

4.M GEOLOGY AND SOILS

This section describes the regulatory and environmental setting for geology and soils. This section also addresses geologic and soil impacts that could result from construction and operation of the Seawall Lot 337 and Pier 48 Mixed-Use Project (proposed project). This section includes analysis of seismic impacts related to fault rupture, seismically induced ground shaking, and seismically induced ground failure (i.e., liquefaction); soil erosion or loss of topsoil; construction on unstable soil or geologic units; construction on soils subject to expansion and contraction; and direct or indirect destruction of a unique paleontological resource or geologic feature. The discussion of erosion presented in this section relates to the information presented in Section 4.N, *Hydrology and Water Quality*, specifically, the discussion of the requirements of the National Pollutant Discharge Elimination Program (NPDES) General Construction Stormwater Permit and the NPDES General Municipal Stormwater Permit and how they pertain to erosion control. No responses to the notice of preparation (NOP) (Appendix 1) were received relevant to geology and soils. The study area for this analysis is defined as the project site.

ENVIRONMENTAL SETTING

REGIONAL PHYSIOGRAPHY

San Francisco is located in the northern portion of the San Francisco Peninsula, which is part of the geologically complex California Coast Ranges geomorphic province.¹ The Coast Ranges province is characterized by a series of northwest-trending ridges and valleys that run roughly parallel to the San Andreas fault zone and can be further divided into the northern and southern ranges, which are separated by San Francisco Bay (Bay). The Bay lies within a broad depression created from an east-west expansion between the San Andreas and the Hayward fault systems. The tectonic forces that dominate the region developed from the margin between the Pacific Plate and the North American Plate where the Pacific Plate slowly creeps northward past the North American Plate on the San Andreas, Hayward, and associated subsidiary faults. The Bay and northern portion of the San Francisco Peninsula are within a structural down-dropped block between the Northern Santa Cruz Mountains to the west and Diablo Mountain Range to the east. Much of the Coast Range province is composed of marine sedimentary deposits and volcanic rocks. The relatively thick marine sediments dip east beneath the alluvium of the Great Valley. West of the San Andreas fault lies the Salinian Block, a granitic core that extends from the southern end of the province to north of the Farallon Islands.

¹ Norris, Robert M., and Robert W. Webb. 1990. *Geology of California*. Second edition. John Wiley & Sons Inc.

PROJECT AREA GEOLOGY

The Northern Coast Ranges, where project activities would occur, are composed largely of the Franciscan Complex or Assemblage, which is composed of an amalgamation of semicoherent blocks called *terranes*. San Francisco contains one of these terranes, the Alcatraz terrane. Within the basement of the Alcatraz terrane, Franciscan Complex (also known as Franciscan Formation) rock outcrops are exposed in areas such as Yerba Buena Island, Alcatraz Island, and Angel Island. The Franciscan Complex consists primarily of graywacke, shale, greenstone (altered volcanic rocks), basalt, chert (ancient silica-rich ocean deposits), sandstone, shale, and serpentinite. Most of these rock units originated as ancient seafloor sediments and were displaced and deformed through long periods of tectonic forces. More recently deposited dune sand mantles the Franciscan Complex over large areas of San Francisco. The sand dunes of San Francisco once formed one of the most extensive coastal dune systems on the West Coast, underlying about one-third of San Francisco.

For more than a century, and especially following the 1906 earthquake, tens of millions of cubic meters of fill have been placed along Bay margins.² Much of the fill used along the San Francisco waterfront consists of clay- to cobble-sized materials, including former dune sand that was excavated during the building of San Francisco, hauled to the waterfront, and dumped on top of the Bay Mud (discussed in more detail below) or other surface material. Typical fill also consists of rubble (concrete, bricks, and wood) from building demolition, notably after the 1906 earthquake and fire, as well as assorted organic and non-organic debris, refuse, some hazardous substances, and other materials. Much of the artificial fill materials were emplaced prior to regulations that began in the mid-1960s and would not qualify as engineered fill under current standards. Because they were not emplaced with the use of modern engineering compaction techniques to increase their liquefaction resistance, these largely unconsolidated to semi-consolidated sediments are vulnerable to liquefaction and amplification of strong ground motions. Some areas with the artificial fills have yet to be shaken strongly during a major earthquake.³ There is considerable variation in the type, depth, age, and nature of the fill, depending on the source of the fill and original configuration of the Bay shoreline.

² Hicock, Christopher, Robert Givler, Greg De Pascale, and Ranon Dulberg. 2008. *Detailed Mapping of Artificial Fills, San Francisco Bay Area*. Prepared by William Lettis & Associates, Inc. September. (National Earthquake Hazards Reduction Program, U.S. Geological Survey Award Number 07HQGR0078.) Available: <http://earthquake.usgs.gov/research/external/reports/07HQGR0078.pdf>. Accessed: October 5, 2015.

³ Hicock, Christopher, Robert Givler, Greg De Pascale, and Ranon Dulberg. 2008. *Detailed Mapping of Artificial Fills, San Francisco Bay Area*. Prepared by William Lettis & Associates, Inc. September. (National Earthquake Hazards Reduction Program, U.S. Geological Survey Award Number 07HQGR0078.) Available: <http://earthquake.usgs.gov/research/external/reports/07HQGR0078.pdf>. Accessed: October 5, 2015.

In some Bay margin areas, including the project site, these artificial fills are underlain by soft, compressible estuarine deposits known as Bay Mud. The Bay Mud can be further divided into younger Bay Mud and older Bay Mud, which can vary in engineering properties, depending on thicknesses and degrees of consolidation. Bay Mud is generally found along the shorelines, including adjacent to the project site. It generally consists of uniform gray, soft, saturated clay and silt with organic material and some sand. Lenses of sand, silt, and organic material (peat) are present within the mud. Younger Bay Mud is commonly divided into an upper “soft” member and an underlying semi-consolidated member. It is present near the ground surface (under the fill cover) and forms the Bay bottom. It is saturated, soft, and compressible. When loads (such as buildings) are placed on it, the soft mud can compress and settle. Placement of the loads could also result in plastic deformation and lateral movement, sometimes accompanied by upthrusting in adjacent areas (creation of so-called mud waves) or underwater landsliding. Younger Bay Mud has low shear strength (resistance to downslope movement of rock and soil). For these reasons, Younger Bay Mud is not considered suitable material for bearing foundations of anything but very light structures and is usually not relied upon to support vertical loads.

During boring probes,^{4,5} the project site was found to be underlain by approximately 10 to 40 feet of heterogeneous fill of variable density, made up of brick, rock, concrete, debris, gravel, and sand. The fill is underlain by approximately 35 to 45 feet at the shoreline at the Pier 48 site⁶ and 45 to 70 feet at the Seawall 337 site⁷ of weak, soft to medium-stiff, compressible Younger Bay Mud of Holocene age. At the Seawall 337 site, the deeper fill material (below a depth of about 15 to 20 feet) represents a Bay Mud wave. A Bay Mud wave can occur when heavy fill loads are placed on the Bay Mud and cause a bearing capacity failure of the Bay Mud. The fill material placed on the Bay Mud is pushed down into it. At some sites where boring tests were conducted for project-specific geotechnical studies, a layer of dense to very dense sand with clay and clayey sand was present under the layer of Younger Bay Mud from approximately 60

⁴ Langan Treadwell Rollo. 2014. *Geotechnical Evaluation of Shoreline Conditions at Pier 48*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, California. (Langan Project No. 750604203.) March 5.

⁵ Treadwell & Rollo. 2013. *Liquefaction and Lateral Spread Potential at Seawall Lot 337*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, CA. (Project No. 750604203.) December 23.

⁶ Langan Treadwell Rollo. 2014. *Geotechnical Evaluation of Shoreline Conditions at Pier 48*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, California. (Langan Project No. 750604203.) March 5.

⁷ Treadwell & Rollo. 2011. *Preliminary Geotechnical Investigation: Seawall Lot 337 – Mission Bay, San Francisco, California*. Prepared for Mission Rock Development. September 8.

to 80 feet below ground surface.^{8,9,10} The layer of sand that underlies Younger Bay Mud in Mission Bay is identified in other studies as the Colma Formation of Pleistocene age.¹¹ The Younger Bay Mud and the layer of sand/Colma Formation are underlain by 60 to 80 feet of Old Bay Clay of Pleistocene age, which is medium stiff to very stiff and overconsolidated.¹² The Old Bay Clay is underlain by dense to very dense sand, with clay and clayey sand, over bedrock. Bedrock was encountered during the boring at between 160 and 260 feet below ground surface.^{13,14} Bedrock was found to be highly weathered, weak, and fractured Franciscan Formation shale, sandstone, and serpentinite. Groundwater was encountered between 6.5 and 9 feet below ground surface.¹⁵

GEOLOGIC HAZARDS

SLOPE FAILURE

Slope failures, commonly referred to as landslides, include many phenomena that involve the downslope displacement and movement of material, triggered either by static (i.e., gravity) or dynamic (i.e., earthquake) forces. Exposed rock slopes undergo rockfalls, rockslides, or rock avalanches, while soil slopes experience soil slumps, rapid debris flows, or deep-seated rotational slides. Slope stability can depend on a number of complex variables, including the geology, structure, and amount of groundwater, as well as external processes such as climate, topography, slope geometry, and human activity. The factors that contribute to slope movements include those that decrease the resistance in the slope materials and those that

⁸ Langan Treadwell Rollo. 2014. *Geotechnical Evaluation of Shoreline Conditions at Pier 48*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, California. (Langan Project No. 750604203.) March 5.

⁹ Treadwell & Rollo. 2001. *Pier 48 Foundation Evaluation, San Francisco, California*. Log of Boring B-2.

¹⁰ Treadwell & Rollo. 2001. *Pier 48 Foundation Evaluation, San Francisco, California*. Log of Boring B-3.

¹¹ Simpson, L.A., and G.E. Treadwell & Rollo, Inc. 2006. Case Studies in Mission Bay, San Francisco: Deep Foundations in Challenging Soil Conditions. In *DFI Proceedings of the 31st Annual Conference on Deep Foundations*. Washington, D.C.

¹² An *underconsolidated* clay has not yet achieved equilibrium under the existing load, a *normally consolidated* clay has completed consolidation under the existing load, and an *overconsolidated* clay has undergone a pressure greater than its current load.

¹³ Treadwell & Rollo. 2011. *Preliminary Geotechnical Investigation: Seawall Lot 337 – Mission Bay, San Francisco, California*. Prepared for Mission Rock Development. September 8.

¹⁴ Langan Treadwell Rollo. 2014. *Geotechnical Evaluation of Shoreline Conditions at Pier 48*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, California. (Langan Project No. 750604203.) March 5.

¹⁵ Section 4.N, *Hydrology and Water Quality*, reports that the depth to groundwater is 10 to 20 feet below ground surface (Department of Toxic Substances Control. 2002. Hazardous Soils Report – Covenant to Restrict Use of Property Environmental Restriction, H&H Site located at China Basin Channel and Terry A. Francois Boulevard, City and County of San Francisco.) This slight discrepancy does not affect the findings in this analysis.

increase the stresses on the slope. Landslides can occur on slopes of 15 percent or less, but the probability is greater on steeper slopes that exhibit old landslide features such as scarps, slanted vegetation, and transverse ridges.

