitigation measure is to simply avoid placing structures on or near active fault traces. However, because of the complexity of most active fault zones, particularly at the surface where they may become braided, splayed or segmented, locating and evaluating the active traces is often not an easy task. A geologic investigation, which may include fault trenching, must be performed if structures designed for human occupancy are proposed within an Alquist-Priolo Earthquake Fault Zone. The study must evaluate whether or not an active segment of the fault extends across the area of proposed development. Based on the results of these studies, appropriate structural setbacks can be recommended. Specific guidelines for evaluating the hazard of fault rupture are presented in Note 49, published by the CGS, which is available on the world wide web at: www.consrv.ca.gov/DMG/pubs/notes/49/index.htm. Similar studies are proposed herein for the fault hazard management zones defined around faults not yet zoned as active by the State, but which have either been shown to be active, or are thought to be active by association with other nearby, active faults.

A common misperception regarding setbacks is that they are always 50 feet from the active fault trace. In actuality, geologic investigations are required to characterize the ground deformation associated with an active fault. Based on these studies, specific setbacks are delineated. If a fault trace is narrow, with little or no associated ground deformation, a setback distance less than 50 feet may be recommended. Conversely, if the fault zone is wide, with multiple splays, or is poorly defined, a setback distance greater than 50 feet may be warranted. Structural setbacks from reverse faults, such as the Sierra Madre, may also be asymmetrical across the trace of the fault, with a wider setback zone defined for the upper plate, where past earthquakes have shown that most damage occurs. State law allows local jurisdictions to establish minimum setback distances from a hazardous fault, and some communities have taken a prescriptive approach to this issue, establishing specific setbacks from a fault, rather than allowing for different widths depending on the circumstances. For example, the City of West Hollywood requires a 50-foot setback from the Hollywood fault for conventional structures, and 100-foot setback for critical and high-occupancy facilities.

1.6.2 Secondary Fault Rupture and Related Ground Deformation

Primary fault rupture is rarely confined to a simple line along the fault trace. As the rupture reaches the brittle surface of the ground, it commonly spreads out into complex fault patterns of secondary faulting and ground deformation. In the 1992 Landers earthquake, the zone of deformation around the main trace ranged up to hundreds of feet wide (Lazarte et al., 1994). Surface displacement and distortion associated with secondary faulting and deformation can be relatively minor or can be large enough to cause significant damage to structures.

Secondary fault rupture refers to ground surface displacements along faults other than the main traces of active regional faults. Unlike the regional faults, these subsidiary faults are not deeply rooted in the Earth's crust and are not capable of producing damaging earthquakes on their own. Movement along these faults generally occurs in response to movement on a nearby regional fault. The zone of secondary faulting can be quite large, even in a moderatesized earthquake. For instance, in the 1971 San Fernando quake, movement along subsidiary faults occurred as much as 2 km from the main trace (Ziony and Yerkes, 1985).

Secondary faulting in thrust fault terrain is very complex, and numerous types of faulting have been reported. These include splays, branches, tear faults, shallow thrust faults, and back-thrusts, as well as faults that form in the shallow subsurface as a result of folding in sedimentary layers. Identified by Yeats (1982), fold-related types include flexural slip faults (slippage along bedding planes), and bending-moment faults (tensional or compressional tears in the axis of folding). A striking example of flexural slip along bedding planes occurred during the Northridge earthquake, when numerous bedding plane faults ruptured across the surface of newly graded roads and pads in a subdivision near Santa Clarita. The ruptures were accompanied by uplift and warping of the nearby ground (Treiman, 1995).

Secondary ground deformation includes fracturing, shattering, warping, tilting, uplift and/or subsidence. Such deformation may be relatively confined along the rupturing fault, or spread over a large region (such as the regional uplift of the Santa Susana Mountains after the Northridge earthquake). Deformation and secondary faulting can also occur without primary ground rupture, as in the case of ground deformation above a blind (buried) thrust fault.

MITIGATION OF SECONDARY FAULT RUPTURE AND GROUND DEFORMATION

Geotechnical investigations for future developments, especially in the hillside areas of the City, should consider this hazard. The methodology for evaluating these features is similar to that used for evaluating primary fault rupture (CGS, previously CDMG Note 49).

Lazarte (1994) outlined three approaches to mitigation of fault rupture hazard, which could be applied to secondary deformation as well. The first is avoidance, by the use of structural setback zones. The second is referred to as “geotechnical engineering.” This method consists of placing a compacted fill blanket, or a compacted fill blanket reinforced with horizontal layers of geogrid, over the top of the fault trace. This is based on observations that the displacement across a distinct bedrock fault is spread out and dissipated in the overlying fill, thus reducing the severity of the displacement at the surface. The third method is “structural engineering.” This refers to strengthening foundation elements to withstand a limited amount of ground deformation. This is based on studies of foundation performance in the Landers earthquake showing that structures overlying major fault ruptures suffered considerable damage but did not collapse. Application of the second and third methods requires a thorough understanding of the geologic environment and thoughtful engineering judgment. This is because quantifying the extent of future displacement is difficult, and there are no proven engineering standards in place to quantify the amount of mitigation needed (for instance how thick a fill blanket is needed).

1.7 Geologic Hazards Resulting from Seismic Shaking

1.7.1 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 (see Section 1.5 above). 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 (see Plate 2-1, in Chapter 2). 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 1-3, 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 1-3 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. 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).

LIQUEFACTION MITIGATION MEASURES

In accordance with the SHMA, all projects within a State-delineated Seismic Hazard Zone for liquefaction must be evaluated by a Certified Engineering Geologist and/or Registered Civil Engineer (this is typically a civil engineer with training and experience in soil engineering). Most often however, it is appropriate for both the engineer and geologist to be

NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

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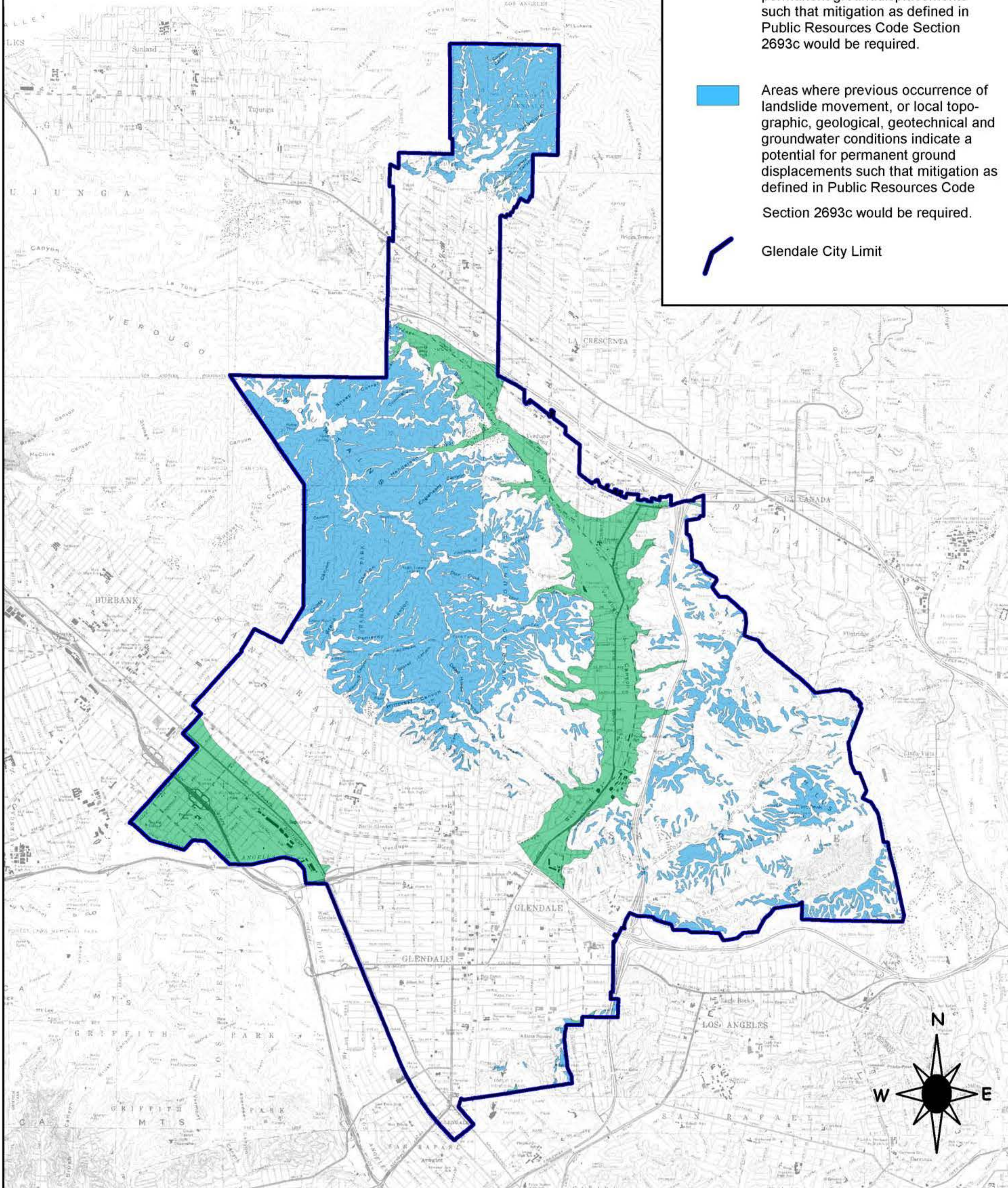

Scale: 1:60,000

1000 0 1000 2000 3000

Meters

5000 0 5000 10000 15000

Feet

Base Map: USGS Topographic Map from Sure!MAPS RASTER

Sources: California , Division of Mines and Geology, 1999 (Sunland Los Angeles, Burbank, Hollywood, and Pasadena Quadrangles)

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Project Number: 2103
Date: July, 2003

Seismic Hazards Map

Glendale, California

Plate 1-3

involved in the evaluation, and in the implementation of the mitigation measures. In order to assist in the implementation of the SHMA, the State has published specific guidelines for evaluating and mitigating liquefaction (California Division of Mines and Geology, 1997). Furthermore, in 1999, a group sponsored by the Southern California Earthquake Center (SCEC, 1999) published recommended procedures for carrying out the CGS guidelines. In general, a liquefaction study is designed to identify the depth, thickness, and lateral extent of any liquefiable layers that would affect the project site. An analysis is then performed to estimate the type and amount of ground deformation that might occur, given the seismic potential of the area.

Mitigation measures generally fall in one of two categories: ground improvement or foundation design. Ground improvement includes such measures as removal and recompaction of low density soils, removal of excess ground water, in-situ ground densification, and other types of ground improvement (such as grouting or surcharging). Special foundations that may be recommended range from deep piles to reinforcement of shallow foundations (such as post-tensioned slabs). Mitigation for lateral spreading may also include modification of the site geometry or inclusion of retaining structures. The type (or combinations of types) of mitigation depend on the site conditions and on the nature of the proposed project (CGS, previously CDMG, 1997).

It should be remembered that Seismic Hazard Zone Maps may not show all areas that have the potential for liquefaction, nor is information shown on the maps sufficient to serve as a substitute for detailed site investigations.

1.7.2 Seismically Induced Settlement

Under certain conditions, strong ground shaking can cause the densification of soils, resulting in local or regional settlement of the ground surface. During strong shaking, soil grains become more tightly packed due to the collapse of voids and pore spaces, resulting in a reduction of the thickness of the soil column. This type of ground failure typically occurs in loose granular, cohesionless soils, and can occur in either wet or dry conditions. Unconsolidated young alluvial deposits are especially susceptible to this hazard. Artificial fills may also experience seismically induced settlement. Damage to structures typically occurs as a result of local differential settlements. Regional settlement can damage pipelines by changing the flow gradient on water and sewer lines, for example.

Fracturing and offset of the ground can also occur. During the Northridge earthquake, extensive ground fracturing developed along the margins of Potrero Canyon at the alluvium/bedrock contact. Investigations after the earthquake showed that the fractures, which were both tensional and compressional in nature, formed as a result of ground lurching and differential settlement in the alluvium (Rymer et al., 1995).

Those portions of the Glendale area that may be susceptible to seismically induced settlement are the alluvial surfaces and larger drainages that are underlain by late Quaternary alluvial sediments (similar to the liquefaction-susceptible areas shown on Plate 1-3). Sites near the base of the Verdugo and San Gabriel Mountains and the San Rafael Hills, and along the margins of the larger drainage channels may be particularly vulnerable.

MITIGATION OF SEISMICALLY INDUCED SETTLEMENT

Mitigation measures for seismically induced settlement are similar to those used for liquefaction. Recommendations are provided by the project's geologist and soil engineer, following a detailed geotechnical investigation of the site. Overexcavation and recompaction is the most commonly used method to densify soft soils susceptible to settlement. Deeper overexcavation below final grades, especially at cut/fill, fill/natural or alluvium/bedrock contacts may be recommended to provide a more uniform subgrade. Overexcavation should also be performed so that large differences in fill thickness are not present across individual lots. In some cases, strengthened foundations and/or fill compaction to a minimum standard that is higher than that required by the UBC may be recommended.

