Date: May 2, 2011

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Subject: **Preliminary literature and geomorphic evaluation of the eastern Santa Monica Fault Zone and potential impacts associated with fault surface rupture relative to proposed LA Metro stations in Century City, California.**

Mr. Rochefort,

Kenney GeoScience (KGS) is pleased to provide you this report providing preliminary findings regarding potential fault surface rupture hazards associated with two proposed LA Metro Stations in the Century City area. Specifically, to evaluate potential fault surface rupture hazard associated with the Santa Monica Fault Zone relative to the Base and Constellation Boulevard proposed LA Metro Stations. The Base Station is proposed along Santa Monica Boulevard near the intersection of Avenue of the Stars, and the Constellation Station is proposed along Constellation Boulevard and the intersection of Avenue of the Stars. This report also provides a preliminary evaluation of fault parameters such as reasonable anticipated moment magnitude and displacement per event for future major earthquakes on the Santa Monica Fault Zone. The results of this study are based on evaluation of previously published and unpublished geologic studies, and a regional and site geomorphic analysis of the Santa Monica Fault Zone.

EXECUTIVE SUMMARY

- Only one strong geomorphic lineament was identified referred herein as the Santa Monica Fault Lineament (SMFL) and it clearly does not exhibit significant vertical displacement.

- A couple of very weak geomorphic lineaments are observed in the Cheviot Hills south of the SMFL that may be associated with faulting but could easily have resulted from erosion of the hills. The likelihood of a well defined north dipping reverse fault reaching the surface during repeated major earthquakes in the Cheviot Hills is considered very low.

- No geomorphic scarp displaying significant vertical displacements was observed in the Century City area of the proposed Base and Constellation Stations. Thus, no scarp was identified in the study area that would have accommodated approximately 1 meter of offset across a discrete reverse fault over the course of thousands of years and presumably numerous major earthquakes. Therefore, it is the conclusion of this report that a north dipping reverse fault reaching the surface and accommodating even 1 meter of vertical displacement per event does not exist in the study area.

- The relatively strong geomorphic SMFL was likely produced by a near surface steeply dipping secondary strike-slip fault to the SMFZ or by erosion along a fold (kink) in the older alluvial fan sediments and surfaces produced by motion across a blind reverse fault strand to the SMFZ.

- A lack of any strong geomorphic scarp lineaments and evidence of vertical uplift and warping during the late Quaternary within the Cheviot Hills suggests that reverse faults exhibiting vertical displacements reside at depth beneath the Cheviot Hills. It is possible due to the distribution of deformation through the hills that the total magnitude of displacement of the SMFZ during a major earthquake would likely be distributed to a number of faults and many of these faults would not reach the surface (blind). In addition, relative uplift appears to have occurred parallel to and west of the poorly understood West Beverly Hills Lineament (WBHL). The combination of these two mechanisms of deformation may provide the best explanation of local tectonics.

- The total displacement during a major earthquake in the Century City area would likely be much less than the average displacement observed along the entire fault length. It was determined via a source parameter evaluation of the Santa Monica Fault Zone (SMFZ) that reasonable source parameters would include a moment magnitude Mw=7.1, with an average vertical displacement of ~2 meters (see next section for summary of source parameter evaluation). Thus, in the area of the proposed LA Metro Century City stations at the presumed eastern end of the SMFZ, the total displacement during a major earthquake would be much less than 2 meters. For discussion, we could reasonably indicate that the total vertical displacement may be on the order of 1 meter or less.

- The estimated1 meter or less of proposed total vertical displacement entering the Cheviot Hills during a major earthquake on the SMFZ may be partitioned to a series of bifurcated blind faults at depth causing local uplift and relatively small scale offsets across numerous strands.

- Although a subsurface investigation would need to be conducted to better understand near surface faulting in the Century City area, based on the results of this study, no geomorphic structures were observed in the region that have accommodated repeated displacements from many paleoearthquakes on the SMFZ. This observation suggests that if surface displacements occur in the area during a major earthquake on the SMFZ that the magnitude of slip is small (on the order of centimeters) across any one structure.

- Regardless of the mechanism that produced the SMFL it appears based on evaluation of the data that the active surface expression of the Santa Monica Fault Zone is weakening and possibly terminating within the Cheviot Hills near the Western Beverly Hills Lineament (WBHL).

- For design purposes, the proposed Base Station along Santa Monica Boulevard is located within the SMFL. Various fault models are provided in this report that provide geomorphic evidence that it is unlikely that a north dipping reverse fault produced the SMFL, that there is a relatively low to moderate probability that a strike-slip fault resides within the SMFL, and that there is a reasonable probability that no fault resides in the area of the Base Station as the SMFL may have been produced by erosion along a fold axis associated with blind faulting. In addition, if a strike-slip fault exists along the SMFL near the Base Station, geomorphic evidence indicates that the amount of slip across the fault per event is likely very small (centimeters).

- In the case of the proposed Constellation station, no moderately strong or strong geomorphic lineaments were identified in the area of the station. A very weak geomorphic lineament associated with a series of weak changes in slope across designated terraces transects the proposed station location.

- For design purposes and at a minimum, the Base and Constellation stations should anticipate near surface fracturing, minor uplift, warping/tilting and possible small scale offsets during a major earthquake on the Santa Monica and possibly Newport Inglewood fault zones.

- A future subsurface fault investigation utilizing one or a combination of fault trenching, seismic lines, continuous cores, large diameter bucket auger and CPT, would be required to better understand the style, location and magnitude of faulting in the area of the proposed Base and Constellation Stations.

- On a side note, based on my cross section analysis, it appears that the proposed Constellation station may reside in man made artificial fill placed within a local drainage (see Section A-A' on Plate E).

Site Description

The project site involves two proposed LA Metro underground mass transit stations in Century City referred to herein as the Base Station and Constellation Station (Plate B). The Century City stations are components of Option 4 of the Westside Subway Extension (Metro, 2010). The Base Station would be along Santa Monica Boulevard as the primary location with the alternative option of placing the station along Constellation Boulevard. The Base Station runs beneath the center line of Santa Monica Boulevard at the intersection of the Avenue of the Stars. Constellation Station is proposed beneath the center line of Constellation Boulevard with a center point at the intersection of the Avenue of the Stars. Plate G provides a design map of the Base Station along Santa Monica Boulevard.

Methodology and Data Sources

The findings in this report were achieved by the evaluation of pertinent existing published reports regarding the geologic history of the northern Los Angeles Basin with an emphasis on the eastern end of the Santa Monica Fault within the Cheviot Hills. Some important studies for this report include Hoots and Kew (1931); Wright (1991), Pipkin and Proctor (1992), Doland and Sieh (1992), Dolan and Pratt (1997), Pratt et al. (1998), Dolan Sieh and Rockwell (2000), Catchings et al. (2008 and 2010) and Metro (2010).

A geomorphic analysis of 1923 to 1925 USGS 5-foot contour topographic maps provided the primary data base for the evaluation of late Quaternary fault locations and characteristics of deformation. The 5-contour maps utilized were from a geologic map by Hoots and Kew (1931) that provides the base maps in Plates B and C.

Field mapping was conducted on April 5, 2011 along Club View Drive and Santa Monica Boulevard to evaluate existing topography along roadways and the Los Angeles Country Club.

Evaluation of faulting in the region of the proposed stations was limited due to the development of the area in the early 1900's (i.e. limits usefulness of aerial photographs), and lack of near site subsurface studies (paleoseismic trench studies, boring, CPT, etc).

Local Geology Near Century City

The local geology of the area near Century City exhibits elevated and dissected Quaternary (Late to latest Pleistocene) older alluvial fan deposits north of a relatively strong north-east-east trending geomorphic lineament mapped as the surface trace of the Santa Monica Fault by Dolan and Sieh (1992) and the east extension of the Petrero fault by Wright (1991). This lineament will be referred to herin as SMFL and is located essentially along the northern side of Santa Monica Boulevard in the Cheviot Hills that appears to have been constructed along an old railroad line (see Plate B).

The Cheviot Hills are generally considered as a group of eroding low lying hills south of the SMFL that extend eastward across the West Beverly Hills Lineament (WBHL; Plates B and C). These hills expose Quaternary Older alluvium (Qpt by Hoots and Kew, 1931; Qoa) that overly late Quaternary interbedded marine and terrestrial fan deposits (unit Qm of Hoots and Kew, 1931; Dibblee, 1991).

Although the Cheviot Hills are generally shown on geologic and topographic maps south of the SMFL, the area geomorphically connects with the previously described elevated and dissected series of Quaternary fan deposits (unit Qpt) north of Santa Monica Boulevard (Plate B). In addition, the Cheviot Hills and Beverly Hills Oil fields continue north across Santa Monica Boulevard. Within the Cheviot Hills numerous stream and marine terraces (likely fill and cut types) exist suggesting that latest Quaternary erosion and deposition occurred in the area during local uplift. No Quaternary marine deposits (unit Qm) are identified on the surface north of Santa Monica Boulevard however these sediments likely exist at fairly shallow depths beneath the alluvial fan deposits as shown on cross sections by Wright (1991) and Tsutsumi et al. (2001). Thus, geomorphic features change across the SMFL suggesting that this lineament is likely associated with a Quaternary deformational structure such as a fault. This will be discussed in more detail in the Findings section of this report.

At depth, Wright (1991) indicates that the Cheviot Hills exhibits a doubling plunging, west-northwest trending anticline and that the steep south flank of the fold is broken by the Rancho Thrust Fault over a kilometer deep (Figures 1 and 2). Wright (1991) also shows this antiform north of the SMFL associated with the Sawtelle Oil Field (see Plate B, inset cross section). These folds are shown on cross sections through the area by Tsutsumi et al. (2001) as well.

Wright (1991) and Tsutsumi et al. (2001) indicate that the SMFZ in the Cheviot and Beverly Hills has had a complex geologic history since the Miocene that involved numerous strands with varying levels of activity and sense of movement (normal vs reverse) throughout the late Cenozoic. Many of these faults no longer reach the surface within the Cheviot Hills (Figure 2). Many faults in the Santa Monica Fault Zone exhibited normal (extensional) displacement during the Miocene and subsequently experienced a tectonic inversion to exhibit a reverse sense of movement since the Pliocene (Wright, 1991; Tsutsumi et al., 2001).

Figure 1: Modified structural map from Wright (1991, Figure 14) showing the mapped surface trace of the active Potrero Canyon fault and the inactive Santa Monica Fault (structural contours) as it trends eastward into the Cheviot-Beverly Hills area. A literal interpretation of the Wright (1991) cross sections I-I' to H-H' indicate that with the Cheviot-Beverly Hills area, at least one strand of the Santa Monica Fault reaches the surface but that all other strands do not.

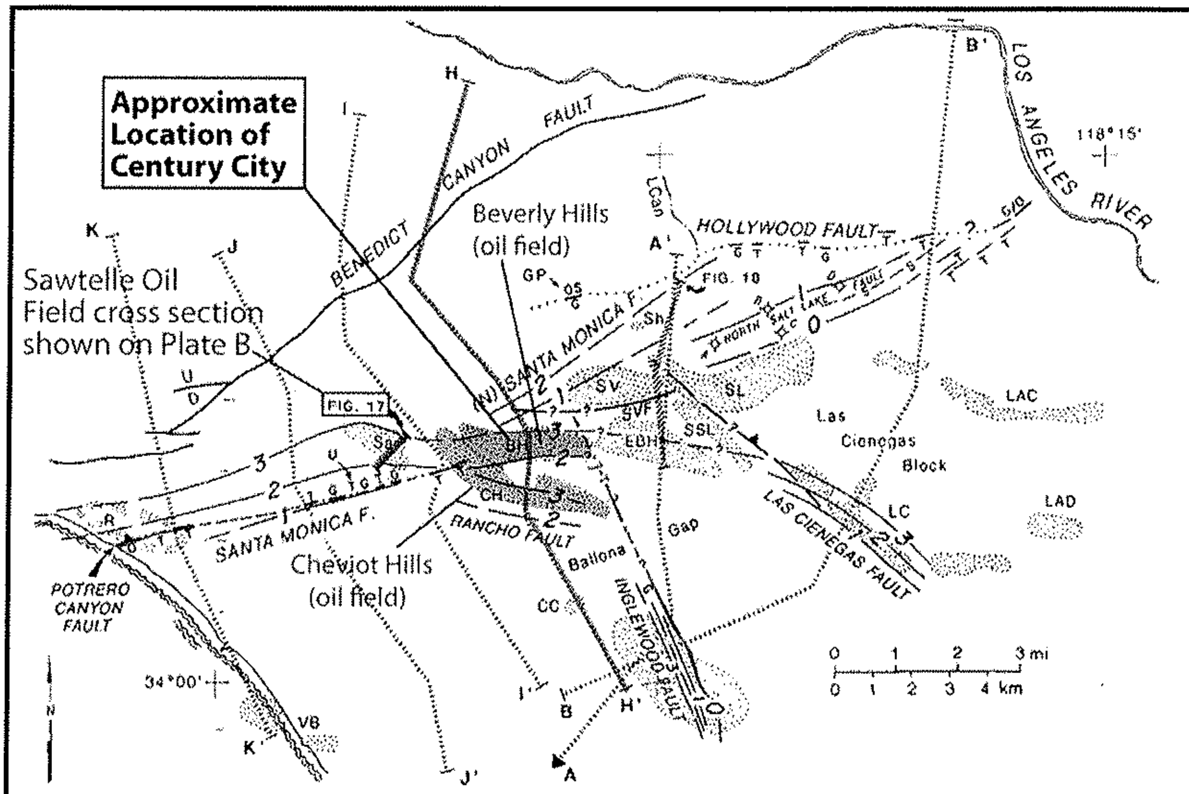
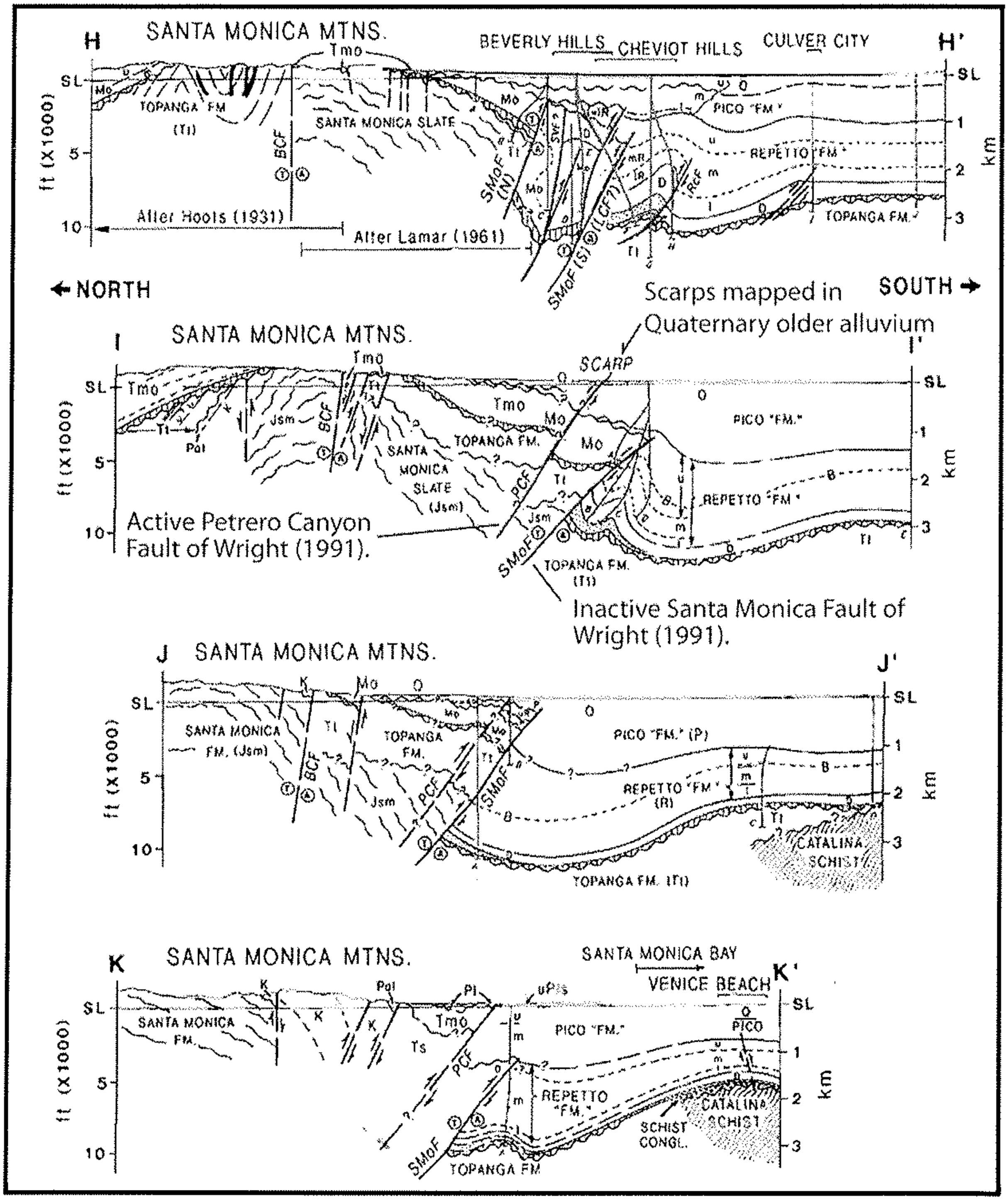


Figure 14. Map showing major faults in the northwestern Los Angeles basin. Fault-plane contours on the Inglewood, Las Cienegas, North Salt Lake, Rancho, and Santa Monica faults are based on subsurface well data. Contour interval: 1 km. Evidence of the surface traces of the Hollywood and Potrero Canyon faults and the northern extension of the Inglewood fault includes outcrop data (O), topography (T), and geotechnical data (G) from trenches and borings, plus soil contacts (S) and oil seepages (OS) (see text for sources). For other symbols, etc., see Figure 9.

Cross sections AA' and BB' are in Figure 8; cross sections HH' to KK' are in Figure 15. Also shown are locations of four core holes (listed in Appendix 2) that define the North Salt Lake fault and cross sections through the Sawtelle oil field (Figure 17), the East Beverly Hills, and San Vicente oil fields (Figure 18). Oil fields (stippled) are Beverly Hills (BH), Cheviot Hills (CH), Culver City (CC), East Beverly Hills (EBH), Inglewood (I), Las Cienegas (LC), Los Angeles City (LAC), Los Angeles Downtown (LAD), Salt Lake (SL), San Vicente (SV), Sawtelle (Sa), Sherman (Sh), South Salt Lake (SSL), Venice Beach (VB), and the undeveloped Riviera (R) discovery. GP is Greystone Park, LCan is Laurel Canyon, U is University High School.

Figure 2: Modified cross sections from Figure 15 of Wright (1991). Cross section H-H' transects the region of the Cheviot Hills near the proposed Base Station indicating that the Santa Monica Fault Zone locally consists of numerous essentially blind reverse faults that terminate within subsurface sediments with the Cheviot Hills.