The best available predictor of where slides and earth flows might occur is the distribution of past movements.¹⁶ In 1997, the U.S. Geological Survey (USGS) released a preliminary map and geographic information system (GIS) database that summarize the distribution of landslides that are evident in the landscape of the San Francisco Bay region.¹⁷ The map is a digitized nine-county compilation of existing landslides. It has been used to divide the area into four landslide zones (i.e., mostly landslides, many landslides, few landslides, flatland). Project construction would occur adjacent to the San Francisco waterfront, within an area of gentle low-elevation slopes with little or no potential for the formation of slumps, translational slides, or earthflows, except along streambanks and terrace margins. The California Geological Survey also identifies this area as not being subject to landslide.¹⁸

SOIL HAZARDS

In urbanized areas, native soils are commonly no longer present or have been reworked and combined with imported fill materials over a long history of earthwork activities associated with development. Within the project site, the San Francisco waterfront areas where project construction would occur have been subject to many changes over the years, including the placement of fill and debris. Soils mapped by the federal Natural Resources Conservation Service (NRCS) along the waterfront near the project site fall primarily under three classifications: Urban land-Orthents, reclaimed complex (0 to 2 percent slopes); Urban Land; and Urban land-Orthents, cut-and-fill complex (5 to 75 percent slopes).¹⁹ These classifications indicate that the soils present at the project site are highly disturbed and not native soils.

¹⁶ Nilsen, T.H., and B.L. Turner. 1975. *Influence of Rainfall and Ancient Landslide Deposits on Recent Landslides (1950-71) in Urban Areas of Contra Costa County, California*. (U.S. Geological Survey Bulletin 1388.) Available: <http://pubs.er.usgs.gov/publication/b1388>. Accessed: October 5, 2015.

¹⁷ Wentworth, C.M., S.E. Graham, R.J. Pike, G.S. Beukelman, D.W. Ramsey, and A.D. Barron. 1997. Part C, Summary of Distribution of Landslide and Earth Flows in the San Francisco Bay Region, California. In *San Francisco Bay Region Landslide Folio*. (Open File Report 97-745.) Available: <http://pubs.usgs.gov/of/1997/of97-745/sf-sef.pdf>. Accessed: October 5, 2015.

¹⁸ California Geologic Survey. 2000. *Seismic Hazard Zones: City and County of San Francisco*. Available: <http://gmw.consrv.ca.gov/shmp/MapProcessor.asp?MapNavAction=&Action=IMap&Location=NoCal&FCIass=Quad&FID=San%20Francisco%20North&Liq=false&Land=false&Bore=false&Road=true&City=false&x1=539765.7922388642&y1=4192422.2105356133&x2=557219.3179211357&y2=4177877.605800387#>. Accessed: October 5, 2015.

¹⁹ Natural Resources Conservation Service. 2015. *Soil Survey for San Francisco through SoilWeb Earth*. U.S. Department of Agriculture. Available: <http://casoilresource.lawr.ucdavis.edu/soilweb-apps/>. Accessed: October 5, 2015.

Problematic soils, such as those that are corrosive or expansive, can damage structures and buried utilities and increase maintenance requirements. Corrosive soils damage concrete and uncoated steel, undermining their integrity over time. The fill at the project site is moderately to severely corrosive, and the Bay Mud is severely corrosive.

Expansive soils are characterized by their ability to undergo significant volume change (i.e., to shrink and swell) because of variations in moisture content. Changes in soil moisture can result from rainfall, landscape irrigation, utility leakage, roof drainage, and/or perched groundwater.²⁰ Expansive soils are typically very fine grained and have a high to very high percentage of clay. Expansion and contraction of expansive soils in response to changes in moisture content can lead to differential and cyclical movements that can cause damage and/or distress to structures and equipment. Changes in moisture content can result in foundation damage, other structural damage, warping, cracking of paved surfaces, rupture of utility lines, and other types of damage. Construction on expansive soils can undermine a structure's future stability. According to the preliminary geotechnical report prepared for the proposed project, fill at the project site is not expansive.²¹ Bay Mud underlying the fill is expansive; however, it is not subject to volume changes because it is below the groundwater level, and as long as it remains underwater, would not undergo moisture changes.²²

Geologic or soil units can become unstable or prone to settlement for a variety of reasons. Settlement is one cause of subsidence. Immediate settlement occurs when a load from a structure or the placement of new fill material is applied, causing distortion in the underlying materials. This settlement occurs quickly and is typically complete after placement of the final load. Consolidation settlement occurs in saturated clay from the volume change caused by squeezing out water from the pore spaces. Consolidation occurs over a period of time and is followed by secondary compression, which is continued change in the pore spaces under continued application of the load. Consolidation settlement from Bay Mud deposits, as well as poorly engineered fill materials, is one of the characteristic hazards in San Francisco Bay, including Mission Bay. Soils tend to settle at different rates and by varying amounts, depending on the load weight or changes in properties over an area, which is referred to as the differential settlement of the soils. Settlement can also occur as a result of seismicity (see discussion under *Earthquake-Induced Settlement*, below).

²⁰ Perched groundwater is a local saturated zone above the water table that typically exists above an impervious layer (such as clay) of limited extent.

²¹ Treadwell & Rollo. 2011. *Preliminary Geotechnical Investigation: Seawall Lot 337 – Mission Bay, San Francisco, California*. Prepared for Mission Rock Development. September 8.

²² Treadwell & Rollo. 2011. *Preliminary Geotechnical Investigation: Seawall Lot 337 – Mission Bay, San Francisco, California*. Prepared for Mission Rock Development. September 8.

REGIONAL FAULTING AND SEISMIC HAZARDS

The San Francisco Bay Area is situated near the boundary between two major tectonic plates, the Pacific Plate to the southwest and the North American Plate to the northeast. Since the Miocene epoch (approximately 23 million years ago), about 200 miles of right-lateral movement²³ has occurred along the San Andreas fault zone to accommodate the relative movement between these two plates. The movement between the Pacific Plate and the North American Plate generally occurs across a 50-mile-wide zone, extending from the San Gregorio fault to the southwest to the Great Valley Thrust Belt to the northeast. In addition to the right-lateral slip movement between the two tectonic plates, portions of the North American Plate have moved toward each other during the last 3.5 million years, resulting in compressional forces at the latitude of San Francisco Bay.

ACTIVE AND POTENTIALLY ACTIVE FAULTS

Figure 4.M-1, on the following page, shows the locations of active²⁴ and potentially active²⁵ faults in the San Francisco Bay region. The San Andreas, Hayward-Rodgers Creek, Calaveras, Concord-Green Valley, and San Gregorio strike-slip faults are active faults of the San Andreas system that accommodate predominantly lateral movement between the North American and Pacific tectonic plates. Active blind and reverse thrust faults²⁶ in the San Francisco Bay region that accommodate compressional movement include the Monte Vista-Shannon and Mount Diablo faults. The closest faults to the project site are the San Andreas, Hayward, San Gregorio, and Calaveras faults. Table 4.M-1, page 4.M-9, summarizes the distance from the project site, direction to the fault, and estimated maximum earthquake moment magnitude (M_w)²⁷ for each fault located within approximately 30 miles of the project site.

²³ The Pacific Plate and the North American Plate are moving past each other along the San Andreas fault zone; “right-lateral movement” means that they are moving to the right relative to each other.

²⁴ An active fault is one that shows geologic evidence of movement within Holocene time (approximately the last 11,000 years).

²⁵ A potentially active fault is one that shows geologic evidence of movement during the Quaternary (approximately the last 1.6 million years).

²⁶ A reverse fault is one with predominantly vertical movement in which the upper block moves upward in relation to the lower block; a thrust fault is a low-angle reverse fault. Blind thrust faults are low-angled subterranean faults that have no surface expression.

²⁷ An earthquake is classified by the amount of energy released, expressed as the magnitude of the earthquake. Until relatively recently, magnitudes have been quantified using the Richter scale. However, seismologists now use a moment magnitude (M_w) scale because it provides a more accurate measurement of the size of major and great earthquakes. Moment magnitude is directly related to the average slip and fault rupture area.

TABLE 4.M-1. MAJOR SAN FRANCISCO BAY AREA FAULTS NEAR THE PROJECT SITE

Fault Name	Age^f	Maximum Historic Earthquakes^a	Moment Magnitude (Mw)^{b, g}	Approximate Distance from Project Site (mi)^{c, d}
N. San Andreas	historic	7.8 (1906)	7.9	8
Hayward-Rodgers Creek	historic	6.8 (1868)	7.1	10
San Gregorio	historic	3–6.4 (1270–1400 AD)	7.3	12
Mount Diablo Thrust	Quaternary (estimated) ^h	n/a	6.7	21
Calaveras	historic	6.5 (1861)	6.8	21
Concord-Green Valley	historic	5.4 (1955)	6.9	24
Monte Vista-Shannon	Quaternary (estimated) ^e	n/a	6.8	24

Sources:

- ^a. U.S. Geological Survey. 2015a. *Historic Earthquakes in the United States and Its Territories*. Available: <http://earthquake.usgs.gov/earthquakes/states/historical.php>. Accessed: October 1, 2015.
- ^b. California Geological Survey. 2002. *Probabilistic Seismic Hazard Assessment for the State of California, Appendix A, in Fault Source Parameters*. (CDMG Open File Report 96-08.) Available: <http://www.consrv.ca.gov/CGS/rghm/psha/ofr9608>. Accessed: October 1, 2015.
- ^c. Treadwell & Rollo. 2011. *Preliminary Geotechnical Investigation: Seawall Lot 337 – Mission Bay, San Francisco, California*. Prepared for Mission Rock Development. September 8.
- ^d. U.S. Geological Survey. 2015b. *Quaternary Faults in Google Earth*. Available: <http://earthquake.usgs.gov/hazards/qfaults/google.php>. Accessed: October 5, 2015.
- ^e. Bryant, W.A., compiler. 2000. Fault Number 56, Monte Vista-Shannon Fault Zone. In *Quaternary Fault and Fold Database of the United States*. U.S. Geological Survey website. Available: <http://earthquakes.usgs.gov/hazards/qfaults>. Accessed: October 5, 2015.

Notes:

- ^f. Historic faults are Holocene faults that have also demonstrated fault movement within the last 200 years. Holocene faults are those that have shown geologic evidence of movement within Holocene time (approximately the last 11,000 years). Quaternary faults have demonstrated displacement within last 1.6 million years.
- ^g. Moment magnitude is related to the physical size of a fault rupture and movement across a fault. It provides a physically meaningful measure of the size of a faulting event.
- ^h. Because the Mount Diablo thrust is a blind fault and does not have a surface expression, it is difficult to date its activity.

MHE = maximum historic earthquake; Mw = moment magnitude.

Since 1800, four major earthquakes have been recorded on the San Andreas fault. In 1836, an earthquake with an estimated Mw of 6.4 occurred east of Monterey Bay (San Juan Bautista) on the San Andreas fault.²⁸ Shortly thereafter, in 1838, an earthquake with an Mw of about 7.5 occurred on the San Andreas fault. The San Francisco earthquake of 1906 caused the most significant damage in the history of the Bay Area in terms of loss of lives and property damage. This earthquake created a surface rupture along the San Andreas fault from Shelter Cove to San Juan Bautista, approximately 290 miles in length. It had an Mw of about 7.9 and was felt 350 miles away in Oregon, Nevada, and Los Angeles. The most recent large earthquake to affect the Bay Area was the Loma Prieta earthquake on October 17, 1989. The epicenter of this earthquake was approximately 60 miles from the project site in the Santa Cruz Mountains. The earthquake had an Mw of 6.9.

On the Hayward fault, an earthquake with an estimated Mw of 6.8²⁹ occurred in 1868 on the southern segment (between San Leandro and Fremont). In 1861, an earthquake of unknown magnitude (probably an Mw of about 5.6) was reported on the Calaveras fault.³⁰ The most recent significant earthquake on this fault was the 2007 Alum Rock earthquake, with an Mw of 5.7.

USGS estimates that there is a 72 percent probability of a strong earthquake (Mw 6.7 or higher) occurring on one of the regional faults in the 30-year period between 2014 and 2044.³¹

FAULT RUPTURE

Fault rupture almost always follows pre-existing faults, which are zones of weakness. Surface rupture occurs when movement on a fault deep within the earth breaks through to the surface. According to the preliminary geotechnical report prepared for the project site, there is very low potential for fault rupture within the project site because no active faults cross the project site.³²

²⁸ California Geological Survey. 2004. *Significant California Earthquakes*. Available: http://www.conservation.ca.gov/CGS/rghm/quakes/Pages/eq_chron.aspx. Accessed: October 5, 2015.

