2.2.2 Geologic Resources

This section assesses potential impacts from faulting and seismicity, soil and sediment, liquefaction, subsidence, and tsunami and seiche associated with implementation of the proposed project. This assessment is based on information provided in the *Seismic Ground Motion Study Report for Gerald Desmond Replacement Bridge Project* (EMI, 2005) and *Port Wide Ground Motion Study for Port of Long Beach* (EMI, 2006).

2.2.2.1 Regulatory Setting

For geologic and topographic features, the key federal law is the Historic Sites Act of 1935, which establishes a national registry of natural landmarks and protects "outstanding examples of major geological features." Topographic and geologic features are also protected by CEQA.

This section also discusses geology, soils, and seismic concerns as they relate to public safety and project design. Earthquakes are a prime consideration in the design and retrofit of structures. Caltrans Office of Earthquake Engineering is responsible for assessing the seismic hazard for bridge projects. The current policy is to use the anticipated MCE, from young faults in and near California for ordinary standard bridges (Caltrans, 2004). Caltrans, with the support of an external Seismic Advisory Board, has developed a set of seismic performance criteria for new major long-span bridges (ATC, 1996). In these criteria, safety-evaluation and functional-evaluation design earthquakes are defined. The safety-evaluation earthquake (SEE) may be defined probabilistically as an earthquake with a 1,000- to 2,000-year return period, and the probabilistic safety-evaluation ground motion must be determined on a site-specific basis. The functional-evaluation earthquake (FEE) is intended to represent an event that has a reasonable probability of not being exceeded during the life of the bridge.

2.2.2.2 Affected Environment

During the 1800s, the shoreline in the project area consisted of a tidal estuary at the mouth of the Los Angeles River. An offshore sandbar called Rattlesnake Island protected this estuary. Development of the various harbor facilities through dredging and construction of landfills has resulted in substantial alteration of the original shoreline. Rattlesnake Island was broadened to become Terminal Island. Wilmington Slough was dredged to form the West Basin of the Los Angeles Harbor. The Los Angeles River was diverted to the east side of Long Beach Harbor to control the severe silting that occurred whenever the river flooded.

Between 5,000 and 20,000 ft (1,520 and 6,100 m) of poorly to moderately consolidated marine sediment and unconsolidated alluvium underlie the coastal plain between the Newport-Inglewood Fault and San Pedro Bay. The marine sedimentary rocks range in age from middle Miocene to Pliocene (14 million to 2 million years ago). The unconsolidated alluvium ranges in age from Pleistocene to Holocene (2 million years ago to the present). In the project area, sedimentary rocks consist of the Pliocene Repetto Siltstone, and the Malaga Mudstone and Valmonte Diatomite of the Miocene Monterey Formation. The Catalina Schist underlies these sedimentary rocks. The Catalina Schist is exposed only in the Palos Verdes Hills, but it is encountered in numerous oil wells at depths of 5,000 to 14,000 ft (1,520 to 4,270 m) below sea level.

Faulting and Seismicity

The southern California area is seismically active; however, seismicity in the Los Angeles Basin does not clearly correlate to surface faults. There is no concentration or clustering of earthquakes in the site region except along the Newport-Inglewood Structural Zone (NISZ) where a series of aftershocks from the 1933 event are located. It has been suggested that as much as 40 percent of the tectonic strain in southern California is not released on known faults (Ward, 1994).

The largest historical earthquake within the Los Angeles Basin was the 1933 Long Beach earthquake of Magnitude (M) 6.4 and Local Magnitude (ML) 6.3. The 1971 San Fernando (ML 6.4, M 6.7) earthquake occurred outside of the basin along the northern margin of the San Fernando Valley within a zone of mapped surface faults. The more recent 1987 Whittier earthquake (ML 5.9, M 5.9) and the 1994 Northridge (ML 6.4, M 6.7) earthquake occurred under the San Gabriel Valley and the San Fernando Valley, respectively, but they were not associated with surface faults.

The Long Beach earthquake was generally believed to have been associated with the NISZ (Benioff, 1938). This association was based on abundant ground failures along the trend, but no unequivocal surface rupture was identified. Hauksson and Gross (Hauksson and Gross, 1991) re-evaluated the seismic history and relocated the 1933 earthquake to a depth of approximately 6.2 mi (10 km) below the Huntington Beach-Newport Beach city boundary.

The following sections describe the principal active faults in the Los Angeles region that might contribute to ground shaking in the POLB area. Exhibit 2.2.2-1 shows the locations of these faults. This information is provided from a regional perspective for understanding the nature of the faults.

Palos Verdes Fault

The Palos Verdes fault extends through the POLA from the east side of the Palos Verdes Peninsula southeasterly to the Lasuen Knoll area offshore and northwesterly into the Santa Monica Bay (SMB), for a total length of approximately 62 mi (100 km) (Exhibit 2.2.2-1).

