4.9

GEOLOGY, SOILS, AND SEISMICITY

4.9.1 INTRODUCTION

Information about the geological conditions and seismic hazards in the study area was summarized in the FEIR, and was based on the *Geotechnical Exploration Findings and Recommendations Report* (Earth Tech, Inc. 2003) prepared during the Conceptual Engineering design phase of the Project. During the Preliminary Engineering design phase, several additional geotechnical and seismic study reports were prepared, which are listed in Chapter 13, *Bibliography*. The purposes of the studies were to evaluate the general subsurface conditions and seismicity in the Project area, evaluate engineering properties related to soil conditions, and provide preliminary geotechnical recommendations for the BART Extension Project.

To evaluate the geologic conditions representative of the study area during the Preliminary Engineering design phase, readily available geologic publications and consultants' reports were reviewed, and subsurface exploration was conducted. The subsurface exploration consisted of 141 geotechnical borings and 23 cone penetrometer tests (CPTs) that were drilled or pushed during preliminary engineering for the first 9.3 miles of the BART Extension Project (from the planned BART Warm Springs Station to the east tunnel portal). The sampling depths generally ranged from 25 to 100 feet below ground surface (bgs). For the tunnel alignment, 76 geotechnical borings were drilled. Of these, 20 were drilled at three proposed underground stations (Alum Rock, Downtown San Jose,and Diridon/Arena), 53 along the tunnel alignment, and 3 at the portals. In addition, 146 CPTs were performed along the tunnel alignment, including 38 CPTs at the three proposed underground stations. The sampling depths for the borings and CPTs ranged from near surface to up to approximately 220 feet bgs. For the yard and shops facility, 32 geotechnical borings and 35 CPTs were drilled or pushed. The sampling depths for the borings and CPTs ranged from 20 to 81 feet bgs. Other tests, including those that measure groundwater levels, were also conducted with the methods described in the geotechnical study reports.

4.9.2 ENVIRONMENTAL SETTING

4.9.2.1 Faults and Seismicity

The FEIR did not include a discussion of the Silver Creek fault. This fault is partially located in the study area. Its southern reach is exposed at the surface, while the northern reach, which crosses the BART tunnel alignment west of Alum Rock Station, is an inferred fault that is buried beneath undisturbed Quaternary sediments. A recent study concluded that the potential for fault rupture along the northern reach is negligible (Geomatrix 2004; HMM/Bechtel 2005).

Table 4.9-1 is revised from the FEIR to include updated information on the faults in the region, along with information on their location and past and probable future seismic activity, including 2002 data from the Working Group on California Earthquake Probabilities (the FEIR included 1999 data). Also, the main mapped thrust faults of the Foothills Thrust Belt are listed and the Silver Creek Fault is added.

4.9.2.2 Soils and Surficial Deposits

Based on geotechnical investigations conducted during the Preliminary Engineering design phase of the Project, near surface soil conditions beneath the study area generally consist of low to medium plasticity, stiff clays with interbedded clayey sand, silty sand, and gravel layers. These findings are consistent with the findings during the Conceptual Engineering design phase.

4.9.2.3 Liquefaction

Based on geotechnical investigations conducted during the Preliminary Engineering design phase of the Project, about half of the study area is within areas of high to very high liquefaction susceptibility, and about half is within areas of moderate susceptibility based on seismic hazard evaluation and mapping by the California Geological Survey (see Section 4.9.3.2). These findings are consistent with the findings during the Conceptual Engineering design phase.

4.9.3 REGULATORY SETTING

The FEIR did not include a discussion of the laws and regulations applicable to geology, soils, and seismicity. Therefore, the discussion is provided here.

4.9.3.1 Alquist-Priolo Earthquake Fault Zoning Act

The State of California maps Earthquake Fault Zones around active faults under the Alquist-Priolo Earthquake Fault Zoning Act. The purpose of the Act is to regulate development on or near faults traces to reduce the hazard of fault rupture and to prohibit the location of most structures intended for human occupancy across these traces. The Act only addresses the hazard of surface fault rupture and does not address other earthquake hazards such as earthquake-induced landslides, ground shaking, and liquefaction.

4.9.3.2 Seismic Hazards Mapping Act

The California Geological Survey addresses earthquake hazards other than surface fault rupture under the Seismic Hazards Mapping Act. Under the Act, various Seismic Hazard Zones are delineated on maps that identify areas potentially susceptible to earthquake-induced landslides and liquefaction. When a project falls in a Seismic Hazard Zone, the seismic hazard potential must be evaluated with site-specific studies and standard analysis procedures to identify ways to reduce hazards, as necessary.