Based on the literature reviewed for this report, no absolute ages of the local alluvial and marine deposits currently exist. A prominent preserved but dissected fan terrace surface exists in the study area (Cheviot Hills and north of Santa Monica Boulevard) that may loosely correlate with a 50,000 year old fan surface (terrace) identified by Dolan, et al. (2000) located approximately two miles west of Century City near the intersection of Sawtelle Boulevard and Ohio Avenue (Plate B - Veterans Administration Building site). This preserved terrace surface is designated 315T immediately north of Santa Monica Boulevard and 300T within the Cheviot Hills to the south on Plate C.

<u>General Fault Setting</u>

Southern California is a seismically active region exhibiting many active and potentially active faults (Plate A; Jennings, 1994; Bryant and Hart, 2007). The focus area of this study is in Century City located in the northern Los Angeles Basin just south of the Santa Monica Mountains (Plate A). Three active fault systems trend toward and likely terminate in the region of the site including the eastern end of the Santa Monica Fault Zone (SMFZ; Dolan et al. 2000a), northern end of the Newport Inglewood Fault Zone (NIFZ) and the western extension of the Hollywood Fault Zone (HFZ, Dolan et al., 2000b).

The SMFZ and HFZ both generally strike east west south of the Santa Monica Mountains (Plates A and B). The NIFZ trends nearly north-south and its northern end is currently mapped south of the Cheviot Hills (Plate A). Along the general strike of the NIFZ, a currently not well understood structure referred to as the West Beverly Hills Lineament (WBHL) transects the Cheviot Hills and continues north of Santa Monica Boulevard along the eastern flank of the elevated older alluvial deposits (Plate B).

Although the SMFZ and HFZ are considered active based on paleoseismic studies (Dolan et al., 1997; Dolan et al., 2000a, Dolan et al., 2000b), the State of California has not designated a Fault-Rupture Hazard Zone under the guidelines of the Alquist-Priolo act of 1972 for either fault zone to date (Bryant and Hart, 1997).

The SMFZ, HFZ and WBHL are discussed in more detail below.

Santa Monica Fault Zone

Dolan et al., (2000a) indicates that the SMFZ is part of a system of west-trending reverse, oblique-slip and left-lateral strike-slip faults that extends for >200km along the southern edge of the Transverse Ranges (Plate A). The Transverse Ranges is an east-west series of mountains produced by regional compressional tectonic forces that began between 2.5 and 5 million years ago. Dolan and Sieh (1992) referred to the SMFZ system as the Transverse Ranges Southern Boundary fault system. The SMFZ proper extends from Santa Monica along the Pacific Coast to the Cheviot Hills for a distance of approximately 12 to 14 km; however, the fault zone is believed to continue offshore to approximately Point Dume (Dolan et al., 2000a; Plate A). If the SMFZ continues off shore the approximate total length of the fault is considered approximately 40 km (Dolan et al., 2000a).

Wright (1991) and Tsutsumi (2001) provide deep well data indicating that the SMFZ has had a complex history involving numerous strands since the Miocene. During the Miocene, extensional normal faults occurred in the vicinity of the SMFZ participating in the creation of the Los Angeles Basin. Oil well and seismic reflection data suggest that the SMFZ consists of a northern and southern strand (Wright, 1991; Tsutsumi et al., 2001). The southern strand was originally a normal fault in the Miocene that since began accommodating reverse motion (Wright, 1991; Tsutsumi et al., 2001). The youngest documented sediments offset by the southern strand of the SMFZ are latest Pliocene and the fault is not documented to offset Quaternary deposits (i.e. Pico Formation; Wright, 1991; Tsutsumi et al., 2000).

The northern strand of the SMFZ is structurally above the southern strand and is considered active based on paleoseismic studies conducted at University High School and the Veterans Hospital Administration property (Crook and Proctor, 1992; Dolan et al., 2000a). Wright (1991) refers to the northern strand of the Santa Monica Fault as the Petrero Fault, and the southern fault strand as the Santa Monica Fault (SMoF). Figures 3 and 4 below provide structural contour maps by Wright (1991) demonstrating the complex history of the Santa Monica Fault (SoF, south strand) particularly in the region of the Cheviot Hills. Numerous fault strands of the SMFZ in the region of the Cheviot Hills are also shown in cross sections by Tsutsumi et al., (2001).

Figure 3 Structure Contour map of the northern Los Angeles Basin of the base of the lower Pliocene horizon (~4.5 Ma) of the Repetto Formation (Figure 9 of Wright, 1991). Faults associated with the Santa Monica Fault Zone are drawn as red with the triangle tips pointing in the down dip direction (north). This figure indicates that there was a hiatus of local deformation associated with the Santa Monica Fault Zone in the area of the Cheviot Hills in the early Pliocene. Contour interval is 2000 feet relative to below mean sea level.

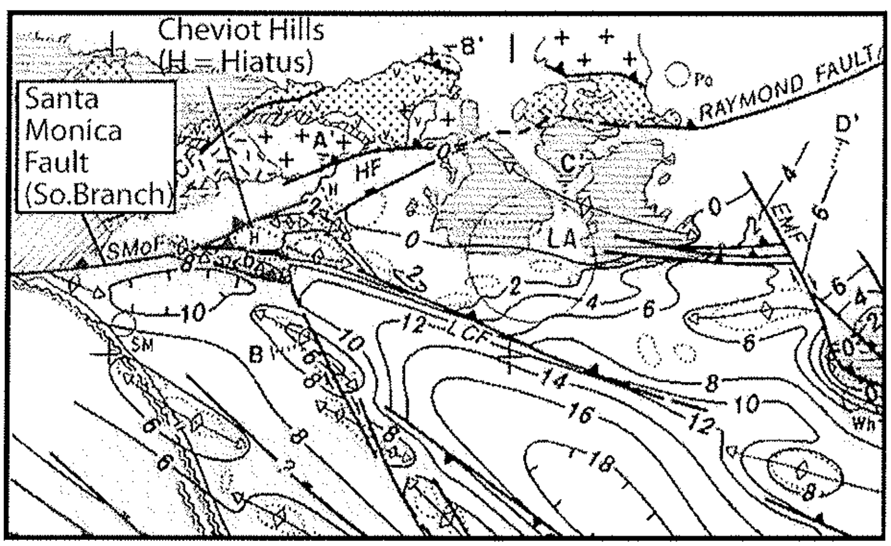
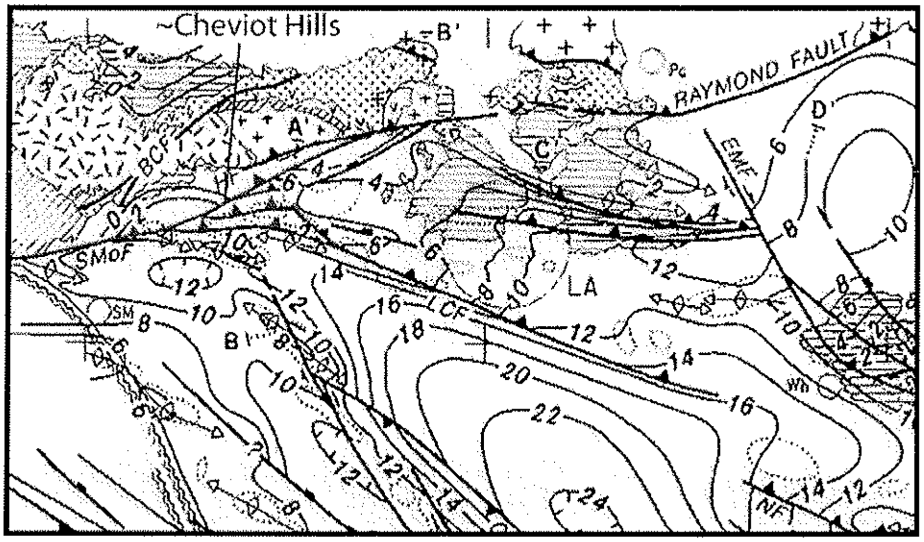


Figure 4 Structure contour map of the northern Los Angeles Basin (same area as Figure 3 above) during the late middle Miocene (~14 Ma). Contour interval is 2000 feet relative to below mean sea level.



Some of the active strands of the SMFZ are clearly associated with a series of scarps (lineaments) developed in deformed (uplifted) Quaternary Older Alluvial (Qoa) deposits (Crook and Proctor, 1992, Dolan et al., (2000a). A subsurface paleoseismic study along one of these scarps in the Veterans Administration Hospital site (Plate B) by Dolan et al. (2000a) identified that possibly 5 major earthquakes occurred on the Santa Monica Fault during the past ~50,000 years and that the fault zone probably experienced a major earthquake between 1,000 to 3,000 years ago. Catchings et al. (2008) interpreted seismic data showing that two shallow-depth low-angle fault strands which they referred to as Fault A (northern fault) and Fault B (southern fault). It should be pointed out that there is disagreement regarding the presence of the southern near surface fault south of the Veterans Administration Hospital (see Catchings, et al., 2010) and that no paleoseismic study has yet to expose a north dipping reverse/thrust fault associated with the SMFZ. Catchings et al. (2008) indicates that the northern near surface strand (their Fault A) likely projects to the surface near the base of the mapped topographic scarp very close to where it is also considered by Dolan et al., (2000a) and that the structurally lower strand (Catchings Fault B) extends toward the surface nearly 200 meters (~660-feet) south of the topographic scarp.

Numerous fault studies utilizing near surface trenching and seismic data have observed a series of relatively dense near-vertical faults in the hanging wall of the SMF (elevated portion of the local scarp) at both the University High School site (Crook and Proctor, 1992) and the Veterans Administration Hospital study site (Crook and Proctor, 1992; Dolan and Pratt, 1997; Pratt et al., 1998; Dolan et al., 2000a; Catchings et al., 2008). The fault trenching study by Dolan et al. (2000a) identified structural evidence strongly suggesting that motion on the near vertical secondary "hanging wall" faults is nearly pure strike-slip.

Dolan et al. (2000b) conducted an excellent analysis of the geomorphology of the onshore (terrestrial) section of the SMFZ which is provided below.

The most recently active trace of the Santa Monica fault onshore is marked by a series of south-facing scarps that extend 11.5 km from the west Beverly Hills lineament north of Century City, westward through west Los Angeles, Westwood, Santa Monica, and Pacific Palisades, where the fault trends offshore at Portrero Canyon (see Plate B). In contrast to the mountain-front location of the Hollywood fault, the Santa Monica fault scarps are 3-4 km south of the topographic mountain front. The presence of the deeply dissected old alluvial fans between the active fault and the mountain front and the conspicuous lack of active alluvial fans at the mountain front suggest relatively little, if any, recent uplift along any faults at the mountain front. In contrast, apices of young fans along the well-defined scarp imply that most recent deformation is occurring along these scarps.

Some earlier maps (e.g., Crook et al., 1983) show the Santa Monica fault extending eastward across the alluvial plain south of Beverly Hills and Hollywood. East of the west Beverly Hills lineament, however, no geomorphologic evidence of recent surficial fault activity is seen in the gently sloping alluvial plain along strike of the Santa Monica fault. This suggests that the Santa Monica fault, at least in its most recent incarnation, does not extend east of the west Beverly Hills lineament as a surficial feature.

A nearly continuous, N60E-trending scarp characterizes the easternmost 3 km of the Santa Monica fault. The scarp extends along the northern edge of Santa Monica Boulevard, which was originally built as a trolley line that followed the natural break in slope provided by the scarp; a major bend in the boulevard south of Westwood follows a bend in the scarp. The scarp height along this reach ranges from 7 to 12 m. West of the major bend south of Westwood the fault trends ~N70E for ~600 meters to the eastern edge of the 925-meter wide drainage of Sepulveda Canyon, where late Holocene erosion and deposition have obscured the scarp. The large Sepulveda fan is to the south of the fault; lines drawn on the fan surface perpendicular to contours converge on the fan's apex, which is located approximately at the fault crossing of the Sepulveda drainage. The scarp reappears on the west side of the Sepulveda fan near the southwest corner of the West Los Angeles Veteran's Administration Hospital grounds. The scarp height increases westward as onlapping distal Sepulveda fan deposits thin westward away from the fan apex.

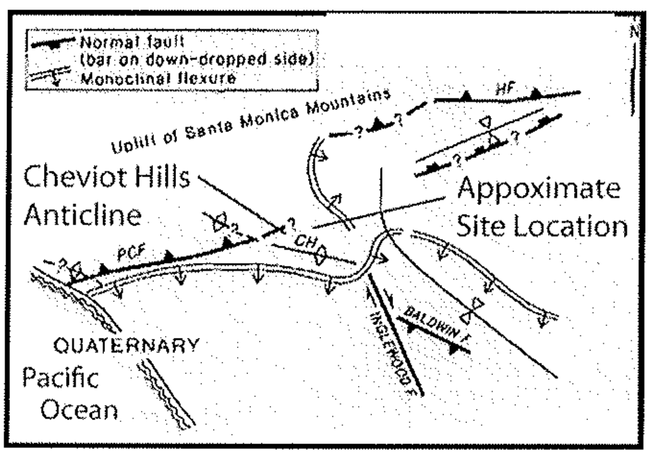
The central reach of the fault, between Interstate Highway 405 and the coast, exhibits three distinct, left-stepping, en echelon scarps. The eastern two scarp segments trend generally N70E, whereas the western segment changes trend westward, from N60E to N80W. Scarp heights typically range from 8 to 12 m for the two eastern scarps, although at the terminations of individual segments the scarp heights decrease to zero. The three en echelon segments overlap by as much as 750 meters. This overlap, as well as the lateral decrease in scarp height on the individual segments toward their terminations, is especially well illustrated along Bundy Drive in Santa Monica, where the two eastern segments overlap. The spacing between the two overlapping segments there, measured perpendicular to fault strike, is ~300 meters west of the western end of the easternmost en echelon segment (near the corner of Bundy Drive and Wilshire Boulevard), the scarp projects into the anomalous, N80E- to west-trending western extension. This feature, which projects ~25 m above the surrounding alluvium, probably represents an anticlinal ridge developed above a shallow blind thrust fault that may be a westward continuation of the easternmost en echelon segment.

The westernmost en echelon scarp is broader than the other two, but its total relief (~10m) is similar to that of the scarps to the east. This results in the western scarp being more subdued topographically than the two eastern segments. The surface slope of the western scarp shallows westward, and the scarp is >300 m wide at its western end at Santa Monica Canyon. To the west of Santa Monica Canyon two distinct 3-5-m-high scarps extend across the broad marine terrace along the projected trace of the fault. These scarps project directly into the Portrero Canyon exposure of the fault. It is not clear, however, whether these features are fault scarps or terrace risers associated with Pleistocene (?) fluvial terraces inset into the stage 5e marine terrace. Thus, their presence along the trace of the fault may be simply coincidental.

Plate B shows our evaluation of the same fault scarps and lineaments originally mapped by Crook and Proctor (1992), and Dolan and Sieh (1992). The fault scarps have been confirmed to be associated with strands of the Santa Monica Fault (Crook and Proctor, 1992; Dolan et al., 2000b). Based on the available data, the result of our analysis of the fault scarp-lineaments (Plate B) is generally consistent with earlier work; however, it was not clear that the onshore surface expression of the SMFZ exhibits a series of left-stepping fault traces.

Wright (1991) suggested that during the Quaternary, right-lateral movement on the Newport Inglewood Fault is being absorbed to the north by underthrusting and folding in the Cheviot Hills (Figure 5). This proposed mechanism could thus continue to the present time. An analysis of remnant preserved fan terraces across the western Cheviot Hills and to the north across Santa Monica Boulevard suggest that the style and magnitude of local folding and tilting changes across the mapped scarp of the SMFZ along Santa Monica Boulevard (Plate C). This topic will be discussed in more detail in the Findings section of this report.

Figure 5: Sketch map by Wright (1991, Figure 16) of the general tectonic behavior associated with the Santa Monica (Wrights Potrero Canyon Fault-PCF), Hollywood, and Inglewood fault zones and deformation associated with their intersection during the past 2 million years (Quaternary) in the region of the Cheviot Hills. The figure indicates that the Cheviot Hills anticline formed during the Quaternary and that complex deformation occurred in this region during the past 2 million years. Wright proposes that the Cheviot Hills anticline was produced by right-lateral motion on the Inglewood fault zone pushing toward the Santa Monica Fault Zone (Wrights PCF). Although this figure is generalized and not intended to be interpreted too literally, it is worth noting that Quaternary deformation in the area of the Cheviot Hills consisted of motion across the northern strand of the Santa Monica Fault Zone (Wrights PCF) that died out toward the east in the Cheviot Hills and secondary folding and uplift in the Cheviot Hills.



The late Quaternary Santa Monica Fault is believed to terminate prior to the West Beverly Hills Lineament (WBHL; discussed below) and possibly within the Cheviot Hills. Dolan and Sieh (1992) and Dolan et al. (2000a) provides geomorphic evidence that likely no active strands of the Santa Monica Fault extend east of the WBHL. Interpretation of Wright (1991) also suggests that the Santa Monica Fault (his

Potrero Fault) dies out within the Cheviot Hills and thus does not extend east of the northern projection of the Inglewood Fault (see Figure 5 for generalized Quaternary map by Wright).

Hollywood Fault Zone

The HFZ is an east-west trending reverse left-lateral, oblique slip fault extending along the base of the eastern Santa Monica Mountains. Based on geomorphic analysis (Dolan et al., 1997), the fault extends from close to the West Beverly Hills Lineament in the west to close to the Los Angeles River to the east. The HFZ is considered active based on Paleoseismic studies (Dolan et al., 1997). Although as pointed out by Dolan et al., (2000a; 2000b), the strongly dissected older alluvial fan surfaces extending from the base of the Santa Monica Mountains to close to Santa Monica Boulevard to the south do not appear to be deformed by recent (since latest Quaternary) faulting. However, a north dipping reverse fault was identified at UCLA that offset Quaternary older alluvium that essentially is on strike with the Hollywood Fault Zone mapped to the east (Crook and Proctor, 1992; see Plate B). In addition, there may be a slight warping of the Quaternary older alluvium fan surfaces along strike of the Hollywood fault immediately west of the West Beverly Hills Lineament (WBHL, Plate C). This suggests the possibility that the Hollywood Fault may extend west of the WBHL as a blind fault beneath the Quaternary older alluvial fan surfaces.

West Beverly Hills Lineament

The WBHL is a relatively strong north-northwest striking geomorphic lineament extending through a relatively linear canyon in the Cheviot Hills in the south to Santa Monica Boulevard, to along an east facing slope formed within Quaternary older alluvium north of Santa Monica Boulevard (Plates B and C). Thus, north of Santa Monica Boulevard, the lineament is defined as simply the contact and relative relief between the elevated and eroded Quaternary older alluvium (network of tributary channels eroding into preserved fan terrace surfaces) to the west, and a relatively recent fan apron to the east (Plate B). The lineament appears to mark the location of a 1.5 km left step in the eastern and western limits of the Santa Monica and Hollywood fault respectively. The Metro (2010) report provides a good summary regarding the lack of understanding regarding the type of structure the WBHL represents at depth.