²⁹ U.S. Geological Survey. n.d. *Historic Earthquakes: Hayward, California, 1868, October 21, 15:53 UTC, Magnitude 6.8*. Available: http://earthquake.usgs.gov/earthquakes/states/events/1868_10_21.php. Accessed: October 5, 2015.

³⁰ Kelson, I.I., J.S. Hoefft, and M. Buga. 2008. *Assessment of Possible Surface Rupture on the Northern Calaveras Fault, Eastern San Francisco Bay Area*. (U.S. Geological Survey, National Earthquake Hazards Reduction Program Award No. 07HQGR0082.) June. Available: <http://earthquake.usgs.gov/research/external/reports/07HQGR0082.pdf>. Accessed: October 5, 2015.

³¹ UCERF3. 2015. *UCERF3: A New Earthquake Forecast for California's Complex Fault System*. (Fact Sheet 2015-3009.) Available: <http://www.wgcep.org/sites/wgcep.org/files/fs2015-3009.pdf>. Accessed: October 5, 2015.

³² Treadwell & Rollo. 2011. *Preliminary Geotechnical Investigation: Seawall Lot 337 – Mission Bay, San Francisco, California*. Prepared for Mission Rock Development. September 8.

GROUND SHAKING

The intensity of the seismic shaking, or strong ground motion, on the project site during an earthquake would depend on the distance between the project site and the epicenter of the earthquake, the magnitude of the earthquake, and the geologic conditions underlying and surrounding the project site. Earthquakes occurring on faults close to the project site would most likely generate the largest ground motions.

According to the shaking hazard mapping done by the Association of Bay Area Governments (ABAG), it is expected that the San Francisco shoreline within the project site would experience violent ground shaking due to an earthquake along the peninsula segment of the San Andreas fault and very strong to violent ground shaking due to an earthquake along the combined northern and southern segments of the Hayward fault.³³ These are the faults closest to the project site. Additionally, the Community Safety Element of the San Francisco General Plan (General Plan) contains shaking hazard maps for San Francisco.³⁴ The maps cited above refer to updated versions of the same source maps.

LIQUEFACTION AND OTHER SEISMICALLY INDUCED GROUND FAILURE

Liquefaction is a phenomenon in which saturated granular sediments temporarily lose their shear strength during periods of strong earthquake-induced ground shaking. The susceptibility of a site to liquefaction is a function of the depth, density, and water content of the granular sediments and the magnitude of the earthquakes that are likely to affect the site. Saturated, unconsolidated silts, sands, silty sands, and gravels within 50 feet of the ground surface are most susceptible to liquefaction. Liquefaction-related phenomena include vertical settlement from densification, lateral spreading, ground oscillation, flow failures, loss of bearing strength, subsidence, and buoyancy effects.

Much of the landside portion of the San Francisco shoreline, including the project site where construction would occur, is within a liquefaction hazard zone that was identified by the California Geological Survey as part of the Seismic Hazards Mapping Act (although the mapping does not extend into the Bay).³⁵ As noted above, areas of artificial fill, especially any

³³ Association of Bay Area Governments. n.d. *Shaking Scenarios*. Resilience Program. Available: <http://gis.abag.ca.gov/website/Hazards/>. Accessed: October 5, 2015.

³⁴ City and County of San Francisco. 2012. *Community Safety Element*. October. Available: http://www.sf-planning.org/ftp/general_plan/community_safety_element_2012.pdf. Accessed: October 5, 2015.

³⁵ California Geologic Survey. 2000. *Seismic Hazard Zones: City and County of San Francisco*. Available: <http://gmw.consrv.ca.gov/shmp/MapProcessor.asp?MapNavAction=&Action=IMap&Location=NoCal&FCIass=Quad&FID=San%20Francisco%20North&Liq=false&Land=false&Bore=false&Road=true&City=false&x1=539765.7922388642&y1=4192422.2105356133&x2=557219.3179211357&y2=4177877.605800387#>. Accessed: October 5, 2015.

fill placed before the 1960s, can be susceptible to liquefaction. The 2012 San Francisco Seismic Hazard Zones map³⁶ of the Community Safety Element of the San Francisco General Plan, which shows areas that are susceptible to seismically induced liquefaction, indicates that much of landside portion of the San Francisco shoreline is within a potential liquefaction hazard zone. The potentially liquefiable layers are discontinuous and random across the project site, leading to variability in the magnitude of potential liquefaction-induced settlement across the project site. The largest predicted magnitude of liquefaction-induced settlement of 3 to 5 inches occur generally near the north and south ends of Seawall Lot 337 and along Terry A. Francois Boulevard at the west end of Pier 48.^{37,38}

The project site has also been subject to lurch cracking and sand boils during historic seismic activity.³⁹ Lurch cracking refers to fractures, cracks, and fissures that result from ground shaking and the associated settlement of poorly consolidated soil or fill. Sand boils are eruptions of liquefied sand that are forced up through cracks or fissures in the overlying soil as a result of the pressure of the overlying sediments. The potential for lurch cracking and sand boils is greatest in areas where the water table is high, such as at the project site.

LATERAL SPREADING

Of the liquefaction hazards, lateral spreading generally causes the most damage. This is a phenomenon in which large blocks of intact, non-liquefied soil move downslope on a broad or wide liquefied layer.⁴⁰ When lateral displacement occurs, the mass moves toward an unconfined area, such as a descending slope or stream-cut bluff. Slopes between 0.3 and 3 percent can displace the surface by several meters to tens of meters. Areas of observed lateral spreading in San Francisco are limited mainly to areas where fill has been placed over marsh and Bay Mud deposits.⁴¹

The project site is located in areas of the waterfront where fill has been placed over marsh or Bay Mud; accordingly, it is subject to lateral spreading. The preliminary geotechnical studies prepared for the project site show that some layers in the 40-foot-thick fill layer have lateral

³⁶ City and County of San Francisco. 2012. *Community Safety Element*. October. Available: http://www.sf-planning.org/ftp/general_plan/community_safety_element_2012.pdf. Accessed: October 5, 2015.

³⁷ Treadwell & Rollo. 2013. *Liquefaction and Lateral Spread Potential at Seawall Lot 337*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, CA. (Project No. 750604203.) December 23.

³⁸ Langan Treadwell Rollo. 2014. *Geotechnical Evaluation of Shoreline Conditions at Pier 48*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, California. (Langan Project No. 750604203.) March 5.

³⁹ Langan Treadwell Rollo. 2014. *Geotechnical Evaluation of Shoreline Conditions at Pier 48*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, California. (Langan Project No. 750604203.) March 5.

⁴⁰ Youd, T.L., and D.M. Perkins. 1978. *Mapping Liquefaction Induced Ground Failure Potential*. Proceedings of the American Society of Civil Engineers, Journal of the Geotechnical Engineering Division.

⁴¹ Youd, T.L., and S.N. Hoose. 1978. *Historic Ground Failures in Northern California Triggered by Earthquakes*. Geological Survey Professional Paper 993.

spread potential of approximately 4 to 8 feet.^{42,43,44} The existence of a vertical reinforced-concrete curtain wall (seawall), constructed in 1926, at Pier 48⁴⁵ may limit the extent of lateral spread flow or movement in the upper 12 feet. However, the wall could fail and/or the fill could migrate beneath the seawall and laterally spread toward the free face of the slope.⁴⁶ Where movement occurs, a rotational failure is likely. With a rotational failure, the slope slides along a failure surface and comes to rest with a more stable configuration. With the high potential for lateral spreading in the fill, there may be a progressive failure at the project site, which may extend to about 110 feet west of the seawall at the shoreline.⁴⁷ The deformations associated with this progressive failure could extend approximately 2 to 4 feet and affect improvements at or east of Terry A. François Boulevard.

EARTHQUAKE-INDUCED SETTLEMENT

Settlement of the ground surface can be accelerated and accentuated by earthquakes. During an earthquake, settlement can occur as a result of the relatively rapid rearrangement, compaction, and the settling of subsurface materials (particularly loose, noncompacted, and variable sandy sediments). Settlement can occur both uniformly and differentially (i.e., where adjoining areas settle at different rates). Areas are susceptible to differential settlement if underlain by compressible sediments, such as poorly engineered artificial fill or Bay Mud.

Borings performed at the project site show that fill above the groundwater is sufficiently dense and/or cohesive; the potential for seismic densification is low—approximately 1 inch.⁴⁸ However, the potential for seismically induced settlement from other seismically induced sources could be much greater. Settlement due to liquefaction could be on the order of 5 inches, and lateral ground displacements due to lateral spreading could be on the order of 4 to 8 feet.⁴⁹

⁴² Treadwell & Rollo. 2011. *Preliminary Geotechnical Investigation: Seawall Lot 337 – Mission Bay, San Francisco, California*. September 8. Prepared for Mission Rock Development.

⁴³ Treadwell & Rollo. 2013. *Liquefaction and Lateral Spread Potential at Seawall Lot 337*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, CA. (Project No. 750604203.) December 23.

⁴⁴ Langan Treadwell Rollo. 2014. *Geotechnical Evaluation of Shoreline Conditions at Pier 48*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, California. (Langan Project No. 750604203.) March 5.

⁴⁵ Langan Treadwell Rollo. 2014. *Geotechnical Evaluation of Shoreline Conditions at Pier 48*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, California. (Langan Project No. 750604203.) March 5.

⁴⁶ Langan Treadwell Rollo. 2014. *Geotechnical Evaluation of Shoreline Conditions at Pier 48*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, California. (Langan Project No. 750604203.) March 5.

⁴⁷ Langan Treadwell Rollo. 2014. *Geotechnical Evaluation of Shoreline Conditions at Pier 48*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, California. (Langan Project No. 750604203.) March 5.

⁴⁸ Langan Treadwell Rollo. 2014. *Geotechnical Evaluation of Shoreline Conditions at Pier 48*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, California. (Langan Project No. 750604203.) March 5.

⁴⁹ Langan Treadwell Rollo. 2014. *Geotechnical Evaluation of Shoreline Conditions at Pier 48*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, California. (Langan Project No. 750604203.) March 5.

EARTHQUAKE-INDUCED LANDSLIDES

Earthquake motions can also induce substantial stresses in slopes, causing earthquake-induced landslides or ground cracking when the slope fails. Earthquake-induced landslides can occur in areas with steep slopes that are susceptible to strong ground motion during an earthquake. The 1989 Loma Prieta earthquake triggered thousands of landslides over an area of 770 square miles.

Within the project site, the San Francisco waterfront where construction would occur is relatively flat and not likely to be affected by earthquake-induced landslides. There are no mapped zones of potential earthquake-induced landslides.⁵⁰ The Seismic Hazard Zones map of the Community Safety Element of the General Plan, which shows areas that are susceptible to seismically induced landslide, indicates that none of the project site is located within a potential landslide hazard area.

PALEONTOLOGICAL SETTING

Paleontological resources, or fossils, are the remains, imprints, or traces of animals, plants, and invertebrates from a previous geological period. Collecting localities and the geologic formations containing those localities are also considered paleontological resources, representing a limited, nonrenewable resource. Once destroyed, they cannot be replaced.

The deposition and preservation of paleontological resources relate to the lithologic (rock) unit in which they occur. If a rock type was created in a deposition environment that was not conducive to the deposition and preservation of fossils, fossils will not be present. Lithologic units that may be fossiliferous include sedimentary and volcanic formations. Pleistocene sediments in the San Francisco Bay are known to yield vertebrate fossils.⁵¹

The Franciscan Formation present at the project site is of Jurassic to Cretaceous age (150 to 66 million years ago).⁵² The Old Bay Clay present at the project site was deposited in an estuarine environment during late Pleistocene time (2.6 million to 11,700 years ago), an interglacial period with high sea levels. The Colma Formation present at the project site was formed from

⁵⁰ California Geologic Survey. 2000. *Seismic Hazard Zones: City and County of San Francisco*. Available: <http://gmw.consrv.ca.gov/shmp/MapProcessor.asp?MapNavAction=&Action=IMap&Location=NoCal&FCIass=Quad&FID=San%20Francisco%20North&Liq=false&Land=false&Bore=false&Road=true&City=false&x1=539765.7922388642&y1=4192422.2105356133&x2=557219.3179211357&y2=4177877.605800387#>. Accessed: October 5, 2015.