TABLE 4.9-1:

Faults in the Vicinity of the Silicon Valley Rapid Transit Corridor Study Area

FAULT/THRUSTS	LOCATION AND DESCRIPTION	SEISMIC ACTIVITY
Hayward Fault	Closest active fault to the study area. Extends 100 km from the area of Mount Misery in San Jose to Point Pinole on San Pablo Bay.	Last major earthquake occurred in October 1868 and had a Richter magnitude of 7. Capable of generating MCE of Mw 7.1 (WGCEP 2002).
Hayward Southeast Extension	Sequence of southwest–verging, reverse faults, located in the restraining left-step between the Calaveras and Hayward faults.	Capable of creating a MCE of Mw 6.7, with a recurrence interval of 292 years (WGCEP 2002).
Rodgers Creek Fault	44 km long, northern continuation of Hayward Fault.	Most likely source of the next Mw 6.7 or larger earthquake in the Bay Area, with 27 percent probability of occurring in the time period 2002 to 2031 (WGCEP 2002).
Calaveras Fault	Main component of the San Andreas system, branching off the main San Andreas Fault south of Hollister, extending northward for approximately 120 km and ending in the area of Danville.	Generated a number of moderate-size earthquakes in historic time, including the 1979 local magnitude (ML) 5.9 Coyote Lake and 1984 ML 6.2 Morgan Hill events. WGCEP (2002) suggests that the probability of one earthquake with mean magnitude from M 5.8 to M 6.9 occurring in 2002-2031 is 59 percent.
Foothills Thrust Belt	Sequence of southwest dipping thrusts, bounded by the San Andreas Fault to the west. From north to south, the main mapped thrust faults include the Stanford, Pulgas, Monte Vista, Shannon, Berrocal, Sierra Azul, and Sargent faults.	Active faults, capable of generating MCE of Mw 6.8 (Fenton and Hitchcock 2001).[1]
San Andreas Fault	Extends from the Gulf of California, Mexico, to Point Delgado on the Mendocino Coast in Northern California, a total distance of 1,200 km.	Largest active fault in California, responsible for the largest earthquake in the state, the 1906 Mw 7.9 San Francisco earthquake. Assigned a recurrence interval of 378 years to a Mw 7.9 1906-type event (WGCEP 2002).
San Gregorio Fault	Principal active fault west of the San Andreas Fault in the coastal region of Central California.	WGCEP (2002) assigns a MCE of Mw 7.4 with a recurrence interval of 1,202 year for an earthquake rupturing the entire length of the fault.
Monterey Bay-Tularcitos Fault	Zone of strike-slip faulting comprising the Monterey Bay, Navy, and Tularcitos faults.	The largest historical earthquakes that have occurred in this zone are Mw 5.8 earthquakes on February 1870 and March 1910. No other historical earthquakes of magnitude greater than 5.0 have occurred in the Monterey Bay source zone.
Concord-Green Valley Fault	Continuation of the Concord Fault on the northern side, the Green Valley Fault is a northwest-striking right-lateral strike-slip fault of the San Andreas system.	WGCEP (2002) assigns a MCE of Mw 6.7 with a recurrence interval of 580 years for an earthquake rupturing the entire length of the fault.
West Napa Fault	North-northwest-striking right lateral strike-slip fault located along the western side of Napa Valley, from south of Napa to Yountville, a distance of approximately 25 km.	Rupture of the entire fault would generate a MCE of Mw 6.5 (WGNCEP 1996) with a recurrence interval of 700 years.
Greenville Fault	North-northwest to northwest-striking strike-slip fault of the San Andreas system in the northern Diablo Range, extending from Bear Valley to just north of Livermore Valley.	WGCEP (2002) assigned a maximum earthquake of Mw 6.9.
Ortigalita Fault	North-northwest-striking, right-lateral strike-slip fault, 66 km long, located in the southern Diablo Range.	The MCE is Mw 6.9, with an effective recurrence of 1,100 years (WGNCEP 1996).
Coast Range-Sierran Block Boundary	Complex zone of thrust faulting that marks the boundary between the Coast Range block and the Sierran basement rocks that are concealed beneath the Great Valley sedimentary rocks of the Sacramento and San Joaquin Valleys.	The closest segments of the Coast Range-Sierran Block Boundary are capable of generating a MCE of Mw 6.6 to 6.7 (WGNCEP 1996).
Sacramento Delta Faults	Consist of a number of Quaternary active thrust faults (Roe Island Thrust, Potrero Hills Thrust Fault, Pittsburg-Kirby Hills Fault, and Midland Fault) beneath a series of right-stepping en echelon anticlines to the north of Mount Diablo.	The Mw of MCE and slip rates for these faults are as follows: Roe Island Thrust Fault – MCE of Mw 5.5 to 6.0; Potrero Hills Thrust Fault – MCE of Mw 6.0; Pittsburg-Kirby Hills Fault – MCE of Mw 6.3; Midland Fault – MCE of Mw 6.3.
Mount Diablo Thrust Fault	Northeast dipping, southwest propagating thrust fault beneath the Mount Diablo anticline.	Capable of generating a MCE of Mw 6.8 (Unruh 1995)[2]