> *Various tectonic interpretations have been proposed for the WBHL. For example Dolan et al (1997) speculated that it may represent an east-dipping normal fault associated with extension along the left step between the Hollywood and Santa Monica faults. Others have speculated that the WBHL may be the northernmost of a series of en echelon, left-stepping, right-lateral strike-slip faults of the Newport Inglewood fault (Wright 1991, Dolan and Sieh, 1992, Hummon et al. 1994, Tsutsumi et al. 2001), or a fold scarp along the northern extension of the back limb of the gently east-dipping Compton blind thrust fault (Dolan et al. 1997). However Lang (1994) reported that subsurface mapping within the Cheviot Hills and Beverly Hills oil fields, constrained by dense subsurface control, precludes the existence of the WBHL* [as produced by a distinct fault]. *Thus the prospect that the WBHL is the surface manifestation of an active fault has not been confirmed. Further evaluation of the WBHL and its significance to the project will be performed during forthcoming design level investigations for the project.*

Wright (1991) also shows a monoclinal (fold) flexture in the general area of the WBHL (see Figure 5) that developed during the Quaternary. It is therefore not well understood if the WBHL represents a tectonic structure (fault or folding), or simply due to erosion associated with south flowing streams across an uplifting area.

FINDINGS

Evaluation of Potential Moment Magnitudes and Displacements for the Santa Monica Fault Zone

Fault source parameters were estimated during this study and the analysis is provided in Appendix A. A summary of the findings is provided below.

Mw estimates for a fault length of 40 km

Mw = ~7.1 with average displacement D = 1.85 m (most probable).
Mw = ~6.9 with average displacement D = 1.00 m.
Mw = ~7.3 with *maximum* displacement D = 3.00 m (least probable).

Mw estimates for a fault length of 12 km

Mw = ~6.4 with average displacement of D = 0.55 m.

Note: Anderson, et al. (1996) proposes a correlation between slip rate and earthquake magnitude suggesting that the largest earthquakes will occur on the slowest slipping faults if the rupture length is held constant. Thus, slip rate is an important fault parameter regarding estimating major earthquakes magnitudes for specific faults. Essentially, their results suggest that a pure moment magnitude calculation as provided above may underestimate Mw values for faults exhibiting relatively slow slip rates as is currently understood for the Santa Monica Fault.

Geomorphic Evaluation of the Santa Monica Fault Zone – Century City Area

A geomorphic analysis was performed during this study utilizing 5-foot topographic contour maps prepared by the United States Geological Society in 1923 through 1925. The contours provided on the Hoots and Kew (1931) map (used as the base map in Plates B and C) were determined prior to mass urbanization in the region and thus provide an excellent representation of the natural landscape. Lineaments and alluvial terraces were mapped during the analysis that assisted in providing information regarding the potential location of near surface faulting and to characterize local deformation. The terrace and lineament evaluations are discussed separately below.

Alluvial and Marine Terrace Evaluation In the Century City Area

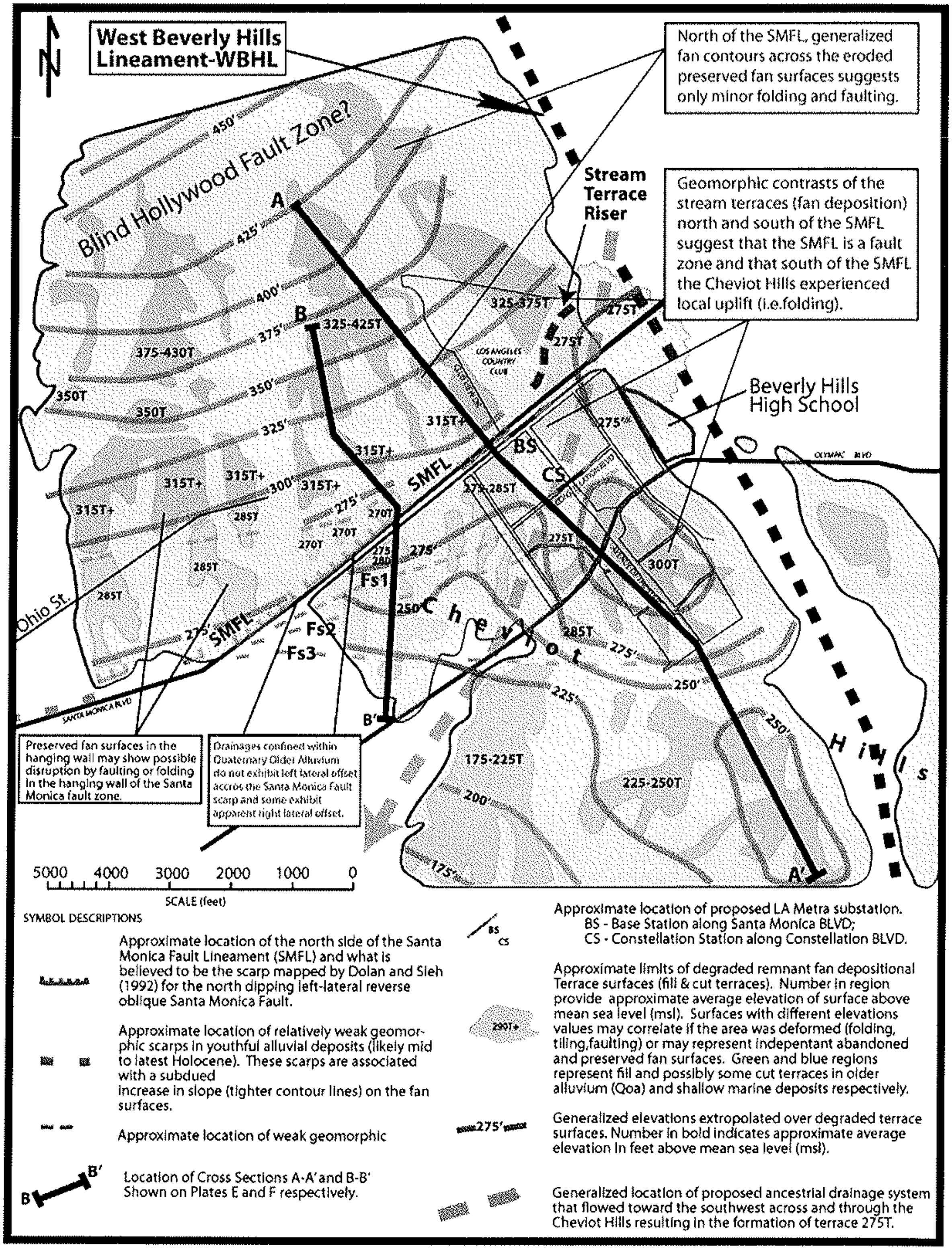
Actively depositing alluvial fans generally exhibit a network of distributary channels spreading out from the mountain front down slope and a relatively even slope (parallel and consistent contour lines on a topographic map). When an alluvial fan is no longer forming and deposition has ceased on the surface, generally the distributary drainage system is no longer supported and is replaced over time with a tributary drainage system as the fan sediments begin to erode. Elevated older alluvial fan deposits (Quaternary Older Alluvium-Qoa) can exhibit relatively deep canyons associated with a tributary system with remnants of the original fan surfaces preserved along the crests of the drainages. This is the case in the area of Century City. The preserved fan surfaces created by the cessation of deposition are referred to as fill terraces, which is generally the dominant form of terraces for alluvial fan systems.

Remnant terrace surfaces are preserved in the Century City area produced by erosion of the original fan sediments. It appears based on their relatively planar surfaces that some are clearly preserved and can be correlated across drainages and across the Santa Monica Fault Lineament (SMFL, discussed in the next section). These surfaces are green on Figure 6. However, cut terraces can also occur where the preserved surface was created by erosion, which may be the case for some of the marine terraces shown in blue on Figure 6 within the Cheviot Hills. Terraces were designated with average elevations across the surfaces. For example, the 315T terrace surface has an approximate average elevation of 315 feet above mean sea level (Figure 6 and Plate C).

Connecting common terrace elevations across the gullies from one preserved terrace surface to another provides a series of contours across both the older alluvial deposits north of the SMFL and within the Cheviot Hills south of the SMFL (Figure 6). These averaged contour lines are shown as dark green on Figure 6 and designated with it approximate elevation. Comparison of these extrapolated contours clearly show that the SMFL marks a strong change in the local geomorphology from the north within the area dominated by Quaternary older alluvium (fan fill terraces) and to the south where both older alluvium and marine terraces occur. The contours north of the SMFL indicate typical evenly spaced (constant slope) fan contours that on average trend northeast to southwest suggesting that the area has not been locally deformed with the exception of possibly vertical displacements across secondary faults north of the western end of the SMFL between terraces 315T and 285T. However, the relative elevations between these terraces could have been produced by deposition of different stream terraces or possibly local warping. In addition, there is a possible gentle warp of the dissected alluvial fan surface at elevations 425 to 450-feet above mean sea level that possibly could be associated with blind faulting associated with the western end of the Hollywood Fault Zone (see Figure 6 and Plate C).

South of the SMFL within the Cheviot Hills, the correlated terrace surfaces within both older alluvium and underlying marine sediments do not exhibit typical fan morphology but instead appear to demonstrate that local deformation and cross cutting drainages have occurred. The average strike of the extrapolated contour lines in this region is northwest to southeast and in strong contrast compared to north of the SMFL. Figure 6 shows a possible location of an ancestral drainage that entered the northern Cheviot Hills north of Beverly Hills High School at terrace 275T and flowed toward the southwest through the axis of this portion of the Cheviot Hills. In fact, terrace 275T bounded by the stream terrace riser to the north appears to geomorphicaly connect with the relatively young fan surface in the region of the WBHL to the east (Plate C and Figure 6). If a relatively young channel had cut across the northern Cheviot Hills and eroded into Quaternary older fan deposits (i.e. sediments associated with terraces 315T and 300T), it suggests that the Cheviot Hills have been locally uplifted since the late Quaternary.

Figure 6: Surface elevation contour map of terraces in the Century City area. This figure is simplified from Plate C. See text for discussion.



Although the age of the older alluvial stream terraces is unknown, similar geomorphic position suggests for example that stream terraces in the 300's (i.e. dark green on Plate C) may roughly correlate with a 50,000 year old terrace deposit evaluated at the Veterans Administration Hospital Site located a couple of miles west of Century City (Dolan et al., 2000a). However this age is speculative and a local soil profile analysis would need to be conducted to better estimate the age of the remnant terrace surfaces and deposits. Dolan and Sieh (1992) indicate that Hoots (1930) collected marine macrofossils from a marine terrace at elevation 57 to 63 meters (~173 to 206 feet above mean sea level) that indicates that the sediments were deposited in the mid to late Pleistocene. This terrace may correlate at least in terms of average elevation with a relatively prominent blue terrace surface shown on Plate C along the western flank of the Cheviot Hills.

Lineament Evaluation for the Santa Monica Fault Zone

Geomorphic lineaments represent roughly linear features observable for example on aerial photos and topographic maps. The features often correlate with erosion structures associated with bedrock foliation, bedding, and folding, or groundwater barriers and fault zones. Three types of lineaments are generally identified which include tonal (color contrast), vegetation and topographic. Tonal and vegetation lineaments are commonly identified on aerial photographs. Topographic lineaments, which are referred herein as geomorphic lineaments, can be identified on both aerial photographs and topographic maps. Lineaments are typically evaluated with a simple relative scale of strong to weak.

During this study no aerial photographs were evaluated and thus no tonal or vegetation lineaments were identified. Geomorphic lineaments were identified on the Hoots and Kew (1931) geologic-topographic map areas dominated by alluvial sediments (Plates B and C). The identified scarps shown on Plate B associated with the Santa Monica Fault are geomorphic (topographic) lineaments associated with changes in slope across alluvial fan surfaces. Changes in slope are identified by a tightening of a number of topographic contours relative to the original even spaced contours associated with the original fan surfaces. Weak lineaments associated with moderately subtle and broad increases in fan surface slopes across older alluvium (Qoa) suggest that surface deformation associated with the SMFZ is warping (folding) the surface. This is the case in the region east of Santa Monica Canyon to just south of Brentwood Knoll, which was mapped as a scarp associated with the Santa Monica Fault Zone by Dolan and Sieh (1992) and consistent with mapping in this report (Plate B).

Relatively strong lineaments generally trending between N60E to N70E associated changes in slope between Holocene alluvium at the base and elevated Quaternary older alluvium were identified in the region of University High School and the Veterans Administration Hospital property (Plate B). Both seismic and subsurface paleoseismic investigations conducted within these properties determined that the lineaments were produced by motion across the north dipping reverse Santa Monica Fault Zone (Crook and Proctor, 1992; Dolan and Pratt, 1997; Pratt et al., 1998; Dolan et al., 2000; Catchings et al., 2008). In addition, relatively deep well data evaluated by Wright (1991) appears to confirm that the lineaments are associated with the SMFZ, which he referred to as the Potrero Canyon Fault (PCF). It is at Potrero Canyon along the Pacific coast (Plate B) that Hoots and Kew (1931) mapped the only known natural exposure of the SMFZ. Note that the Potrero Fault of Wright (1991) likely connects with his Santa Monica Fault at depth.

Toward the east and entering into the Cheviot Hills, a relatively strong and straight geomorphic lineament trending approximately N50E exists along the current location of Santa Monica Boulevard (Plates B and C). This lineament is referred to herein as the Santa Monica Fault Lineament (SMFL, Plates B and C). A railroad line also runs parallel to the location of Santa Monica Boulevard in the early 1920's and thus it is difficult to know based on evaluation of the contours on Plate B what the natural lineament may have looked like. It is likely that the original railroad and Santa Monica Boulevard took advantage of the geomorphic erosional swale (depression area) of the lineament itself to transect through the Cheviot Hills.

Within the Cheviot Hills, Dolan and Sieh (1992) mapped the SMFL lineament as trending N60E for approximately 3 km west of the WBHL and as a continuation of the identified SMFZ scarps at the Veterans Administration Hospital site. The Dolan and Sieh (1992) geomorphic study indicates that the SMFL scarps range in height of 7 to 12 meters high. However, cross sections A-A' and B-B' shown on Plates E and F respectively demonstrate an alignment of preserved fan surfaces across the SMFL along Santa Monica Boulevard that surprisingly do not clearly indicate that correlated terraces to the north have moved upwards respective to the south. In fact, section B-B' appears to indicate that a likely correlative fan surface 315T north of the SMFL projects to a lower elevation than terrace 275-280T south of the SMFL. In addition, section A-A' (Plate E) shows that the 315T terrace north of the SMFL appears to not exhibit vertical displacement across the SMFL to a likely correlated terrace at average elevation 300T and there is a lack of surface outcrops of underlying unit Qm north of the SMFL. Regarding this last point, if the SMFL was produced by repeated vertical displacements across a north dipping reverse fault, it seems reasonable that underlying unit Qm would be exposed north of the SMFL similar to Qm exposures south of the SMFL (Plates B and C). Based on these data it appears likely that the SMFL is not a scarp associated with a north dipping reverse fault but instead may be associated with a steeply dipping dominantly strike slip fault or simply an structure controlled feature created primarily by erosion.

Additional evidence suggesting that the SMFL along the northern Cheviot Hills may have been produced by strike-slip faulting is the very straight alignment of the lineament transecting the hills, and a couple of south flowing drainages that turn abruptly and essentially captured when they encounter the SMFL. Thus, it may be possible that the SMFL resulted from a high angle strike-slip fault in the hanging wall of the Santa Monica Fault Zone similar to structures observed in trenching and seismic studies at the Veterans Administration Hospital site although at a larger scale. However, a model is also provided that suggests that the swale defining the SMFL was simply produced by erosion along a fold axis associated with a blind reverse fault.

Based on the provided geomorphic evidence, it appears likely that the SMFL was produced by either near surface strike-slip faulting in the hanging wall of the SMFZ, or by differential erosion along a fold axis that may overlie a blind reverse fault.

Evaluation of Potential Fault Deformation in the Century City area

Based on evaluation of the provided data in this report it appears clear that an understanding of the location, magnitude and style of deformation associated with the Santa Monica Fault Zone (SMFZ) in the region of the Base and Constellation Stations (Plate C) is poorly known. No local subsurface geologic data was available at the time of the preparation of this report. It does seem likely that the Santa Monica Fault Lineament (SMFL) mapped along Santa Monica Boulevard is associated with some form of faulting. Below three Fault Models (No.1, No.2, and No.3) are examined providing supportive and non-supportive evidence for each.

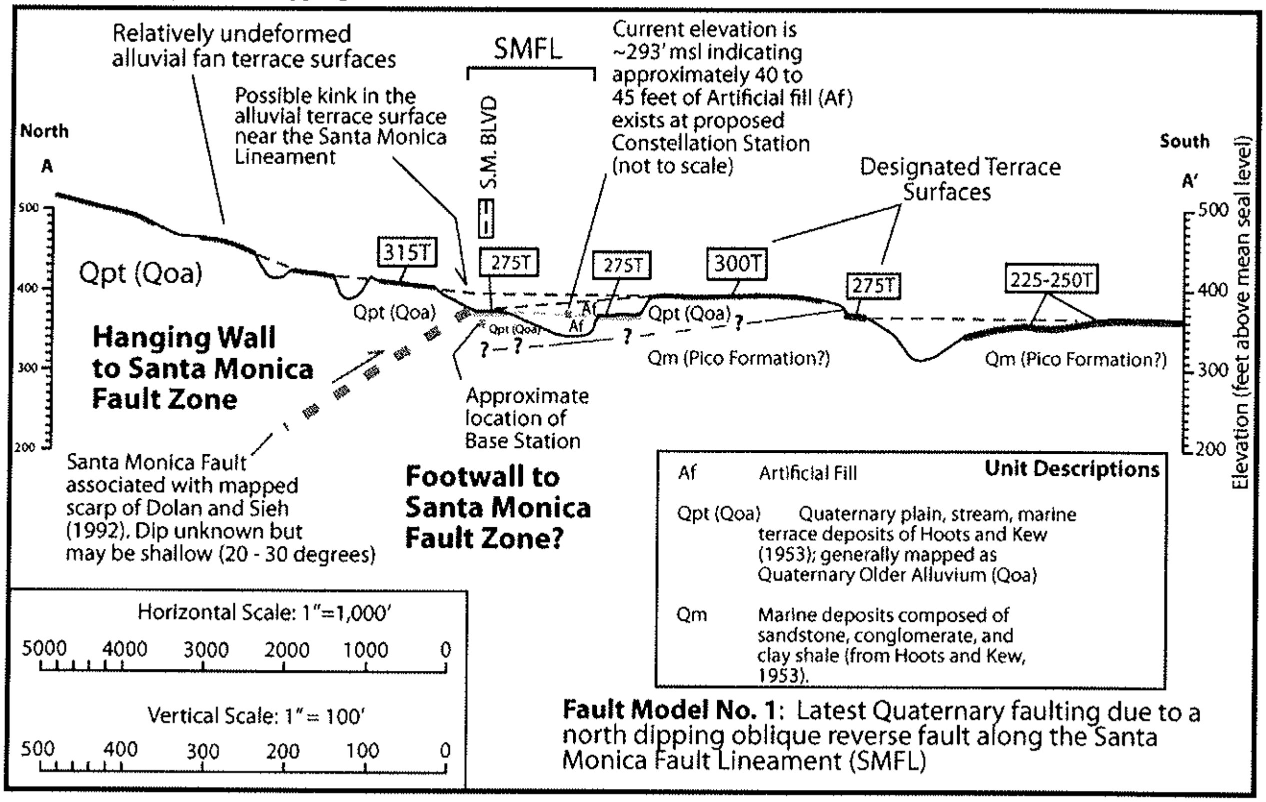
Fault Model 1 – SMFL Produced by a North Dipping Reverse Fault

In this model, the SMFL was produced by a north dipping dominantly reverse fault exhibiting vertical motion of the hanging wall (sediments above the fault) that projects to the surface somewhere south of the base of the northern "scarp" along the north side of Santa Monica Boulevard. Although based on the geomorphic analyses provided in this report, Fault Model No. 1 seems unlikely, it is provided here for discussion purposes and because in a simple interpretation, could be the interpreted mechanism and location of faulting based on published fault behavior characteristics in the area (i.e. Dolan and Sieh, 1992 could be over interpreted at the scale of this project site). The location of the north dipping Santa Monica Fault is shown on Plates B and C as red lines and north pointing tick marks. The current inflection point of the base of the scarp is mapped a few feet north on Club View Drive from Santa Monica Boulevard as shown on a composite photograph on Plate H. In addition, this where it is believed Dolan and Sieh (1992) placed the base of the fault scarp.