The Palos Verdes fault is predominantly a strike-slip fault, but it has a small vertical component (approximately 10 percent to 15 percent). The slip rate of the Palos Verdes fault is based primarily on the geophysical and geological studies in the outer harbor of the POLA by McNeilan *et al.* (1996). McNeilan *et al.* estimated a long-term horizontal slip rate of between 0.078 and 0.137 inches per year (in/yr) (2.0 and 3.5 millimeters per year [mm/yr]) with a range of approximately 0.09 to 0.117 in/yr (2.3 to 3.0 mm/yr) for the middle- to late-Holocene time period. Such a slip rate makes the Palos Verdes fault one of the most active faults in the Los Angeles region.

There are virtually no direct data to constrain the recurrence interval for large earthquakes on the Palos Verdes fault. There have been no significant earthquakes on the fault since the arrival of the Franciscan missionaries in the 1700s. Using the empirical data of Wells and Coppersmith (1994) to indirectly make judgments on how long it would take to store up enough strain to generate an M 6.8 to 7.4 earthquake, it appears that recurrence intervals for such earthquakes on the Palos Verdes fault would range from a few hundred to a few thousand years. For example, fault rupture scenarios evaluated by McNeilan *et al.* ranged from 180 to 630 years for an M 6.8 event, 400 to 440 years for an M 7.1 event, 1,000 to 1,100 years for an M 7.2 event, and 830 to 1,820 years for an M 7.4 event. Other scenarios may be just as likely and would yield similar ranges.

Newport-Inglewood Structural Zone

The NISZ consists of the northwest-southeast trending series of faults and folds forming an alignment of hills in the western Los Angeles Basin extending from the Baldwin Hills on the north to Newport Beach on the south (Exhibit 2.2.2-1).

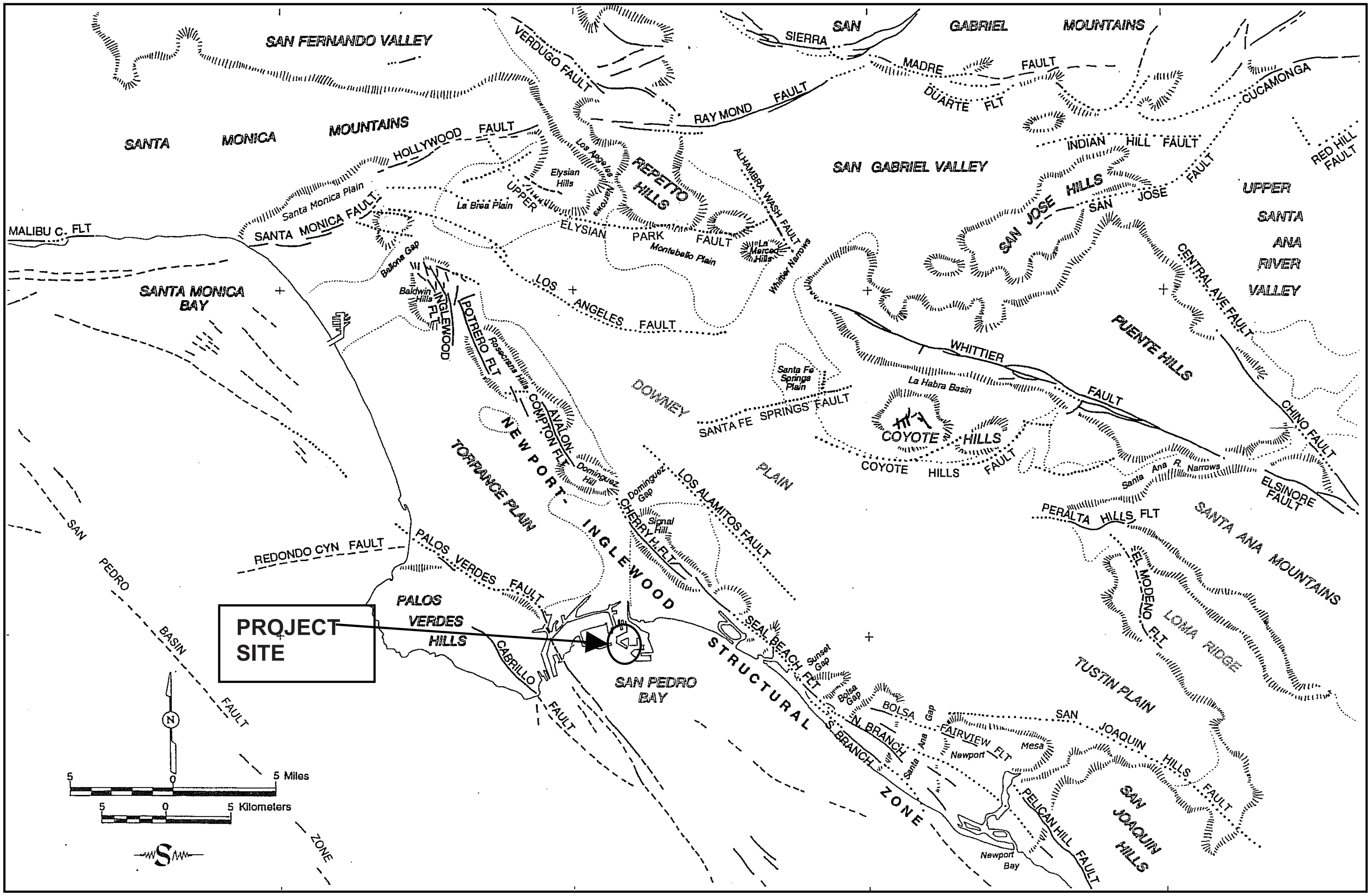
The maximum earthquake used for the NISZ in local geotechnical investigations has generally been M 7.0. This may be relatively small for a feature as long as the SMB zone, but the magnitude is based on the concept that the zone consists of shorter discontinuous faults, or segments, that behave independently. The fault was the source of the 1993 Long Beach earthquake of M 6.3, but as with the Palos Verdes fault, the history of earthquakes on the NISZ is incomplete, so it is difficult to estimate a maximum earthquake. Empirical fault-length/earthquake-magnitude relations (Wells and Coppersmith, 1994) suggest an MCE of approximately 7.0.