1.7.3 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 rock slides 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 1-3). 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 2.4.1 of this report.

MITIGATION OF SEISMICALLY INDUCED SLOPE FAILURE

Existing slopes that are to remain adjacent to or within developments should be evaluated for the geologic conditions mentioned above. In general, slopes steeper than about 15 degrees are most susceptible, however failures can occur on flatter slopes if unsupported weak rock units are exposed in the slope face. For suspect slopes, appropriate geotechnical investigation and slope stability analyses should be performed for both static and dynamic (earthquake) conditions. For deeper slides, mitigation typically includes such measures as buttressing slopes or regrading the slope to a different configuration. Protection from rockfalls or surficial slides can often be achieved by protective devices such as barriers, rock fences, retaining structures, catchment areas, or a combination of the above. The runout area of the slide at the base of the slope, and the potential bouncing of rocks must also be considered. If it is not feasible to mitigate the unstable slope conditions, building setbacks should be imposed.

In accordance with the SHMA, all development projects within a State-delineated Seismic Hazard Zone for seismically induced landsliding must be evaluated by a State-licensed engineering geologist and/or civil engineer (for landslide investigation and analysis, this typically requires both). In order to assist in the implementation of the SHMA, the State has published specific guidelines for evaluating and mitigating seismically induced landslides (CGS, previously CDMG, 1997). More recently, the Southern California Earthquake Center (SCEC, 2002) sponsored the publication of the "Recommended Procedures for Implementation of DMG Special Publication 117." These procedures are expected to be adopted by the Los Angeles County and other cities and counties in California in the next year or so, pending some slight revisions and further discussions among the geotechnical community.

1.7.4 Deformation of Sidehill Fills

Sidehill fills are artificial fill wedges typically constructed on natural slopes to create roadways or level building pads. Deformation of sidehill fills was noted in earlier earthquakes, but this phenomenon was particularly widespread during the Northridge earthquake. Older, poorly engineered road fills were most commonly affected, but in localized areas, building pads of all ages experienced deformation. The deformation was usually manifested as ground cracks at the cut/fill contacts, differential settlement in the fill wedge, and bulging of the slope face. The amount of displacement on the pads was generally 8 cm or less, but this resulted in minor to severe property damage (Stewart et al., 1995). This phenomenon was most common in relatively thin fills (9 m or less) placed near the tops or noses of narrow ridges (Barrows et al., 1995).

MITIGATION OF SIDEHILL FILL DEFORMATION

Hillside grading designs should be evaluated during site-specific geotechnical investigations to determine if there is a potential for this hazard. There are currently no proven engineering standards for mitigating sidehill fill deformation, consequently current published research on this topic should be reviewed by project consultants at the time of their investigation. It is thought that the effects of this hazard on structures may be reduced by the use of post-tensioned foundations, deeper overexcavation below finish grades, deeper overexcavation on cut/fill transitions, and/or higher fill compaction criteria.

1.7.5 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).

MITIGATION OF RIDGETOP FISSURING AND SHATTERING

Projects located in steep hillside areas should be evaluated for this hazard by an Engineering Geologist. Although it is difficult to predict exactly where this hazard may occur, avoidance of development along the tops of steep, narrow ridgelines is probably the best mitigation measure. For large developments, recontouring of the topography to reduce the conditions conducive to ridgetop amplification, along with overexcavation below finish grades to remove and recompact weak, fractured bedrock might reduce this hazard to an acceptable level.

1.7.6 Seiches

Reservoirs, lakes, ponds, swimming pools and other enclosed bodies of water are subject to potentially damaging oscillations (sloshing), or seiches. This hazard is dependent upon specific earthquake parameters (e.g. frequency of the seismic waves, distance and direction from the epicenter), as well as site-specific design of the enclosed bodies of water, and is thus difficult to predict.

MITIGATION OF SEICHES

The degree of damage to small bodies of water, such as to swimming pools, would likely be minor. However, property owners downslope from pools that could seiche during an earthquake should be aware of the potential hazard to their property should a pool lose substantial amounts of water during an earthquake. Site-specific design elements, such as baffles, to reduce the potential for seiches is warranted in tanks and in open reservoirs or ponds where overflow or failure of the structure may cause damage to nearby properties. Damage to water tanks in recent earthquakes, such as the 1992 Landers-Big Bear sequence and the 1994 Northridge, resulted from seiching. As a result, the American Water Works Association (AWWA) Standards for Design of Steel Water Tanks (D-100) provide new criteria for seismic design (Lund, 1994).

1.8 Vulnerability of Structures to Earthquake Hazards

This section assesses the earthquake vulnerability of structures and facilities common in the Glendale area. This analysis is based on past earthquake performance of similar types of buildings in the U.S. The effects of design earthquakes on particular structures within the city are beyond the scope of this study. However, utilizing a recent standardized methodology developed for the Federal Emergency Management Agency (FEMA), general estimates of losses are provided in Section 1.9 of this report.

Although it is not possible to prevent earthquakes from occurring, their destructive effects can be minimized. Comprehensive hazard mitigation programs that include the identification and mapping of hazards, prudent planning and enforcement of building codes, and expedient retrofitting and rehabilitation of weak structures can significantly reduce the scope of an earthquake disaster.

With these goals in mind, the State Legislature passed Senate Bill 547, addressing the identification and seismic upgrade of Unreinforced Masonry (URM) buildings. In addition, the law encourages identification and mitigation of seismic hazards associated with other types of potentially hazardous buildings, including pre-1971 concrete tilt-ups, soft-stories, mobile homes, and pre-1940 homes.

1.8.1 Potentially Hazardous Buildings and Structures

Most of the loss of life and injuries due to an earthquake are related to the collapse of hazardous buildings and structures. FEMA (1985) defines a hazardous building as "any inadequately earthquake resistant building, located in a seismically active area, that presents a potential for life loss or serious injury when a damaging earthquake occurs." Building codes have generally been made more stringent following damaging earthquakes.

Building damage is commonly classified as either structural or non-structural. Structural damage impairs the building's support. This includes any vertical and lateral force-resisting systems, such as frames, walls, and columns. Non-structural damage does not affect the integrity of the structural support system, but includes such things as broken windows, collapsed or rotated chimneys, unbraced parapets that fall into the street, and fallen ceilings.

During an earthquake, buildings get thrown from side to side and up and down. Given the same acceleration, heavier buildings are subjected to higher forces than lightweight buildings. Damage occurs when structural members are overloaded, or when differential movements between different parts of the structure strain the structural components. Larger earthquakes and longer shaking duration tend to damage structures more. The level of damage can be predicted only in general terms, since no two buildings undergo the exact same motions, even in the same earthquake. Past earthquakes have shown us, however, that some types of buildings are far more likely to fail than others.

Unreinforced Masonry Buildings - Unreinforced masonry buildings (URMs) are prone to failure due to inadequate anchorage of the masonry walls to the roof and floor diaphragms, lack of steel reinforcing, the limited strength and ductility of the building materials, and sometimes, poor construction workmanship. Furthermore, as these buildings age, the bricks and mortar tend to deteriorate, making the buildings even weaker.

In response to the 1986 URM Law, Glendale issued Chapter 58 of the City Code requiring all URMs in the City to be identified (see Section 1.3.6). In the year 2000, the City of Glendale reported to the Seismic Safety Commission that 703 URMs had been identified in the City. Of these, only 1 building (the Casa de Adobe de San Rafael) was considered of historical significance. By 2000, all 703 building owners had been notified about the hazards of URM construction, and 491 of the URMs had been retrofitted in accordance with the provisions of Chapter 58. Two more buildings had retrofit permits issued, but the work had not yet begun. Finally, another 206 URMs had been demolished or were slated for demolition, leaving only four buildings for which mitigation plans were not yet available (Seismic Safety Commission, 2000). In 2002, City records show that retrofitting had not yet begun at only two buildings, and that one other building was being retrofitted.

Soft-Story Buildings - Of particular concern are soft-story buildings (buildings with a story, generally the first floor, lacking adequate strength or toughness due to too few shear walls). Apartments above glass-fronted stores, and buildings perched atop parking garages are common examples of soft-story buildings. Collapse of a soft story and "pancaking" of the remaining stories killed 16 people at the Northridge Meadows apartments during the 1994 Northridge earthquake (EERI, 1994). There are many other cases of soft-story collapses in past earthquakes. The City of Glendale Engineering Section has identified approximately 520 buildings in the City that are of soft-story construction.

Wood-Frame Structures - Structural damage to wood-frame structures often results from an inadequate connection between the superstructure and the foundation. These buildings may slide off their foundations, with consequent damage to plumbing and electrical connections. Unreinforced masonry chimneys may also collapse. These types of damage are generally not life threatening, although they may be costly to repair. Wood frame buildings with stud walls generally perform well in an earthquake, unless they have no foundation or have a weak foundation constructed of unreinforced masonry or poorly reinforced concrete. In these cases, damage is generally limited to cracking of the stucco, which dissipates much of the earthquake's induced energy. The collapse of wood frame structures, if it happens, generally does not generate heavy debris, but rather, the wood and plaster debris can be cut or broken into smaller pieces by hand-held equipment and removed by hand in order to reach victims (FEMA, 1985).

Pre-Cast Concrete Structures - Partial or total collapse of buildings where the floors, walls and roofs fail as large intact units, such as large pre-cast concrete panels, cause the greatest loss of life and difficulty in victim rescue and extrication (FEMA, 1985). These types of buildings are common not only in southern California, but abroad. Casualties as a result of collapse of these structures in past earthquakes, including Mexico (1985), Armenia (1988), Nicaragua (1972), El Salvador (1986 and 2001), the Philippines (1990) and Turkey (1999) add to hundreds of thousands. In southern California, many of the parking structures that failed during the Northridge earthquake, such as the Cal-State Northridge and City of Glendale Civic Center parking structures, consisted of pre-cast concrete components (EERI, 1994).

Collapse of this type of structure generates heavy debris, and removal of this debris requires the use of heavy mechanical equipment. Consequently, the location and extrication of victims trapped under the rubble is generally a slow and dangerous process. Extrication of trapped victims within the first 24 hours after the earthquake becomes critical for survival. In most instances, however, post-earthquake planning fails to quickly procure equipment needed to move heavy debris. The establishment of Heavy Urban Search and Rescue teams, as recommended by FEMA (1985), has improved victim extrication and survivability. Buildings that are more likely to fail and generate heavy debris need to be identified, so that appropriate mitigation and planning procedures are defined prior to an earthquake.

Tilt-up Buildings - Tilt-up buildings have concrete wall panels, often cast on the ground, or fabricated off-site and trucked in, that are tilted upward into their final position. Connections and anchors have pulled out of walls during earthquakes, causing the floors or roofs to collapse. A high rate of failure was observed for this type of construction in the 1971 San Fernando and 1987 Whittier Narrows earthquakes. Tilt-up buildings can also generate heavy debris.

Reinforced Concrete Frame Buildings - Reinforced concrete frame buildings, with or without reinforced infill walls, display low ductility. Earthquakes may cause shear failure (if there are large tie spacings in columns, or insufficient shear strength), column failure (due to inadequate rebar splices, inadequate reinforcing of beam-column joints, or insufficient tie anchorage), hinge deformation (due to lack of continuous beam reinforcement), and non-structural damage (due to the relatively low stiffness of the frame). A common type of failure observed following the Northridge earthquake was confined column collapse (EERI, 1994), where infilling between columns confined the length of the columns that could move laterally in the earthquake.

Multi-Story Steel Frame Buildings - Multi-story steel frame buildings generally have concrete floor slabs. However, these buildings are less likely to collapse than concrete structures. Common damage to these types of buildings is generally non-structural, including collapsed exterior curtain wall (cladding), and damage to interior partitions and equipment. 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.

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.

Mobile Homes - 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.

Combination Types - 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.

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 also 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.

1.8.2 Essential Facilities

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 1-4 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 1-2), liquefaction-susceptible areas (Plate 1-3), unstable slope areas (Plates 1-3 and 2-4), potential dam failure inundation areas (Plate 3-3), fire hazard zones (Plate 4-2), and sites that generate hazardous materials (Plate 5-1).

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.

1.8.3 Lifelines

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.
- 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.

NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

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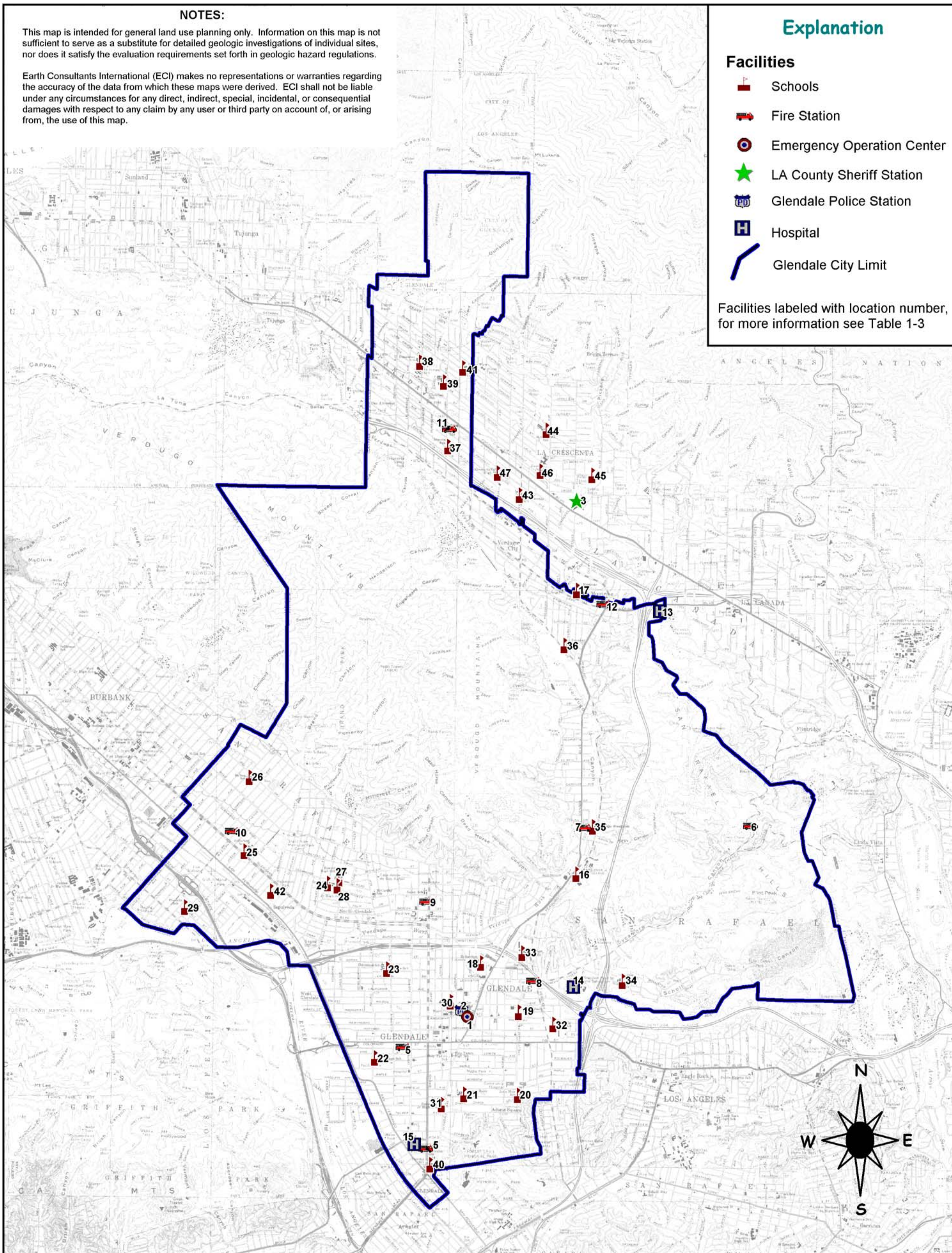

Scale: 1:60,000

1000 0 1000 2000 3000

Meters

5000 0 5000 10000 15000

Feet

Base Map: USGS Topographic Map from Sure!MAPS RASTER
Source: City of Glendale Planning Department data

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Critical Facilities Map

Glendale, California

Plate 1-4

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.

1.9 HAZUS Earthquake Scenario Loss Estimations for the City of Glendale

HAZUS-99TM 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:

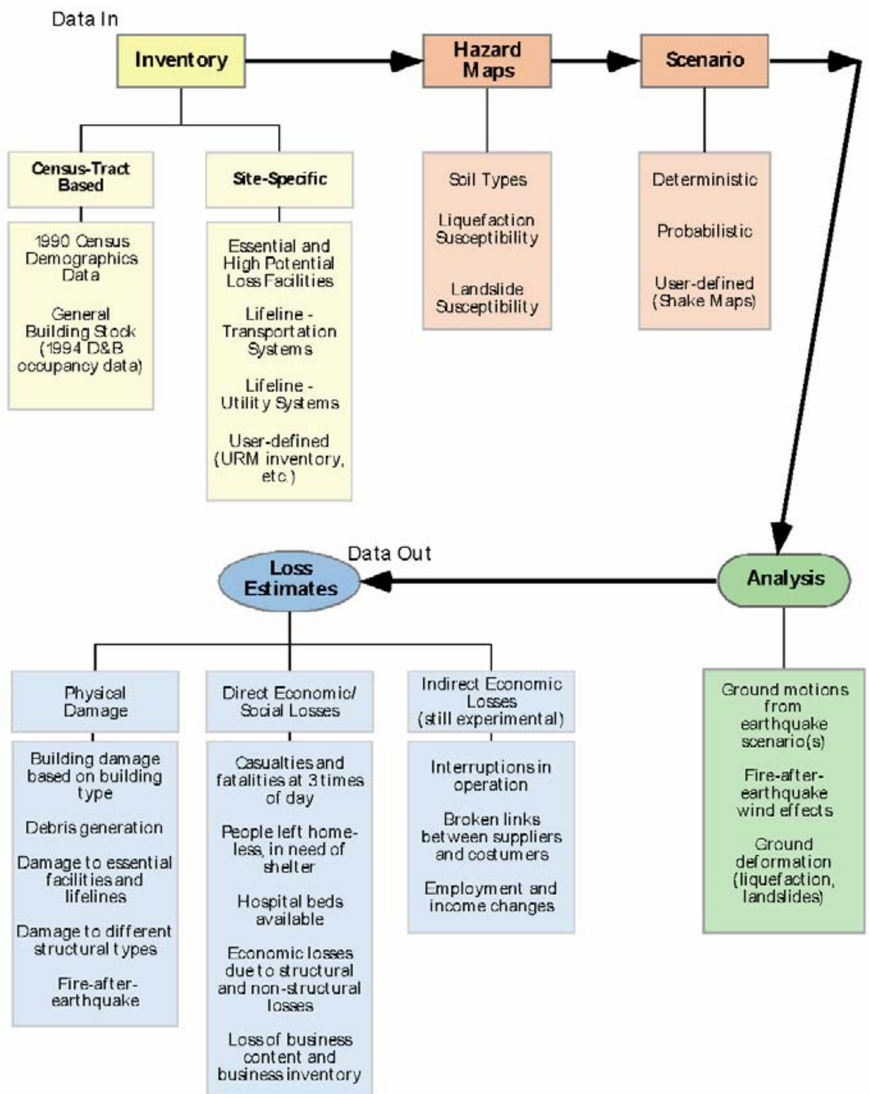
- HAZUS is driven by statistics, and thus is most accurate when applied to a region, or a class of buildings or facilities. It is least accurate when considering a particular site, building or facility.
- Losses estimated for lifelines may be less than losses estimated for the general building stock.
- 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.

1.9.1 Methodology, Terminology and Input Data Used in the Earthquake Loss Estimations for the City

The flow chart in Figure 1-4 illustrates the modules (or components) of a HAZUS analysis. The HAZUS software uses population data by census tract and general building stock data from Dunn & Bradstreet (DNB).

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.



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Project Number: 2103
Date: July, 2003

Generalized Flow Chart Summarizing the HAZUS Methodology

Figure 1-4

Critical Facilities: 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.

Transportation and Utility Lifelines: 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

Building Damage Classification - 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.

<u>**Wood, Light Frame**</u>:

- 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.

Incorporation of Historic Building Code Design Functions - 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.

Fires Following Earthquakes - Fires following earthquakes can cause severe losses. In some instances, these losses can outweigh the losses from direct damage, such as collapse of buildings and disruption of lifelines. Many factors affect the severity of the fires following an earthquake, including but not limited to: ignition sources, types and density of fuel, weather conditions, functionality of water systems, and the ability of fire fighters to suppress the fires.

A complete fire-following-earthquake model requires extensive input about the readiness of local fire departments and the types and availability (functionality) of water systems. The fire following earthquake model presented here is simplified. With better understanding of fires that will be garnered after future earthquakes, forecasting capability will undoubtedly improve. For additional information regarding this topic, refer to Section 4.6.

Debris Generation - 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.

Estimating Casualties - 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 1-3.

Table 1-3: 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.

1.9.2 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 1-4).

Table 1-4: 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).

1.9.3 Inventory Data Used in the HAZUS Loss Estimation Models for Glendale

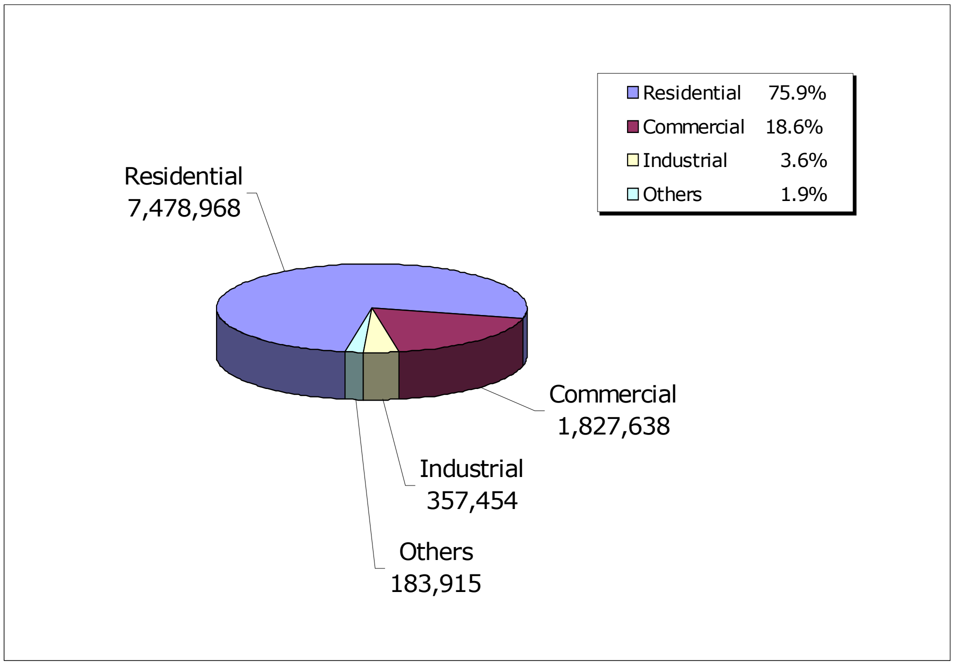
As mentioned previously, the population data used for the Glendale analyses were modified using the recently available 2000 Census data. The general building stock and population inventory data conform to census tract boundaries, and the census tract boundaries generally conform to the City limits, with 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 1-5). 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 1-5
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 1-4.

1.9.4 *Estimated Losses Associated with the Earthquake Scenarios*

HAZUS loss estimations for the City of Glendale based on four of the earthquake scenarios modeled are presented concurrently below. For the complete master reports for these scenarios, refer to Appendix C. 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.

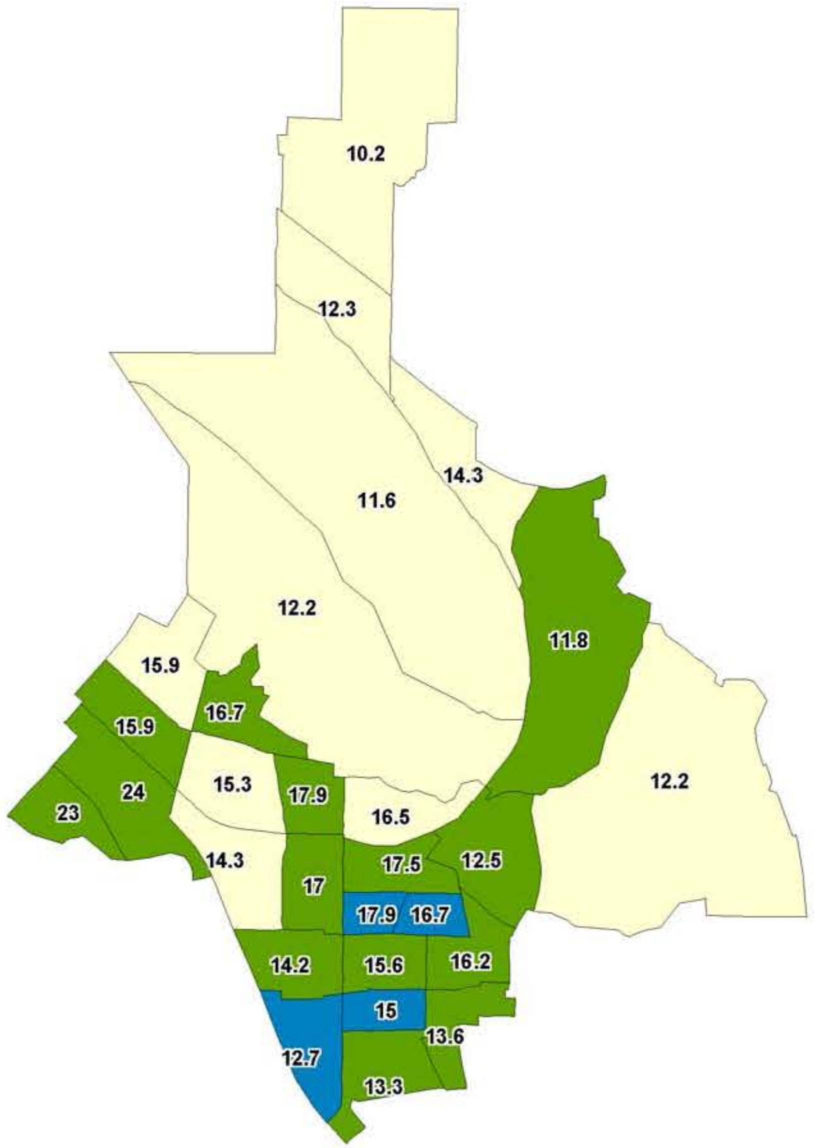
Building Damage - HAZUS estimates that between approximately 350 and 5,000 buildings will be at least moderately damaged in response to the earthquake scenarios presented herein, with the lower number representative of damage as a result of an earthquake on the San Andreas fault, and the higher number 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 1-5 summarizes the expected damage to buildings by general occupancy type, while Table 1-6 summarizes the expected damage to buildings in Glendale, classified by construction type.