⁵¹ University of California Museum of Paleontology. 2015. *Specimens*. Available: http://ucmpdb.berkeley.edu/cgi/ucmp_query2. Accessed: October 8, 2015.

⁵² Simpson, L.A., and G.E. Treadwell & Rollo Inc. 2006. Case Studies in Mission Bay, San Francisco: Deep Foundations in Challenging Soil Conditions. In *DFI Proceedings of the 31st Annual Conference on Deep Foundations*. Washington, D.C.

subsequent glaciation during the Wisconsin period (85,000 to 11,000 years ago), which exposed the Bay floor and resulted in sand deposits, now known as the Colma Formation, on top of the Yerba Buena Mud. Approximately 20,000 years ago, sea levels began to rise with the melting of the glaciers. Approximately 10,000 years ago, water re-entered the Bay through the Golden Gate, and estuarine deposits in the form of Bay Mud began a process of deposition that continues through to this day. The formations from most recent to oldest and therefore also from shallowest to deepest in Mission Bay are Younger Bay Mud, Colma Formation, Old Bay Clay, sand and clay, and Franciscan Formation.⁵³ Old Bay Clay, as discussed under *Project Area Geology*, above, is encountered approximately 45 to 85 feet below ground surface.^{54,55} The layer of Colma Formation is not continuous across Mission Bay.⁵⁶

The geologic units present in the project area; their paleontological sensitivity, as defined in the Methods for Analysis section, below; and information about the fossil history of the geologic unit are shown in Table 4.M-2 on the following page. Unlike archaeological sites, which are narrowly defined, paleontological sites are defined by the entire extent (both areal and stratigraphic) of a unit or formation. In other words, once a unit is identified as containing vertebrate fossils, or other rare fossils, the entire unit is a paleontological site.⁵⁷ For this reason, the paleontological sensitivity of geologic units is described and analyzed broadly rather than within the context of a specific site. Colma and Franciscan Formations, which have high paleontological sensitivity, are described below.

⁵³ Keller, B.R. 2009. Literature Review of Unconsolidated Sediment in San Francisco Bay and Nearby Pacific Ocean Coast. *San Francisco Estuary and Watershed Science* 7(1). Available: <http://escholarship.org/uc/item/5rh9t1jj>. Accessed: April 7, 2016.

⁵⁴ Langan Treadwell Rollo. 2014. *Geotechnical Evaluation of Shoreline Conditions at Pier 48*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, California. (Langan Project No. 750604203.) March 5.

⁵⁵ Treadwell & Rollo. 2013. *Liquefaction and Lateral Spread Potential at Seawall Lot 337*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, CA. (Project No. 750604203.) December 23.

⁵⁶ Simpson, L.A., and G.E. Treadwell & Rollo, Inc. 2006. Case Studies in Mission Bay, San Francisco: Deep Foundations in Challenging Soil Conditions. In *DFI Proceedings of the 31st Annual Conference on Deep Foundations*. Washington, D.C.

⁵⁷ Society of Vertebrate Paleontology. 2010. *Standard Procedures for the Assessment and Mitigation of Adverse Impacts to Paleontological Resources*. Impact Mitigation Guidelines Revision Committee. Available: http://vertpaleo.org/The-Society/Governance-Documents/SVP_Impact_Mitigation_Guidelines.aspx. Accessed: April 8, 2016.

TABLE 4.M-2. GEOLOGIC UNITS AND PALEONTOLOGICAL SENSITIVITY IN THE PROJECT AREA

Age	Geologic Unit ^{a,b}	Paleontological Sensitivity
Holocene	Younger Bay Mud	Low
Pleistocene	Colma Formation	High
Pleistocene	Old Bay Clay	Undetermined
Cretaceous-Jurassic	Franciscan Formation	High

Sources:

- a. Simpson, L.A., and G.E. Treadwell & Rollo Inc. 2006. Case Studies in Mission Bay, San Francisco: Deep Foundations in Challenging Soil Conditions. In *DFI Proceedings of the 31st Annual Conference on Deep Foundations*. Washington, D.C.
- b. Rodda, P.U., and N. Baghai. 1993. Late Pleistocene Vertebrates from Downtown San Francisco, California. *Journal of Paleontology* 67:1,058–1,063.

COLMA FORMATION

The Colma Formation consists of moderately sorted fine to medium fine sand with small to moderate amounts of silt and clay, with some beds of gravel and cobbles near Colma, California.⁵⁸ The origin of the materials is terrestrial deposition associated with the onset of Wisconsin glaciation (approximately 83,000 to 120,000 years ago).^{59, 60} Vertebrate fossils documented from the Colma Formation include *Mammuthus Columbia* and *Bison latrons*.⁶¹ For this reason, this geologic unit is considered to have high paleontological sensitivity.

In Mission Bay, where encountered, the Colma Formation varies from approximately 3 to 60 feet thick.⁶² Site-specific geotechnical investigations encountered this formation between approximately 60 and 80 feet below ground surface at the project site.^{63,64}

⁵⁸ Schlocker, J. 1974. *Geology of the San Francisco North Quadrangle, California*. (Geological Survey Professional Paper 782.) Washington, DC: United States Printing Office. Available: <http://pubs.usgs.gov/pp/0782/report.pdf>. Accessed: April 13, 2016.

⁵⁹ Simpson, L.A., and G.E. Treadwell & Rollo, Inc. 2006. Case Studies in Mission Bay, San Francisco: Deep Foundations in Challenging Soil Conditions. In *DFI Proceedings of the 31st Annual Conference on Deep Foundations*. Washington, D.C.

⁶⁰ Caskey, S.J., K. Grove, C. Li, and G. Berger. 2004. *Constraints on Late Pleistocene and Active Uplift Rates along the Serra Fault and the Timing of Late Pleistocene Transpressional Deformation along the San Andreas Fault, Northern San Francisco Peninsula*. (U.S. Geological Survey award number 04HQGR0024.) Available: <http://earthquake.usgs.gov/research/external/reports/04HQGR0024.pdf>. Accessed: April 12, 2016.

⁶¹ Rodda, P.U., and N. Baghai. 1993. Late Pleistocene Vertebrates from Downtown San Francisco, California. *Journal of Paleontology* 67:1,058–1,063.

⁶² Simpson, L.A., and G.E. Treadwell & Rollo, Inc. 2006. Case Studies in Mission Bay, San Francisco: Deep Foundations in Challenging Soil Conditions. In *DFI Proceedings of the 31st Annual Conference on Deep Foundations*. Washington, D.C.

⁶³ Treadwell & Rollo. 2001. *Pier 48 Foundation Evaluation, San Francisco, California*. Log of Boring B-2.

⁶⁴ Treadwell & Rollo. 2001. *Pier 48 Foundation Evaluation, San Francisco, California*. Log of Boring B-3.

FRANCISCAN FORMATION

The Franciscan Formation consists of sandstone, shale, siltstone, chert, and other oceanic deposits and ultramafic volcanic rock in the California Coast Ranges. In the San Francisco North quadrangle, the formation is characterized by 80 percent greywacke sandstone, 10 percent shale and siltstone, 6 percent mafic volcanic rocks, 3 percent radiolarian chert, and less than 1 percent conglomerate, limestone, and glaucophane schist. Ultramafic rock, principally serpentine, has intruded all of these deposits. The origin of the materials is oceanic deposits (from approximately 150 to 66 million years [Ma] ago).⁶⁵ Although vertebrate fossils in Franciscan Formation are rare, documented instances include three aquatic reptiles.⁶⁶ For this reason, this geologic unit is considered to have high paleontological sensitivity.

The Franciscan Formation in Mission Bay is eroded and highly sheared.⁶⁷ It was encountered between 160 and 260 feet below ground surface at the project site.⁶⁸

REGULATORY FRAMEWORK

FEDERAL

Earthquake Hazard Reduction Act of 1977. Federal laws codified in United States Code Title 42, Chapter 86, were enacted to reduce risks to life and property from earthquakes in the United States through the establishment and maintenance of an effective earthquake hazards reduction program. Implementation of these requirements are regulated, monitored, and enforced at the state and local levels. Key regulations and standards are summarized below.

STATE

California Building Code. California Code of Regulations (CCR), Title 24, Part 2, the California Building Code (CBC), provides minimum standards for building design in the state. The 2016 CBC, effective January 1, 2017, is the current code and based on the current (2015) International Building Code (IBC).

⁶⁵ Schlocker, J. 1974. *Geology of the San Francisco North Quadrangle, California*. (Geological Survey Professional Paper 782.) Washington, DC: United States Printing Office. Available: <http://pubs.usgs.gov/pp/0782/report.pdf>. Accessed: April 13, 2016.

⁶⁶ Hilton, R.P. 2003. *Dinosaurs and Other Mesozoic Reptiles of California*. University of California Press. Appendix: Summary of the Mesozoic Reptilian Fossils of California.

⁶⁷ Simpson, L.A., and G.E. Treadwell & Rollo, Inc. 2006. *Case Studies in Mission Bay, San Francisco: Deep Foundations in Challenging Soil Conditions*. In *DFI Proceedings of the 31st Annual Conference on Deep Foundations*. Washington, D.C.

⁶⁸ Treadwell & Rollo. 2011. *Preliminary Geotechnical Investigation: Seawall Lot 337 – Mission Bay, San Francisco, California*. September 8. Prepared for Mission Rock Development.

Each jurisdiction in California may adopt its own building code, based on the 2016 CBC. Local codes are permitted to be more stringent than the 2016 CBC but, at a minimum, are required to meet all state standards and enforce the regulations of the 2016 CBC, beginning January 1, 2017. The Port of San Francisco (Port) has adopted the 2016 CBC with some amendments.

Chapter 16 of the CBC deals with structural design requirements governing seismically resistant construction (Section 1604), including, but not limited to, factors and coefficients used to establish a seismic site class and seismic occupancy category for the soil/rock at the building location and the proposed building design (Sections 1613.5 through 1613.7). Chapter 18 includes, but is not limited to, the requirements for foundation and soil investigations (Section 1803); excavation, grading, and fill (Section 1804); allowable load-bearing values of soils (Section 1806); and the design of footings, foundations, slope clearances (Sections 1808 and 1809), retaining walls (Section 1807), and pier, pile, driven, and cast-in-place foundation support systems (Section 1810). Chapter 33 includes, but is not limited to, requirements for safeguards at work sites to ensure stable excavations and cut-or-fill slopes (Section 3304). Appendix J of the CBC includes, but is not limited to, grading requirements for the design of excavations and fills (Sections J106 and J107) and erosion control (Sections J109 and J110).

California Division of Occupational Safety and Health Regulations. Construction activities are subject to occupational safety standards for excavation, shoring, and trenching, as specified in California Division of Occupational Safety and Health (Cal/OSHA) regulations (CCR, Title 8).

Alquist-Priolo Earthquake Fault Zoning Act. California's Alquist-Priolo Earthquake Fault Zoning Act (Alquist-Priolo Act) (Public Resources Code [PRC] Section 2621 et seq.), originally enacted in 1972 as the Alquist-Priolo Special Studies Zones Act and renamed in 1994, is intended to reduce the risk to life and property from surface fault rupture during earthquakes. The Alquist-Priolo Act prohibits the location of most types of structures intended for human occupancy⁶⁹ across the traces of active faults and strictly regulates construction in the corridors along active faults (earthquake fault zones). It also defines criteria for identifying active faults, giving legal weight to terms such as *active*, and establishes a process for reviewing building proposals in and adjacent to earthquake fault zones.