The recurrence interval for the maximum earthquake on the NISZ is very long, on the order of a thousand years or more (Schell, 1991; Freeman *et al.,* 1992; Shlemon *et al.,* 1995; Grant *et al.,* 1997).

Although there is quite a wide range of slip rates proposed by various published sources, most of them are of uncertain validity because they are based on short-term, local, vertical components rather than regional horizontal slip. Grant *et al.* (1997) inferred a minimum rate of 0.013 to 0.02 in/yr (0.34 to 0.55 mm/yr), but Shlemon *et al.* estimated a rate of 0.059 to 0.098 in/yr (1.5 to 2.5 mm/yr). The southern segment of the SMB system comprising the Rose Canyon fault in the San Diego area has a slip rate of approximately 0.043 to 0.059 in/yr (1.1 to 1.5 mm/yr) (Lindvall and Rockwell, 1995). The northern part of the NISZ is commonly considered to have a much lower rate, on the order of 0.004 in/yr (0.1 mm/yr). Most seismic hazard studies have used a long-term rate of 0.02 in/yr (0.5 mm/yr) based on offset of Pliocene fold structures and strata (Schell, 1991; Freeman *et al.,* 1992).

Cabrillo Fault

The Cabrillo fault forms a prominent northeast facing scarp in the 100,000 year-old terrace in the San Pedro-Point Fermin area (refer to Exhibit 2.2.2-1). The fault dips approximately 50 degrees to 70 degrees easterly with a vertical displacement of approximately 100 to 200 ft (30 to 61 m) (Woodring *et al.,* 1946). The fault trends northwesterly inland for approximately 4.3 mi (7 km) (Woodring *et al.,* 1946; Dibblee, 1999). Southerly from Cabrillo Beach, the fault extends offshore for a distance of approximately 6.8 mi (11 km) where it appears to merge with the Palos Verdes fault



PROJECT SITE

Source: Earth Mechanics, Inc., 2005.

Exhibit 2.2.2-1
Los Angeles Regional Faults Map

(Vedder *et al.,* 1986; Fischer *et al.,* 1987). The offshore fault is shown as a zone of disruption up to 1,640 ft (500 m) wide.

The fault is considered to be predominantly a strike-slip fault due to its association with the Palos Verdes fault, but it may also have a normal component of displacement. Based on empirical fault-length/earthquake-magnitude relationships (Wells and Coppersmith, 1994), the fault could be capable of approximately an M ~ 6.25 to 6.5 earthquake. Fischer *et al.* (1987) estimated a vertical slip rate of 0.016 to 0.027 in/yr (0.4 to 0.7 mm/yr), which is greater than the Palos Verdes fault estimates. Most studies suggest that the Cabrillo fault is a minor feature, and Ward and Valensise (1994) estimated a slip rate of 0.004 in/yr (0.1 mm/yr) estimated a slip rate of 0.004 in/yr (0.1 mm/yr).

Sierra Madre Fault

Based on worldwide empirical fault-length/ earthquake-magnitude relationships (Wells and Coppersmith, 1994), the Sierra Madre fault is capable of producing earthquakes in the 7.0 to 7.5 magnitude range (Dolan *et al.,* 1995). If the fault ruptures one of the segments independently, then earthquakes of M 7.0 are more likely; if more than one segment ruptures together, then larger earthquakes are possible.

Approximately 12.4 mi (20 km) of the westernmost part of the Sierra Madre fault ruptured the ground surface during the 1971 San Fernando earthquake (M 6.7). Geological studies (trenching) of the 1971 rupture suggested that a previous rupture had occurred on this fault within the prior few hundred years (Bonilla, 1973).