FAULT/THRUSTS	LOCATION AND DESCRIPTION	SEISMIC ACTIVITY
Los Medanos Thrust	Underlies the asymmetric, southwest-tilted Los Medanos and Concord anticlines.	The MCE for the thrust ranges from Mw 5.8 to 6.3 (Unruh 1997)[3]
East Bay Thrust Domains	Region of elevated topography between the Hayward and Calaveras faults. Consists of three domains: Western East Bay Hills, Southern East Bay Hills, and Northern East Bay Hills domains.	The Mw of MCE these domains can generate are as follows: Western East Bay Hills Domain - capable of generating MCE of Mw 6 (Wakabayashi and Sawyer 1998);[4] Southern East Bay Hills Domain - capable of generating earthquakes of Mw 6.3 to 6.5; Northern East Bay Hills Domain - capable of generating earthquakes of Mw 6.3 to 6.8 (Geomatrix Consultants 1998).
Quien Sabe Fault	Right-lateral strike-slip fault, 22 km long, located to the east of Tres Piños.	Capable of generating a MCE of Mw 6.4 (WGNCEP 1996).
Silver Creek Fault	Generally a north-northwest trending oblique-reverse-slip fault that extends over a distance of about 50 to 70 km, subparallel to and west of the Hayward and Calaveras fault zone (Fenton and Hitchcock, 2001).	Maximum magnitude distribution for the faults is in the range of 6.3 to 6.9 (HMM/Bechtel 2005).

NOTES:

km = kilometer(s)

MCE = maximum credible earthquake

Mw = moment magnitude

1 Fenton, C.H. and C.S. Hitchcock 2001. "Recent geomorphic and paleoseismic investigations of thrust faults in Santa Clara Valley, CA." Ferriz, H., and R. Anderson (eds.), Engineering Geology Practice in Northern California: California Geological Survey Bulletin 210, p. 71-89.

2 Unruh, J.R. and T.L. Sawyer 1995. "Late Cenozoic growth of the Mt. Diablo fold-and-thrust belt, central Contra Costa County, California, and Implications for Transpressional Deformation of the northern Diablo Range," American Association of Petroleum Geologists, 1995, Pacific Section Convention Abstracts, p. 47.

3 Unruh, J.R. and T.L. Sawyer 1997. "Assessment of blind seismogenic sources, Livermore Valley, eastern San Francisco Bay region," final technical report submitted to the U.S. Geological Survey, National Earthquake Hazards Reduction Program Award No. 1434-95-G-2611.

4 Wakabayashi, J. and T.L. Sawyer 1998. Holocene (?) oblique slip along the Miller Creek fault, eastern San Francisco Bay Area, California: EOS, v. 79, no. 45.

Sources: URS Corporation 2002; Working Group on California Earthquake Probabilities (WGCEP) 2002, HMM/Bechtel 2005; Geomatrix Consultants 2004; Kleinfelder, Inc. 2006

4.9.3.3 California Building Code

The California Building Code is contained in the California Code of Regulations, Title 24, Part 2, which is a portion of the California Building Standards Code, and includes design and construction requirements related to fire and life safety and structural safety. The California Building Code incorporates the Uniform Building Code (a widely adopted model building code in the United States) by reference, and includes necessary California amendments. These amendments include criteria for seismic design.

4.9.4 PROJECT IMPACTS AND MITIGATION MEASURES

This section includes updated information based on the geotechnical investigations conducted during the Preliminary Engineering design phase. The discussion applies to the design and operational phase of the Project. Potential impacts related to the construction phase are discussed in Section 4.18.