The data presented in Tables 1-5 and 1-6 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 Plate 1-5. 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.

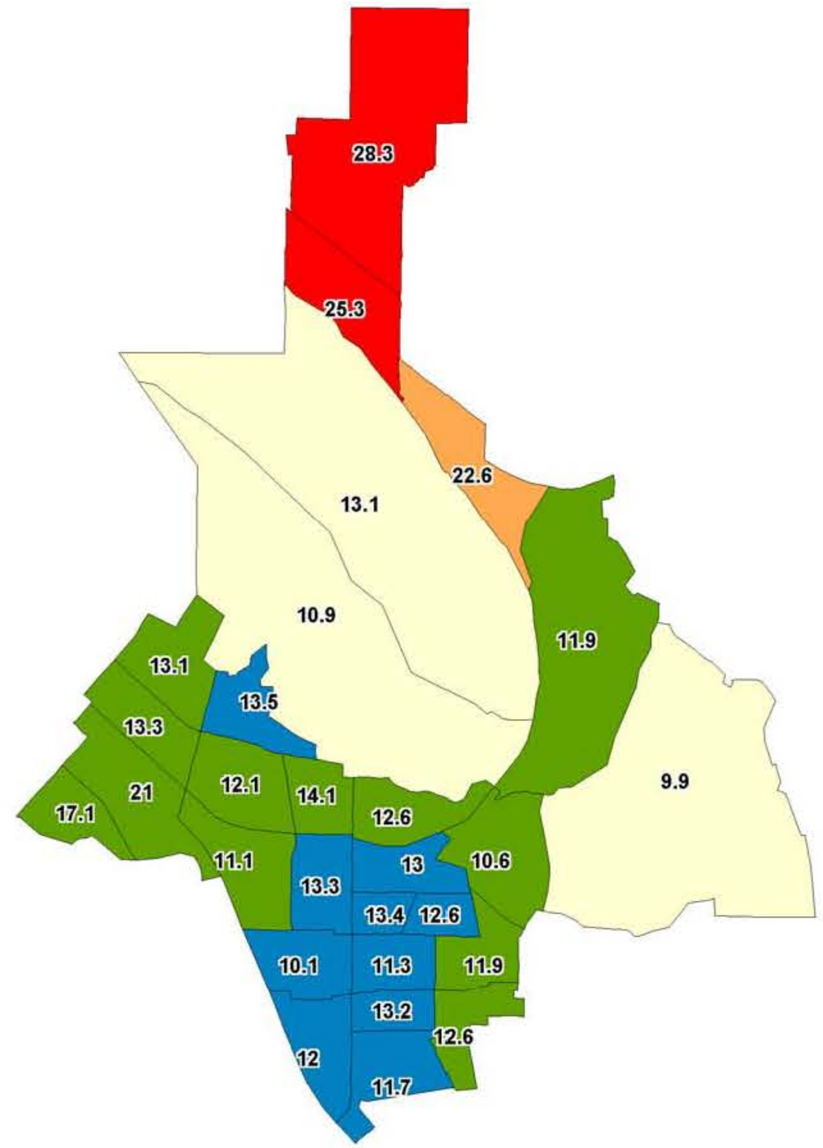
Table 1-5: Number of Buildings Damaged, by Occupancy Type

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

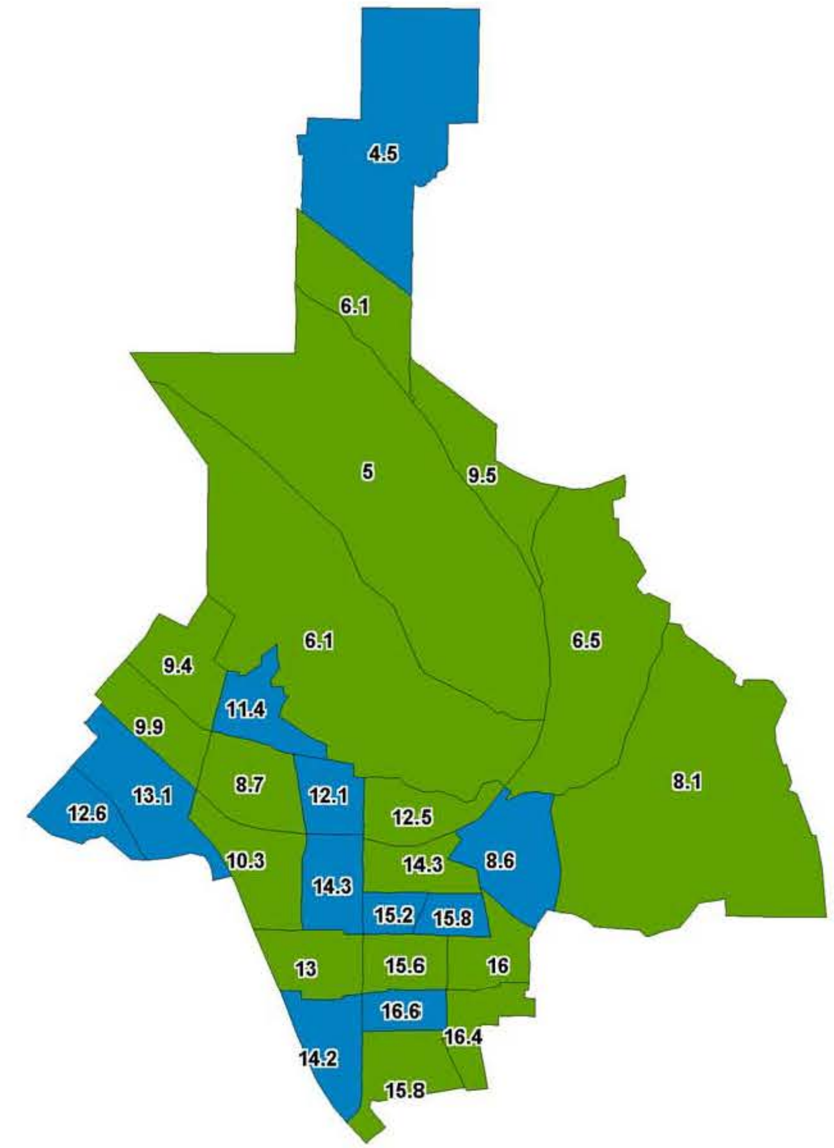
Although the numbers presented in Table 1-5 only hint at it, the commercial and industrial structures will also be impacted. The Sierra Madre and Verdugo earthquakes have the potential to damage about 10 percent and 14 percent of the commercial and industrial buildings, respectively, in the City. The 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 Plate 1-6. All three earthquakes shown on Plate 1-6 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.



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

Earth Consultants International

Project Number: 2103
Date: July, 2003

Residential Buildings With At Least Moderate Damage > 50%*

(Based on Three Earthquake Scenarios)

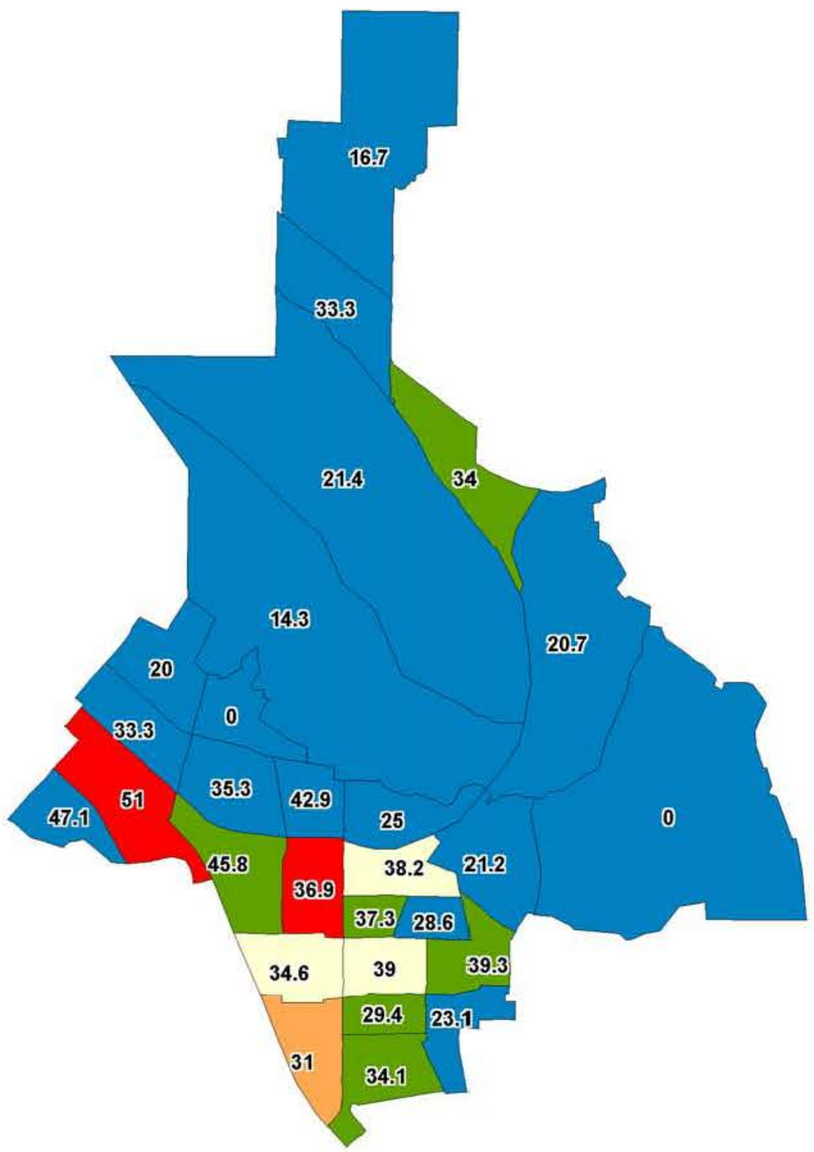
Glendale, California

Plate 1-5

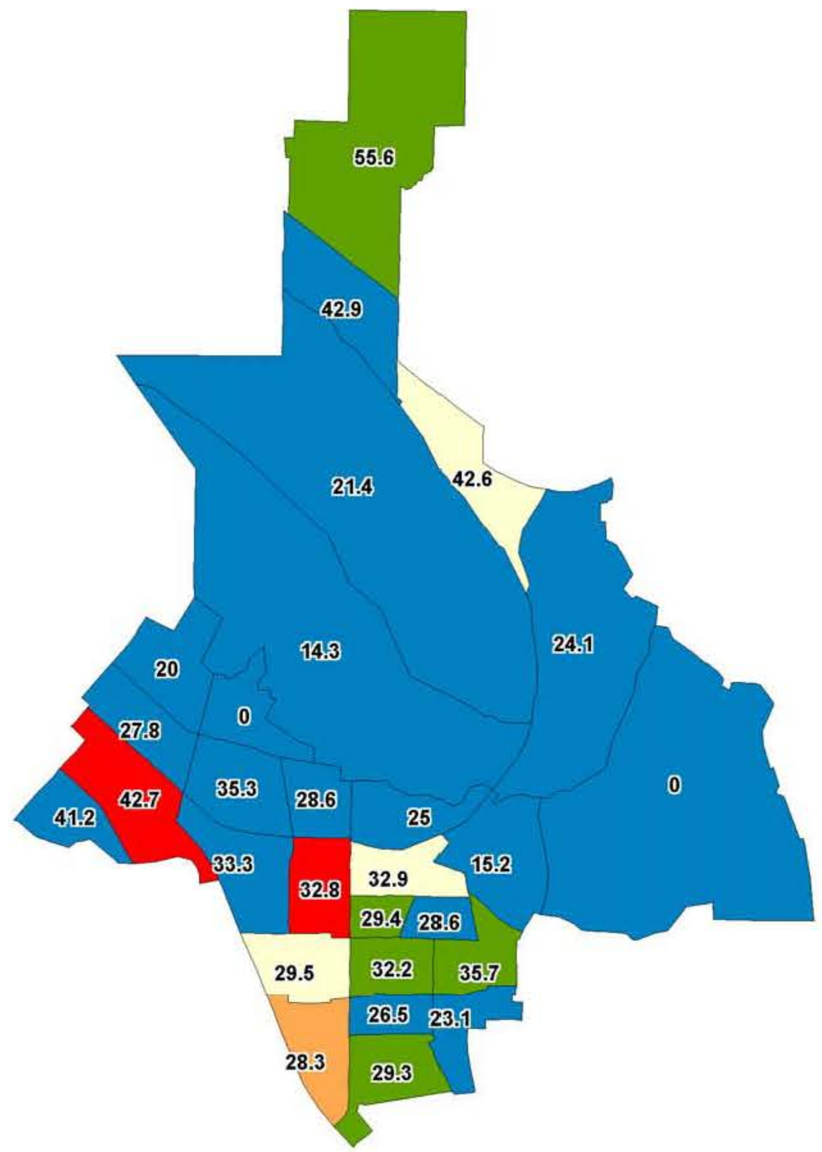
Table 1-6: Number of Buildings Damaged, by Construction Type