Some geological studies have indicated that the average rate of displacement for the Sierra Madre fault may be as high as approximately 0.117 to 0.156 in/yr (3 to 4 mm/year) (Southern California Earthquake Center, n.d.); however, recent paleoseismological studies suggested an average slip rate of only 0.023 in/yr (0.6 mm/yr) (Rubin *et al.,* 1998). This lower rate is based on only one locality within a very long and complex branching fault system; therefore, this rate may not be representative of the entire fault zone. Paleoseismological studies by Tucker and Dolan (2001) on the eastern part of the fault near Azusa revealed a similar minimum slip rate of 0.023 to 0.035 in/yr (0.6 to 0.9 mm/yr).

Malibu Coast, Santa Monica, Hollywood Fault System (Southern Frontal Fault System)

The fault system consists of the Santa Monica and Hollywood faults and smaller segments, such as the Malibu Coast and Potrero faults. Continuation of the fault to the west of Santa Monica is uncertain, and the fault system may be related to the Dume-Anacapa fault zone in the offshore area south of Malibu. Together, these faults form the southern boundary fault of the Santa Monica Mountains.

Documented slip rates are less than 0.039 in/yr (1.0 mm/yr), but this estimate suffers from lack of data on the lateral slip (Dolan *et al.,* 1997). The California Geological Survey assumes a slip rate up to approximately 0.039 in/yr plus or minus 0.02 in/yr (1.0 mm/yr plus or minus 0.5 mm/yr) (California Geological Survey, 2003).

The great length of the fault system suggests that it is capable of generating a large earthquake (M~7.5), but the discontinuous nature of faulting suggests that faults may behave independently and perhaps a smaller maximum earthquake (M~6.5 to 7.0) is more appropriate. Dolan *et al.* (1997) postulated an M 6.6 event for the Hollywood fault. The earthquake recurrence interval is very long and could be on the order of a few thousand years (Dolan *et al.,* 1997).

San Pedro Basin Fault

The fault trends southeasterly from near the base of the Malibu-Santa Monica shelf, past the subsea Redondo Knoll, to approximately Avalon Knoll east of Catalina Island, a distance of approximately 43 to 50 mi (70 to 80 km). The fault is expressed as a complicated association of folds, flower structures, and tensional (normal) structures. The fault dips steeply to nearly vertical, which, along with the structural expression, indicates it is a strike slip fault (Fisher *et al.,* 2003). Southeast of the Palos Verdes Peninsula, this fault coincides with the western limit of a dense distribution of small-magnitude (M 3 to 5) earthquakes.

The slip rate is unknown, but the similarity of geomorphology, structures, and length to the NISZ suggest that they are similar features; therefore, they could have similar slip rates of approximately 0.039 in/yr (1 mm/yr) and similar maximum earthquakes. Fault-length/earthquake-magnitude relationships (Wells and Coppersmith, 1994) indicate a maximum earthquake of approximately M 7.0 to 7.2, but the feature is highly segmented, indicating smaller magnitudes (M~ 6.5-7.0) may be more likely.

Elysian Park Fold and Thrust Belt

The Elysian Park Fold and Thrust Belt (EPFT) was initially identified by Davis *et al.* (1989), who postulated that the Los Angeles area is underlain by a deep master detachment fault and that most of the folds and faults in the region result from slip along the detachment, causing folding and blind thrust faulting at bends and kinks in the detachment fault. Shaw and Suppe (1996) further developed and refined the detachment/blind thrust model.

The detachment/blind thrust model was initially embraced primarily because the 1987 Whittier Narrows earthquake occurred in proximity to one of the postulated thrust ramps beneath the EPFT. Subsequent work has highly modified the original model (e.g., Shaw and Suppe, 1996; Oskin and Sieh, 1998; Bullard and Lettis, 1993; Shaw and Shearer, 1999; Shaw *et al.,* 2002).

Shaw and Suppe (1996) postulated a slip rate of 0.066 plus or minus 0.016 in/yr (1.7 plus or minus 0.4 mm/yr) for the Elysian Park thrust. Estimates of earthquake magnitudes associated with these thrust faults range from 6.6 to 7.3 depending on the size (area) of the individual segments and whether they rupture independently or together. Recurrence interval estimates range from 340 to 1,000 years. Oskin *et al.* (2000) model the Upper Elysian Park thrust as extending from the Hollywood fault to the Alhambra Wash fault with a slip rate of 0.031 to 0.086 in/yr (0.8 to 2.2 mm/yr) and M 6.2 to 6.7 earthquakes with a recurrence interval in the range of 500 to 1300 years. The California Geological Survey, following the lead of Oskin *et al.* (2000), modeled the Upper Elysian Park thrust as a feature approximately 11.2 mi (18 km) long and dipping 50 degrees northeasterly, with a slip rate estimate of approximately 0.051 plus or minus 0.016 in/yr (1.3 plus or minus 0.4 mm/yr).

Puente Hills Fault System

The Puente Hills Thrust fault system (PHT) is the name currently given to a series of northerly dipping subsurface thrust faults (blind thrusts) extending approximately 24.8 to 30 mi (40 to 45 km) along the eastern margin of the Los Angeles Basin.