Under the Alquist-Priolo Act, faults are zoned and construction along or across them is strictly regulated if they are "sufficiently active" and "well defined." A fault is considered sufficiently active if one or more of its segments or strands shows evidence of surface displacement during Holocene time (defined for purposes of the act as referring to approximately the last 11,000

⁶⁹ With reference to the Alquist-Priolo Act, a *structure for human occupancy* is defined as one "used or intended for supporting or sheltering any use or occupancy, which is expected to have a human occupancy rate of more than 2,000 person-hours per year" (California Code of Regulations, Title 14, Division 2, Section 3601[e]).

years). A fault is considered well defined if its trace can be clearly identified by a trained geologist at the ground surface or in the shallow subsurface, using standard professional techniques, criteria, and judgment.

Seismic Hazards Mapping Act. Similar to the Alquist-Priolo Act, the Seismic Hazards Mapping Act (SHMA) of 1990 (PRC Sections 2690–2699.6) is intended to reduce damage resulting from earthquakes. Although the Alquist-Priolo Act addresses surface fault rupture, the Seismic Hazards Mapping Act addresses other earthquake-related hazards, including strong ground shaking, liquefaction, and seismically induced landslides. Its provisions are similar in concept to those of the Alquist-Priolo Act (i.e., the state is charged with identifying and mapping areas at risk of strong ground shaking, liquefaction, landslides, and other corollary hazards, and cities and counties are required to regulate development within mapped seismic hazard zones).

A primary purpose of the Seismic Hazards Mapping Act is to assist cities and counties in preparing the safety elements of their general plans and encourage land use management policies and regulations that reduce seismic hazards. The intent of this act is to protect the public from the effects of strong ground shaking, liquefaction, landslides, ground failure, or other hazards caused by earthquakes. Under the Seismic Hazards Mapping Act, permit review is the primary mechanism for local regulation of development. Specifically, cities and counties are prohibited from issuing development permits for sites within seismic hazard zones until appropriate site-specific geologic and/or geotechnical investigations have been carried out and measures to reduce potential damage have been incorporated into the development plans. In addition, the California Geologic Survey's Special Publication 117A, Guidelines for Evaluating and Mitigating Seismic Hazards in California, provides guidance for evaluating earthquake-related hazards for projects in designated zones with required investigations and recommending mitigation measures, as required by PRC Section 2695(a).

Liquefaction hazards mapping has been conducted for the part of the Bay that includes the project site. As discussed under *Liquefaction*, the project site is within a mapped liquefaction hazard zone that requires special study and would be subject to the requirements specified above.

National Pollutant Discharge Elimination Program Construction General Permit. Under the authority of the federal Clean Water Act, Section 402 (NPDES, the State Water Resources Control Board (SWRCB) permits all regulated construction activities under Order No. 2009-0009-DWQ (adopted September 2, 2009). Section 402 requires, prior to beginning any construction activities, the permit applicant to obtain coverage under the Construction General Permit by preparing and submitting a Notice of Intent (NOI) to the SWRCB and preparing and implementing a Stormwater Pollution Prevention Plan (SWPPP), in accordance with Construction General Permit requirements, for all construction activities that disturb 1 acre or more of land surface. Construction activities that are subject to the Construction General Permit include clearing, grading, and disturbances to the ground, such as stockpiling or excavation, that result in soil disturbances of at least 1 acre of total land area. The SWPPP has two major

objectives: (1) to help identify the sources of sediment and other pollutants that affect the quality of stormwater discharges and (2) to describe and ensure the implementation of best management practices (BMPs) to reduce or eliminate sediment and other pollutants in stormwater as well as non-stormwater discharges. BMPs implemented under the SWPPP to reduce or eliminate sediment would reduce erosion.

Implementation of the permit requirements would be necessary (and required) to control erosion during construction activities at the project site. Compliance with the state permit is enforced and monitored by the State Water Resources Control Board. See also the discussion in Section 4.N, *Hydrology and Water Quality*.

LOCAL

Port of San Francisco Building Code. The Port Building Code, an amendment to the CBC, applies to projects constructed on Port property. The operative version of the Port Building Code, published 2016, incorporates and amends the 2016 CBC; the effective date is January 1, 2017. The 2016 Port Building Code is administered by the Port Commission through the Chief Harbor Engineer and establishes minimum building requirements to safeguard the public health, safety, and general welfare. Chapter 16 of the 2016 Port Building Code applies to structural design, including seismic considerations. Chapter 16 of the 2016 Port Building Code amends Chapter 16 of the 2016 CBC to address structural design criteria related to flood hazard and wave loads from a 100-year flood event and to reduce the risk of damage to unreinforced masonry buildings, but is otherwise the same as Chapter 16 of the 2016 CBC. The 2016 Port Building Code Chapters 18 and 18A apply to soils and foundations and make no amendments to Chapters 18 and 18A of the 2016 CBC. Chapter 33 applies to safeguards during construction. Appendix J applies to grading.

San Francisco General Plan. The Community Safety Element⁷⁰ of the General Plan states the following objective:

- Objective 1: Reduce structural and nonstructural hazards to life safety and minimize property damage resulting from future disasters.

The following four policies related to geology and soils support this objective:

- Policy 1.3: Assure that new construction meets current structural and life safety standards.
- Policy 1.6: Consider site soils conditions when reviewing projects in areas subject to liquefaction or slope instability.

⁷⁰ City and County of San Francisco. 2012. *Community Safety Element*. October. Available: http://www.sf-planning.org/ftp/general_plan/community_safety_element_2012.pdf. Accessed: October 5, 2015.

- Policy 1.7: Consider information about geologic hazards whenever City decisions are made that will influence land use, building density, building configurations, or infrastructure are made.
- Policy 1.16: Preserve, consistent with life safety considerations, the architectural character of buildings and structures important to the unique visual image of San Francisco, and increase the likelihood that architecturally and historically valuable structures will survive future earthquakes.

The Community Safety Element includes maps of potential hazard areas, including liquefaction and potential liquefaction areas.

The Environmental Protection Element of the General Plan contains the following objective:

- Objective 7: Ensure that the land resources in San Francisco are used in ways that both respect and preserve the natural values of the land and serve the best interests of all the city's citizens.

The following three policies related to geology and soils support this objective:

- Policy 7.3: Require that filling of land adhere to the highest standards of soils engineering consistent with the proposed use.
- Policy 7.4: Assure the correction of landslide and shore erosion conditions where it is in the public interest to do so.
- Policy 7.5: Prohibit construction, as a general rule, on land subject to slide or erosion.

ENVIRONMENTAL IMPACTS

This section describes the impact analysis related to geology and soils for the proposed project. It describes the methods that were used to determine the impacts of the proposed project and lists the thresholds that were used to conclude whether an impact would be significant. Measures to mitigate (i.e., avoid, minimize, rectify, reduce, eliminate, or compensate for) significant impacts accompany the discussion of each identified significant impact.

SIGNIFICANCE CRITERIA

The proposed project would be considered to have a significant effect if it would result in any of the conditions listed below.

- Expose people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving:
 - Rupture of a known earthquake fault, as delineated on the most recent Alquist-Priolo Earthquake Fault Zoning Map issued by the State Geologist for the area or other substantial evidence of a known fault (refer to Division of Mines and Geology Special Publication 42).

- Strong seismic ground shaking.
- Seismically related ground failure, including liquefaction.
- Result in substantial soil erosion or the loss of topsoil.
- Be located on a geologic unit or soil that is unstable or would become unstable as a result of the project and potentially result in on or offsite landslides, lateral spreading, subsidence, liquefaction, or collapse.
- Be located on expansive soil, as defined in Table 18 1 B of the Uniform Building Code, creating substantial risks to life or property.
- Directly or indirectly destroy a unique paleontological resource or site or unique geologic feature.

METHODS FOR ANALYSIS

For the purpose of this analysis, it is assumed that the proposed project would be designed and constructed in compliance with all applicable building codes and state law, as described above in the *Regulatory Framework* section.

GEOLOGY AND SOILS

Impacts related to geology and soils were analyzed qualitatively, based in part on analysis presented in the preliminary geotechnical studies and geotechnical evaluations that were conducted for the project site.^{71,72,73} The analysis was also based, in part, on data from peer-reviewed and government reports and mapping, including information about landslide and earth flows;⁷⁴ soils data from the Natural Resources Conservation Service;⁷⁵ mapping of seismic

⁷¹ Treadwell & Rollo. 2011. *Preliminary Geotechnical Investigation: Seawall Lot 337 – Mission Bay, San Francisco, California*. September 8. Prepared for Mission Rock Development.

⁷² Treadwell & Rollo. 2013. *Liquefaction and Lateral Spread Potential at Seawall Lot 337*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, CA. (Project No. 750604203.) December 23.

⁷³ Langan Treadwell Rollo. 2014. *Geotechnical Evaluation of Shoreline Conditions at Pier 48*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, California. (Langan Project No. 750604203.) March 5.

⁷⁴ Wentworth, C.M., S.E. Graham, R.J. Pike, G.S. Beukelman, D.W. Ramsey, and A.D. Barron. 1997. Part C, Summary of Distribution of Landslide and Earth Flows in the San Francisco Bay Region, California. In *San Francisco Bay Region Landslide Folio*. (Open File Report 97-745.) Available: <http://pubs.usgs.gov/of/1997/of97-745/sf-sef.pdf>. Accessed: October 5, 2015.

⁷⁵ Natural Resources Conservation Service. 2015. *Soil Survey for San Francisco through SoilWeb Earth*. U.S. Department of Agriculture. Available: <http://casoilresource.lawr.ucdavis.edu/soilweb-apps/>. Accessed: October 5, 2015.

hazards at and near the project site;^{76,77,78} earthquake probability forecasts;⁷⁹ and mapping of Quaternary faults near the project site.⁸⁰ The analysis focused on the proposed project's potential to have an impact on the environment as a result of project actions.

Impacts on soils and geology would occur if the proposed project were to result in changes to the environment that would cause or exacerbate erosion, slope failure, subsidence, soil expansion and contraction, or seismically induced lateral spreading. Impacts would also occur if the proposed project would change the topography; destroy a unique geologic feature, physical feature, or paleontological resource; or be located on soils that would be incapable of supporting an alternative wastewater system, if included in the project. As discussed in Chapter 2, *Project Description*, the proposed project would involve soil excavation to a maximum depth of approximately 33 feet below ground surface for the Mission Rock Square garage. Basements within other new structures would have lesser depths, and no excavation would be required for pile driving. Construction of the proposed project would involve pile driving to an average depth of 230 feet for the proposed buildings and a maximum depth of 175 feet for streets, the promenade and boardwalk at China Basin Park, and utilities, which would be within the bedrock (encountered during the boring at between 160 and 260 feet below ground surface). As discussed above under *Project Area Geology*, groundwater is at approximately 6.5 to 9 feet below ground surface. As shown in Table 4.M-3, on the following page, the total volume of excavated materials from the project site with the proposed development would be approximately 208,560 cubic yards.

Based on the *California Building Industry Association v. Bay Area Air Quality Management District* decision, 62 Cal. 4th 369 (2015), the approach to analyzing impacts determines if a project would substantially exacerbate any existing environmental hazards or conditions and evaluates the potential for such exacerbated hazards to affect future residents or users associated with a proposed project. The analysis does not consider the effects of existing environmental conditions on a project's future users or residents. In these specific instances, it is the project's impact on the environment, not the environment's impact on the project, that compels an evaluation of how future residents or users could be affected by exacerbated conditions.

⁷⁶ California Geological Survey. 2002. *Probabilistic Seismic Hazard Assessment for the State of California, Appendix A, in Fault Source Parameters*. (CDMG Open File Report 96-08.) Available: <http://www.consrv.ca.gov/CGS/rghm/psha/ofr9608>. Accessed: October 1, 2015.