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

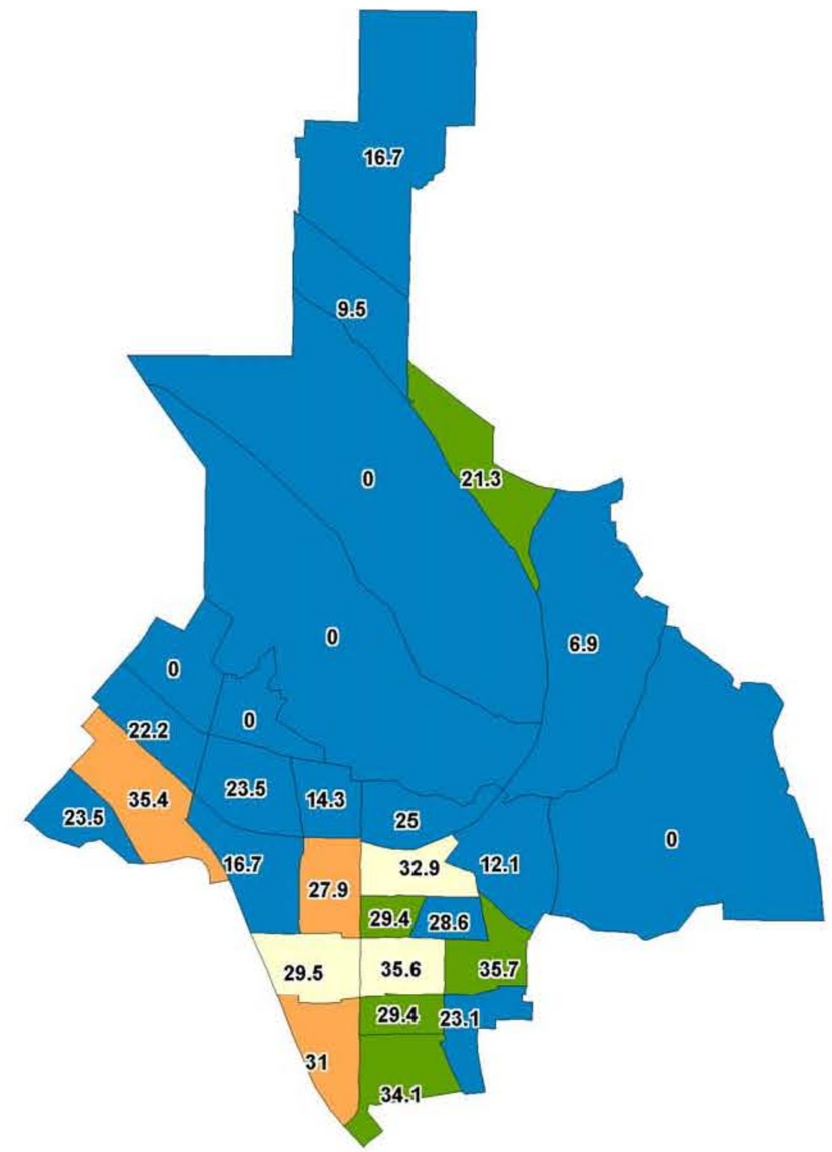
The HAZUS output shows that URMs in Glendale will suffer slight to extensive damage, but that very few are likely to be completely destroyed. This is anticipated to reduce the number of casualties significantly. The numbers show that by retrofitting its URMs, Glendale has already reduced significantly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



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)

- 0-10
- 11-20
- 21-30
- 31-40
- 41 and greater

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

City of Glendale California

Earth Consultants International

Project Number: 2103
Date: July, 2003

Commercial Buildings With At Least Moderate Damage > 50%

(Based on Three Earthquake Scenarios)

Glendale, California

Plate 1-6

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 1-7). These types of buildings also generate heavy debris that is difficult to cut through to extricate victims.

Casualties - Table 1-7 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 1-7), 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 1-7: Estimated Casualties

Type and Time of Scenario			Level 1: Medical treatment without hospitalization	Level 2: Hospitalization but not life threatening	Level 3: Hospitalization and life threatening	Level 4: Fatalities due to scenario event
San Andreas	2AM (maximum residential occupancy)	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 Plate 1-7. 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.

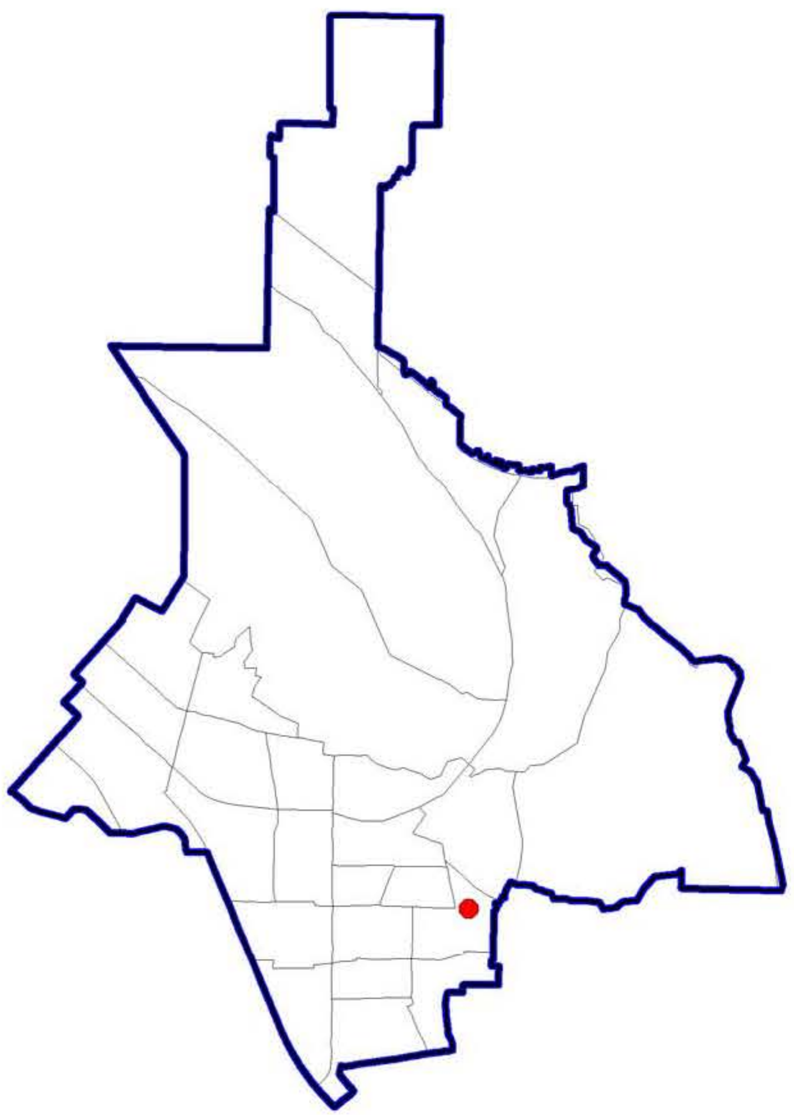
An earthquake on the Verdugo fault is anticipated to cause at least moderate damage to one school in the City – Glendale High (see Plate 1-7), which according to the HAZUS inventory, also houses the Glendale Cosmetology School. The model indicates that none of the other critical facilities in the City 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.

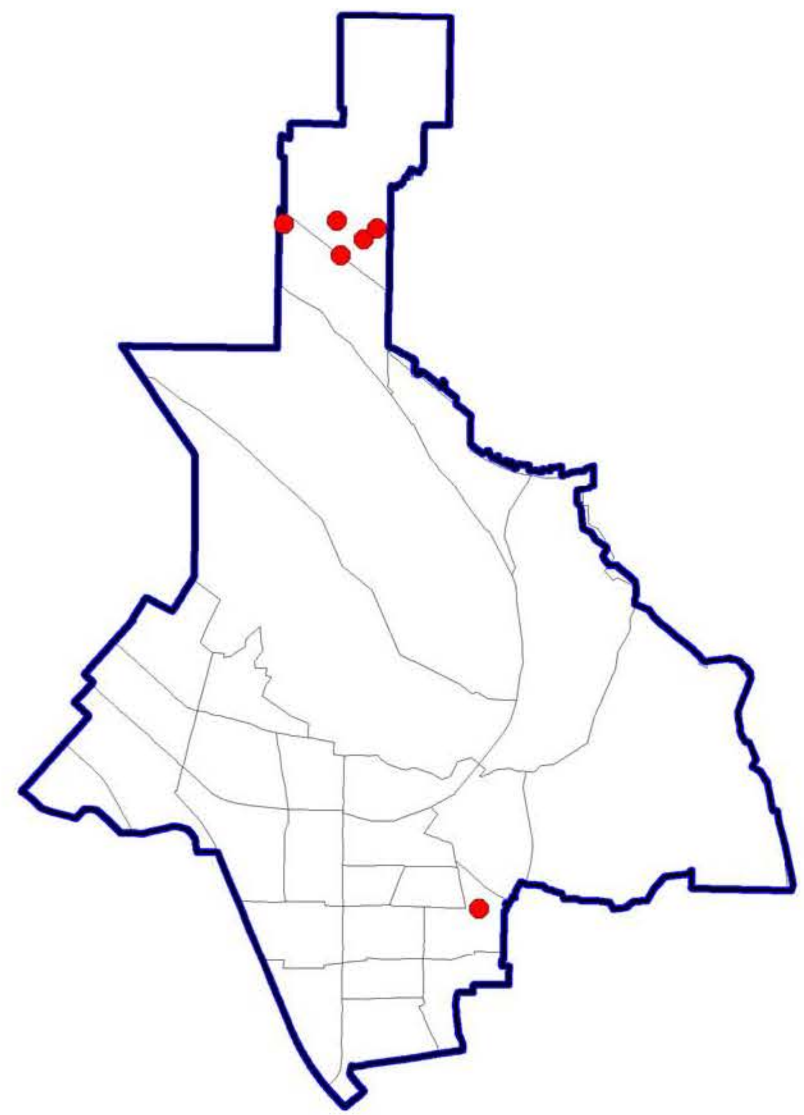
Economic Losses - The model estimates that total building-related losses in the City of Glendale will range from $83 million for an earthquake on the San Andreas fault, to $853 million for an earthquake on the Verdugo fault. Approximately 20 percent of these estimated losses would be related to business 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 1-8 below provides a summary of the estimated economic losses anticipated as a result of each of the earthquake scenarios considered herein.