Reverse faults are generally projected to the surface near the base of scarps as is shown on Figure 7. However, subsurface fault investigations along a scarp associated with the Santa Monica Fault Zone conducted approximately 2 miles west of the proposed stations just west of Highway 405 indicate that the surface projection of the northern most strand of the north dipping Santa Monica Fault resides south of the base of the scarp (Dolan et al., 2000; Catchings et al., 2010; Catchings et al., 2008). In addition, the Catchings 2008 study indicated that the fault likely responsible for producing the scarp may be 7 meters deep (23 feet) just south of the base of the scarp. Assuming a 25 degree dip of the fault at 7 meters depth at the base of the scarp equates to a surface projection of the fault approximately 15 meters (50 feet) south of the base of the scarp. It should be pointed out that the scarp at the fault trenching sites is characterized by younger alluvium at the toe of the slope and that the scarp along Santa Monica Boulevard likely exposes older alluvium along both the scarp slope and base. This distinction may be significant in terms of predicting the surface project of the fault. A scarp characterized with younger alluvium at the base indicates that the young surface has deposited over the true base of the scarp and migrated up slope thus moving the base inflection point of the slope to the north. In contrast, the fault has a higher likelihood of projecting to near the base of the scarp slope if older alluvium exists along both the scarp slope and outboard of the scarp because in this scenario the inflection point of the base of the scarp has remained essentially in the same location due to a lack of deposition. However, both of these scenarios become complicated and thus possibly incorrect if the reverse fault is blind (fault rupture during a major event does not reach the surface) in which case the surface project of the fault would certainly be south of the base of the scarp.

Inherent in Fault Model No.1 for a single relatively well defined north dipping reverse fault is a well defined hanging wall and footwall above and below the fault respectively (Figure 7). Plate G provides a preliminary fault map relative to the proposed Base Station that shows the surface projection of the fault at the change in slope at the south end of Club View Drive (also see photographs on Plate H). If this is the correct surface projection of the Santa Monica Fault Zone and there are not other southward faults, then the Base and Constellation Stations would technically be in the footwall of the Santa Monica Fault and thus may not experience a large magnitude of displacement or deformation during a major earthquake event. In general for reverse faults, hanging wall rocks experience more more secondary deformation (folding, faulting, tilting) than footwall rocks (Philip and Meghraoui, 1983). However, fault trenching and seismic studies at the Veterans Administration Hospital site have demonstrated that the primary near surface strands of the Santa Monica Fault generally lie many feet south of the identified scarps at least where younger alluvium is exposed at the base of the scarp as discussed earlier. In addition, this report presented geomorphic data suggesting that the region of the Base and Constellation Stations within the Cheviot Hills have been uplifted since the late Pleistocene. Thus, without some site specific subsurface data, it is essentially impossible to know the true surface project, style and width of deformation of the Santa Monica Fault Zone based on the current geomorphic data.

Figure 7: Modified Cross Section A-A' from Plate E highlighting potential fault characteristics for Fault Model No. 1 involving a north dipping reverse fault at the base of the north side of the SMFL.



Fault Model No.2 – SMFL Produced by a Steeply Dipping Strike-Slip Fault

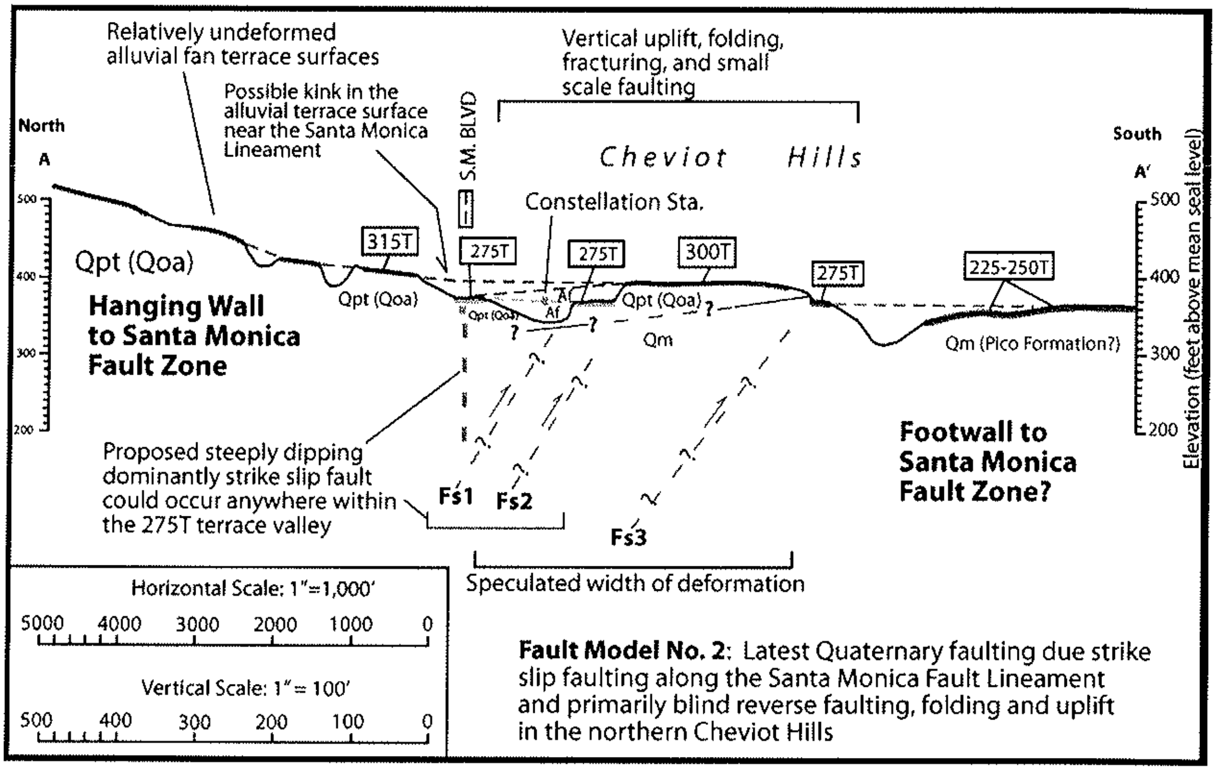
If the SMFL was produced by a secondary high angle fault similar to structures seen in fault studies in the University High School and Veterans Administration Hospital sites (Crook and Proctor, 1992; Dolan et al., 2000a), then it suggests that the region of the proposed Base and Constellation Stations are located within the fault deformation zone (Figure 8). In other words, there potentially exists in this model a relatively wide deformation zone (folding, fracturing, small scale faults, tilting, etc) separating the hanging wall and footwall regions.

The interpretation that the SMFL was produced by a dominantly strike-slip steeply dipping fault indicates that the north dipping reverse faults associated with the SMFZ likely occur south of the SMFL. Geomorphic evidence provided in this report indicates that the Cheviot Hills have experience fault deformation primarily in the form of vertical uplift and folding and a paucity of fault surface rupture. Based on these findings, it appears reasonable that north dipping reverse faults associated with the SMFZ extend under the Cheviot Hills as blind faults essentially on a similar strike of the fault zone in the west. This type of faulting is generalized on Figure 8 as various fault strands Fs1, Fs2 and Fs3. However, proposed blind subsurface faults Fs1, Fs2 and Fs3 are not complete conjecture. Fs1 and Fs3 represent weak geomorphic lineaments through the Cheviot Hills associated with weak saddles and slope breaks across designated terraces. Fs2 is simply projected along a similar strike of the SMFZ west of the bend in Santa Monica Boulevard.

Topographic contour analysis of terrace surfaces in the Cheviot Hills indicates that the relative magnitude of uplift may have been greater immediately west of the West Beverly Hills Lineament (WBHL) and decreases toward the west. In addition, the contours suggest that the Cheviot Hills may represent an antiformal type structure that strikes parallel to the WBHL. This indicates that uplift and deformation in the Cheviot Hills may be due to the complex interaction between the SMFZ, WBHL and possibly the Newport Inglewood Fault Zone to the south. This model is very similar to that described by Wright (1991) for the Quaternary behavior of the eastern SMFZ (see Figure 5).

The data and analysis presented here brings into question whether or not the mapped SMFL was even produced by a north-dipping reverse fault as discussed earlier. If it was, then the strike-slip fault producing the SMFL along Santa Monica Boulevard could occur anywhere within the erosional swale (see Figure 8). This point is also made on Cross Sections A-A' and B-B' on Plates E and F respectively.

Figure 8: Modified Cross Section A-A' from Plate E highlighting potential fault characteristics for Fault Model No. 2 involving a steeply dipping dominantly strike-slip fault as the causative agent to produce the SMFL.



Fault Model No.3 – SMFL Produced by erosion along a fault induced fold axis

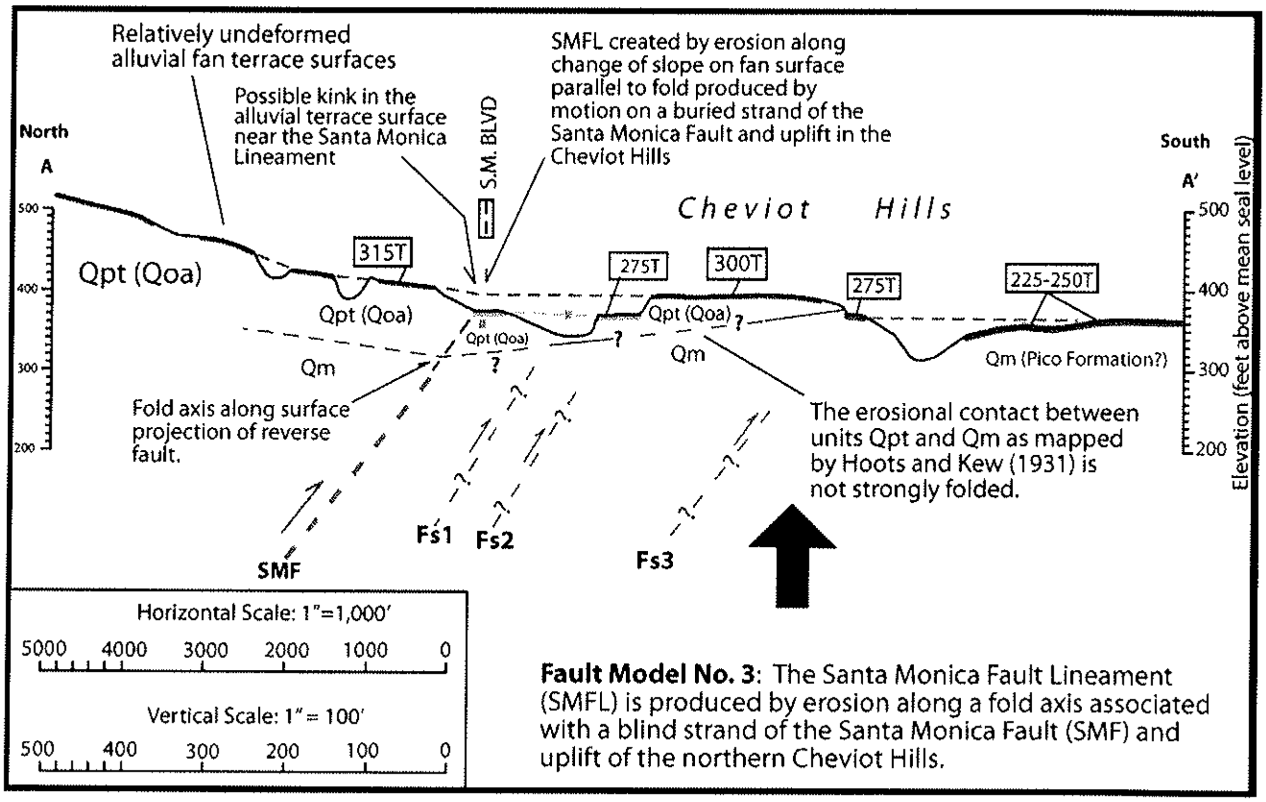
In this model a fault strands associated with the Santa Monica Fault Zone exhibiting a reverse component are blind causing uplift north of the SMFL and within the Cheviot Hills resulting in a kink fold axis parallel to the SMFL (Figure 9). Repeated events across the buried strand projecting to the SMFL would presumably move sediments upwards north of the SMFL relative to the south and produce a change in slope along the SMFL which may cause increased erosion along the SMFL to eventually develop into a relatively strong lineament (Figure 9). In addition, uplift across the northern Cheviot Hills produced by possible blind reverse faults and/or some mechanism associated with the WBHL would also contribute to a change in slope, possible plateau geomorphology and erosional characteristics south of the SMFL.

This model is supported by the relatively strong change of slope (the kink) of the older alluvial fan surfaces (terraces) observed across the SMFL. The surface expression of the kink may have been sufficient to capture drainage flow and thus allow for increased erosion along the SMFL as the general area was uplifted and the fan system as a whole was eroding. In addition, terrace 275T is postulated herein as produced by a southward flowing ancient channel system that entered the Cheviot Hills at the same location of the east end of the SMFL and had the ability to transect the Cheviot Hills during uplift (Figure 6).

This model is also supported by the contradictory observation of apparent right-laterally offset drainages across the SMFL. Most published literature support that the lateral component of motion across the Santa Monica Fault Zone is left-lateral and thus would produced left-laterally deflected drainages. However, if erosion is the dominant process producing the swale along the SMFL then tributary drainages on the eroding older fan surfaces that are captured along the SMFL could exhibit either an apparent left- or right-lateral deflection.

Active reverse fault strands of the SMFZ may become blind near the western limit of the SMFL near the northeastward turn in Santa Monica Boulevard along the western Cheviot Hills (Plates B and C). In the area of the turn in the SMFZ from ~N70E west of the SMFL to ~N50E along the SMFL relatively strong apparent geomorphic scarps exist that are very similar to the scarps investigated in the Veterans Administration Hospital site located ~2miles west of Century City shown to be produced by near surface reverse faults.

Figure 9: Modified Cross Section A-A' from Plate E highlighting potential fault characteristics for Fault Model No. 3 suggesting that the SMFL was produced by erosional processes along a fold kink of the older alluvial fan sediments above a blind strand of the Santa Monica Fault.



CONCLUSIONS

No geomorphic scarp displaying evidence of significant vertical displacements was observed in the Century City area of the proposed Base and Constellation Stations. Only one strong geomorphic lineament was identified referred herein as the Santa Monica Fault Lineament (SMFL) and it clearly does not exhibit significant vertical displacements of terrace surfaces across the structure. This is shown on Cross Sections A-A' and B-B' on Plates E and F respectively. A couple of very weak geomorphic lineaments are observed in the Cheviot Hills south of the SMFL that may be associated with faulting but more likely resulted from erosion within the hills. There are sufficient preserved terrace surfaces in the Cheviot Hills providing structural marker horizons to indicate that the likelihood of a well defined north dipping reverse fault reaching the surface in this area is low. Therefore Fault Model No.1 is considered unlikely due to the lack of apparent vertical separation of correlation of preserved terrace surfaces across the SMFL.

Fault Model No. 2 suggesting that the SMFL was produced by a hanging wall secondary strike-slip fault is supported by its linearity, lack of vertical apparent motion across the structure, and presumably uplift south of the structure associated with blind reverse strands of the SMFZ in the Cheviot Hills. However this model is not supported by the presence of apparent right-laterally deflected drainages across the SMFL.

Fault Model No. 3 provides a scenario where the SMFL was produced by a northern blind strand of the SMFZ causing a fold axis in the older alluvial sediments and surfaces (terraces) allowing for a deflection of drainages along the SMFL thus increasing and concentrating erosion along its length. This deformation model also involves a second local source of uplift west of the WBHL. Wright (1991) and other publications suggest that the relative highlands west of the WBHL have been uplifted relative to areas east of the WBHL (see Figure 5). In other words, the Cheviot Hills extend well south of any of the project reverse fault strands (blind or not) associated with the SMFZ and areas north of the SBFL are also vertically above areas to the east of the WBHL. Although the structure of the WBHL is speculative, it does appear that late Quaternary relative vertical separation has occurred across the WBHL and that this uplift would have likely involved the Cheviot Hills and the older alluvial fan surfaces north of the SMFL in a zone roughly parallel to the WBHL. Therefore it seems likely based on evaluation of all the data, that two forms of deformation have occurred in the Century City area during the late Quaternary. Relatively broad north to south uplift occurring west of the WBHL and additional deformation where blind strands of the SMFZ enter into the Cheviot Hills likely causing the development of the SMFL. The uplift associated with the WBHL may have caused the bend from ~N70E of the general strike of the SMFZ to ~N50E of the SMFL in the Cheviot Hills (Plate B).

Fault Model No.3 is supported by the observation of apparent right-laterally offset drainages along the SMFL that could be produced by just erosion, the capturing of an ancient channel system that emanated from the relatively young fan surfaces overlying the WBHL that cut through the Cheviot Hills, and the lack of vertical separation across the SMFL. The ancient channel system is associated with the 275T terrace surface and essentially represents an antecedent stream through the Cheviot Hills. In other words, the stream system that formed terrace 275T was able to cut through the Cheviot Hills as the hills were uplifting during the late Quaternary. Based on the evaluation of all the data, Fault Model No.3 is considered the most probable deformation model for the Century City area.