⁷⁷ Youd, T.L., and S.N. Hoose. 1978. *Historic Ground Failures in Northern California Triggered by Earthquakes*. Geological Survey Professional Paper 993.

⁷⁸ Youd, T.L. and D.M. Perkins. 1978. *Mapping Liquefaction Induced Ground Failure Potential*. Proceedings of the American Society of Civil Engineers, Journal of the Geotechnical Engineering Division.

⁷⁹ UCERF3. 2015. UCERF3: A New Earthquake Forecast for California's Complex Fault System. (Fact Sheet 2015-3009.) Available: <http://www.wgcep.org/sites/wgcep.org/files/fs2015-3009.pdf>. Accessed: October 5, 2015.

⁸⁰ U.S. Geological Survey. 2015b. *Quaternary Faults in Google Earth*. Available: <http://earthquake.usgs.gov/hazards/qfaults/google.php>. Accessed: October 5, 2015.

TABLE 4.M-3. MAXIMUM DEPTH OF EXCAVATION AND VOLUME OF EXCAVATED MATERIAL

Building	Volume of Excavated Material for Demolition and Grading, Infrastructure, and Foundations (cubic yards)
AREA 1 (Building A, G, K, China Basin Park, Pier 48)	26,650
AREA 2 (Buildings B, C, D)	37,610
AREA 3 (Buildings E, F, Mission Rock Square, Below Grade Parking)	117,000
AREA 4 (Buildings H, I, J, Channel Plaza)	27,300
Total Volume of Excavated Materials	208,560

PALEONTOLOGICAL RESOURCES

The fossil-yielding potential of geologic units depends on the geologic age and origin of the underlying rocks as well as on the processes that the rocks have undergone, both geologic and anthropogenic.⁸¹ The methods used to analyze potential impacts on paleontological resources involved the following steps:

- Identify the geologic units in the paleontological study area.
- Evaluate the potential of the identified geologic units to contain significant fossils (their “paleontological sensitivity”).
- Identify and evaluate impacts on paleontologically sensitive geologic units as a result of project construction and operations that involve ground disturbance.
- Evaluate impact significance.

Ground disturbance caused by project implementation would take place only during the construction phase; therefore, paleontological impact analysis addresses construction-related impacts only.

To identify the geologic units in the paleontological study area, government reports and peer-reviewed journal articles regarding the geologic units underlying the project site were consulted.^{82, 83} To evaluate the paleontological sensitivity of the geologic units, first the

⁸¹ *Anthropogenic* means caused by human activity.

⁸² Keller, B.R. 2009. Literature Review of Unconsolidated Sediment in San Francisco Bay and Nearby Pacific Ocean Coast. *San Francisco Estuary and Watershed Science* 7(1). Available: <http://escholarship.org/uc/item/5rh9t1jj>. Accessed: April 7, 2016.

⁸³ Goldman, H.B. 1969. *Geologic and Engineering Aspects of San Francisco Bay Fill*. California Division of Mines and Geology, San Francisco, CA. (Special Report 97.) Prepared for San Francisco Bay Conservation and Development Commission, San Francisco, CA.

University of California Museum of Paleontology database was searched for records of fossils in these geologic units.⁸⁴ The database contains records for more than 400,000 specimens and more than 100,000 localities. Searches were based on geologic unit and reviewed by geographic context.

Next, the paleontological sensitivity of the units was assessed. The Impact Mitigation Guidelines Revisions Committee of the Society of Vertebrate Paleontology (SVP) has published Standard Guidelines.⁸⁵ The Standard Guidelines include procedures for the investigation, collection, preservation, and cataloging of fossil-bearing sites. The Standard Guidelines are widely accepted among paleontologists and followed by most investigators. The Standard Guidelines identify the two key phases of paleontological resource protection: (1) assessment and (2) implementation. Assessment involves identifying the potential for a project site or area to contain significant nonrenewable paleontological resources that could be damaged or destroyed by project excavation or construction. Implementation involves formulating and applying measures to reduce such adverse effects. *Paleontological potential* is the potential for yielding abundant fossils, a few significant fossils, or evidence for new and significant taxonomic, phylogenetic, paleoecologic, taphonomic, biochronologic, or stratigraphic data. The SVP defines the level of potential as one of four sensitivity categories for sedimentary rocks: High, Undetermined, Low, and No Potential as defined below.⁸⁶

- **High Potential.** Assigned to geologic units from which vertebrate or significant invertebrate, plant, or trace fossils have been recovered and sedimentary rock units that are suitable for the preservation of fossils (e.g., middle Holocene and older fine-grained fluvial sandstones...fine-grained marine sandstones, etc.).
- **Undetermined Potential.** Assigned to geologic units for which little information is available concerning their paleontological content, geologic age, and depositional environment. In cases where no subsurface data already exist, paleontological potential can sometimes be assessed by subsurface site investigations.

⁸⁴ University of California Museum of Paleontology. 2016. *University of California Museum of Paleontology Advanced Specimen Search*. Available: <http://ucmpdb.berkeley.edu/advanced.html>. Accessed: April 8, 2016.

⁸⁵ Society of Vertebrate Paleontology. 2010. *Standard Procedures for the Assessment and Mitigation of Adverse Impacts to Paleontological Resources*. Impact Mitigation Guidelines Revision Committee. Available: http://vertpaleo.org/The-Society/Governance-Documents/SVP_Impact_Mitigation_Guidelines.aspx. Accessed: April 8, 2016.

⁸⁶ Society of Vertebrate Paleontology. 2010. *Standard Procedures for the Assessment and Mitigation of Adverse Impacts to Paleontological Resources*. Impact Mitigation Guidelines Revision Committee. Available: http://vertpaleo.org/The-Society/Governance-Documents/SVP_Impact_Mitigation_Guidelines.aspx. Accessed: April 8, 2016.

- **Low Potential.** Field surveys or paleontological research may allow a determination that a geologic unit has low potential for yielding significant fossils (e.g., basalt flows). Mitigation is generally not required to protect fossils.
- **No Potential.** Some geologic units have no potential for containing significant paleontological resources, such as high-grade metamorphic rocks (e.g., gneisses and schists) and plutonic igneous rocks (e.g., granites and diorites). Mitigation is not required.

Data from the University of California Museum of Paleontology database were analyzed to assign each geologic unit in the study area a paleontological sensitivity category, according to the SVP's Standard Guidelines. To identify and evaluate impacts on paleontologically sensitive geologic units resulting from project and program actions, the depth of ground disturbance was assessed, with consideration of the location of geologic units with high potential and undetermined potential.

LAND USE ASSUMPTIONS

As described in Chapter 2, *Project Description*, this environmental impact report (EIR) analyzes two land use assumptions: High Commercial and High Residential. These assumptions represent the full range of land uses and the building program that could be developed on the project site under the proposed flexible zoning for Blocks H, I, and J. Although the land use mix between High Commercial and High Residential would differ, the two assumptions would have similar total square footages, similar building configurations (with the exception of the building heights on Blocks H, I, and J where the High Residential Assumption has greater proposed heights than the High Commercial Assumption), and similar construction characteristics. Therefore, the differences between the two assumptions would not result in any meaningful difference in potential impacts on geology and soils. As such, the following analysis applies to both the High Commercial and High Residential land use assumptions.

TOPICS NOT EVALUATED IN DETAIL

Because of the nature of the proposed project, there would be no impact related to the following topics for the reasons described below:

Expose people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving landslide. The project site is nearly level and not adjacent to any hillsides where seismically induced landslides or other downslope movements of rock or soil could pose a hazard. The project site is not located within a mapped landslide hazard area,

according to the California Geological Survey Seismic Hazard Zonation Program.⁸⁷ The proposed project would not cause or exacerbate a landslide hazard. Because the proposed project would not increase the exposure of people to landslide hazards, this impact is not evaluated further.

Have soils incapable of adequately supporting the use of septic tanks or alternative wastewater disposal systems where sewers are not available for the disposal of wastewater. Wastewater produced by the proposed project would be conveyed to the City's combined sewer system. Stormwater would be separated and treated before discharge to the Bay. New construction of alternative wastewater disposal systems is not required as part of the proposed project. Further, existing alternative wastewater disposal systems or septic tanks would not be used as part of the proposed project. Therefore, no impacts related to soils that are incapable of adequately supporting the use of septic tanks or alternative wastewater disposal systems would occur, and this impact is not discussed further.

Substantially change the topography or any unique geologic or physical features. The project site, located along the San Francisco Bay waterfront, is generally flat and has no unique geologic or physical features. Therefore, no impacts related to alteration of topography or changes to unique geologic or physical features would occur, and this impact is not discussed further.

IMPACTS AND MITIGATION MEASURES

Impact GE-1a. The project would not expose people or structures to risk of loss, injury, or death involving rupture of a known earthquake fault. (Less than Significant)

As discussed under *Fault Rupture* in the *Environmental Setting* and *Alquist-Priolo Earthquake Fault Zoning Act* in the *Regulatory Framework*, the project site is not located within an Alquist-Priolo Earthquake Fault Zone, nor do any active or potentially active faults exist within or near the project site. The nearest active fault is the San Andreas fault, located approximately 8 miles west of the project site. Therefore, the potential for surface fault rupture to affect the project site is extremely low. Further, no components of the proposed project would cause or worsen rupture of any known or unknown earthquake fault. Therefore, project implementation would not exacerbate the risk of loss, injury, or death from fault rupture compared to existing conditions. The impact would be *less than significant*. No mitigation is required.

⁸⁷ California Geologic Survey. 2000. *Seismic Hazard Zones: City and County of San Francisco*. Available: <http://gmw.consrv.ca.gov/shmp/MapProcessor.asp?MapNavAction=&Action=IMap&Location=NoCal&FCl ass=Quad&FID=San%20Francisco%20North&Liq=false&Land=false&Bore=false&Road=true&City=false&x1=539765.7922388642&y1=4192422.2105356133&x2=557219.3179211357&y2=4177877.605800387#>. Accessed: October 5, 2015.

Impact GE-1b. The project would not expose people or structures to risk of loss, injury, or death involving strong seismic ground shaking. (Less than Significant)

Development of the proposed project would involve the construction and occupancy of new buildings in a location where strong seismic ground shaking can be expected to occur over the life of the project. Buildings would be constructed on piles, with foundations designed to withstand seismic activity. As discussed above, the project site is located near several faults that are capable of generating a large earthquake, and there is a 72 percent likelihood that a magnitude 6.7 earthquake will occur in the Bay Area in the next 30 years. If the project buildings are not properly constructed, ground shaking could result in significant damage to structures, including collapse.

As stated above, the state Seismic Hazards Mapping Act of 1990 (Public Resources Code [PRC] Sections 2690 to 2699.6) was enacted to identify and map seismic hazard zones in order for cities and counties to encourage land use management policies and regulations to reduce and mitigate those seismic hazards to protect public safety. PRC Section 2697 requires that prior to approval of a project within a seismic hazard zone, cities and counties shall require a geotechnical report defining and delineating seismic hazard on the site. In conjunction with these provisions in the Public Resources Code, California Code of Regulations (CCR) Title 14, Section 3724, specifies that a project located in a state seismic hazard zone shall be approved only when the nature and severity of the seismic hazards at the site have been evaluated in a geotechnical report and appropriate mitigation measures have been proposed. The California Department of Conservation, California Geological Survey issued Special Publication 117A, *Guidelines for Evaluating and Mitigating Seismic Hazards in California* (2008) to provide considerations for earthquake hazard mitigation.