Table 1-8: Estimated Economic Losses

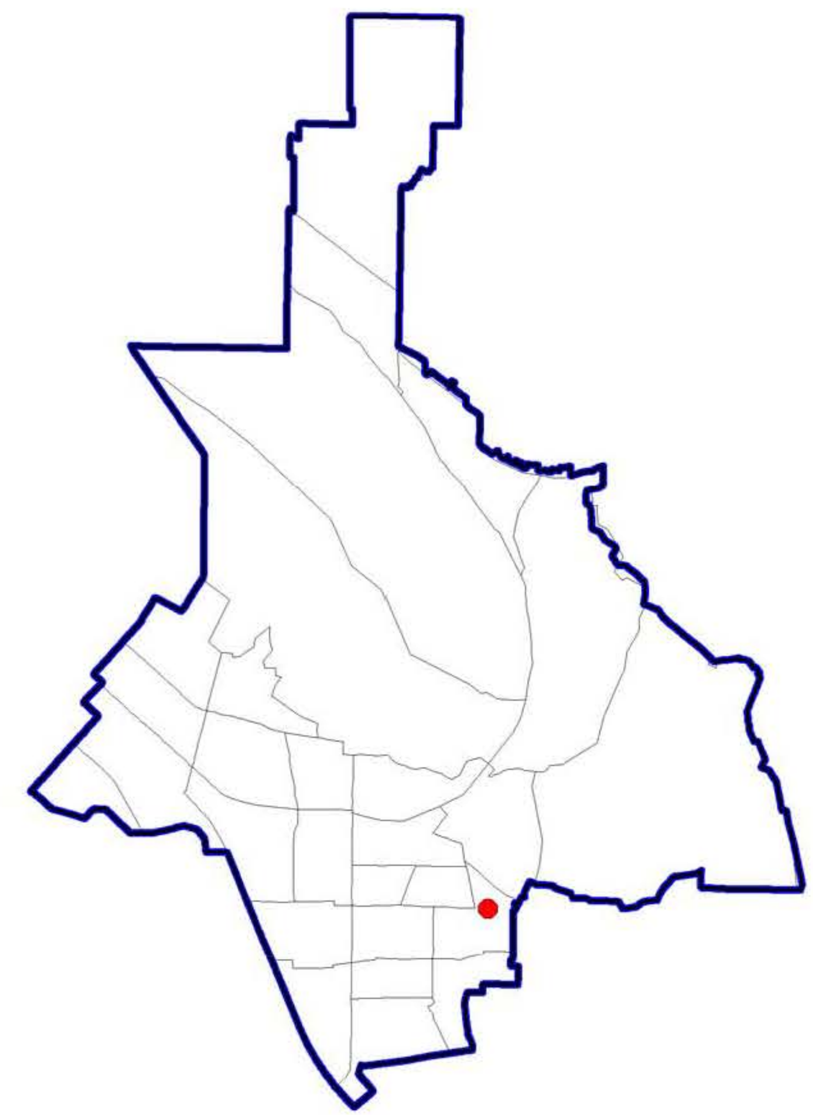
Scenario	Property Damage	Business Interruption	Total
San Andreas	$69.8 Million	$13.5 Million	$83.3 Million
Sierra Madre	$639.7 Million	$158.2 Million	$797.8 Million
Verdugo	$680.4 Million	$72.7 Million	$853.0 Million
Raymond	$560.1 Million	$127.6 Million	$687.7 Million



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

EXPLANATION

● Location of school with at least moderate damage

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

Earth Consultants International

Project Number: 2103
Date: July, 2003

Schools With At Least Moderate Damage > 50%*

(Based on Three Earthquake Scenarios)

Glendale, California

Plate 1-7

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.

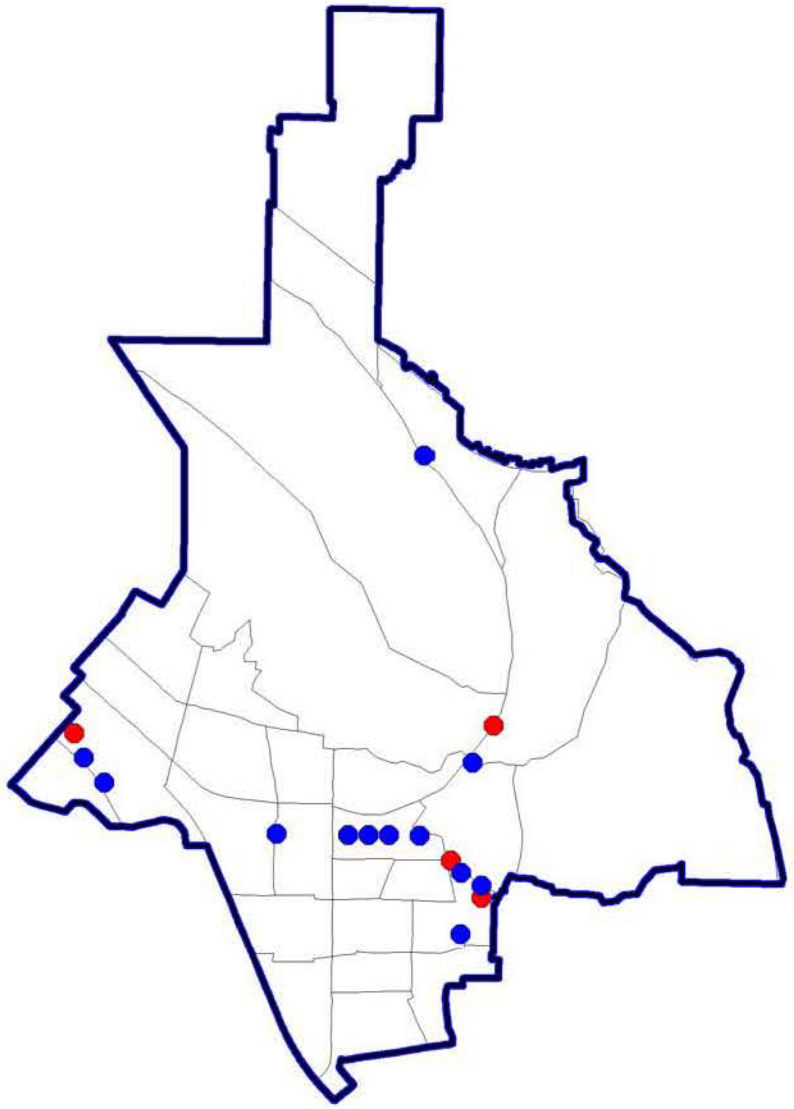
Table 1-9: Estimated Shelter Requirements

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

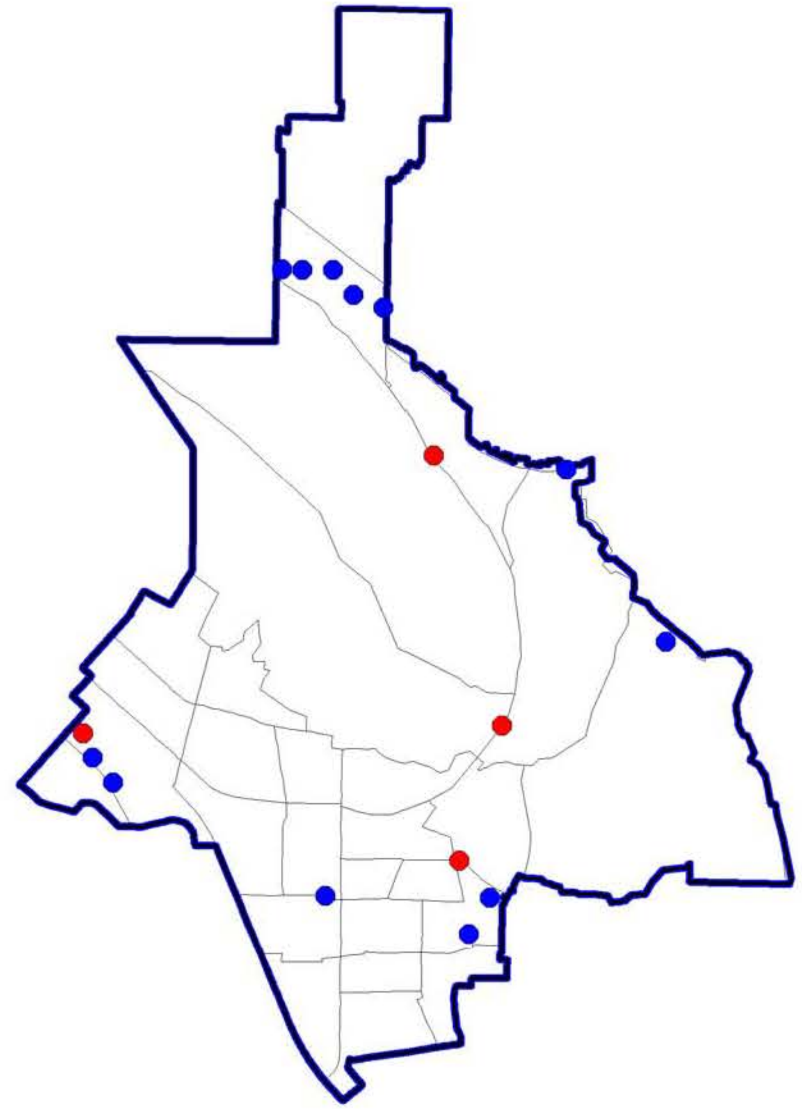
Transportation Damage – Damage to transportation systems in the City of Glendale is based on a generalized inventory of the region as described in Table 1-10. Road segments are assumed to be damaged by ground failure only; therefore, the numbers presented herein may be low given that, based on damage 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.

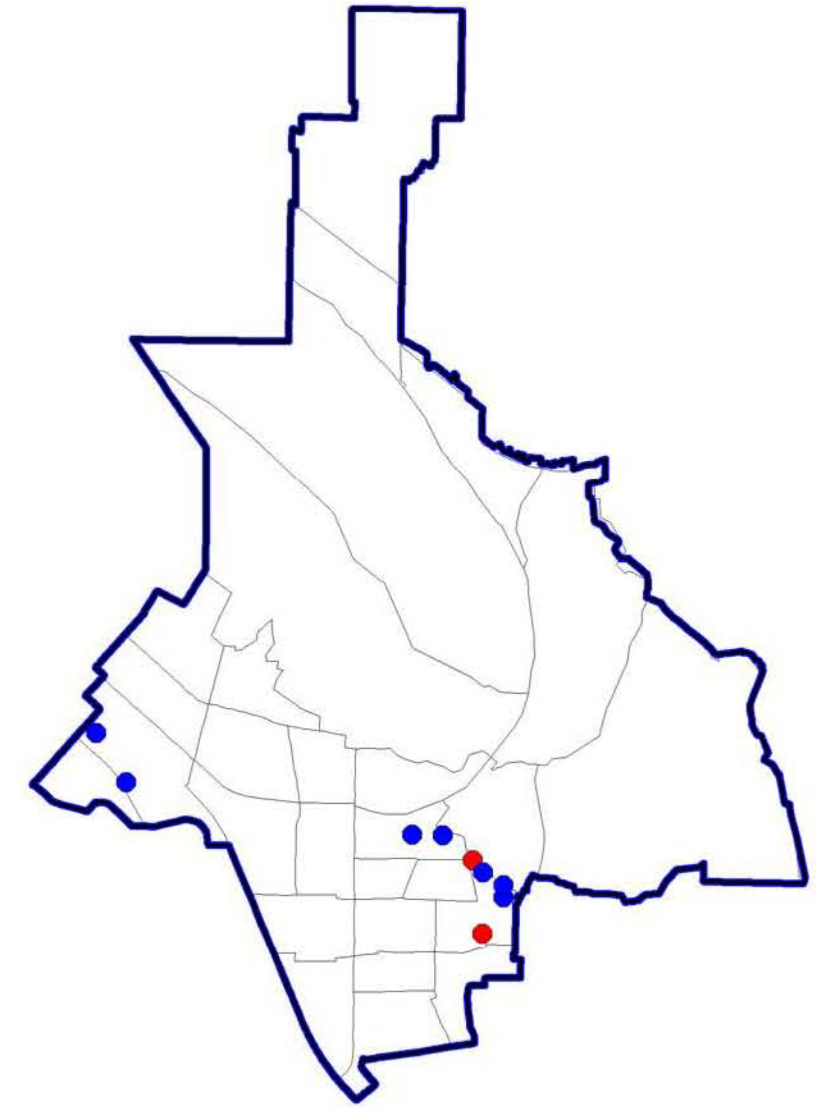
Alternatively, an earthquake on the Sierra Madre fault is expected to damage about 27 bridges in the Glendale area, with 5 of them considered to be completely damaged. Temporary repairs are expected to make all but 2 of the bridge locations more than 50 percent functional one day after the earthquake. 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 Plate 1-8.



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

EXPLANATION

Bridge Damage

- ● At least Moderate Damage
- ● Complete Damage

Earth Consultants International

Project Number: 2103
Date: July, 2003

Bridge Damage

(Based on Three Earthquake Scenarios)

Glendale, California

Plate 1-8

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 1-10: 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 1-11. 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 1-11: 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.

Fire Following Earthquake - HAZUS uses a Monte Carlo simulation model to estimate the number of ignitions and the amount of burnt area as a result of an earthquake. For the earthquake scenarios ran for Glendale, HAZUS estimates between 3 and 11 ignitions immediately following an earthquake, with the San Andreas fault earthquake scenario triggering 3 ignitions, and the Verdugo and Sierra Madre faults triggering 11 ignitions each. The Raymond and Hollywood faults are both expected to trigger 10 ignitions in the City. The burnt area resulting from these ignitions will vary depending on wind conditions. Normal wind conditions of about 10 miles per hour (mph) are expected to result in burn areas of between 1.9 and 6.7 percent of the region's total area. If Santa Ana wind conditions are present at the time of the earthquake, the burnt areas can be expected to be significantly larger.

The fires triggered by an earthquake on the San Andreas fault are anticipated to displace as few as 30 people (if the winds are low), and as many as 308 people (if 30 mph winds are blowing through the area at the time). The fires triggered by the other earthquake scenarios are expected to impact between 116 and 354 people (if winds are low), and as many as 2,047 to 2,919 people (if 30 mph winds are present). Additional information regarding fires after earthquakes and the resultant losses estimated for the City of Glendale are provided in Chapter 4, Section 4.6.

