5 Geologic and Geotechnical Assessments

5.1 Regional and Site Geology

Gilpin Geosciences, Inc. assessed the site conditions and prepared an engineering geologic evaluation of the project area, which is included as Appendix D. The site is located in the Coast Ranges geomorphic province that is characterized by northwest-southeast trending valleys and ridges. These are controlled by folds and faults that resulted from the collision of the Farallon and North American plates and subsequent shearing along the San Andreas Fault.

The Merced Formation crops out in a broad trough that is partially exposed along the coastal bluffs of the site vicinity. It is of Plio-Pleistocene age (5 million to 10,000 years ago) and is characterized by sands and fine-grained deposits deposited in near-shore ocean environments with some units deposited onshore as dune fields. It is mapped as filling a northwest-southeast trending, fault-bounded basin that is exposed for approximately 3.8 miles along the sea cliffs from Mussel Rock on the south to the north end of Lake Merced. The Merced Formation is overlain by the Late Pleistocene age (125,000 to 10,000 years ago) Colma Formation, which is composed of sandy near-shore and beach deposits and recent dune sands.

Several investigators have mapped the Merced Formation in the bluffs in the site vicinity. Hall (1966 and 1967) and Clifton and Hunter (1987) mapped the Merced Formation in detail to understand the age range and rapid changes in depositional environments preserved in the deposits outcropping along the Fort Funston / Thornton Beach coastal bluffs.

Strike and dip of bedding within the Merced Formation sand and mud units varies along the coastal bluffs north of Fort Funston. Strike and dip are approximately NW with a dip angle of 8 to 75 degrees northeast. A review of orientation and dips gives some suggestion of a shallowing dip along the section of the coastal bluff associated with the complex landsliding.

The site is blanketed by sands of the Colma Formation. The Colma sands at the site vary in thickness from about 25 feet to 40 feet, are moderately cemented to uncemented, and contain varying amounts of clay and silt. A few feet of recent dune sand and/or sand fill locally overlie the Colma sands.

The bluff top areas in the site vicinity have a long history of shallow and deep-seated landsliding. The landslide events that have occurred in the vicinity are compiled in Table 1 of Appendix D and include off-site areas of the Olympic Club, Thornton State Beach, and Thornton Beach Road (which is currently washed out). The area from the southern edge of Fort Funston to Thornton Beach includes a large rotational landslide. However, depositional units of the Colma and underlying Merced Formation could be mapped on the coastal bluffs. The largest of these landslides is the Thornton Beach landslide shown in Figures 1 and 2 of Appendix D.

Evidence of deep-seated landsliding in the vicinity of Thornton State Beach is based on dramatic topographic and historic movement data. The toe of the bluff along much of the project area forms the eastern edge of a large linear depression. The depression resulted from the movement of a large coherent block of Merced Formation material toward the ocean. This depression, or graben, extends from just south of John Daly Boulevard north to the southern end of the Fort Funston facilities. Since the graben formed, erosion and shallow landsliding of the bounding slopes have partly filled it. The bluff forms the headscarp of the landslide that may extend to depths of approximately 140 feet below sea level.

Bonilla (1960) mapped landslide deposits, described the Thornton Beach landslide complex, and estimated the depth of the landslide basal slip surface at approximately 140 feet below sea level based on the geometry of the blocks involved and detailed surface mapping. Bonilla's interpretation is shown on Figures 1 and 3 in Appendix D.

Although the age of this landslide is not known, it is estimated (based on a study of the slope stability and assumed local bluff retreat rates) to have originated around 400 years ago (Liebhart, 2002). The slide topography is shown on the earliest U.S. Coast and Geodetic topographic map of the area published in 1869.