Whether or not the SMFL was produced by a north-dipping reverse fault (Fault Model No.1), a steeply dipping strike-slip fault (Fault Model No.2), or a kink fold axis (Fault Model No.3), it appears based on evaluation of the data that the active surface expression of the Santa Monica Fault Zone is weakening and possibly terminating within the Cheviot Hills near the WBHL. The Evidence for this is the lack of a vertical displacement across the SMFL scarp, local uplift of the Cheviot Hills, lack of any geomorphic evidence of the SMFZ east of the WBHL (Dolan et al., 2000a), and a general decrease in the width of hanging wall deformation toward the east along the length of the SMFZ (see Plate B). With this in mind, the total displacement during a major earthquake near the proposed Base Station would likely be much less than the average displacement observed along the entire fault length. It was determined via a source parameter evaluation of the SMFZ (Appendix A) that reasonable source parameters for the SMFZ would include a moment magnitude Mw=7.1, with an average vertical displacement of ~2 meters (see next section for summary of source parameter evaluation). Thus, in the area of the proposed LA Metro Century City stations at the presumed eastern end of the SMFZ, the total displacement during a major earthquake would be much less than 2 meters. For discussion, we could reasonably indicate that the total vertical displacement may be on the order of 1 meter or less.

Based on the geomorphic data provided in this report, no scarp was identified in the study area that would have accommodated approximately 1 meter of offset across a discrete reverse or left –lateral fault over the course of thousands of years and presumably numerous major earthquakes. Therefore, it is the conclusion of this report that a north dipping reverse fault or a dominantly left-lateral fault accommodating close to 1 meter of displacement per event does not exist in the study area. If reverse faulting does enter into this region it therefore likely does not reach the surface and is primarily manifested by warping and uplift of the Cheviot Hills. The 1 meter or less of proposed total vertical displacement entering the Cheviot Hills could be partitioned to a series of bifurcated blind faults at depth causing local uplift and relatively small scale offsets across numerous strands. The reality of this discussion is simply that the nature of faulting and deformation in the area is not well understood and in particular, the nature and location of the fault possibly responsible for producing the SMFL however based on the geomorphic data, it is difficult to place more than just a few centimeters of slip per event across any fault that may have produced the SMFL. As discussed earlier, Fault Model No.3 provides an erosion model for producing the SMFL along a fold axis above a blind reverse fault strand of the SMFZ. Therefore, it is possible that the SMFL was not produce by a surface rupturing fault at all.

The location of the proposed Base Station is within the swale defining the SMFL, which the interpretation of geomorphic data provided in this report suggests was produced by either a strike-slip fault exhibiting by definition dominantly lateral (horizontal) displacements (Fault Model No.2) or by erosion along a blind fault fold axis (Fault Model No.3). If Fault Model No.2 is true, then the presumably steeply dipping strike-slip fault zone could reach the surface anywhere within the SMFL geomorphic swale or even across most of the width of the swale. Also, because the SMFZ is considered to be a reverse left lateral oblique fault zone, the proposed strike-slip fault producing the SMFL would be by default a secondary fault within the hanging wall of the SMFZ in which case would likely accommodate a very small percentage of total displacement during a major earthquake (much less than ~1 meter). However, the lack of left laterally deflected drainages across the SMFL suggests that repeated left-lateral displacements have not occurred over the course of many earthquakes which indicates that the SMFL was either not created by a strike-slip fault, or that the lateral displacement per event may be very small.

In the case of the proposed Constellation station, no moderately strong or strong geomorphic lineaments were identified in the area of the station. A very weak geomorphic lineament associated with a series of weak changes in slope across designated terraces transects the proposed station location (Fs1). However, there is evidence suggesting the general area of the Cheviot Hills has been vertically uplifted and possibly tilted during the late Quaternary and is continuing till the late Holocene. In addition, it is reasonable to assume based on the provided data and analysis of this report, that the area of the proposed Constellation and Base Station are underlain by at least one if not more blind reverse faults associated with the eastern end of the SMFZ. In addition and discussed earlier, mechanisms for local deformation may be more complicated with the possibility that it involves kinematics between the poorly understood WBHL, SMFZ and Inglewood Fault Zone.

Therefore at a minimum, engineering should consider that the proposed Base and Constellation stations could experience minor fracturing, and tilting and relatively small scale offsets across secondary faults during a major earthquake on the Santa Monica Fault Zone and even possibly during an event on the Newport Inglewood fault due to the postulated kinematic involvement of the various faults in the region.

Although numerous fault deformation models are presented in this report primarily based on geomorphology and that a subsurface investigation is recommended to understand the location and style of local faulting, it is my opinion based on the provided data that no significant fault reaches the surface in the Century City area that would exhibit ~ 1 meter of offset in a narrow zone per event, and that it is possible that no surface rupturing faults exist near the proposed Base and Constellation Stations.

On a side note, based on my cross section analysis, it appears that the proposed Constellation station may reside in man made artificial fill placed within a local drainage (see Section A-A' on Plate E).

Thank you for the opportunity to provide this geomorphic fault evaluation report to you and if you have any questions please do not hesitate to contact me.

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APPENDIX A

Evaluation of fault source parameters for the Santa Monica Fault Zone

Seismic Moment (Mo) was calculated utilizing the equation:

Mo = uAD Kanamori and Anderson (1975)

u = rigidity constant- Shear Modulus (3.0×10^{11} dyne/cm^2 from DePolo and Slemmens 1990. Note that values of u range from $.0 \times 10^{11}$ dyne/cm^2 to 3.5×10^{11} dyne/cm^2 for southern California. The 3.0 value was utilized as this is the same value used by Wells and Coppersmith (1994).

A = area of seismogenic fault plane in units of cm.
The area was calculated by assuming that the seismogenic portion of the fault was on a 30 degree dipping plane from a depth of 2 to 14 km.

D = Average Displacement on the fault in cm.

Moment magnitude (Mw) was calculated utilizing the equation:

Mw = 2/3Log(Mo) – 10.7 Hanks and Kanamori (1979).

Santa Monica Fault Parameters

Fault Length:

Based on evaluation of published reports and fault maps, and geomorphic evaluation of the Santa Monica Fault (terrestrial), a reasonable surface expression of the Santa Monica Fault includes the terrestrial Santa Monica fault (~12 km) and offshore faults running parallel to the Malibu Coast fault in the Pacific Ocean (24 km). This equals a total mapped length (Jennings, 1994) of 36 km. However, fault rupture is known to extend at depth without surface rupture, which indicates that the published fault length for the Santa Monica Fault of 40km is reasonable (Dolan et al., 2000a). The 40 km depth was utilized in the provided calculations.

The ~12 km terrestrial length of the Santa Monica fault (SMF) extends from the Pacific Ocean coastline eastward to the West Beverly Hills Lineament within the Cheviot Hills which provides a reasonable boundary between the SMF and the Hollywood fault (HF) to the east. It is not fully understood whether or not the SMF extends further east of the Cheviot Hills since the latest Quaternary. Wright (1991) indicates that older strands of the SMF clearly extended to the east and southeast from the Cheviot Hills. Geomporphic analysis of the SMF suggest that at least since the late Quaternary the eastward termination of the fault zone may be near the West Beverly Hills Lineament. Also, based on published data, the SMF may have a larger vertical component than the Hollywood fault suggesting slightly varying stress regimes for the two fault zones weakly supporting a non-coseismic event involving the SMF and HF zones.

Fault Rupture Area:

The fault rupture area (length times down-dip width) was calculated based on a fault plane dipping 30 degrees. The Santa Monica fault has a complex history extending back to normal displacement during the Miocene that subsequently was reactivated (Wright, 1991). Boring data evaluation by Wright (1991) and near surface seismic profiling (Catchings, et al., 2008; Dolan and Pratt, 1997; Pratt et al., 1998 indicate that the fault dips to the north, and that the near surface dip may be as low as 20 degrees. However, the true dip extending to the brittle ductile shear zone (~14km) is not fully known. Fault motion since the latest Quaternary is considered to be oblique left lateral reverse. For the calculation of fault area, a dip of 30 degrees was utilized on a plane extending from a depth of 2 to 14 km.

Average Displacement:
Kanamori and Anderson (1975) indicate that the average displacement value should be utilize in the seismic moment calculations. During fault rupture, displacement is obviously zero at the ends of the rupturing fault somewhere below the surface, and has a max somewhere along the length of the rupturing fault (thus not to be assumed near the center region). In theory, the average displacement value is simply the average displacement occurring across the entire rupturing fault plane. The average displacement values were determined utilizing Wells and Coppersmith (1994). Unfortunately, Wells and Coppersmith (1994) provides source parameters for reverse, lateral (strike-slip) and normal faults and thus does not provide data involving oblique faults although oblique earthquake event data was utilized in their regressions. However, regression curves for all of these fault types on Figure 13 comparing surface rupture length and average displacement all intersect near the surface rupture length of 40 km. This provides an average displacement value of D = ~1.85 meters.

Note: Wells and Coppersmith were also utilized to compare the relationships of numerous fault parameters during this analysis.

Estimated reasonable Mw values for the Santa Monica Fault Zone

Mw estimates for a fault length of 40 km ($A = 9.6x10^{12}$ cm^2).

Mw = ~7.1 with average displacement D = 185 cm (most probable).
Mw = ~6.9 with average displacement D = 100 cm.
Mw = ~7.3 with *maximum* displacement D = 300 cm (least probable).

Mw estimates for a fault length of 12 km ($A = 2.88x10^{12}$ cm^2)

Mw = ~6.4 with average displacement of D = 55 cm.

Note: Anderson, et al. (1996) proposes a correlation between slip rate and earthquake magnitude suggesting that the largest earthquakes will occur on the slowest slipping faults if the rupture length is held constant. Thus, slip rate is an important fault parameter regarding estimating major earthquakes magnitudes for specific faults. Essentially, their results suggest that a pure moment magnitude calculation as provided above may underestimate Mw values for faults exhibiting relatively slow slip rates as is currently understood for the Santa Monica Fault.

Failure Analysis Associates

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Hazard Assessment Study Westside Subway Extension Project Century City Area, California

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February 7, 2012

1106070.000 A0T0 0112 PM03

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Appendix B Curriculum Vitae of Project Members

Executive Summary

This report summarizes the results of Exponent- Failure Analysis Associates' (Exponent) evaluation of Parson Brinkerhoff's safety assessment for the Westside Subway Extension Project, which is proposed to be constructed beneath portions of the City of Beverly Hills and contiguous portions of the City of Los Angeles. Exponent evaluated relevant geological, geotechnical, petrochemical and structural engineering hazards associated with the proposed construction, and evaluated the methodologies and metrics used to form the project's safety assessment conclusions. This evaluation is based on preliminary design documents prepared by Parsons Brinkerhoff on behalf of the Los Angeles County Metropolitan Transit Authority, reviewer comments, and other relevant documents.

The Westside Subway Extension Project is currently evaluating two tunnel alignment options through the Century City area, a southerly route associated with a station on Constellation Boulevard and a northerly route associated with a station on Santa Monica Boulevard. The choice between these two station alternatives is a critical design milestone that drives the rest of the design. A station located on Santa Monica Boulevard will be associated with construction of the subway tunnel beneath Santa Monica Boulevard and Wilshire Boulevard within the City limits. A station on Constellation Avenue would necessitate construction of the tunnel beneath historical Beverly Hills High School (BHHS), as well as a number of residences and businesses on the western side of the City.

While the *Century City Area Tunneling Safety Report* and *Century City Area Fault Investigation Report* outline many of the hazards associated with the tunneling project, such as fault rupture, gas explosion and ground settlement, Exponent's overarching opinion is that neither report demonstrates the presented findings as based on rigorous risk assessment(s) on these subjects. Specifically, no attempt is made to quantify or even qualitatively assess the potential risks from these scenarios. No quantitative or qualitative risk assessments have been presented to either a) estimate the likelihood of such events or b) characterize the potential severity of such events to the public.

Based on the findings reported in the Metro-sponsored reports and supporting review comments, momentum seems to be building against construction of a station on Santa Monica Boulevard based on perceived fault rupture hazards. It is Exponent's view that the alternative Constellation Boulevard station, while generally in a more favorable location with regards to faulting issues, is instead faced with potential methane gas hazards that could represent at least as great a hazard to the public as the faulting hazards associated with the Santa Monica Boulevard station. In the absence of a quantitative risk assessment, the choice between the stations is more likely to be made on the basis of risk perception rather than risk quantification. Additional steps can and should be performed at both station locations to better quantify the seismic and gas hazards at these locations. Potential adjustments to the proposed locations should also be considered.

The proposed tunneling project has been characterized as having a low probability of causing disturbance to overlying structures based on the application of a simplified methodology for assessing such hazards and optimistic assessments of tunneling proficiency using pressure-face tunnel boring machines (TBMs). Frequent reference is made to previous favorable experience in the Los Angeles Basin using such devices. Such references, however, have little meaning in the absence of detailed data from the earlier projects.

Even if the actual ground disturbances turn out to be as low as anticipated, the subway tunnels are projected to extend beneath older neighborhoods that are underlain by old, fragile water lines that could experience damage as a result of even minor soil disturbances. Special precautions will be needed to safeguard these lines from damage during construction.

Gas hazards will not be insignificant for the proposed project. Most of the narrative in the reports focuses on gas hazards within the tunnel segments during construction. Almost no attention is paid to the potential for gas releases to the surface as a result of tunneling activities or to the future safe operation of the Constellation station, which would extend into geological deposits that have been closely associated with gas hazards at other locations in the Los Angeles Basin.

Substantial shortcomings exist in the efforts carried out to date to locate early wildcat wells along the proposed subway alignments, especially in the vicinity of BHHS. The reports are mute regarding the potential surficial hazards of encountering well casings during drilling or the ramifications of having to stop drilling and remove a casing while the TBM is parked beneath a sensitive structure. It is Exponent's opinion that unknown factors such as these will preclude tunneling beneath the high school while in session.

With regards to future construction of deep foundations in the vicinity of subway tunnels, the reports are somewhat vague and address only the concerns raised by BHHS. Other stakeholders along the route may also anticipate future construction activities that could be potentially impacted by the presence of underlying subway tunnels.

During our review process Exponent recognized a short-coming of the presented assessment methodology that focuses solely on the safety issues, namely the lack of life-cycle analysis of the considered tunnel alignments of the Westside Subway Extension Project. Such an analysis would allow consideration of the safety risk management issues of the project within the broader spectrum of environmental and economic aspects of the selection process.

In summary, it is Exponent's opinion that additional effort is needed to accurately identify, quantify, rank and mitigate the potential hazards posed by the proposed Westside Subway Extension Project before one of the two presented alternatives, or a third alternative, are selected for implementation.

Limitations

The opinions and comments formulated during this assessment are based on information available at the time of the investigations. Exponent has no direct knowledge of, and offers no warranty regarding, the conditions beyond what was reviewed during our investigation. Comments regarding these conditions are professional opinions, derived in accordance with current standards of professional practice based on our engineering experience and judgment. Exponent has exercised usual and customary care in the conduct of this assessment. No guarantee or warranty as to future performance of any reviewed condition is expressed or implied.

The findings presented herein are made to a reasonable degree of engineering certainty, based on information possessed by Exponent as of the date of this report. This report may be supplemented to expand or modify our findings based on additional work or review of additional information.

1. Introduction

This report summarizes the results of Exponent Failure Analysis Associates' (Exponent) evaluation of Parson Brinkerhoff's safety assessment for the Westside Subway Extension Project, which is proposed to be constructed beneath portions of the City of Beverly Hills (City) and contiguous portions of the City of Los Angeles (Los Angeles). Exponent evaluated relevant geological, geotechnical, petrochemical and structural engineering hazards associated with the proposed construction, and evaluated the methodologies and metrics used to form the project's safety assessment conclusions. This evaluation is based on preliminary design documents prepared by Parsons Brinkerhoff on behalf of the Los Angeles County Metropolitan Transit Authority, reviewer comments, and other relevant documents specifically cited herein.

On October 28, 2010, the Metro Board approved the Draft Environmental Impact Statement/Environmental Impact Report for the Westside Subway Extension Project, which included two tunnel alignment options through the Century City area (Constellation Boulevard or Santa Monica Boulevard). The choice between these two station alternatives is a critical design milestone that will effectively drive the rest of the design. A station located on Santa Monica Boulevard will be associated with construction of the subway tunnel beneath Santa Monica Boulevard and Wilshire Boulevard within the City limits. A station on Constellation Avenue would necessitate construction of the tunnel beneath historical Beverly Hills High School (BHHS), as well as a number of residences and businesses on the western side of the City.

During the October 28 meeting, concerns were expressed regarding the safety of tunneling under BHHS. To address the tunneling safety concerns, the Metro Board approved the following motion*:*

- *Staff fully explore the risks associated with tunneling under the [Beverly Hills] High School, including but not limited to the following: risk of settlement, noise, vibration, risks from oil wells on the property, impact to use of the school as an emergency evacuation center, and overall risk to student faculty and community;*

Exponent has reviewed the *Century City Area Tunneling Safety Report* and *Century City Area Fault Investigation Report* which were commissioned by Metro Staff in response to the above motion and are intended to provide a sound basis for the Board to make a decision on which proposed station to adopt. Exponent's preliminary opinions are organized as follows:

2. Exponent Assessment Overview
3. Hazard Potential and Alternatives for the Santa Monica Station
4. Hazard Potential and Alternatives for the Constellation Station
5. General Tunneling Hazards, including potential impacts on historical Beverly Hills High School
6. Conclusions

2. Exponent Assessment Overview

While the *Century City Area Tunneling Safety Report* (Safety Report) and *Century City Area Fault Investigation Report* (Fault Report) do outline many of the hazards associated with the tunneling project, Exponent's overarching opinion is that neither report includes or is evidently based on the finding of any relevant risk assessment(s) on this subject.

The Metro-commissioned reports discuss various hazards such as gas explosion, ground settling, and impact to the existing seismic faults. However, no attempt is made to quantify or even qualitatively assess the potential risks from these scenarios. Based on the available reports, no quantitative or qualitative risk assessments have been performed to either a) estimate the likelihood of such events or b) characterize the potential severity of such events to the public or students at the BHHS.