Shaw and Shearer (1999) proposed that the Puente Hills fault system was capable of generating approximately M 6.5 to 7.0 earthquakes and had a slip rate of between 0.02 to 0.078 in/yr (0.5 to 2.0 mm/yr). The 0.02-in/yr (0.5-mm/yr) rate was derived by dividing the postulated slip by the age of strata (i.e., Quaternary ~1.6 million years), whereas the 0.078-in/yr (2.0-mm/yr) slip rate was derived by assuming that all of the unaccounted-for, geodetically determined, crustal shortening of ~0.312 to 0.371 in/yr (~ 8 to 9.5 mm/yr) across the Los Angeles Basin is occurring on the Puente Hills fault system.

Using empirical data on rupture area, magnitude, and coseismic displacement, Shaw *et al.* (2002) estimated earthquakes of M 6.5 to 6.6 and multi-segment rupture of M 7.1. The recurrence intervals for these events are on the order of 400 to 1,320 years for single events and 780 to 2600 years for M 7.1 events. Paleoseismological studies using trenching and borings in the Santa Fe Springs area identified four buried folds that they interpreted to be a result of M = 7.0± earthquakes within the past 11,000 years (Dolan *et al.,* 2003).

THUMS-Huntington Beach Fault

The THUMS-Huntington Beach (THB) fault has been interpreted in many different ways. It has been interpreted as a high-angle normal fault and an oblique right-lateral normal fault (Truex, 1974; Clarke *et al.,* 1987; Wright, 1991).

In the area between Long Beach and Huntington Beach, several offshore geophysical (seismic-reflection) investigations for numerous oil and engineering projects (e.g., pipelines, offshore power plant, drilling islands) have documented several near-surface faults, but these are short, small displacement, discontinuous, random features that do not appear to align such that they could be considered representative of a major regional active fault.

If the THB fault is projected dipping downward to the east, it would intersect the NISZ at approximately 5 to 5.5 mi (8 to 9 km) depth, raising the issue of whether it cuts off the NISZ or whether the NISZ cuts off the THB. The high degree of young deformation on the NISZ and its historical seismic activity indicate that the NISZ is more active; therefore, it favors the latter interpretation.

Compton-Los Alamitos Thrust Ramp

The Compton-Los Alamitos (CLA) thrust model was developed by Shaw and Suppe (1996) following the lead of Davis *et al.* (1989). The feature comprises a thrust ramp and several overlying folds, which are postulated to result from slip on the deep detachment and interconnected thrust ramps.

Folded Pliocene and Quaternary strata indicate slip rates of 0.055 in/yr (1.4 mm/yr). Assuming that slip is released in large earthquakes, Shaw and Suppe (1996) estimate earthquake magnitudes of 6.3 to 6.8 on individual ramp segments, and M 6.9 to 7.3 if segments rupture together. Recurrence intervals are estimated from empirical earthquake-magnitude/fault-displacement relationships (Wells and Coppersmith, 1994). Estimates of earthquake recurrence intervals range from 380 years for single segments to 1,300 years for multiple segment ruptures.

Los Alamitos Fault

The Los Alamitos fault is a northwest-southeast trending subsurface fault along the northeast side of the NISZ. The fault is not well known because it is not exposed at the surface. The fault extends upward from the basement rocks to an elevation of approximately -300 ft (mean sea level [MSL]), and is subparallel to the NISZ from at least Seal Beach to Rosecrans. The fault is shown as a dotted feature (i.e., buried fault) on the state fault map of Jennings (1994) who assigned it an age of late Quaternary. The Los Angeles County Seismic Safety Element (1990) shows it as potentially active. The fault is shown on the Caltrans seismic hazard map with a maximum earthquake magnitude of 6.0 (Mualchin, 1996).

Although there is no documented surface faulting or even late-Quaternary displacement, the fault should be considered a potential source of small- or moderate-magnitude earthquakes, similar to other buried faults in the Los Angeles Basin. For seismic design purposes, an M 6.0 to 6.5 earthquake is appropriate for the maximum earthquake based on the fault's length according to the empirical fault-length/earthquake-magnitude relationships of Wells and Coppersmith (1994).

Other Faults

There are several minor unnamed faults on the offshore San Pedro shelf. These features were detected by various geophysical surveys for local pipelines. These features are too small and discontinuous to represent a seismic hazard; therefore, they are not significant for seismic design. An example of this type of feature is the Navy Mole Fault.

Soil and Sediment

In the natural regime, the site area was within the delta of the Los Angeles River and its tributaries, and it was characterized by meandering channels, marshes, tidal channels, and islands. Since the early part of the 20th century, the area has been dredged and filled extensively to form the wharves and shipping channels of the Ports. Although modified extensively, the configuration of many of the channels and wharves still reflect the approximate configuration of the natural channels and islands. For example, Terminal Island was a long narrow sand spit (bay-mouth bar) under natural conditions, which has since been widened with fill. Gerald Desmond Bridge crosses a channel between Terminal Island and the "mainland" of Long Beach.