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.

1.10 Reducing Earthquake Hazards in the City of Glendale

This section identifies and discusses the opportunities available for seismic upgrading of existing development and capital facilities, including potentially hazardous buildings and other critical facilities. Many of the issues and opportunities available to the City apply to both new development and redevelopment and infilling. Issues involving rehabilitation and strengthening of existing development are decidedly more complex given the economic and societal impacts inherent to these issues.

Prioritizing rehabilitation and strengthening projects requires that the City consider where its resources would be better spent to reduce earthquake hazards in the existing development, and how the proposed mitigation programs can be implemented so as not to cause undue hardship on the community. Rehabilitation programs should target, on a priority basis, potentially hazardous buildings, critical facilities, and high-risk lifeline utilities.

Recent earthquakes, with their relatively low loss of life, have demonstrated that the best mitigation technique in earthquake hazard reduction is the constant improvement of building codes with the incorporation of the lessons learned from past earthquakes. The most recent building codes (UBC 1997; CBC 1998, 2001) are a prime example in incorporation of lessons and further reduction of the earthquake hazard. However, while new building codes reduce the hazard, increases in population leading to building in vulnerable areas and the aging of the existing building stock work toward increasing the earthquake hazard of a given region.

1.10.1 1997 Uniform Building Code Impacts on the City of Glendale

Two significant changes were incorporated into the 1997 Uniform Building Code (UBC – which is the basis for the 1998 and 2001 California Building Code) that impact the City of Glendale. The first change is a revision to soil types and amplification factors, and the second change is the incorporation of the proximity of earthquake sources in UBC seismic zone 4, which includes the City of Glendale. These changes represent the most significant increases in ground shaking criteria in the last 30 years. The new soil effects are based on observations made as a result of the Mexico City, Loma Prieta and other earthquakes, and impact all buildings in the City of Glendale. In addition, in the current code, soil effects impact buildings of short predominant period of ground shaking (low-rises), whereas in the past, only long-period structures (high-rises) were influenced by UBC requirements. The new ground-shaking basis for code design is now more complicated, however, because of the wide range of soil types and the close proximity of seismic sources. For the City of Glendale, these code changes are warranted. Due to the proximity of the Sierra Madre, Verdugo, Raymond and Hollywood fault systems, the entire area is impacted by the near-source design factors. The 1997 UBC contains detailed descriptions of the incorporation of these new parameters; only a summary is provided below.

Soil Types and Soil Amplification Factors: The seismic design response spectra are defined in terms of two site seismic coefficients Ca and Cv. These coefficients are determined as a function of the following parameters:

- Seismic Zone
- Soil Type, and
- Near Source Factors (UBC Zone 4 only)

The UBC outlines six soil types based on the average soil properties for the top 100 feet of the soil profile. Site-specific evaluation by the project's geotechnical engineer is required to classify the soil profile underlying proposed projects. The soil type parameters are intended to be used by project engineers with Tables 16-S and 16-T of the 1997 UBC. A general description of the 1997 UBC soil types are outlined in Table 1-12, and the soil types in the City of Glendale are illustrated in Plate 1-9.

Table 1-12: UBC Soil Profile Types

Soil Profile Type	Soil Profile Name/ Generic Description	Average Soil Properties for the Upper 100 Feet		
		Shear Wave Velocity (feet/second)	Standard Penetration Test (blows/foot)	Undrained Shear Strength (psf)
SA	Hard Rock	>5,000		
SB	Rock	2,500 to 5,000		
SC	Very dense soil and soft rock	1,200 to 2,500	>50	>2,000
SD	Stiff soil profile	600 to 1,200	15 to 50	1,000 to 2,000
SE	Soft soil profile	<600	<15	<1,000
SF	Soil requiring site-specific evaluation.			

Near- Source Factors: The Glendale area is subject to near-source design factors given the proximity of several active fault systems. These parameters, new to the 1997 Uniform Building Code (UBC), address the proximity of potential earthquake sources (faults) to the site. These factors were present in earlier versions of the UBC for implementation into the design of seismically isolated structures, but are now included for all structures. The adoption into the 1997 code of all buildings in UBC zone 4 was a result of the observation of more intense ground shaking than expected near the fault ruptures at Northridge in 1994, and again one year later at Kobe, Japan. The 1997 UBC also includes a near-source factor that accounts for directivity of fault rupture. The direction of fault rupture was observed to play a significant role in distribution of ground shaking at Northridge and Kobe. For Northridge, much of the earthquake energy was released into the sparsely populated mountains north of the San Fernando Valley, while at Kobe, the rupture direction was aimed at the city and was a contributing factor in the extensive damage. However, the rupture direction of a given source cannot be predicted, and as a result, the UBC requires a general increase in estimating ground shaking of about 20 percent to account for directivity.

Seismic Source Type: Near source factors also include a classification of seismic sources based on slip rate and maximum magnitude potential. These parameters are used in the classification of three seismic source types (A, B and C) summarized on Table 1-13.

NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

Earth Consultants International (ECI) makes no representations or warranties regarding the accuracy of the data from which these maps were derived. ECI shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to any claim by any user or third party on account of, or arising from, the use of this map.

Soil Profile Type	Soil Profile Name/Generic Description	Average Soil Properties for the Upper 100 feet		
		Shear Wave Velocity (feet/second)	Standard Penetration Test (blows/foot)	Undrained Shear Strength (psf)
Sa	Hard Rock	>5,000		
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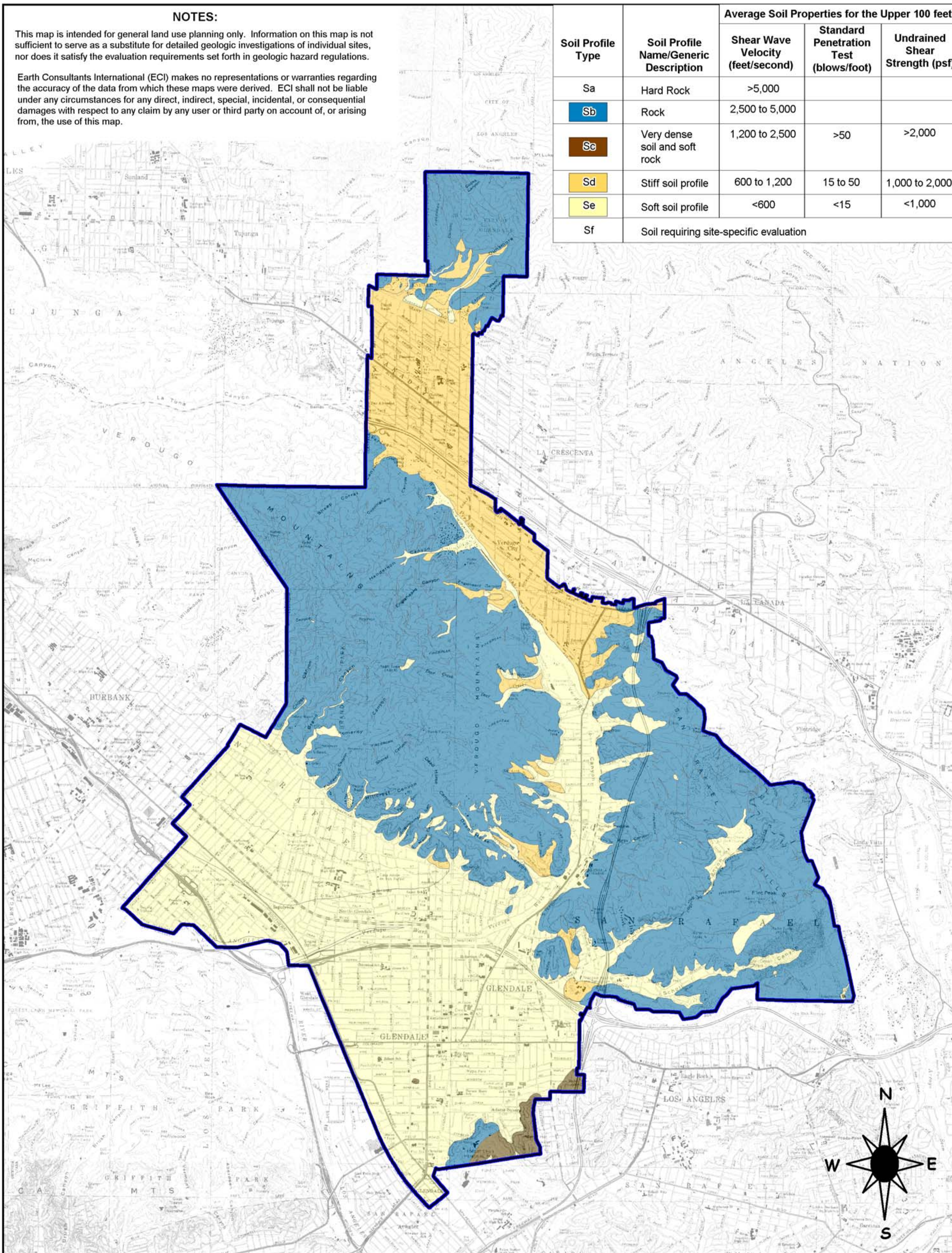
Sc	Very dense soil and soft rock	1,200 to 2,500	>50	>2,000
Sd	Stiff soil profile	600 to 1,200	15 to 50	1,000 to 2,000
Se	Soft soil profile	<600	<15	<1,000
Sf	Soil requiring site-specific evaluation			



Scale: 1:60,000

1000 0 1000 2000 3000 Meters

5000 0 5000 10000 15000 Feet

Glendale City Boundary

Base Map: USGS Topographic Map from Sure!MAPS RASTER
Sources: Based on data from Dibblee (1989a, 1989b, 1991a, 1991b, 2002) and Byer (1968).

Earth Consultants International

Project Number: 2103
Date: July, 2003

Engineering Soil Types in Accordance with 1997 Uniform Building Code

Glendale, California

Plate 1-9

Table 1-13: Seismic Source Type

Seismic Source Type	Seismic Source Description	Seismic Source Definition	
		Maximum Moment Magnitude, M	Slip Rate, SR (mm/yr.)
A	Faults that are capable of producing large magnitude events and which have a high rate of seismicity.	M > 7.0 and	SR > 5
B	All faults other than Types A and C.		
C	Faults which are not capable of producing large magnitude earthquakes and which have a relatively low rate of seismic activity.	M < 6.5	SR < 2

Type A faults are highly active and capable of producing large magnitude events. Most segments of the San Andreas fault are classified as Type A. The Type A slip rate (>5 mm/yr) is common only to tectonic plate boundary faults. Type C seismic sources are considered to be sufficiently inactive and not capable of producing large magnitude events such that potential ground shaking effects can be ignored. Type B sources include most of the active faults in California and include all faults that are neither Type A nor C. The 1997 UBC requires that the locations and characteristics of these faults be established based on reputable sources such as the California Geological Survey (CGS – previously known as the California Division of Mines and Geology - CDMG) and the U.S. Geological Survey (USGS). The CGS classifies the Sierra Madre, Verdugo, Raymond, and Hollywood faults as Type B faults.

To establish near-source factors for any proposed project in the City of Glendale, the first step is to identify and locate the known active faults in the region. The International Conference of Building Officials (ICBO) has provided an Atlas of the location of known faults for California to accompany the 1997 UBC. The rules for measuring distance from a fault are provided by the 1997 UBC. The criteria for determining distance to vertical faults, such as the San Andreas, are relatively straightforward. However, the distance to thrust faults and blind thrust faults is assumed as 0 for anywhere above the dipping fault plane to a depth of 10 kilometers. This greatly increases the areal extent of high ground shaking parameters, but is warranted based on observations of ground shaking at Northridge.

Summary: Seismic codes have been undergoing their most significant changes in history. These improvements are a result of experience in recent earthquakes, as well as extensive research under the National Earthquake Hazard Reduction Program (NEHRP). Inclusion of soil and near-field effects in the 1997 UBC represents a meaningful and impactive change put forth by the geoscience community. Seismic codes will continue to improve with new versions of the building code, and as new data are obtained from both past and future earthquakes.

1.10.2 Retrofit and Strengthening of Existing Structures

The UBC is not retroactive, and past earthquakes have shown that many types of structures are potentially hazardous. Structures built before the lessons learned from the 1971 Sylmar earthquake are particularly susceptible to damage during an earthquake, including unreinforced masonry (URM) structures, pre-cast tilt-up concrete buildings, soft-story structures, unreinforced concrete buildings, as well as pre-1952 single-family structures. Other potentially hazardous buildings include irregular-shaped structures and mobile homes. Therefore, while the earthquake hazard mitigation improvements associated with the current building codes address new construction, the retrofit and strengthening of existing structures requires the adoption of ordinances. The City of Glendale has adopted an ordinance aimed at retrofitting unreinforced masonry buildings (URMs).