Methods for performing risk assessments have been well established and such standard risk assessments are routinely performed for various industries. For example, see Figures 1 and 2 for flowcharts that outline the typical steps in project risk methodology and management. These standard risk assessments start out with a definition of acceptable levels of risks and demonstrate that the new projects being undertaken do not increase the risks above these acceptable levels. In addition, such risk assessments also demonstrate that the mitigation measures, if needed to address the hazard scenarios, effectively control the incremental risks to acceptable levels or to ALARP (As Low As Reasonably Practicable) levels. None of these risk assessment or "risk exploration" steps are reported in the Metro-commissioned studies. Examples of the types of analysis that have been performed for projects of this magnitude elsewhere include:

- Qualitative hazards analysis studies, such as Preliminary Hazards Analysis (PHA), Hazard and Operability studies (HAZOP) or Failure Modes and Effects Analysis (FMEA)
- Quantitative Risk Analysis (QRA) studies with Fault Tree Analysis (FTA) or Event Tree Analysis (ETA) approaches
- Probabilistic Risk Analysis (PRA) studies or uncertainty/sensitivity analysis
- Consequence modeling studies (such as fire/explosion modeling or H_2S dispersion analysis)

The Metro-commissioned studies discuss the known hazards, proceed to state that these hazards can be controlled or mitigated based on available technology and then simply dismiss the hazard associated risks as being "low." In fact, the concept of "low risk" is meaningless in the absence of a quantitative or qualitative definition of the term.

Given the list and nature of identified hazards, it is clear that the incremental risk from tunneling under the BHHS is non-zero. It is not clear why the Metro-commissioned reports fail to quantify or even qualitatively characterize this increased risk level to demonstrate risk acceptability. Without quantification and comparison of potential risks for both the alternative tunnel alignment options (Constellation Boulevard or Santa Monica Boulevard), it is not possible to make a sound assessment and decide as to which alternative tunnel alignment option imposes a higher risk and which risk mitigation measures may be appropriate.

Perhaps the Metro staff or consultants have prepared such risk assessments and do have a basis to conclude that the "*risks associated with tunneling under the [Beverly Hills] High School, including but not limited to the following: risk of settlement, noise, vibration, risks from oil wells on the property, impact to use of the school as an emergency evacuation center, and overall risk to student faculty and community*" are indeed low, but simply have not provided the City or Exponent with the detailed risk assessment reports from such studies. If so, Exponent stands ready to additionally review such risk assessments, if any, and revise our present opinions.

The following sections provide technical review comments on the major components of the proposed Westside Subway Extension Project. These sections provide Exponent's assessments of the detailed geological, geotechnical, petrochemical and structural engineering data and conclusions summarized in the Metro-commissioned reports.

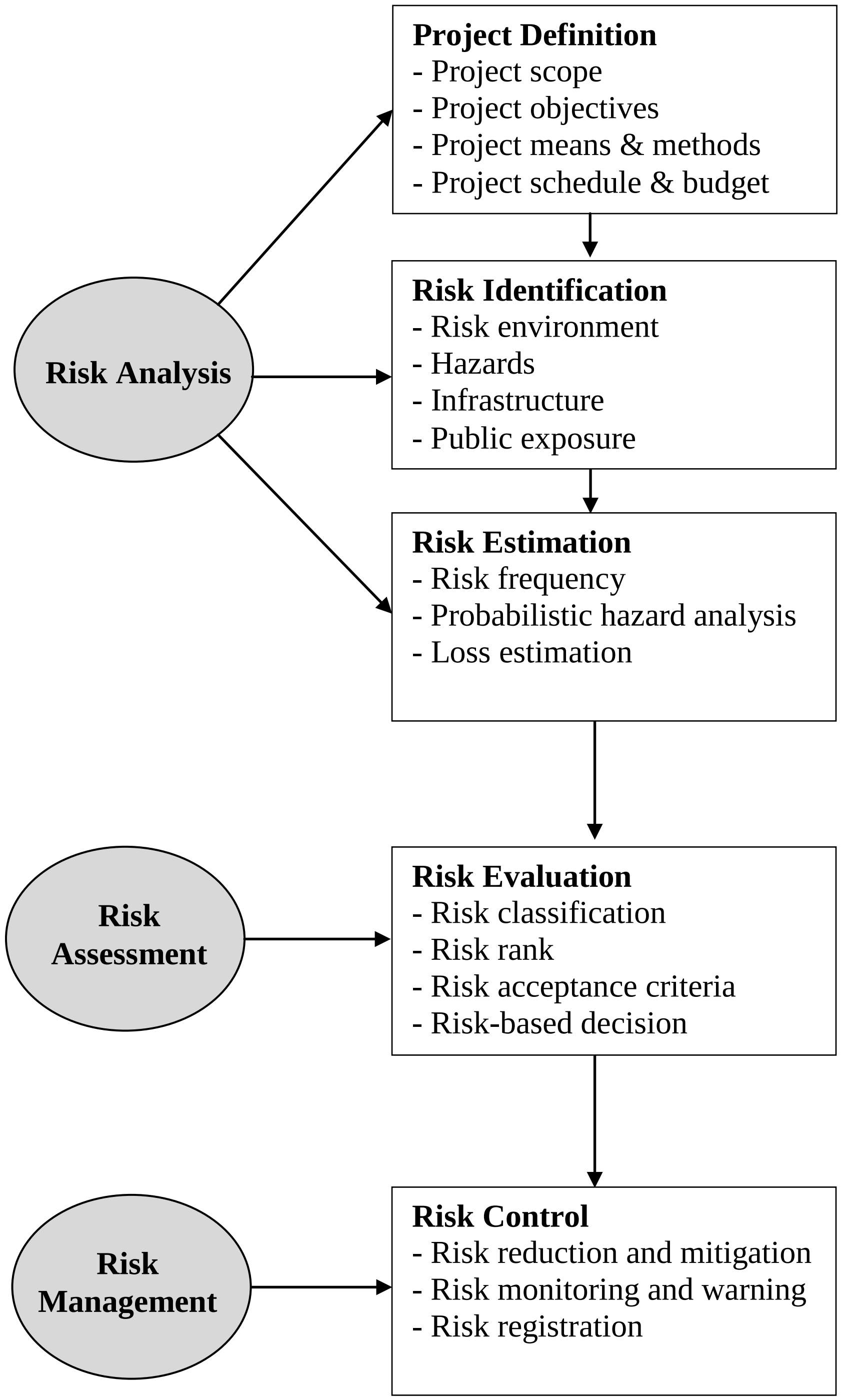

Figure 1. Risk management methodology and flowchart, adopted from Hu *et al*. (2007).

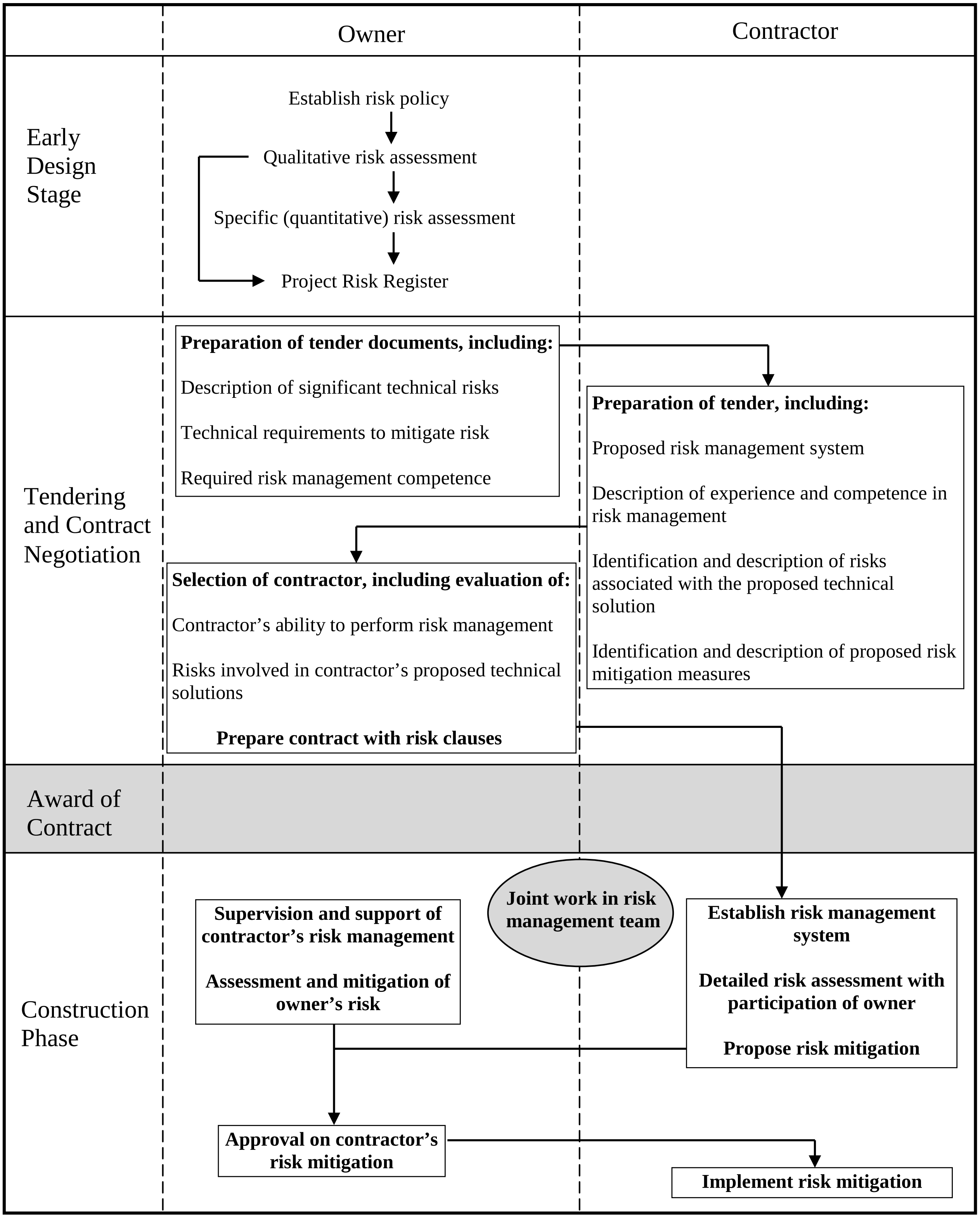

Figure 2. Risk management activity flow for owner and contractor (Eskesen *et al*., 2004).

3. Santa Monica Station

3.1 Introduction

As currently proposed, the footprint of the Santa Monica Station would straddle the Los Angeles-Beverly Hills municipal boundary, with approximately two-thirds of the ~1,200-foot long station located on the Los Angeles side of the boundary, the remainder on the Beverly Hills side (Fault Report, Appendix B, Plate 2). This proposed station footprint was moved to this location from its preliminary proposed location just northwest of Avenue of the Stars in Century City to avoid placement of the structure over inferred branches of the active Santa Monica fault system.

3.2 Fault Rupture Hazard

Several dozen cone penetration tests (CPTs) and approximately another dozen continuously-sampled soil borings were performed in the vicinity of the Santa Monica Station (revised eastern alternative) as part of the Fault Report. These data were used to construct geologic cross sections oriented both along and across Santa Monica Boulevard, including the area of the proposed station. These geologic interpretations included the inferred locations of buried faults associated with both the active Santa Monica fault zone and with the West Beverly Hills Lineament (WBHL), which is inferred in the Fault Report to represent the northerly extension of the active Newport-Inglewood Fault Zone.

As shown on Plate 2 of the Fault Report, the currently proposed footprint of the Santa Monica Station is intercepted by several newly interpreted faults within the WBHL. As shown on Plate 5 of the Fault Report, these fault locations are, for the most part, interpreted on the basis of inferred offsets in the Quaternary[1] stratigraphy underlying the study area. The data and interpretations presented in the Fault Report provide evidence that faulting has likely occurred in the WBHL during the Quaternary period. It must be recognized, however, that the data and methodology utilized have several limitations:

1) The precise locations of the inferred faults are in some places not tightly constrained, due to the spacing between neighboring borings or CPTs. The exploratory borings are spaced at intervals ranging from a few feet to over 100 feet.
2) In light of the interpreted tectonic environment of the WBHL, it is possible that, at least locally, the inferred discrete vertical offsets in the subsurface stratigraphy shown on Plate 5 are instead manifested in the subsurface as monoclinal folds. The engineering and statutory consequences of folded strata are different than that of true fault offsets.
3) The ages of the sedimentary units exhibiting inferred tectonic offset have not been determined; except in unusual cases (i.e., a nuclear power plant) the presence of pre-

[1] The Quaternary period includes both the Pleistocene epoch (1.8 million years ago to 11,000 years ago) and the Holocene epoch (11,000 years ago to present).

Holocene fault displacement does not generally place statutory limitations on site development.

4) The WBHL is manifested at the ground surface as a boundary between two disparate geomorphic and sedimentary environments. As a result, non-tectonic lateral discontinuities in the Quaternary stratigraphy should be anticipated to occur across this feature. It is not clear how the interpreted subsurface stratigraphy may reflect or have been affected by this process.

3.3 Co-Seismic Ground Deformation Hazard

The Fault Report raised concerns that the proposed Santa Monica Station would be potentially subjected to diverse and complex deformations in a future seismic event due to its location near two intersecting fault zones. It is noted, however, that Plate 5 shows the inferred presence of late Pleistocene marker beds (M_E and M_G) that exhibit remarkable lateral continuity and minimal evidence of tectonic disturbance over a distance of over 1,300 feet west of the Los Angeles-Beverly Hills municipal boundary (see Figure A-1 in Appendix A of this report). This observation does not support the contention that the area between the faults would experience excessive or unusual deformations in the event of a future earthquake on one of the adjacent faults.

3.4 Potential Future Steps

Due to potential engineering challenges associated with the Constellation Station and the associated southerly tunnel alignment (discussed below), further work should be done to evaluate the feasibility of constructing a station on Santa Monica Boulevard. As shown on Figure A-1, the currently proposed location for the Santa Monica Station is intercepted by several inferred faults within the WBHL. Although these strands have not been definitively shown to demonstrate Holocene activity, a reasonable probability exists that faults within the WBHL could be kinematically related to the active Newport-Inglewood and/or Santa Monica faults. Also shown on Figure A-1 is a potential "central alternative" that minimizes the potential WBHL fault impacts, remains east of the Santa Monica fault zone, and also overlies the undisturbed marker bed sequence cited in Section 3.3. Additional investigations that could be performed to vet the potential "central alternative" include:

- Evaluate data from prior AMEC borings (see Figure A-2) to obtain more information regarding the nature, location and recency of movement of the most westerly inferred fault in the WBHL (indicated by red arrows on Figure A-1).
- Consider excavation and logging of a fault trench parallel to Santa Monica Boulevard on the vacant parcel to the south of proposed "central alternative," or advancing additional CPTs to gather more information on this inferred fault (see Figure A-2).
- Consider drilling angled borings targeted at locating buried sub-vertical faults and/or folded strata.

4. Constellation Station

4.1 Introduction

As currently proposed, the footprint of the Constellation Station extends approximately 1,200 feet eastward from Century Park East beneath Constellation Boulevard (Fault Report, Appendix B, Plate 2). The Constellation Station is associated with construction of the southern tunnel alternative, which extends beneath BHHS and other older structures in the western portion of Beverly Hills.

4.2 Fault Rupture Hazard

The Constellation Station lies approximately 900 feet south of the nearest mapped strand of the Santa Monica fault (Fault Report, Appendix B, Plate 3). The station is also depicted on the cited plate as lying approximately 150 feet west of the westernmost inferred fault in the WBHL. While the distance between the station and the nearest fault in the Santa Monica fault zone appears robust, the distance from the Constellation Station to the nearest fault in the WBHL is much less certain. Generally, this inferred fault location shares all the limitations cited above (points 1-4, Section 3.2) for the Santa Monica Boulevard Station. More specifically, the nearest inferred fault trace to the Constellation Station is very poorly constrained due to the 450-foot gap between the bracketing borings used to make the fault interpretation: boring 69-036-1 on the west, and a cluster of borings located just inside the Beverly Hills municipal border on the east (see Figure A-3). As shown on Figure A-3, the inferred fault could pass much closer (possibly beneath) the eastern end of the proposed station (area indicated as "Uncertain Structure" on Figure A-3).

4.3 Gas Hazard

In comparison with the potential station locations on Santa Monica Boulevard, the Constellation Station would be excavated into older deposits of the Lakewood and San Pedro Formations. These units were deposited in a shallow marine environment in Pleistocene time. The Westside Extension Transit Corridor Study, Final Alternatives Analysis Report, Chapter 4.0 (January 2009) included the following recommendation:

> "Minimize construction in the gas and tar bearing formations as much as possible, particularly the San Pedro Formation's unsaturated zones. These zones were found to have high methane and hydrogen sulfide (H_2S) concentrations during explorations for Metro's Mid-City alignments in the 1990's."

The same report also cited an earlier (1994) report entitled "Mid-City Re-Assessment Study" that recommended that all structures be raised above the San Pedro Formation to the extent possible, especially if it were un-saturated, to mitigate against potential gassy ground conditions.

Evidently, the San Pedro Formation contains local lenses of petroliferous oil sands that represent a principal source of the gas.

As shown on Figure A-3, the Constellation Station is anticipated to be founded above the water table (blue line) within the San Pedro Formation (purple hue), a situation which represents an unfavorable gas condition as defined in the 1994 report. Data reported in Figure 5 of Appendix B of the Safety Report generally confirm that the San Pedro Formation is gassy in this area, with soil methane values ranging from 0.5 to 12 percent by volume. The highest concentration of methane gas encountered in the footprint area of the Constellation Station was a reading of 12 percent by volume in boring M-119, encountered at a depth of about 75 feet in the San Pedro Formation. Two of the three readings in boring B-3, the only other exploratory boring tested for gas that reached the San Pedro Formation, were in the 6 to 7 percent by volume range. Methane is explosive between its Lower Explosive Level (LEL) of 5% by volume and its Upper Explosive Level (UEL) of 15% by volume (Ulery, 2008). High concentrations of soil gas can be mitigated by engineering controls. However, it is clear that gassy ground conditions would strongly affect the design, construction and future operation of the Constellation Station. Additional discussion on gas hazards is given in Section 5.3 of this report.

4.4 Potential Future Steps

Two principal geotechnical uncertainties concerning the Constellation Station are: 1) the location of the most westerly interpreted fault in the WBHL and 2) the relative extent of gassy ground conditions in the San Pedro Formation underlying the station. With regards item to 1, old AMEC borings in the area (green highlighted area on Figure A-4) should be reviewed as a first step in better characterizing the location of potential buried faults in this area. Additional studies (borings) may also be needed to better establish the location of the inferred fault in this area. Additional borings in the footprint area of the Constellation Station would also be helpful in more fully characterizing the gassy ground conditions so far indicated in this area. Angled borings should be considered as an aid in locating buried sub-vertical faults and/or folded strata.