The 1957 Daly City earthquake triggered a number of landslides along the coastal bluffs between Pacifica and Lake Merced, damaging the coast highway (State Route 1), which formerly ran along the coastal bluffs south of Thornton State Beach. The highway was abandoned in 1958 because of ongoing landslides. However, a portion of the highway was repaired and used for beach access. It was called Thornton Beach Road. Landslides and erosion eventually forced closure of this road as well. Since then, heavy rains in 1982 and 1983, and reported road drainage problems, appear to have started a cycle of cliff erosion that has undermined and washed out Thornton Beach Road and buried the parking lot that was situated in the depression.

The 1989 Loma Prieta earthquake caused shaking that triggered a very large block failure in the coastal bluff approximately 2 miles south of Thornton Beach (Sitar, 1991). Because of this long history of slope instability, potential liquefaction and earthquake-induced landslide hazards have been mapped along the coastal bluffs, as shown on Figure 5 in Appendix D (CGS, 2000). Slope instability, liquefaction potential, and seismic hazards should be considered during subsequent design phases.

The Serra Fault has been mapped crossing the site (Kennedy, 2002 and 2004). The Serra Fault is the northernmost fault in the Foothills thrust system, a zone of northwest-striking thrust faults adjacent to and northeast of the Peninsula Segment of the San Andreas Fault. The thrust faults generally dip southwest towards the San Andreas Fault and probably merge with it at depth. The Serra Fault is mapped as a blind feature in the site vicinity (it is not exposed at the surface but buried beneath young surficial deposits). Kennedy (2002 and 2004) has shown that folding in the Merced Formation units is compatible with thrusting on the Serra Fault. The Serra Fault is probably not seismogenic (capable of generating an earthquake), but it is subject to displacements during large earthquake events on the San Andreas Fault. Recent investigations along the Serra Fault trace south of the site (Kennedy and Hitchcock, 2004) have determined that the fault appears to have been active in the Holocene age (11,000 years ago or less). Faults interpreted by Marliave (1945 and 1947) in the Vista Grande Tunnel construction documents may be related to the Serra Fault. Marliave estimated the total fault offset at up to 40 feet.

5.2 Regional Seismicity

The seismicity in the Daly City area is related to activity on the San Andreas system of active faults. The faults in this system are characterized by right lateral, strike-slip movements that are predominantly horizontal. The major active faults in the area are the San Andreas, Hayward, and San Gregorio Faults. These and other active[2] or potentially active[3] faults of the region are shown on Figure 3, Appendix D. The

[2] Active faults are defined as those exhibiting either surface ruptures, topographic features created by faulting, surface displacements of Holocene age (younger than 11,000 years old), tectonic creep along fault traces, and/or close proximity to linear concentrations or trends of earthquake epicenters.
[3] Potentially active faults are those that show evidence of displacement of surficial deposits of Quaternary age (less than 2 milllon years old).

distance of some of these faults from the site and their estimated maximum credible events are summarized in Table 5.1.

Three major earthquakes have been recorded on the San Andreas Fault since 1800. In 1838, an earthquake occurred with an estimated intensity of about VII on the Modified Mercalli Intensity Scale, as shown on Figure 8 in Appendix D, corresponding to a Magnitude of about 7. The San Francisco Earthquake on April 18, 1906 caused the most significant damage in the history of the Bay Area in terms of loss of life and property damage. This earthquake surface rupture along the San Andreas extended approximately 270 miles in length and recorded displacements of up to 21 feet. The Magnitude-8.3 event was felt in Oregon, Nevada, and Los Angeles. The epicenter of the 1906 event is estimated to be offshore of the San Francisco coastline and within a few miles of the project site.

Another smaller, but notable, earthquake on the San Andreas Fault occurred on March 22, 1957. The epicenter of the Daly City Magnitude-5.4 earthquake was near Mussel Rock, about two miles south of the site. Although this was a relatively small earthquake of short duration (about five seconds of strong shaking), it caused liquefaction-induced landslides along the banks of Lake Merced and slope failures along California Route 1.