Chapter 18 and 18A of the 2016 CBC relate to Soils and Foundations. In particular, Section 1803 addresses the purpose, scope, and content of geotechnical investigations, including when a report is required as well as the qualifications for report preparers and reviewers. Section 1808 specifies design criteria for foundations. In addition to Section 1808, shallow foundations shall also comply with the criteria in Section 1809 and deep foundations shall also comply with the criteria in Section 1810. Geotechnical investigations provide design criteria that minimize impacts associated with strong ground shaking during an earthquake. The proposed project would be constructed in phases that may involve other developers. The project sponsor, or subsequent developer, would be required to prepare design-level geotechnical reports for each phase of the proposed project in accordance with the SHMA, CGS Special Publication 117A, the 2016 Port Building Code, and 2016 CBC requirements and implement the project-specific recommendations contained therein. During the final design, development of individual blocks and foundation recommendations, which may involve further geotechnical exploration, would be required. For high-rise structures, a unique foundation recommendation report would be required for each building. The design-level

geotechnical reports would be subject to review and approval by the Port in order to secure project building permits. Preliminary geotechnical recommendations from the geotechnical investigations conducted to date are described below.

Planned seismic upgrade work at Pier 48 would occur over approximately 16 total months. Existing timber piles would be extracted where appropriate. The seismic upgrade would consist of new piles located below a new heavily reinforced concrete apron. The apron would be located at both the northern and southern perimeter of Pier 48, replacing the existing exterior deck in these locations. These piles would include 62 approximately 30-foot-long precast concrete piles and 44 approximately 120-foot-long steel-cased concrete-filled piles. The precast concrete piles would be driven into the soil. The steel casing of the steel-cased piles would be installed in the soil with a vibratory hammer. After the steel casings are installed, each pile would be drilled to remove soil and the soil replaced with reinforced concrete.

Implementation of proper design and construction methods, as outlined in design-level geotechnical reports prepared in accordance with the SHMA, CGS Special Publication 117A, the 2016 Port Building Code, and 2016 CBC, which would be monitored and enforced through the building permit process, would minimize the effects of seismically induced ground shaking. Furthermore, the preliminary geotechnical reports prepared for the proposed project did not identify any seismic or geologic hazards that are unique to the project site or otherwise uncharacteristic of the project area that cannot be mitigated by compliance with standard building code requirements.

Similar to the discussion above under Impact GE-1a, no components of the proposed project would alter the seismic environment or affect the risk of seismically induced ground shaking. Therefore, under project implementation, there would be no change in the exposure of people or structures to risk of loss, injury, or death from seismic ground shaking compared to existing conditions. Therefore, project implementation would not exacerbate existing vulnerability to seismically induced ground shaking at the project site. The impact would be *less than significant*. No mitigation is required.

Impact GE-1c. The project would not expose people or structures to risk of loss, injury, or death involving seismically related ground failure, including liquefaction. (Less than Significant)

As discussed under Impact GE-1b, the project area could be subject to very strong to violent ground shaking in the event of a major earthquake. As discussed above under *Regional Faulting and Seismic Hazards*, the project site is subject to liquefaction, lateral spreading, and earthquake-induced settlement hazards. Loads, such as buildings or utilities, constructed on the project site would exacerbate soil displacement as a result of strong ground shaking during an earthquake.

The project site is located within a liquefaction hazard zone, as identified by the California Geological Survey. Because of the shallow groundwater table and the relatively shallow liquefiable deposits, lateral spreading, lurch cracking, and the development of sand boils could accompany generalized liquefaction. Potential lateral spreading at Pier 48 would be on the order of 4 to 8 feet. Potential lateral spreading at the shoreline could extend up to approximately 110 feet west of the seawall.⁸⁸ As stated above, lateral spreading is generally the most damaging type of seismically induced ground failure. The impact related to lateral spreading is discussed in detail under Impact GE-3, below.

Earthquake-induced settlement due to liquefaction is expected to be up to 5 inches, depending on the location.⁸⁹ Because of the variation in subsurface conditions, settlement after liquefaction is expected to be erratic and vary significantly across the project site. Ground settlement would create a downward frictional load on piles that support structures and could have adverse effects on site drainage, utilities, and transitions between on-grade and pile-supported structures.

If project foundations are not properly designed, seismically induced ground failure could expose people at the project site to risk of injury or death. However, as discussed under Impact GE-1b, the proposed project would be required to comply with the SHMA, CGS Special Publication 117A, the 2016 Port Building Code, and 2016 CBC and prepare and implement the recommendations of design-level geotechnical reports, which would minimize impacts associated with strong ground shaking during an earthquake. Recommendations may include installation of stone columns and deep soil mixing.⁹⁰

As evidenced by the level of development throughout the Bay Area, successful building construction is possible in a seismically active zone, even where seismic hazards are known to exist. Implementation of proper design and construction methods, as set forth in the SHMA, CGS Special Publication 117A, the 2016 Port Building Code, and 2016 CBC, which is monitored and enforced through the building permit process, would minimize the effects of ground failure. Furthermore, the preliminary geotechnical reports prepared for the proposed project did not identify any seismic or geologic hazards that are unique to the project site or otherwise uncharacteristic of the project area that cannot be minimized through compliance with standard building code requirements. Therefore, the impact would be *less than significant*. No mitigation is required.

⁸⁸ Langan Treadwell Rollo. 2014. *Geotechnical Evaluation of Shoreline Conditions at Pier 48*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, California. (Langan Project No. 750604203.) March 5.

⁸⁹ Langan Treadwell Rollo. 2014. *Geotechnical Evaluation of Shoreline Conditions at Pier 48*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, California. (Langan Project No. 750604203.) March 5.

⁹⁰ Langan Treadwell Rollo. 2014. *Geotechnical Evaluation of Shoreline Conditions at Pier 48*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, California. (Langan Project No. 750604203.) March 5.

Impact GE-2. The project would not result in substantial soil erosion or the loss of topsoil. (Less than Significant)

In general, construction activities and pedestrian travel can disturb vegetation and ground cover that serves to stabilize surface soils, making the soils more susceptible to erosion. Without proper soil stabilization controls, construction activities such as excavation, backfilling, and grading can also increase the potential for exposed soils to be eroded by wind or stormwater runoff, resulting in long-term soil loss. Project construction activities could also result in the loss of topsoil, a fertile soil horizon that typically contains a seed base, if there is a well-developed topsoil horizon and it is mixed with other soil horizons or otherwise lost during excavation and backfilling.

Because the soils at the project site are not native soils, as discussed under *Soil Hazards*, there would be no loss of topsoil. With respect to loss of topsoil, there would be *no impact*.

As discussed in Section 4.N, *Hydrology and Water Quality*, project construction activities such as new building construction, rehabilitation of existing facilities, paving for parking lots, cut-and-fill activities, grading and excavation, and landscaping could increase erosion. However, all project construction activities would be subject to existing regulatory requirements. Because land disturbance associated with the proposed project would be more than 1 acre, coverage under the Construction General Permit would be required, including development of and compliance with a SWPPP. BMPs implemented in the SWPPP would include a range of stormwater control BMPs (e.g., installing erosion control features, such as silt fences, staked straw wattles, and geofabric, to prevent silt runoff to storm drains or waterways). Soils and backfill would be stockpiled, protected, and replaced at the conclusion of construction activities. Disturbed soil would be revegetated as soon as possible with the appropriate selection and schedule for turf, plants, and other landscape vegetation. No disturbed surfaces would be left without erosion control measures in place during the wet season, which generally occurs between October 1 and April 30. In addition, coverage under the Construction General Permit typically covers dewatering activities, which would be required during project construction to accommodate excavation for foundations that would extend below groundwater. Implementation of a SWPPP, as required by law, would reduce this impact to a *less-than-significant level*.

Impact GE-3. The project would not be located on geologic unit or soil that is unstable or would become unstable and potentially result in lateral spreading, subsidence, liquefaction, or collapse. (Less than Significant)

Collapse is likely when there is an underground void, such as an abandoned mine or utility vault, or weak rock, such as karst limestone. Because underground voids or weak rocks are not present at the project site, there would be no risk of collapse.

The potential for settlement on the undisturbed project site is small, approximately only 1 inch. However, other factors can increase the potential magnitude of settlement, such as liquefaction. At the project site, as discussed above under *Liquefaction and Other Seismically Induced Ground Failure*, the project site is vulnerable to seismically induced liquefaction. Because the liquefiable layers are discontinuous and random across the site, there would be variability in the magnitude of potential liquefaction-induced settlement across the project site if a load were to be placed on the soil. Specifically, under the proposed project, there is potential for seismically induced settlement of 1 to 5 inches. Further, in locations where there is a liquefiable layer between the surface soil and underlying soil on a slope, the surface soil may be transported downslope, initiated by either seismic or gravitational forces, in a phenomenon referred to as lateral spreading. As discussed above under *Lateral Spreading* and in the preliminary geotechnical study prepared for the proposed project, some soil layers in the 40-foot-thick fill layer at the project site have this characteristic and, accordingly, lateral spread potential of approximately 4 feet if the existing seawall limits the lateral spread flow or movement.⁹¹ However, the magnitude of lateral spreading that the seawall could contain is unknown. As discussed under *Lateral Spreading* in the *Regional Faulting and Seismic Hazards* section, above, lateral spreading at the project site could be rotational in nature, leading to a progressive failure that could affect an area as far away as 110 feet west of the seawall.⁹² Therefore, the potential for lateral spreading under the proposed project is substantial. However, as discussed under Impact GE-1b, the proposed project would comply with the SHMA, CGS Special Publication 117A, the 2016 Port Building Code, and 2016 CBC, which requires a geotechnical report to be prepared that addresses ground stability and improvements. The geotechnical report would include recommendations for foundation support and ground improvement. Recommendations for ground improvement at the shoreline could include deep dynamic compaction and/or stone column installation to minimize the potential for liquefaction and lateral spreading.^{93,94} If deep dynamic compaction is used, uneven compaction of the ground surface and a corresponding

⁹¹ Treadwell & Rollo. 2013. *Liquefaction and Lateral Spread Potential at Seawall Lot 337*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, CA. (Project No. 750604203.) December 23.

⁹² Langan Treadwell Rollo. 2014. *Geotechnical Evaluation of Shoreline Conditions at Pier 48*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, California. (Langan Project No. 750604203.) March 5.

⁹³ Treadwell & Rollo. 2013. *Liquefaction and Lateral Spread Potential at Seawall Lot 337*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, CA. (Project No. 750604203.) December 23.

⁹⁴ Compaction grouting and rapid impact compaction for the shoreline were considered in the liquefaction and lateral spread investigation but both were rejected for this site (Treadwell & Rollo 2013, *Liquefaction and Lateral Spread Potential at Seawall 337*). The grout injection process was rejected because there is too little overburden (soil weight) to resist heave, including periods during the grout injection process, which involves high injection pressures. The rapid impact compaction process was rejected because the process has shown only moderate success in improving the ground and mitigating for liquefaction and lateral spreading potential in Mission Bay.

need for regrading are likely to result. Installations of stone columns could result in heave or settlement and a corresponding need for regrading. The use of lightweight geofabric as new fill could be recommended. Recommendations for ground improvement at Pier 48 could include stone columns and deep soil mixing.⁹⁵ The ground should be improved to a minimum distance of 35 to 50 feet below ground surface. The stone columns and deep soil mixing should extend at least 3 feet into the Bay Mud and span the width of Pier 48. Similar to the shoreline, installations of stone columns could result in heave or settlement and a corresponding need for regrading.

The preliminary geotechnical reports prepared for the proposed project did not identify any seismic or geologic hazards that are unique to the project site or otherwise uncharacteristic of the project area that cannot be minimized by compliance with standard building code requirements. Therefore, the impact would be *less than significant*. No mitigation is required.

Impact GE-4. The project would not create substantial risks to life or property through location on expansive or corrosive soil. (Less than Significant)

As discussed under *Soil Hazards*, expansive soils undergo significant volume changes when moisture content changes, which could occur as site conditions are altered by excavation and construction activities. Fill at the project site is not expansive, and the underlying Bay Mud at the project site, although expansive, is not subject to expansion/contraction because it is under the groundwater level and therefore not subject to moisture changes. The risk to structures from construction on expansive soils at the project site is low.