5. General Tunneling Hazards

5.1 Potential Damage to Buildings During Tunneling

5.1.1 General Considerations

According to the Safety Report, expected settlements under the proposed tunnels will be less than 0.5 inches, with distortion angles of 0.75×10^{-3}. A distortion angle of 0.75×10^{-3} equates to a differential settlement of approximately 1 inch in 110 feet, which is below the threshold of expected damage to buildings. However, according to reports describing surface effects during the tunneling of the Metro Red Line subway (Bell Consulting, 2004[2]), settlements were much higher (2 to 10 inches) than originally predicted (0.5 inches). If settlements reached 2 inches, 4 times the expected 0.5 inches and resulting 1 inch in 28 feet of differential settlement, cracking of wall panels in buildings would be expected. Larger amounts of differential settlement could lead to significant cosmetic damage and possible structural damage. It appears that settlement considerations in the Safety Report only account for deformations along a profile perpendicular to the centerline of the tunnels. Differential settlements would also be expected between areas ahead and behind the advancing boring machine.

It is also important to note that the settlement calculations described in the Safety Report do not appear to consider consolidation settlements related to ground water loss. Water losses were also reported to be a contributor to settlements during the Metro Red Line tunneling (Bell Consulting, 2004[2]; Wiss, Janney, Elstner, 1995). Any loss in pressure at the face of the tunneling machine could result in significant water losses, depending on the particular geology and water conditions at the pressure loss location. Also, tunneling across fault lines could cause previously isolated drainage layers to connect and drain ground water.

5.1.2 Beverly Hills High School (BHHS)

As currently proposed (Fault Report, Appendix B, Plate 3), the southerly route associated with the Constellation Station would pass beneath a number of structures in the western portion of Beverly Hills, most notably BHHS. Figure 4 of Appendix B of the Safety Report shows a geotechnical cross section beneath the high school. The cross section indicates that the tunnels are to be constructed almost entirely through saturated sand and silty sand deposits of the Lakewood Formation.

Within the narrative of the Safety Report, considerable emphasis is placed on prior experience *in similar ground conditions* gained using pressure-face TBMs on the MGLEE project. On page 4-4 of the report, it is stated that, "The tunnels were advanced through old alluvium, consisting of layers of sand and clay." Figure 4-3 provides a schematic geologic profile that indicates that the MGLEE tunnels were extended through both clay/silt intervals and sand/gravel intervals.

[2] http://www.bellconsulting.com/studies/hollywood.htm

However, the diagram is not sufficiently detailed to provide an adequate comparison with the detailed information available on Figure 4 of Appendix B of the Safety Report. Finally, a published description of the ground conditions encountered during drilling (Robinson and Bragard, 2007) states:

> "The geology for [the] most part was a mixed percentage of sandy clays and clayey sands. At no point did we have pure sand or pure clay. This combination of ground types was actually quite good. The clayey ground had enough sand in it to prevent the muck from getting to[o] sticky, and we rarely plugged the cutterhead or screws. The sandy ground had enough clay content to give it some body, and didn't allow the sandy ground to pack, or lose all its water content…"

Based on the information available for review, the geological conditions that would be encountered at tunneling depth beneath BHHS would differ, perhaps significantly, from those considered typical during drilling of the MGLEE. This difference may or may not affect the tunneling performance of the pressure-face TBMs anticipated for use in this project. However, based on the previous narrative, due consideration must be given to the probable effect(s) of the TBMs on the sandy soils underlying BHHS. In particular, it will be critical to minimize water losses from the saturated sands during drilling, as significant water losses from the formation could result in ground settlements that exceed specified threshold criteria. It is also important to consider the consequences of an unplanned halt in drilling beneath BHHS, as water losses during an unplanned halt (such as to repair a cutting head or remove an obstruction) could greatly exceed losses experienced during normal operations.

A final geotechnical issue, not addressed in the reviewed documents, is the potential interaction between tunneling, mapped faults, and structures on the BHHS campus. The sub-vertical faults underlying the campus, presuming they exist, represent discontinuities in the soil mass. Surface deformations will likely be concentrated above these faults during drilling as a result of differential settlement.

5.2 Potential Damage to Utilities During Tunneling

The proposed Westside Subway Extension Project will involve tunneling beneath portions of the City that were constructed in the early part of the 20th Century. In many areas, utility lines overlying the proposed subway routes were originally constructed using antiquated standards and materials, and are now also very old. Consideration must be given to the possibility that these very old utility lines may be brittle and unable to tolerate even the projected differential settlements. While all buried utility lines (supplied water, sewer, storm drain, telecommunications, oil, gas, or electricity) can theoretically be damaged by settlement, damage to pressurized lines (water, oil, gas) has the greatest potential to affect both the tunneling work and the built environment.

As an example of the potential hazards associated with tunneling-related utility line ruptures, it is noted that a large sinkhole formed in Hollywood as a result of a water line break caused by tunneling operations for the Metro Red Line in the 1990s. Water lines in that area are, like those in Beverly Hills, relatively old and are more sensitive to changes in environmental and support conditions than what is assumed for standard utility lines. It is our understanding that the sinkhole formed when a section of tunnel that was out of alignment was under repair. Such unplanned work stoppages represent a particular geotechnical hazard because they negate the safety improvements provided by use of pressure-face TBMs.

Moreover, in the last few years Los Angeles has experienced a spate of water line breaks that have been hypothesized to result merely from changes in the watering schedules of residential water users. This phenomenon provides a further indication of the sensitive condition of many older water lines in the Los Angeles Basin.

Also, as described previously, the projected settlements may be focused in areas overlying fault lines. Particular attention must be given to sensitive utility lines crossing these fault lines, such as older pressurized supply lines that have corrosion or brittleness issues. A detailed survey of utility lines crossing the tunnel alignment is recommended. This effort should be coordinated with utility organizations to determine if any sensitive supply lines exist that should be repaired or replaced before tunneling commences in that area. An effort must be made to better constrain the locations of inferred subsurface faults to determine the locations most likely to experience differential settlement during construction.

5.3 Gas and Oil Well Hazards During Tunneling

The proposed tunnel alignment extends through the Methane Zone established by the City of Los Angeles in 2003 as well as active and inactive oil fields. The Safety Report addresses risks associated with tunneling through gassy soils and areas with active and abandoned oil wells. Several previous tunneling projects through gassy soils were summarized in Section 5.5 of the Safety Report; however the absence of incidents in these past projects does not, by itself, ensure that future tunneling in “similar” conditions is inherently safe.

As discussed in Section 4.3 of this report, methane is combustible when mixed with air in the range between 5 and 15 vol % of gas. Occupational Safety and Health Administration (OSHA) requirements state that when air samples indicate methane gas levels at 5% or more of the lower explosive limit (LEL), ventilation must be increased and gas must be controlled. When air samples indicate methane gas levels at 20% or more of the LEL, work must be ceased and employees withdrawn from the tunnel (29 CFR 1926.800). Proper tunnel ventilation procedures should be in place for both the tunnel boring and tunnel operating stages, and the initiating events for tunnel methane explosions, discussed in Kissell (2006), should be addressed when designing a safety plan. Pressure-face tunnel boring machines are considered an improvement to safety as they minimize leakage of gases into the tunnel, minimizing workers’ contact with excavated material at the tunnel face (APTA, 2005). The excavated material or slurry is pumped from the sealer cutter area, through a closed pipe system, to the surface. Thus, proper ventilation should also be in place at or near the soil discharge point during tunneling operations to minimize worker exposure to hazardous levels of gas.

Faults and existing oil wells (active or abandoned) can act as conduit for gases, allowing pockets of concentrated gas to form. Tunneling through gassy ground in Los Angeles for the East Central Interceptor Sewer (ECIS) project (completed in 2004), showed that increases in methane gas were measured when tunneling across or near the Baldwin Hills Fault (15-18% LEL) and the Inglewood Fault (55% LEL) (Keller and Crow, 2004). Subsurface gas conditions were evaluated using measurements from new borings installed for the project and existing data from nearby projects. Methane gas and hydrogen sulfide measurements from several gas monitoring wells and geotechnical borings are provided in Figure 5 of Appendix B of the Safety Report. Maximum methane readings in the Constellation Boulevard Station area were 12 to 24 percent at depths of 75 and 40 feet, respectively. Measurements from seven wells or borings were provided for an area extending approximately 900 feet along the Constellation Boulevard Station area, while measurements from only one boring were provided for an area extending approximately 800 feet on the Beverly Hills High School campus in the active West Beverly Hills Lineament / Newport-Inglewood Fault Zone. Due to the lack of data on the gas levels in the fault zone under BHHS, further gas monitoring and measuring is recommended on the BHHS campus.

According to the Safety Report, the proposed tunnel alignment passes under three BHHS buildings: the BHUSD Administration Building (ca. 1960s), the Adult Instructional Center (ca. 1960s), and the south wing of Building B (ca. 1920s with renovations carried out in 1970s). The tunnel alignment also passes approximately 100 feet northwest of Building F (ca. 1939) and, according to a sketch of the tunnel alignment, approximately 100 feet southeast of Building A (built from 1967 to 1970). Depending on site conditions, dangerous levels of methane gas may accumulate under building foundations or developed areas on the surface (Hamilton and Meehan, 1992). The affected BHHS buildings were built (and some of them renovated) before modern methane mitigation techniques were developed and implemented in the construction of buildings on gassy grounds. Such mitigation techniques include de-watering systems to lower the water table, an impervious membrane layer beneath the building foundation, and gravel blankets or other ventilation systems under the foundation to vent gases away from the underside of the building. Since they were not required, it is very unlikely that these modern techniques were employed in the construction of the buildings on the BHHS campus, and thus, gases may be more prone to accumulate or become trapped under their foundations. Tunneling below these areas, and through an active fault zone, could potentially be more dangerous than tunneling below more modern buildings with methane seepage mitigation measures in place.

The planning and construction activities regarding public schools fall under the Field Act of 1933 (California Education Code §§17280-17317 and 80030-81149), with authority remaining with the California Division of the State Architect (DSA). Other state departments operating with the DSA regarding public schools include the California Department of Toxic Substances Control (DTSC) and the California Environmental Protection Agency. The DTSC, responsible for the evaluation and mitigation of toxic substances, offers guidance on the proper methodologies for soil gas investigations and common remedies for school sites with gas hazards (DTSC, 2003; DTSC, 2005). Using the DTSC methodologies, further investigation on the amount of potentially trapped methane gas under the affected BHHS buildings, and potential mitigation measures, would be prudent.

Existing abandoned oil wells, when encountered during tunneling, can have a significant impact on the project schedule and budget. Undocumented "wildcat" wells have been encountered in the past on Los Angeles area tunneling projects. For example, on the ECIS project an abandoned oil well was encountered that was not on record with the State Department of Oil & Gas and Geothermal Services (DOGGR) and was undetected before excavation began, since the oil well was cut-off below the surface (Keller and Crow, 2004). Considerable efforts were required to successfully, and safely, re-abandon the oil well before further excavation could continue.

According to the Safety Report, a number of oil wells are mapped by DOGGR within 100 feet of the tunnel alignment, and possibly one well is within the tunnel zone; these wells are mapped as abandoned wells. The maps show the approximate locations of the wells and do not account for undocumented wells that may be present. It is our understanding that a surface magnetometer study was conducted in open areas along the proposed tunnel alignment to detect metal and possible well casings near the ground surface (detection depths with electromagnetic methods within about 15 feet of the ground surface), in an effort to locate possible undocumented oil well casings on the BHHS campus. Based on our review of the soil conditions, some areas of the campus are underlain by considerable depths of fill soil that likely post-dates the use of the area as an oil field. The results of the magnetometer survey cannot therefore be considered a robust screening tool for old well casings. Magnetometer probe holes using horizontal directional drilling methods are therefore strongly recommended to screen for buried well casings along the proposed tunnel alignment beneath BHHS.

5.4 BHHS Campus Restrictions During Tunneling

It is anticipated that, due to uncertainties in potential surface manifestations resulting from tunneling (vibrations, settlement, potential gas hazards, potential utility line damage, potential sinkhole formation, etc.), the school campus will need to be evacuated while tunneling takes place beneath BHHS. Alternatively, work could be conducted when school is out of session. The Safety Report does not address this issue. The rate of tunneling can depend on several factors which may be encountered during tunneling, for instance, contaminated soil, abandoned oil wells, and unstable soils. During tunneling for the Metro Gold Line Eastside Extension Project, where gassy soils were also encountered, the maximum advance rate (best day) using TBMs was approximately 90 feet per day (CH2M Hill, 2009). During tunneling for the ECIS project, an average progress rate using a TBM was approximately 40 feet per day (Keller and Crow, 2004). According to maps in the Safety Report, approximately 1,000 feet of twin-bore tunneling would be located under the BHHS buildings. Depending on project scheduling and tunneling rates, a period of several weeks of evacuations could be expected at BHHS while drilling takes place. Planning for the evacuation and accommodation of BHHS staff and students should be considered early in the project design phase.

5.5 Future Construction Concerns

Concerns have been raised about the potential impact of the tunnels on future BHHS plans for subterranean parking on campus. If deep foundations (i.e. piles or drilled shafts) are required below the parking structure (or other potential buildings on campus), care will be required during the planning phase to avoid potential impacts to the tunnels during construction. Also, if the deep foundations are required to be in close proximity to the tunnels, some foundation types may be excluded due to increased soil pressure loads on the tunnel walls.

At this time Exponent does not have information regarding potential future development plans at other businesses or residences along the proposed tunnel alignments. In general, future development at other properties would be expected to be impacted in the same manner as discussed above for BHHS.

5.6 Potential Future Steps

The Safety Report does not address any plans for reconnaissance or monitoring of structures and utility lines before or during tunneling operations. Comprehensive documentation of ground elevations and existing building and structure conditions along the proposed alignment is recommended before tunneling operations begin. This documentation would serve as a baseline for extensive monitoring of any settlement or damage caused by tunneling and also as a reference for any future damage claims made by building or structure owners along the alignment.

It appears that only limited, reconnaissance-level studies of expected ground settlements have been performed using very approximate methods. A more detailed predictive study would be expected for a project of this scale. Such a study should make use of modern finite element codes, incorporate detailed geologic profiles along the alignment, and use the latest soil constitutive models. In concert with the documentation described above, any recorded settlement or damage discovered during tunneling operations should be compared with model predictions. Poor correlation between model predictions and actual soil behavior would allow adjustments to alignment or technique that could limit future damage.

A detailed survey of all utility lines crossing the tunneling alignment is strongly recommended. This effort should be coordinated with utility organizations to determine if any sensitive supply lines exist that should be repaired or replaced before tunneling commences in that area. Other utilities, such as storm drain systems, may not be as critical; however, leaks in the storm drain lines can cause soil settlement over the long term.

During our review process Exponent recognized a short-coming of the presented assessment methodology that focuses solely on the safety issues, namely the lack of life-cycle analysis of the considered tunnel alignments of the Westside Subway Extension Project. Such an analysis would allow consideration of the safety risk management issues of the project within the broader spectrum of environmental and economic aspects of the selection process.

It is recommended that the above listed additional studies be summarized in report(s) with clear action-oriented recommendations and distributed to the parties at stake.

6. Conclusions

It is Exponent's opinion that the *Century City Area Tunneling Safety Report* and the *Century City Area Fault Investigation Report*, while identifying many of the potential hazards associated with the tunneling project, fail to provide relevant risk assessment(s) concerning these hazards. No quantitative or qualitative risk assessments have been presented that either a) estimate the likelihood of such events or b) characterize the potential severity of such events to the public or students at BHHS.

A major milestone in the progress of the Westside Subway Extension Project will be the selection of one of the two Century City station alternatives: Santa Monica Boulevard or Constellation Boulevard. Momentum seems to be building against the Santa Monica Boulevard location based on the findings of the Fault Report. The Constellation Boulevard station, however, is faced with potential methane gas hazards that could represent at least as great a hazard to the public as the faulting hazards associated with the Santa Monica Boulevard station. In the absence of a quantitative risk assessment, the choice between the stations is more likely to be made on the basis of perception of risk than on its quantification. Additional steps can and should be performed at both station locations to better quantify the seismic and gas hazards at these locations. Additional adjustments to the proposed locations should be considered.

The proposed tunneling project has been characterized as having a low probability of causing disturbance to overlying structures, such as BHHS, based on the application of a simplified methodology for assessing such hazards and optimistic assessments of tunneling proficiency using pressure-face TBMs. Frequent reference is made to previous favorable experience in the Los Angeles Basin using such devices. These references, as such, have little meaning in the absence of detailed data from the earlier projects. For example, one of the major causes of tunnel-related settlements, water loss, is hardly mentioned at all in the Metro reports.

Even if the actual ground disturbances turn out to be as low as anticipated, the subway tunnels are projected to extend beneath older neighborhoods that are underlain by old, fragile water lines and other utilities that may be subject to damage as a result of even minor soil disturbances. The practical reality of this situation is that these old utilities will not likely behave in textbook fashion as the tunnels are extended beneath them. Special precautions will be needed to safeguard these lines from damage during construction.

Gas hazards will not be insignificant for the proposed project. Most of the narrative in the reports focuses on gas hazards within the tunnel segments during construction. Almost no attention is paid to the potential for gas releases to the surface as a result of tunneling activities or to the safe operation of the Constellation station, which would extend into geological deposits that have been closely associated with gas hazards at other locations on the Los Angeles Basin.

Substantial shortcomings exist in the efforts carried out to date to locate early wildcat wells along the proposed subway alignments, especially in the vicinity of BHHS. The reports are mute regarding the potential surficial hazards of encountering well casings during drilling or the ramifications of having to stop drilling and remove a casing while the TBM is parked beneath a sensitive structure. It is Exponent's opinion that unknown factors such as these will preclude tunneling beneath BHHS while the school is occupied.

With regards to future construction of deep foundations in the vicinity of subway tunnels, the reports are somewhat vague and address only BHHS concerns. Other stakeholders along the route may also anticipate future construction activities that could be potentially impacted by the presence of the subway tunnels.

Addressing the differences in life-cycle aspects of the potential tunnel alignments could make significant contributions to the decisions based on safety risk management.

In summary, it is Exponent's opinion that much more work needs to be performed to accurately identify, quantify, rank and mitigate the potential hazards posed by the proposed Westside Subway Extension Project before the definitive choice of one of the two presented alternatives or even potentially a third one can be made.