In 1836, an earthquake with an estimated intensity of IX occurred in the vicinity of San Juan Bautista, probably on the San Andreas Fault. An earthquake occurred in 1838 on the southern peninsula segment of the San Andreas Fault (Toppozada and Borchardt, 1998).

In 1868, an earthquake with an estimated maximum intensity of X occurred along the Hayward Fault. This earthquake is believed to have had a Magnitude of 7 or greater. In 1861, an earthquake of unknown Magnitude, estimated at 6.5, was reported on the Calaveras Fault.

5.3 Geotechnical Literature Research

Treadwell and Rollo prepared a geotechnical assessment of the project area by collecting available geotechnical information and interpreting the information relative to the proposed alternative designs. Treadwell and Rollo's report is included as Appendix E. Information was obtained from past construction projects, landslide investigations, historical records, and other sources. In this phase, field subsurface investigations were not performed. Two alignment corridors were explored: a Northern Alignment for Alternatives 1A, 5B, 6, and 7 and a Southern Alignment for Alternative 4. This information could be used to develop a geotechnical exploration program when the preferred alternative is selected.

Treadwell and Rollo reviewed available literature regarding the geotechnical conditions along the Northern and Southern Alignments. A list of pertinent maps, reports, borehole logs, site plans, and other literature used during Treadwell and Rollo's research is presented in Appendix E.

Available geotechnical information in the vicinity of the Northern Alignment consists of a plan and profile drawing of the existing Lake Merced Sewer Tunnel (owned by the City and County of San Francisco). This tunnel is parallel to and located about 100 feet north of the existing Vista Grande Tunnel. The Lake Merced Sewer Tunnel profile begins near John Muir Drive and runs to the San Francisco Outfall Structure at the beach. The profile includes information from six borings drilled from the ground surface to about Elevation -5 to -10 feet (datum not specified), which corresponds to a depth of about 5 feet below the bottom of the Lake Merced Sewer Tunnel.

Available geotechnical information in the vicinity of the Southern Alignment primarily consists of relatively shallow borings (depths of 20 to 70 feet). Two deep borings (110 to 120 feet) were drilled in the vicinity of Skyline Boulevard and the Southern Alignment.

5.4 Anticipated Subsurface Conditions at Westlake Park

Available information indicates that subsurface conditions in the vicinity of Westlake Park consist of up to 10 feet of loose to medium dense sandy fill. The fill is likely underlain by medium dense to dense sand and silty sand layers to depths of about 30 to 40 feet. Beneath depths of 30 to 40 feet are dense to very dense sand with variable amounts of silt and thin layers of silt and clay. These extend to the maximum depth explored: about 72 feet below the present ground surface.

Groundwater was encountered at a depth between 20 and 40 feet. The anticipated groundwater flow into the excavation will affect the constructability of the detention structure. The combination of significant groundwater inflow through the loose to medium dense sand layers may develop into a flowing ground condition. Controling the ground and minimizing surface settlement may be difficult when the ground is flowing. Soft ground excavation methods would be appropriate for construction of a subsurface structure in Westlake Park.

5.5 Anticipated Ground Conditions for New Tunnel

5.5.1 Tunnel Alignments

All of the tunnel alignments are predominantly located in moderately cemented to uncemented sand deposits of the Colma Formation, but may extend into recent dune sands (near the west end). The Colma Formation ranges from 35 to 40 feet thick and contains varying amounts of clay and silt. The Merced Formation, which underlies the Colma sands, consists of sand and fine-grained deposits. Inland, groundwater is anticipated to be located at approximately Elevation 12 feet. At the beach, it will be tidally influenced. These elevations are below the tunnel invert. However, zones of perched groundwater were encountered during the excavation of the original Vista Grande Tunnel.

Geologic conditions along the Northern and Southern Alignment corridors are different. The biggest difference is the presence of significant deep-seated and shallow landslides along the coastline in the Southern Alignment corridor. These slides are presumed to be active although their activity and magnitude of future movement have not been quantified. Their influence on the proposed project features should be evaluated during the detailed design process.