As stated above under *Soil Hazards*, fill at the project site is moderately to severely corrosive, and the Bay Mud at the site is severely corrosive. Chapter 18 and 18A of the 2016 CBC relate to Soils and Foundations. In particular, Section 1803 addresses the purpose, scope, and content of geotechnical investigations, including when a report is required as well as the qualifications for report preparers and reviewers. Section 1808 specifies design criteria for foundations. In addition to Section 1808, shallow foundations shall also comply with the criteria in Section 1809 and deep foundations shall also comply with the criteria in Section 1810. Geotechnical investigations provide design criteria that minimize impacts associated with expansive or corrosive soils. The proposed project would be constructed in phases that may involve other developers. The project sponsor, or subsequent developer, would be required to prepare design-level geotechnical reports, including a soils report, for each phase of the proposed project in accordance with the SHMA, CGS Special Publication 117A, the 2016 Port Building Code, and 2016 CBC requirements and implement the project-specific recommendations contained therein. During the final design, development of individual blocks and foundation recommendations, which may involve further geotechnical exploration, would be required. For

⁹⁵ Langan Treadwell Rollo. 2014. *Geotechnical Evaluation of Shoreline Conditions at Pier 48*. Mission Rock Development, Seawall Lot 337 and Pier 48, San Francisco, California. (Langan Project No. 750604203.) March 5.

high-rise structures, a unique foundation recommendation report would be required for each building. The design-level geotechnical reports would be subject to review and approval by the Port in order to secure project building permits. The soils report would include recommendations for the treatment of site-specific soils hazards, including corrosive soils.

The proposed project would result in modifications to soils at the project site. The modifications would be associated with site clearing, excavation, grading, paving, and backfilling. Further modifications to the soils would result from implementation of the recommendations in the site-specific soils report. These could include admixtures⁹⁶ to minimize corrosivity. Implementation of the project would not cause or worsen the risks associated with expansive or corrosive soils. Therefore, project implementation would not exacerbate risks to life or property due to expansive or corrosive soils compared to existing conditions. The impact would be *less than significant*. No mitigation is required.

Impact GE-5. The project could directly or indirectly destroy a unique paleontological resource or site or unique geologic feature. (Less than Significant with Mitigation)

As discussed above, the project site is underlain by artificial fill and sedimentary deposits. No unique geologic features exist at the ground surface at the project site, and there would be no impact related to such resources. The project site is blanketed by approximately 10 to 40 feet of artificial fill, consisting of brick, rock, concrete, debris, gravel, and sand. The artificial fill is underlain by 37 to 47 feet of weak, soft to medium-stiff, compressible Younger Bay Mud. The Younger Bay Mud is underlain by the Colma Formation, which has high paleontological sensitivity. At the project site, borings found that the fill and Younger Bay Mud are underlain by up to 20 feet of Colma Formation of Pleistocene age in some locations and by 60 to 80 feet of Old Bay Clay of Pleistocene age.^{97,98,99}

Project activities would involve excavation to a depth of 33 feet for the garage, on-land pile driving to an average depth of 230 feet for the steel piles for buildings and a maximum depth of 145 feet for the steel piles for streets and the promenade and boardwalk at China Basin Park, and in-water vibratory hammer driving to an approximate depth of 120 feet for the steel-cased concrete-filled piles. The soil would then be removed by drilling, and the steel pile casings would be filled with reinforced concrete.

⁹⁶ Chemical admixtures are the ingredients added to soil or concrete to modify the properties of the material.

⁹⁷ Treadwell & Rollo. 2001. *Pier 48 Foundation Evaluation, San Francisco, California*. Log of Boring B-2.

⁹⁸ Treadwell & Rollo. 2001. *Pier 48 Foundation Evaluation, San Francisco, California*. Log of Boring B-3.

⁹⁹ Simpson, L.A., and G.E. Treadwell & Rollo Inc. 2006. Case Studies in Mission Bay, San Francisco: Deep Foundations in Challenging Soil Conditions. In *DFI Proceedings of the 31st Annual Conference on Deep Foundations*. Washington, D.C.

The potential to affect fossils varies with the depth of disturbance and previous disturbance. The logistics of excavation also affect the possibility of recovering scientifically significant fossils because information regarding location, vertical elevation, geologic unit of origin, and other aspects of context is critical to the significance of any paleontological discovery.

The Colma Formation has high paleontological sensitivity and could contain vertebrate fossils. As discussed under *Paleontological Setting*, the Colma Formation at the project site extends from approximately 60 to 80 feet below the ground surface. The Franciscan Formation also has high paleontological sensitivity and could contain vertebrate fossils. As discussed under *Paleontological Setting*, the Franciscan Formation at the project site extends from approximately 160 to 260 feet below the ground surface. Drilling and pile driving to an average depth of 230 feet for the proposed buildings and a maximum depth of 145 feet for streets and the promenade and boardwalk at China Basin Park could affect both geologic units, which could contain significant paleontological remains or traces of paleontological remains.

This constitutes a significant impact. Implementation of Mitigation Measure M-GE-5 would reduce the impact to *less than significant with mitigation*.

MITIGATION MEASURE. Drilling and pile driving would not result in destruction of significant paleontological resources with incorporation of Mitigation Measure M-GE-5, Accidental Discovery of Paleontological Resources, which calls for training for construction crews to recognize paleontological resources by a qualified paleontologist, stopping work in case of discovering such resources, evaluation of those resources by a qualified paleontologist and, as appropriate, preparation and implementation of a recovery plan. With implementation of this mitigation measure, this impact would be *less than significant*.

M-GE-5: Accidental Discovery of Paleontological Resource

Given the potential for paleontological resources to be present at the project site at excavation depths within the Colma Formation, the following measures shall be undertaken to avoid any significant adverse effect from the proposed project on paleontological resources. Before the start of any drilling or pile-driving activities, the project sponsor shall retain a qualified paleontologist, as defined by the SVP, who is experienced in teaching non-specialists. The qualified paleontologist shall train all construction personnel who are involved with earthmoving activities, including the site superintendent, regarding the possibility of encountering fossils, the appearance and types of fossils that are likely to be seen during construction, and proper notification procedures should fossils be encountered. Procedures to be conveyed to workers include halting construction within 50 feet of any potential fossil find and notifying a qualified paleontologist, who shall evaluate the significance.

If paleontological resources are discovered during earthmoving activities, the construction crew shall immediately cease work near the find and notify the project sponsor and the San Francisco Planning Department. Construction work in the affected areas shall remain stopped or be diverted to allow recovery of fossil remains in a timely manner. The project sponsor shall retain a qualified paleontologist to evaluate the resource and prepare a recovery plan in accordance with SVP guidelines.¹⁰⁰ The recovery plan may include a field survey, construction monitoring, sampling and data recovery procedures, museum storage coordination for any specimen recovered, and a report of findings. Recommendations in the recovery plan that are determined by the San Francisco Planning Department to be necessary and feasible shall be implemented before construction activities can resume at the site where the paleontological resources were discovered. The San Francisco Planning Department shall be responsible for ensuring that the monitor's recommendations regarding treatment and reporting are implemented.

CUMULATIVE IMPACTS

Impact C-GE-1. The proposed project, in combination with other development within the city, would not substantially increase the risk of exposure for people or structures to seismic hazards. (Less than Significant)

The study area for analyzing seismic effects is the region. The proposed project would not increase the likelihood of surface fault rupture or the intensity of seismic ground shaking, nor would other proposed development within the city. Although the proposed project would increase the likelihood of liquefaction, lateral spreading, and other ground-failure effects, the effects would not cause ground failure in other parts of the city and would not directly affect other projects.

If the proposed project and other development in the city were not properly designed, the projects would create an urban landscape that would be vulnerable to ground failure. However, construction in California is strictly regulated by the SHMA, CGS Special Publication 117A, the 2016 Port Building Code, and CBC, as adopted and enforced by each jurisdiction/authority, including the City and County of San Francisco and the Port, to reduce risks from seismic events to the maximum extent possible. Restrictions on development would be applied in the event that geological or soil conditions pose a risk as a result of site-specific susceptibility to ground failure. Because the City and County of San Francisco and the Port use and enforce the

¹⁰⁰ Society of Vertebrate Paleontology. 2010. *Standard Procedures for the Assessment and Mitigation of Adverse Impacts to Paleontological Resources*. Impact Mitigation Guidelines Revision Committee. Available: http://vertpaleo.org/The-Society/Governance-Documents/SVP_Impact_Mitigation_Guidelines.aspx.

Accessed: April 8, 2016.

requirements of the CBC as part of their respective building codes, new buildings and facilities in the project area would be required to be sited and designed in accordance with the most current geotechnical and seismic guidelines and recommendations. The proposed project and other development projects would implement all necessary design features recommended by site-specific geotechnical studies, as required for all development applications, to reduce the risk from seismic activity, unstable slopes, and soil limitations, as required by law. Therefore, cumulative impacts related to seismic hazards would be *less than significant*.

Impact C-GE-2. The proposed project, in combination with other development within the city, would not substantially increase soil erosion potential. (Less than Significant)

Because erosion and corresponding sedimentation are processes that operate on the watershed level, the study area for erosion impacts for the proposed project is the Mission Bay watershed (see Section 4.N, *Hydrology and Water Quality*). The Mission Bay watershed is considered already built out. Consequently, potential growth would most likely occur as redevelopment and not extensive new development on vacant land or open space. Nonetheless, construction and operation of reasonably foreseeable projects could expose soil surfaces and alter soil conditions. To minimize the potential for cumulatively considerable erosion, all reasonably foreseeable projects would be required to conform to the provisions of applicable local ordinances and state regulations pertaining to erosion and sedimentation control, including the federal and state NPDES program and BMPs in site-specific SWPPPs. Therefore, cumulative impacts related to soil erosion would be *less than significant*.

Impact C-GE-3. The proposed project, in combination with other development within the city, would not substantially increase soil hazards. (Less than Significant)

The study area for the analysis of impacts on development from hazardous soil conditions, specifically expansive and corrosive soils, is limited to the project site. The proposed project would not increase the expansive or corrosive properties of the soils that are present at the project site, nor would other proposed development within the city affect the project site. Further, development is required to undergo an analysis of geological and soil conditions that is applicable to the specific individual project. Restrictions on development would be applied in the event that geological or soil conditions pose a risk as a result of site-specific soil hazards. Because the City and County of San Francisco and Port use and enforce the requirements of the CBC as part of their respective building codes, new buildings and facilities in the project area would be required to be sited and designed in accordance with the most current geotechnical guidelines and recommendations. Proposed projects would include all necessary design features, as recommended by the site-specific geotechnical studies, to reduce the risk from seismic activity, unstable slopes, and soil limitations, as required by law. With adherence to the building code and related plans, regulations, and design and engineering guidelines and practices, cumulative impacts related to soil hazards would be *less than significant*.

Impact C-GE-4. The proposed project, in combination with other development within the city, could result in impacts to paleontological resources. However, the project's contribution would be less than cumulatively considerable. (Less than Significant with Mitigation)

The study area for cumulative impacts on paleontological resources is defined for the proposed project as the San Francisco area, Mission Bay, and San Francisco Bay. In this area, construction activities associated with the proposed project could disturb or destroy paleontological resources that may exist in the study area, thereby contributing to the progressive loss of such resources. Cumulative growth and development in the city could have impacts if important paleontological resources are found during construction activities. Although the potential for other individual projects to affect important paleontological resources is unknown, given the number of projects in the city, it is probable that cumulative growth and development could have impacts on important paleontological resources. Cumulative impacts could be significant. However, Mitigation Measure M-GE-5, Accidental Discovery of Paleontological Resource, would reduce potential impacts to a less-than-significant level. Therefore, although cumulative development impacts related to paleontological resources would be considered significant, the incremental effects of the proposed project, after mitigation, would not be cumulatively considerable.