The site area is underlain by alternating beds of nonindurated (unconsolidated) sands, silts, and clays, with local gravel beds. These are generally considered to be part of the Holocene-latest Pleistocene-age Gaspur Aquifer. The Gaspur deposits fill one of the deep stream channels eroded during the lowered sea level during the Pleistocene ice ages. The Gaspur is approximately 150 to 200 ft (45 to 61 m) thick in the site area. Since approximately 5,000 years ago, when the rising sea level stabilized somewhat near the present level, the site area has alternated between beach, lagoon, and estuary environments in the delta of the Los Angeles River. The site is near the boundary between the natural island and the fill placed to enlarge Terminal Island.

Although quite variable in composition, the sediments underlying the site can be grouped into four general units:

- Unit I: upper unit of loose to dense silty sands and soft to very stiff sandy silts,
- Unit II: a compact to very dense sand unit,
- Unit III: a soft to stiff clayey silt and clay unit, and
- Unit IV: lower sand and silty sand unit.

Unit I is within approximately the upper 20 ft (6 m) and may be fill. The sands of Unit II, from approximately 20 ft (6 m) to 50 ft (15 m) deep, probably represent natural near-shore bay and beach sands deposited within the past few thousand years. The fine-grained deposits of Unit III are from approximately 40 to 50 ft (12 to 15 m) deep to approximately 60 to 70 ft (18 to 21 m) deep, and probably represent lagoon or estuary deposits. The deposits of Unit IV below are primarily sands and silty sands, probably representing stream channel and some bay deposits. This likely represents the early Holocene Gaspur Formation and possibly the Upper

Pleistocene Lakewood Formation at the greatest depths. Bedding was not well developed, but where visible, it is essentially horizontal. Differentiating the young (Holocene) sediments from the Lakewood or San Pedro formations is difficult in boreholes because of their similar origin and characteristics. Except for density, which is generally greater in the older Lakewood and San Pedro formations, the units can only be confidently differentiated by analysis of their fossils.

Liquefaction

Liquefaction susceptibility provides an indication of the possible loss of strength and stiffness of saturated cohesionless soils during a moderate to great earthquake. Physical properties of soil, such as grain size distribution, plasticity index, state of compaction, cementation due to aging effects, and groundwater conditions, influence the degree of resistance to liquefaction.

Saturated portions of the sandy soils of the upper stratum at the project site are potentially susceptible to liquefaction. The liquefiable zone is widespread beneath the main span and both approaches. Beneath the west approach, liquefaction is expected to occur in layers generally up to approximately 13 ft (4 m) thick between the water table near El. -7 ft (-2 m) and El. 46 ft (14 m). Beneath the east approach, where the ground and water table is higher, the liquefiable zone rises higher between the water table near El. 0 and El. -20 ft (-6 m), and grows to approximately 28 ft (8.5 m) in thickness. In the two pylon areas (bridge towers) for the proposed bridge, the liquefaction zone increases to approximately 13 to 20 ft (4 to 6 m) in thickness adjacent to the channel. The materials predominantly represent man-made fills and some natural beach sand.

In addition, localized liquefaction may also occur in discontinuous thin sand lenses embedded in the underlying clay and silt unit of a lower soil stratum down to approximately El. -65 ft (-20 m) at both sides of the channel. These individual lenses predominantly consist of loose to medium dense silty sands with thicknesses of typically less than 5 ft (1.5 m) and limited horizontal extent (exact locations of these pockets of soil cannot be determined).

Subsidence

Subsidence is the sinking of the ground surface, typically caused by extracting fluids from the subsurface. Subsidence has been well documented in the Los Angeles-Long Beach Harbors. Between 1928 and 1965, approximately 29 ft (9 m) of cumulative subsidence was recorded near the eastern end of Terminal Island. A maximum annual rate of subsidence of 2.4 ft (0.7-m) was recorded in 1951, approximately 9 months after the Wilmington Oil Field had attained its peak primary production rate of oil and gas (Mayuga, 1970). Due to the close correlation of the zone of subsidence with areas of oil extraction within the Wilmington Oil Field, it was suggested that the oil production caused reduced subsurface fluid pressure, which in turn induced compaction of the oil-producing zones. This compaction at depth was reflected at the surface by land subsidence. By 1951, subsidence covered an elliptical area of approximately 20 square miles (sq mi) (52 square kilometers [sq km]).

Various oil companies started pilot water injection operations in 1953, 1954, and 1956. The City of Long Beach Department of Oil Properties instituted the first major water injection program in 1958. Since 1958, injection of water into oil-depleted zones has curtailed subsidence, and rebound of much of the subsided area has actually been initiated. By 1967, the area of subsidence had been reduced from 20 to 4 sq mi (52 to 10 sq km), with the subsidence rates decreasing to 1.2 in/yr (30 mm/yr) (Mayuga, 1970). In 1980, the DOGGR, the City of Long Beach, and several oil companies initiated an extensive program to greatly increase water injection. Consequently, if a balance of fluid withdrawal and injection is maintained, regional subsidence should not present further problems in the area.