One “shear” has been mapped in the vicinity of the Southern Alignment and two possible faults were encountered during the excavation of the existing Vista Grande Tunnel. The shear is apparently active and extends up through the Merced Formation and the Colma Formation to the root mat. It may be necessary to develop seismic design provisions for fault offset for tunnels constructed in the Southern Alignment corridor.

The Colma Formation encountered along the alternative tunnel alignments will be in soft ground tunneling conditions. Ground conditions for soft ground tunneling can be described according to six generalized categories, as summarized in Table 5.2. Generally, uncemented to weakly cemented Colma Formation sands are expected to exhibit slow to fast raveling behavior above the groundwater level. Stand-up time (the time between exposure of an area at the crown of the tunnel and the beginning of noticeable inward movement of the ground in said area) is expected to be less than 30 minutes for the uncemented and weakly cemented material. Cleaner, poorly graded sands within the tunnel will exhibit limited or no cohesion and are expected to run when exposed. Cemented Coloma Formation could be encountered in localized areas and will exhibit the characteristics of firm ground.

Although the groundwater level is anticipated to be below the tunnel excavation (except possibly at the west portal), localized flowing ground conditions might be encountered if perched groundwater is breached. Similar running and flowing ground conditions are anticipated in the Merced Formation. Flush flows occurred during the construction of the original Vista Grande Tunnel when tunnel excavation penetrated a fine-grained aquitard. Similar flush flows may be encountered during future tunnel construction. A detailed geotechnical investigation will be needed to determine if these groundwater conditions may be present.

5.5.2 Potential Settlement Due to Tunnel Construction

Appropriate tunneling methods and equipment will have to be selected for this project in order to control loss of ground and subsequent ground deformations and surface settlement. The Southern Alignment crosses beneath a housing subdivision, while the Northern Alignment crosses beneath a large grouping of buildings along John Muir Drive. Ground loss could lead to ground settlement magnitudes significant enough to damage structures within the tunnel's zone of influence. In uncemented sands, loss of ground could lead significant surface settlement and damage to overlaying roadways, utilities, and structures. Significant loss of ground would occur if flowing ground conditions were allowed to develop. In addition to tunneling equipment with the capability of providing face support, ground modification measures may be required to control or mitigate ground loss and resulting surface settlement.

During the construction of the Lake Merced Transport Project, excessive ground settlement was encountered directly above the tunnel. The ground settlement ranged from 2 inches in the Colma Formation to 7 inches in dune sand deposits. These small settlements could result in a trough forming along portions of the alignment.

5.6 Recommended Tunneling Methods

Available subsurface information is insufficient to develop final geotechnical conclusions and recommendations for the proposed alternatives. However, preliminarily, the Northern Alignment appears to be feasible based on our geologic reconnaissance and document review. Based on historic landslide impacts to existing developments and the estimated depth of the failure plan (as presented in the geologic evaluation letter prepared for this project), the Southern Alignment is not considered as feasible an alignment to route tunnels or pipes.

Tunneling machine options for this project include use of a tunnel shield or soft ground tunnel boring machine (TBM). An earth pressure balance (EPB) TBM is considered feasible for this project. These machines can be configured to operate in open mode when the ground is stable. In unstable ground the TBM uses the soil itself, mixed with ground conditioners and water, to form a viscous paste which provides face support and to prevent the sandy soils from plugging. To support slow to fast raveling ground in portions of the face, digger shields are outfitted with breast tables or breasting doors to provide face support while continuing excavation in other areas of the face. Digger shields can also be fitted with a full bulkhead for safety and to support the face in unstable ground. An important feature on this type of shield is the forward projection of the crown of the shield to form a protective hood that can help reduce ground loss. Wheel-type machines are less favorable than the other options because these machines will disturb the entire face and could potentially increase loss of ground in running ground conditions. Wheel-type machines also have no ability to control ground in flowing ground conditions.