Other potentially hazardous buildings, such as pre-1971 concrete tilt-up structures, can be inventoried next. Potentially hazardous buildings can be identified and inventoried following the recommendations set forth in publications such as "Rapid Visual Screening of Buildings for Potential Seismic Hazards: Handbook and Supporting Documentation" and "A Handbook for Seismic Evaluation of Existing Buildings and Supporting Documentation", both prepared by the Applied Technology Council in Redwood City, California, and supplied by the Federal Emergency Management Agency (FEMA publications 154 and 155, and 175 and 178, respectively). The Glendale Building Department has already inventoried the soft-story buildings in the City, but this inventory needs to be kept current and in a digital file that can be improved and modified as necessary.

The building inventory phase of a seismic hazard mitigation program should accurately record the potentially hazardous buildings in an area. To do so, a GIS system is invaluable. The data base should include information such as the location of the buildings, the date and type of construction, construction materials and type of structural framing system, structural conditions, number of floors, floor area, occupancy and relevant characteristics of the occupants (such as whether the building houses predominantly senior citizens, dependent care or handicapped residents, etc.), and information on structural elements or other characteristics of the building that may pose a threat to life.

Once buildings are identified as potentially hazardous, a second, more thorough analysis may be conducted. This step may be carried out by local officials, such as the City's building department, or building owners may be required to submit a review by a certified structural engineer that has conducted an assessment of the structural and non-structural elements and general condition of the building, and has reviewed the building's construction documents (if available). The nonstructural elements should include the architectural, electrical and mechanical systems of the structure. Cornices, parapets, chimneys and other overhanging projections should be addressed too, as these may pose a significant threat to passersby, and to individuals who, in fear, may step out of the building during an earthquake. State of repair of buildings should also be noted, including cracks, rot, corrosion, and lack of maintenance, as these conditions may decrease the seismic strength of a structure. Occupancy should be noted as this factor is very useful in prioritizing the buildings to be abated for seismic hazards.

For multi-story buildings, large occupancy structures, and critical facilities, the seismic analysis of the structure should include an evaluation of the site-specific seismic environment (e.g., response spectra, estimates of strong ground motion duration, etc.), and an assessment of the building's loads and anticipated deformation levels. The resulting data should be weighted against acceptable levels of damage and risk chosen by the City for that particular structure. Once these guidelines are established, mitigation techniques available (including demolition, strengthening and retrofitting, etc.) should be evaluated, weighted, and implemented.

With the inventory and analysis phases complete, a retrofit program can be implemented. Although retrofit buildings may still incur severe damage during an earthquake, the mitigation results in a substantial reduction of casualties by preventing collapse. The societal and economic implications of rehabilitating existing buildings are discussed in many publications, including "Establishing Programs and Priorities for the Seismic Rehabilitation of Buildings - A Handbook and Supporting Report", "Typical Costs for Seismic Rehabilitation of Existing Buildings: Summary and Supporting Documentation," (FEMA Publications 174 and 173, and 156 and 157, respectively). Another appropriate source is the publication prepared by Building Technology, Inc. entitled "Financial Incentives for Seismic Rehabilitation of Hazardous Buildings - An Agenda for Action (Report and Appendices)."

The City of Glendale should set a list of priorities by which strengthening of the buildings identified as hazardous will be established and conducted. Currently, there are no Federal or State mandated criteria established to determine the required structural seismic resistance capacity of structures. Retrofitting to meet the most current UBC standards may be cost-prohibitive, and therefore, not feasible. The City may develop its own set of criteria, however, this task should be carried out following a comprehensive development and review process that involves experienced structural engineers, building officials, insurance representatives, and legal authorities. Selection of the criteria by which the structural seismic resistance capacity of structures will be measured may follow a review of the performance during an earthquake of similar types of buildings that had been retrofit prior to the seismic event. Upgrading potentially hazardous buildings to, for example, 1973 standards may prove inefficient if past examples show that similar buildings retrofit to 1973 construction codes performed poorly during a particular earthquake, and had to be demolished anyway. Issues to be addressed include justification for strengthening a building to a performance level less than the current code requirements, the potential liabilities and limitations on liability, and the acceptable damage to the structure after strengthening (FEMA, 1985).

The mitigation program established by the City could be voluntary or mandatory. Voluntary programs to encourage mitigation of potentially hazardous buildings have been implemented with various degrees of success in California. Incentives that have been used to engender support among building owners include tax waivers, tax credits, and waivers from certain zoning restrictions. Other cities have required a review by a structural engineer when the building is undergoing substantial improvements.

1.11 Summary

Since it is not possible to prevent an earthquake from occurring, local governments, emergency relief organizations, and residents are advised to take action and develop and implement policies and programs aimed at reducing the effects of earthquakes. Individuals should also exercise prudent planning to provide for themselves and their families in the aftermath of an earthquake.

Earthquake Sources:

- The City of Glendale is located in an area where several active faults have been mapped. At least two active faults extend through portions of the City: the Sierra Madre fault along its northern limits, and the Verdugo fault through its central portion. The Raymond and Hollywood faults are generally mapped just south of the City's boundaries, except for the easternmost portion of the Hollywood fault, which actually extends into the southern portion of the City. Given the location of these faults in and near the City, the 1997 Uniform Building

Code requires that Glendale incorporate near-source factors into the design of new buildings. In addition to the faults above, the Elysian Park, Santa Monica, Newport-Inglewood, San Gabriel, Oakridge and several other fault zones have the potential to generate earthquakes that would cause strong ground shaking in Glendale.

- Geologists, seismologists, engineers and urban planners typically use maximum magnitude and maximum probable earthquakes to evaluate the seismic hazard of a region, the assumption being that if we plan for the worst-case scenario, smaller earthquakes that are more likely to occur can be dealt with more effectively.
- A number of historic earthquakes have caused significant ground shaking in Glendale. The 1971 Sylmar and 1994 Northridge earthquakes caused significant damage in the City.

Design Earthquake Scenarios:

- Both the Sierra Madre and Verdugo faults have the potential to generate earthquakes that would be described as worst-case for the City of Glendale. The segment of the Sierra Madre fault that extends through the northern reaches of the City is thought capable of generating an earthquake of magnitude between 7.0 and 7.5. In this report, a magnitude 7.2 earthquake was modeled to obtain loss estimates for the City. A magnitude 7.5 earthquake would cause even higher losses than those presented here. Based on its known length, the Verdugo fault is thought capable of generating an earthquake as large as magnitude 6.7. This estimate of the size of the earthquake that the Verdugo fault is thought capable of generating has not been confirmed through field studies of the fault's previous surface-rupturing events (paleoseismic studies).
- A maximum magnitude earthquake on the Mojave segment of the San Andreas was also considered as a likely earthquake scenario given that this fault is thought to have a relatively high probability of rupturing in the not too distant future. The loss estimation model indicates that the damage caused by an earthquake on the San Andreas fault to the City of Glendale is small compared to the other earthquakes modeled, but not insignificant. Damages of about $83 million were estimated for Glendale if the segment of the San Andreas fault closest to the City breaks in a magnitude 7.1 earthquake. If more than one segment of the fault breaks in the same earthquake, the size of it will be larger, and the damage in Glendale can be anticipated to be more severe.

Fault Rupture and Secondary Earthquake Effects:

- Several active and potentially active faults are known to extend into or across the City, including traces of the Sierra Madre fault, the Verdugo fault, the eastern extension of the Hollywood fault, and the western extension of the Eagle Rock and Sycamore Canyon faults. A fault hazard management zone has been defined around some of these faults – it is proposed that geological studies to evaluate the potential for surface fault rupture should be required in these zones prior to development or redevelopment. A portion of the Sierra Madre fault (the Rowley fault) is zoned under the Alquist-Priolo Earthquake Fault Zoning Act, so geological evaluations to locate the fault are mandated by State law if developments or re-developments amounting to more than 50 percent of the original value of the structure are proposed within this zone. In early aerial photographs of the area, the Verdugo fault appears to have strong geomorphic expression along most of its trace, but unfortunately most of the fault zone is now covered with buildings and roads. This makes it difficult to locate and study the fault. However, given its potential to cause an earthquake that would break the surface, which would cause extensive damage to the buildings and infrastructure built across the traces of the fault, the City should consider implementing a program designed to locate and characterize the fault. Once this is done, structures located across the fault can be moved, strengthened, or demolished. Lots impacted by the fault can be purchased by the City and converted into open space or other suitable land use.

- Currently, shallow ground water levels (< 50 feet from the ground surface) are known to occur along that portion of the Verdugo Wash and its tributaries located north of the Verdugo fault, and in areas near the Los Angeles River. Shallow ground water perched on bedrock may be present seasonally in the canyons draining the south flank of the Verdugo Mountains, especially in the portions of the canyons north of the trace of the Verdugo fault. Seasonal fluctuations in groundwater levels, and the introduction of residential irrigation requires that site-specific investigations be completed to support these generalizations in areas mapped as potentially susceptible to liquefaction.
- Those portions of Glendale that may be susceptible to seismically induced settlement are generally the floodplains and larger drainages that are underlain by late Quaternary alluvial sediments (similar to the liquefaction-susceptible areas). Sites near the base of the San Gabriel and Verdugo Mountains and the San Rafael Hills, at the valley margins, may be particularly vulnerable as a result of differential settlement at the bedrock-alluvial contact.
- The northern and western portions of the Glendale area are most vulnerable to seismically induced slope failure, due to the steep terrain. Some areas in the San Rafael Hills are also susceptible to earthquake-induced slope instability.
- The California Geological Survey (CGS) has completed mapping in the Glendale area under the Seismic Hazards Mapping Act. Geological studies in accordance with the guidelines prepared by the CGS should be followed in those areas identified as having a liquefaction or slope-instability hazard.

Earthquake Vulnerability:

- Most of the loss of life and injuries that occur during an earthquake are related to the collapse of hazardous buildings and structures, or from non-structural components (contents) of those buildings.
- Inventory of potentially hazardous structures, such as concrete tilt-ups, pre 1971- reinforced masonry, and pre-1952 wood-frame buildings, is recommended.
- Most damage in the City is expected to be to wood-frame residential structures, which amount to more than 95 percent of the building stock in the City. Two of the earthquake scenarios modeled for this study suggest that as much as 50 percent of the residential buildings in the City will experience at least some damage. However, the damage to residential structures, although costly, is not expected to cause a large number of casualties.
- The loss estimation models indicate that some of the school buildings in the City are likely to be damaged during an earthquake. Glendale High School consistently received poor marks in the HAZUS analyses. Several schools in the northern portion of the City are expected to experience at least moderate damage as a result of an earthquake on the Sierra Madre fault. Given that the Glendale Unified School District, rather than the City, is responsible for the safety of the school buildings discussed in this report, it is recommended that the City provide the School District with the results of these analyses for the District to use as appropriate.

Given the HAZUS results, it would be prudent for the District to conduct a structural assessment of these schools, and prioritize their structural strengthening.

Earthquake Hazard Reduction:

- The best mitigation technique in earthquake hazard reduction is the constant improvement of building codes with the incorporation of the lessons learned from each past earthquake. This is especially true in areas not yet completely developed, but it is not the most practical option for cities like Glendale, where most of the land is already developed. Nevertheless, for new development, or re-development, where this involves more than 50 percent of the original cost of the structure, the adoption and implementation of the most current building code adopted by the City is warranted. The recent building codes incorporate two significant changes that impact the City of Glendale. The first change is a revision to soil types and amplification factors, and the second change is the incorporation of the proximity of earthquake sources in UBC seismic zone 4. However, since the City of Glendale is mostly developed, and building codes are generally not retroactive, the adoption of the most recent building code is not going to improve the existing building stock, unless actions are taken to retrofit the existing structures. Retrofitting existing structures to the most current building code is in most cases not practicable and cost-prohibitive. However, specific retrofitting actions, even if not to the latest code, that are known to improve the seismic performance of structures should be attempted.
- All of the Glendale area is subject to near-source design factors because the City is traversed by two active fault systems, and located near at least two other potentially significant seismic sources. These parameters, new to the 1997 Uniform Building Code (UBC) and the 1998 and 2001 California Building Codes (CBC), address the proximity and the potential of earthquake sources (faults) to the site.
- While the earthquake hazard mitigation improvements associated with the 1997 UBC address new construction, the retrofit and strengthening of existing structures requires the adoption of ordinances. The City of Glendale has adopted an ordinance aimed at retrofitting unreinforced masonry buildings (URMs). Similar ordinances can be adopted for the voluntary or mandatory strengthening of wood-frame residential buildings, pre-cast concrete buildings, and soft-story structures, among others. Although retrofitted buildings may still incur severe damage during an earthquake, their mitigation results in a substantial reduction of casualties by preventing collapse.
- Adoption of new building codes does not mitigate local secondary earthquake hazards such as liquefaction and ground failure. Therefore, these issues are best mitigated at the local level. Avoiding areas susceptible to earthquake-induced liquefaction, settlement or slope instability is generally not feasible. The best alternative for the City is to require "special studies" within these zones for new construction, as well as for significant redevelopment, and require implementation of the subsequent engineering recommendations for mitigation.