Surface subsidence could also result from a subsurface slope failure adjacent to a ship channel or slip. Although the existing risk is low, the risk of this type of slope failure increases during seismic events.

Tsunami and Seiche

A tsunami is an ocean wave generated by the rapid displacement of a large volume of seawater, resulting from either submarine faulting or large-scale submarine landslides. These waves may travel thousands of miles across the ocean at speeds of hundreds of mph and reach heights of 10 to 100 ft (3 to 30 m) as they approach the shoreline, where they can cause extensive damage to unprotected coastal areas.

A study of potential tsunami activity was conducted by Moffatt and Nichol (2007) for POLB and POLA. The report concluded that (1) a large, locally generated tsunami could have a wave height of approximately 21 ft (7 m) but would only occur once every 10,000 years, and (2) the maximum tsunami wave height in the port would be approximately 2.5 ft (0.75-m). This is lower than the historic tsunami wave heights discussed below due to subsequent Port development.

Historically, California has suffered very little damage from tsunamis. Between 1812 and the present, the only tsunami damage in the Los Angeles area resulted from waves generated by the 1964 Gulf of Alaska and 1960 Chilean earthquakes. The maximum crest-to-trough wave height in the Long Beach - Los Angeles Harbor for the tsunami generated by the Alaska earthquake was approximately 5 ft (1.5 m) and by the Chilean earthquake was approximately 3 ft (1 m). Wave heights in San Pedro Bay associated with other historic tsunamis have generally been less than 3 ft (1 m). The location of the Palos Verdes Hills adjacent to the harbor, and the presence of a harbor breakwater, greatly reduces the potential for damage within the project area from tsunamis.

A seiche is a standing-wave oscillation in an enclosed or semi-enclosed body of water that is potentially destructive to structures along the shore of the water body. Seiches can be generated by earthquakes or by mass movement of soil or rock into the water body. Most of the damage to boats and harbor facilities associated with the tsunami caused by the 1960 Chilean earthquake resulted from a seiche within the Cerritos Channel.

2.2.2.3 Environmental Consequences

Evaluation Criteria

The criteria used in this study to estimate fault activity are described in the Alquist-Priolo Special Studies Zone act of 1972, which addresses only surface fault-rupture hazards. The legislative guidelines to determine fault activity status are based on the age of the youngest geologic unit offset by the fault.

The Seismic Hazards Map Act of 1990 (PRC Sections 2690 and following as Division 2, Chapter 7.8) as supported by the Seismic Hazards Mapping Regulations (CCR, Title 14, Division 2, Chapter 8, Article 10) are intended for the purpose of protecting public safety from the effects of strong ground shaking, liquefaction, landslides or other ground failures, or other hazards caused by earthquakes. Special Publication 117, Guidelines for Evaluating and Mitigating Seismic Hazards in California (CDMG, 1997) constitutes the guidelines for evaluating seismic hazards other than surface fault-rupture, and for recommending mitigation measures as required by PRC Section 2695(a).

No Action Alternative

Under the No Action Alternative, the existing bridge would continue to be used to meet local and regional transportation needs. The bridge was built in 1966 and partially seismically upgraded in 1995 at select columns, such as Piers 15 and 16, which support the main steel truss span. Major seismic deficiencies remain, including lap splices at the base of columns and insufficient confinement reinforcement. These deficiencies substantially reduce the Gerald Desmond Bridge's ability to withstand a MCE without incurring significant damage to the columns and the overall bridge integrity. A major seismic event would likely result in loss of service and bridge demolition.

Construction/Demolition Impacts

<u>North-side Alignment Alternative</u>

The proposed bridge construction project would not adversely affect the geologic environment or geologic processes because:

- Construction would not alter the regional stress regime; thus, it could not possibly trigger an earthquake,
- Construction would not alter the geotechnical properties of harbor sediment or cause regional vibration; thus, it could not possibly cause liquefaction.
- Construction would not alter the regional stress regime; thus, it could not possibly cause seismic ground shaking.
- Construction would not alter the regional tectonic regime; thus, it could not possibly trigger a tsunami.

<u>South-side Alignment Alternative</u>

This alternative would be located on the south side of the Gerald Desmond Bridge. Construction and demolition effects on geologic resources and seismic performance during operation would be the same as the North-side Alignment Alternative.