4.9.4.1 Surface Fault Rupture

There are no known active faults crossing the BART Extension Project, and the study area is not located within an Earthquake Fault Zone, as defined and mapped under the Alquist-Priolo Earthquake Fault Zoning Act. Therefore, the potential for ground rupture due to faulting is considered very low. The closest distance to a mapped active fault trace is the alternative south end of the Hayward Fault at approximately 1.5 kilometer (km) (approximately 1 mile) from the northern end of the Project (the BART Warm Springs Station in Fremont). The Monte Vista-Shannon fault is approximately 11.26 km (7.0 miles) southwest of the yard and shops facility. While the northern reach of the Silver Creek Fault crosses the tunnel alignment west of the Alum Rock Station, a thorough study concluded that the potential for fault rupture along this reach is negligible (Geomatrix Consultants 2004; HMM/Bechtel 2005).

4.9.4.2 Earthquake-Induced Landslides

The Project is located on nearly flat terrain, and the Project area is not identified on any California Geological Survey Seismic Hazard Zone maps as being potentially susceptible to earthquake-induced landslides. Therefore, this potential hazard is considered very low.

4.9.4.3 Ground Shaking

The three active faults with the greatest potential for ground shaking of the Project are the San Andreas, Hayward, and Calaveras faults. However, other faults in the region may also produce significant ground shaking. Therefore, the potential for strong ground shaking is considered moderate to high.

All structures associated with the BART Extension Project would be designed and built in accordance with current seismic design standards contained in the California Building Code and other applicable building codes. Structures would also be designed and built in accordance with seismic design standards contained in the BART Facilities Standards, Release 1.2 (May 2004). The ground motion criteria to be used for seismic design of the BART trackway structures—including tunnels, underground and aboveground passenger stations, bridges, retaining walls, cut-and-cover, and U-wall subway structures—would be in accordance with ***SVRT Tunnel Segment Report on Seismic Ground Motions*** (HMM/Bechtel 2005). These design requirements would reduce the potential exposure of people to hazard from seismic risk associated with ground shaking.

For the BART tunnel, closed-face tunnel boring machines would be used to install pre-cast gasketed segmental concrete lining units. Six or seven units are mechanically connected to each other to form a single ring that connects to the previous ring. This system is referred to as a Precast Concrete Tunnel Lining (PCTL) and is a single-pass lining that would stabilize the ground and limit groundwater inflow into the tunnel excavation (see Section 4.19.2). Due to the jointed construction and resulting inherent flexibility, PCTLs are able to accommodate ground shaking with little or no damage compared to stiffer forms of lining. PCTL systems have been used extensively in seismically active locations, including Japan, Venezuela, Puerto Rico, Iran, Taiwan, Mexico, Turkey, Spain, Italy, Greece, and the United States, and continue to be specified for bored tunnel construction in seismic areas.

4.9.4.4 Liquefaction

The BART Extension Project falls partially or completely within liquefaction hazard areas on three Seismic Hazard Zone maps (Milpitas Seismic Hazard Quadrangle, October 2004; San Jose East Quadrangle, January 2001; and San Jose West Quadrangle, February 2002.). As these maps are based on a broad characterization of soil conditions, site-specific liquefaction studies were conducted along the alignment to account for local soil variations. The results indicated that portions of the Project are susceptible to liquefaction. In locations susceptible to liquefaction, the primary hazards are seismic induced settlement and temporary increase in lateral earth pressures on below-grade structures.

The BART Facilities Standards limit total settlements for trackway structure foundations to 1 inch or less; thus, there would be a need to reduce the liquefaction-related settlement hazard along some portions of the BART alignment. Methods used on recent BART projects include in-situ treatment/densification with vibro-replacement stone columns; load transfer to underlying bearing layers, which are non-liquefiable with soil/cement columns; and the overexcavation method via removal and replacement with compacted engineered fill. Methods considered for the BART Extension Project to eliminate or minimize the effects of seismic liquefaction include, but are not limited to, in-situ densification with stone columns, dynamic compaction, vibro-compaction, surcharging, and/or compaction grouting. The exact methodology(ies) to be used will be determined during final engineering. These design requirements would reduce the potential exposure of people to hazard from seismic risk associated with liquefaction. Therefore, no additional mitigation is required.

CONCLUSION

With implementation of design requirements such as the California Building Code and BART Facilities Standards, the Project design changes would not expose people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving: rupture of a known earthquake fault; strong seismic ground shaking; seismic-related ground failure (including liquefaction); landslide, lateral spreading, subsidence, liquefaction, and collapse as a result of underlying unstable geologic units; or expansive soil. No mitigation is necessary.