<u>Rehabilitation Alternative</u>

Rehabilitation of the Gerald Desmond Bridge would consist of improvements to the existing structure and approaches as discussed in Section 1.6.2. This alternative would not adversely affect the geologic environment or geologic processes because:

- Rehabilitation would not alter the regional stress regime; thus, it could not possibly trigger an earthquake,
- Rehabilitation would not alter the geotechnical properties of harbor sediment or cause regional vibration; thus it could not possibly cause liquefaction.
- Rehabilitation would not alter the regional stress regime; thus, it could not possibly cause seismic ground shaking,
- Rehabilitation would not alter the regional tectonic regime; thus, it could not possibly trigger a tsunami,

Operational Impacts

North-side Alignment Alternative

Operation of the proposed bridge would not affect the probability of the occurrence of geologic hazards discussed in Section 2.2.2.2. This geologic resource impact evaluation indicates that the proposed project has a potential to be exposed to geotechnical impacts or constraints; however, the new bridge structure and foundation would be designed and built to handle seismic loads and to meet current seismic standards. Thus, the proposed bridge would be able to withstand the SEE, which represents a rare earthquake event.

Strong Ground Motion. The intensity of ground shaking at a specific location depends on several factors, including earthquake magnitude, distance from the source epicenter to the site, activity rate, and site response characteristics, particularly near-surface geologic materials. The faults and fault zones described in Section 2.2.2.2 can contribute to seismic risk associated with strong ground motion at the proposed bridge site. All of the faults are considered in the seismic hazard evaluation. Ground shaking generally causes the most widespread effects, not only because it can propagate considerable distances from an earthquake source, but also because it can trigger secondary effects. These secondary effects include liquefaction and lateral expansion, and slope failure with resultant structural damage to buildings and foundations. The proposed bridge would be designed and built to withstand the SEE, which includes the secondary effects described above. Designing the project to withstand the SEE minimizes the risk for bridge failure and reduces the potential for loss of life or property damage associated with bridge failure.

Fault Displacement Surface Rupture. Many recent seismic hazard studies have been conducted within the region, and the project site is reasonably well documented regarding local and nearby faults. Some of these local faults include the THUMS Huntington Beach and the Cabrillo faults, in addition to the Palos Verdes fault. Based on past fault mapping studies, it is generally felt that there are no known faults that would cause ground surface fault rupture hazards at the bridge site.

Liquefaction. The Port, as a whole, has a high potential for soil liquefaction due to the presence of a high groundwater table, man-made fills, and the potential for significant ground shaking associated with a moderate to major earthquake. To minimize the potential adverse effects of liquefaction to the proposed project, the foundation designs for the bridge would incorporate soil-structure interaction features. Large-diameter ductile piles would be used to withstand lateral loading from liquefied soil, and the piles would be driven into deep soil strata to resist downdrag force from shallow liquefied soils.

Extensive preliminary design studies have been conducted for the proposed cable-stayed bridge and concrete approach spans resulting in a report entitled *Preliminary Engineering Bridge Report* dated June 2006 (Parsons, 2006b). This report summarizes various studies, including ground motion, fault displacement surface rupture, liquefaction, and preliminary geotechnical investigations consisting of 21 soil borings to depths ranging from 50 to 195 ft (15 to 59 m). Additional soil investigation would be conducted in the final design. In addition, the Port, Caltrans, and the consultant team developed a Design Criteria Document for the bridge, which provides detailed guidance for the preliminary and final designs of the bridge foundations and all structural components. The foundation design would be developed using the latest analytical methods and applicable codes to ensure that liquefaction issues are fully addressed within the design. The proposed “Shear-Link” design for the bridge towers has been proposed for this project because of its capability to handle seismic loads. The two pylons (or towers) of the main bridge will be designed with shear links. These smaller horizontal elements connect the two halves of each tower to stiffen the pylon system, preventing excessive sway in a major earthquake, while also protecting the main vertical load-carrying members from damage. The links act as "structural fuses" that are designed and detailed to yield and dissipate energy in a seismic event. After a large earthquake, the damaged links can be quickly replaced without significant delays or significant repair to the overall structure. Ground shaking, surface rupture, and liquefaction would not adversely affect the proposed bridge project.

The geographical and morphological setting of the proposed bridge site is protected from tsunami, because the bridge site is not directly exposed to the open ocean. Tsunami modeling only predicts a maximum wave of a couple of feet in height (Moffatt and Nichol, 2007). The morphological setting of the proposed bridge site is protected from seiche because the proposed bridge structures and approaches are elevated and located at higher elevations outside of the harbor; therefore, the potential for tsunami or seiche at the site is not substantial and would not adversely affect the proposed bridge replacement project.

<u>South-side Alignment Alternative</u>

This alternative would have the same operational effects on geologic resources and seismic performance as the North-side Alignment Alternative.

<u>Rehabilitation Alternative</u>

The Rehabilitation Alternative would withstand the MCE based on the “No Collapse” design criteria (see Section 1.6.2.); however, the “No Collapse” criteria imply that even though the bridge would survive the MCE without collapse and loss of life, there would still be a high probability of it being condemned after an MCE. Condemnation of the Gerald Desmond Bridge would adversely affect Port operations and local/regional transportation and goods movement.

2.2.2.4 Avoidance, Minimization and/or Mitigation Measures

No measures are required.