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Appendix A

Figures

*Note: Approximate locations of fault zones based on subsurface representations of faulting

EXPLANATION

Quaternary Sedimentary Deposits

Artificial Fill:

- **Af** — Fill

Alluvial Fan and Fluvial Deposits:

- **Qf/Qfo** — Younger or Older Alluvial Fan Deposits
- **Qfo** — Older Alluvial Fan Deposits (Undifferentiated) - Alluvial Fan Deposits, May Include Fluvial and Estuarine Deposits of Limited Thickness and/or Limited/Uncertain Lateral Extent
- **Qfofl** — Older Fluvial Deposits - Fluvial Deposits of Significant Thickness and Lateral Extent
- **Qfob** — Basal Alluvial Fan Unit - Poorly Sorted Deposits With Variable Calcium Carbonate, Typically Overlies Basal Estuarine Unit

Estuarine Deposits:

- **Qe** — Estuarine Deposits (Undifferentiated) - Includes Variable Sediments Deposited Within Estuarine Environment, Primarily Fine Grained Deposits with Coarser Grained Interbeds, Typically Well Sorted, May Include Fan and Fluvial Deposits of Limited Thickness and/or Limited/Uncertain Lateral Extent
- **Qe_f** — Estuarine Deposits (Fine Grained) - Primarily Silts and Clays, Frequently Laminated/Varved
- **Qe_b** — Basal Estuarine Unit - Primarily Thickly Bedded Clays and Silts with Variable Calcium Carbonate, Typically Overlies San Pedro Formation

Lakewood Formation (Marine Deposits):

- **Qlw_{gr}** — Gravels and Gravelly Sands
- **Qlw_{sp}** — Primarily Poorly Graded Sands
- **Qlw_{sm}** — Primarily Fine Silty Sands, Some Sandy Silts
- **Qlw_{cl}** — Clays and Silts

San Pedro Formation (Marine Deposits):

- **Qsp_{gr}** — Gravels and Gravelly Sands
- **Qsp_{sp}** — Primarily Poorly Graded Sands
- **Qsp_{sm}** — Primarily Fine Silty Sands, Some Sandy Silts
- **Qsp_{cl}** — Primarily Clays and Silts

Marker Beds:

- M_A — Distinct Clay/Silt Bed Overlying Fan Deposits, Possible Weak Soil Development. Equivalent to Marker Bed M_A of Transect 7 Profile
- M_B — Distinct Dark Gray Clay/Silt Bed. Equivalent to Marker Bed M_B of Transect 7 Profile
- M_C — Distinct Gravelly Bed. Equivalent to Marker Bed M_C of Transect 7 Profile
- M_D — Distinct Dark Gray Clay/Silt Bed. Equivalent to Marker Bed M_D of Transect 7 Profile
- M_E — Distinct Clay/Silt Bed Overlying Fan Deposits, Possible Weak Soil Development. Equivalent to Marker Bed M_F of Transect 7 Profile
- M_F — Thick Oxidized Clay/Silt Bed, Coarsens Toward the East
- M_G — Distinct Clay/Silt Bed Overlying Marker Bed M_F, Possible Weak Soil Development

Notes:

- ② Fault, Dips 60°-70°, 1.5 Inch Shear Zone, Qfo_b Above, Qe_b Below
- ③ Possible Minor Fault, Dips 50° Sheared Clay with Planar Surface
- ④ Minor Fault, Dips 45°-50°
- ⑤ Lateral Extent of Marker Beds and Other Thin Beds Shown Adjacent to T2E-B3 Uncertain. Some Degree of Lateral Continuity is Implied Based on Correlation with Transect 7 Profile.
- ⑥ Classification as Qe_b Somewhat Uncertain Due to Limited Sample

Symbols & Graphics:

- Approximate Geologic Bedding Contact Interpretation Based on CPT Data
- Approximate Geologic Contact, Queried Where Uncertain
- Approximate Fault Location
- Sheared Clay/Silt
- Groundwater Measured During Drilling
- Groundwater Encountered During Drilling
- T2-200 — Approximate Seismic P-Wave Shot Point Location Projected to Transect Line
- T2-B10/T2-B9 — Transect & Boring Identification & Location
- T2-C41/T2E-C34 — Transect & CPT Identification & Location

Notes: * Projection of Boring/CPT Noted Unless Within 10 Feet of Transect.
* Orientation of Faults Are Generally Not Well Constrained. Actual Orientations May Vary From Those Shown.
* Fault Dips Measured Where Observed in Core Samples, Direction of Dips Were Not Obtained.

CPT Data:

Sleeve Stress | Tip Stress

(tsf)

VERTICAL SCALE: 1" = 20'-0"

HORIZONTAL SCALE: 1" = 40'-0"

Annotated Geologic Cross Section
Transect 2 & 2East
Showing Potential Santa Monica Station
Location Alternatives

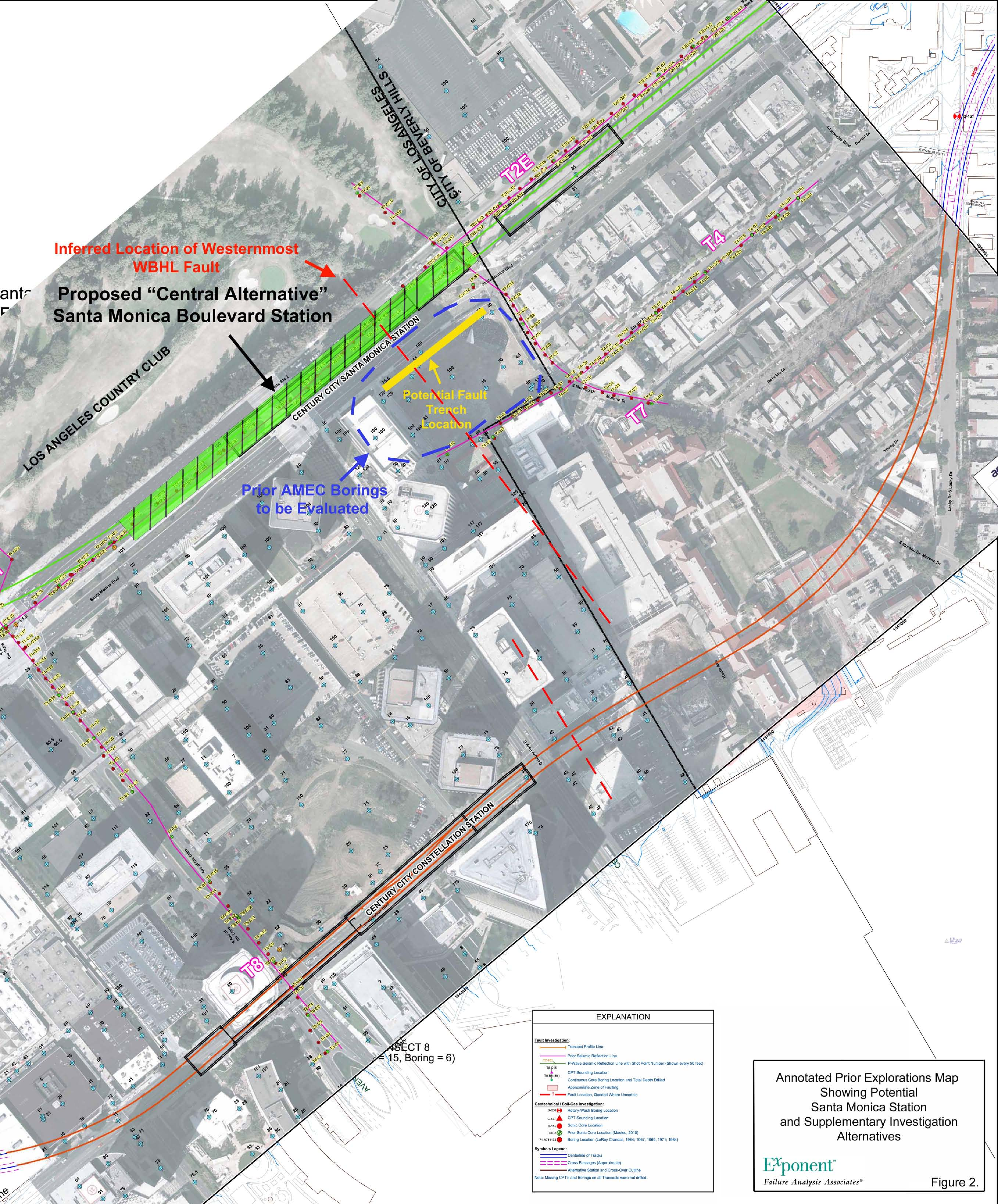
Exponent™
Failure Analysis Associates®

Figure 1.

amec

AMEC Environment & Infrastructure
5628 E. Slauson Avenue, Los Angeles, California 90040
Phone (323) 889-5300 Fax (323) 889-5398

Geologic Section	
JOB: 4953-10-1561	TRANSECT 2 & 2East
LT,LNG:	Century City, Los Angeles, California
SCALE: V: 1" = 20' H: 1"=40'	
DRAWN: V. Nguyen	
CHKD: M. Wickers/M. Farr	PLATE NO. 5
PM: R. Munro	
DATE: 10/14/2011	PROJECT NO. 4953-10-1561



Annotated Prior Explorations Map Showing Potential Santa Monica Station and Supplementary Investigation Alternatives

Figure 2.

GEOLOGY EXPLANATION

Fill	Artificial Fill
Qfo/Qe	Older Alluvial Fan Deposits/Estuarine Deposits
Qlw	Lakewood Formation
Qsp	San Pedro Formation
—c—	Cemented Bed
—x—	Shell Bed
—g—	Gravel Bed
— —	Geologic Contact
— — (red)	Approximate Fault Location
(pink box)	Beverly Hills Lineament/Newport Inglewood Fault Zone

CPT Data:

Sleeve Stress | Tip Stress

(tsf)

VERTICAL SCALE: 1" = 20'-0"

HORIZONTAL SCALE: 1" = 100'-0"

Annotated Geologic Cross Section
Constellation Profile

Exponent
Failure Analysis Associates

Figure 3

Geologic Section

amec
AMEC Environment & Infrastructure

JOB: 4953-10-1561
SCALE: V: 1" = 20' H: 1"=100'
DRAWN: V. Nguyen
CHKD: M. Wickers/P. Elliot
PM: R. Munro
DATE: 10/14/2011

CONSTELLATION PROFILE
WEST BEVERLY HILLS LINEAMENT/NEWPORT INGLEWOOD FAULT ZONE PROFILE ALONG CONSTELLATION BOULEVARD ALTERNATIVE STATION 690+00 TO 730+00
Century City, Los Angeles, California

PLATE NO. 9
PROJECT NO. 4953-10-1561

Annotated Prior Explorations Map Showing Potential Constellation Station and Supplementary Investigation Alternatives

Exponent™
Failure Analysis Associates®

Figure 4.

Appendix B

Curriculum Vitae of Project Members

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Corporate Vice President and Principal Engineer

Professional Profile

Dr. Piotr Moncarz is a Corporate Vice President at Exponent. Dr. Moncarz's efforts are directed particularly in the energy sector, including assistance in power plant development projects, and in the oil and gas industry in programs implementing risk management in system operations. With a background in civil engineering, Dr. Moncarz has worked in the areas of reinforced and prestressed concrete, the study of concrete distress due to material problems and adverse conditions, cracking of concrete, wood mechanics, steel structures, earthquake engineering and seismic assessments, field and analytical structural failure investigations, structural analyses of transmission towers, and investigations of ship and offshore platform failures. Dr. Moncarz is a Stanford Certified Project Manager skilled at providing means and methods to project and program organization and management. For over 15 years Dr. Moncarz has worked on projects associated with energy. He leads Exponent's Energy Initiative Program which includes electric power plants, Liquefied Natural Gas (LNG), oil, natural gas, shale gas, and renewable resources. Dr. Moncarz has conducted energy policy studies focusing on gas for Central Asian Republics and Bangladesh.

Dr. Moncarz serves as a Consulting Professor in the Civil Engineering Department of Stanford University. He is Chairman and Co-Founder of the U.S.-Polish Trade Council of Silicon Valley. Dr. Moncarz also serves on the Board of Directors of the San Francisco Global Trade Council.

Academic Credentials and Professional Honors

Ph.D., Structural Engineering, Stanford University, 1981
M.S., Civil Engineering, University of Colorado, Boulder, 1975
Bridge and Road Construction Vocational School, Poznan, Poland, 1968

Stanford Certified Project Manager, Stanford University Advanced Project Management, 2003

John A. Blume Fellow; E. Kwiatkowski Economy Award of Poland, 1997; Recipient of Gold Engineer Award 2010 of "Technical Review" and Council of Engineers and Technicians of Poland; Polonia Technica, New York, Honorary Membership Award, 2011

Licenses and Registrations

Registered Professional Civil Engineer, California, #36916; Registered Professional Civil Engineer, Nevada, #013278; Registered Professional Civil Engineer, Florida, #0061456; Registered Professional Civil Engineer, Washington, #41579; Registered Professional Engineer, Missouri, #2008011611; Licensed Professional Civil Engineer, Saskatchewan, Canada, #7304; Licensed Professional Engineer, British Columbia, Canada, #N1537

Publications

Moncarz P., Skrobiszewski F, Pniewska J. Successfully transferring Silicon Valley innovation approaches the Polish way – "Krok po Kroku." Proceedings, Triple Helix IX International Conference, Stanford University, CA, July 11–14, 2011.

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Moncarz P, Eiselstein L. Loss of composite system reliability due to long term environmental alteration. Proceedings, International Federation for Information Processing (IFIP), 9th Working Conference on Reliability and Optimization of Structural Systems, Ann Arbor, MI, September 25–27 2000.

Moncarz P, Taylor R. Hyatt failure from the perspective of a forensic engineer. Proceedings, American Society of Civil Engineers, Second Congress, San Juan, Puerto Rico, pp. 28–36, May 2000.

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Moncarz P. The measurement and impact evaluation of corrosion deterioration in reinforced concrete chimneys. Proceedings, International Committee on Industrial Chimneys (CICIND) Meeting, Atlanta, GA, April 1991.

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Moncarz P. The energy challenge of East-Central Europe. University of Washington, Distinguished Polish Speakers Series, Polish American Chamber of Commerce Pacific Northwest, February 10, 2011.

Moncarz P. Intellectual capital i.e. knowledge and experience matter. Global Technology Symposium at Silicon Valley, March 2011.

Moncarz P., Absolwenci kształtuja wizerunek uczelni (alumni shape the image of the university). Senate of Gdansk Technical University Conference, May 25, 2010.

Moncarz P. Poland's energy strategy: Clean coal and renewables. The National Academies, Washington, D.C., December 3, 2009.

Moncarz P. Alumni shape the image of the university. Warsaw University of Technology, November 13, 2009.

Moncarz P. Risk and intellectual property—Innovativeness, competitiveness, employment. Key Note Speaker at Business Council for International Understanding, Vienna, Austria, November 15, 2009.

Moncarz P. Risk and intellectual property—Innovativeness, competitiveness, employment-lead or follow. Association of European Science and Technology Transfer Professionals, Krakow, Poland, October 29, 2009.

Moncarz P. The electricity age for passenger vehicles. Global Technology Symposium at Stanford University, March 27, 2009.

Moncarz P, Harrison, K. Direct and cross examination of an expert witness. Orrin G. Hatch Distinguished Trial Lawyer Lectures Series, Utah, November 8, 2008.

Moncarz P. When mathematics and physics need(ed) to overrule state-of-the-art. West Point Military Academy Center for Faculty Development, March 27, 2008.

Moncarz P. Clean coal technology in the United States. Joint Technology Initiative for Clean Coal Conference organized by National Coordination Center for Research and Development Programs in European Union, Parliament (Sejm) of the Republic of Poland, March 23, 2007.

Moncarz P. Bangladesh gas sector issues, options, and the way forward. Asian Development Bank, July 2006.

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Moncarz P, Hendrickson R. Cracked welds: A big problem waiting to happen. Association of General Contractors of California–Legal Advisory Committee, San Francisco, CA, February 10, 1998.

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Moncarz P. The view from the marketplace. Symposium on International Education, Stanford University, CA, May 1, 1997.

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Moncarz P, Horne R. An assessment of the proposed expansion of the Nakhodka Oil Terminal. Failure Analysis Associates, Inc. Report, November 1992.

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Moncarz P. The Loma Prieta Earthquake: A pictorial essay with engineering comment. PACAM II, Pan American Congress of Applied Mechanics, Valparaiso, Chile, January 2–5, 1991.

Moncarz P, Noakowski P. Analysis of the long term performance of prestressed concrete pipe. XI FIP Congress, Hamburg, West Germany, June 4–9, 1990.

Moncarz P, Osteraas J, Sharma M. Risk analysis of seismically induced damage to critical equipment components, Southvale Technologies. December 1989.

Moncarz P. Investigation of Station Square roof collapse. Burnaby, British Columbia, November 1989.

Moncarz P, Lahnert B. Investigation of Floor Slab Cracks. Sunnyvale, CA, September 1989.

Moncarz P, Luth G, Lahnert B. Investigation of steel erection failure. May 1989.

Moncarz P, Ross B. Failure investigation of concrete runway support system, Ederer 35 Ton Portal Gantry Crane. March 1989.

Moncarz P, Caligiuri R. Conceptual evaluation of selected support and transportation components of mobile service tower. February 1989.

Moncarz P. Application of system reliability concepts and techniques. National Science Foundation Workshop, University of Colorado, Boulder, CO, September 12–14, 1988.

Moncarz P. Performance and failure in construction. Construction Litigation Superconference, San Francisco, CA, December 4, 1987.

Moncarz P, Hooley R. Methodology evaluation in the seismic analysis and design of Titan IV launch feasibility mobile service tower. November 1987.

Moncarz P, Grove S. Investigation of dislodging of a precast concrete tread. November 1987.

Moncarz P, Rau C. Evaluation of Lamellar tearing and repairs. October 1987.

Moncarz P, Day S, William K. Equivalent material properties for reinforced concrete. June 1987.

Moncarz P, Johnston P. Study of subsidence and related damage due to the construction. April 1987.

Moncarz P. Construction failures: Generic and case study. 2nd Annual Construction Litigation Conference, New York, NY, April 9, 1987.

Moncarz P, Derbalian G. Prying action analysis of cable tray base plate and comparison of stiffness of channel with a bolt hole to a solid section. March 1987.

Moncarz P, Derbalian G, Thomas J, Lange C. A literature survey on the effects of oversize bolt holes in base plates and a recommended methodology for evaluating the acceptability of specific oversize bolt holes. February 1987.

Moncarz P. Structural failures—Are they necessary? Department of Civil Engineering, Stanford University, February 18, 1987.

Moncarz P. Rolm Building 3, Santa Clara, California: Review of structural integrity. December 1986.

Ross B, Moncarz P, Andrew S, Santana C. Structural and risk analyses of a helicopter accident. October 1986.

McCarthy R, Lange, R, Moncarz P. The Impact of "Downsizing," the American Automobile Fleet on Overall Motor Vehicle Safety. August 1986.

Moncarz P, Bobroff C. Investigation of KYA–FM Radio Tower Failure. June 1986.

Moncarz P. Failure analysis. American Institute of Architects, Santa Clara Valley Chapter, April 23, 1986.

Moncarz P, Heiman T. Investigation of Golden Gate Bridge sidewalk cracking. February 1986.

Moncarz P, Heiman T. Investigation of parking garage slab. February 1986.

Moncarz P, Wolf J. Investigation of waterproofing failure at Palo Alto Redwoods. August 1985.

Moncarz P, Rau C. Analysis and testing of the Hilton Tower curtain wall. April 1985.

Moncarz P, Ross B. Investigation of catastrophic upset in the fluid catalytic cracking unit at Texas City refining petrochemical plant. March 1985.

Moncarz P, Shyne J, Derbalian G. Preliminary investigation of Conduit No. 27 failures at water main from Foothills Treatment Plant to Highlands Pump Station in Colorado. March 1985.

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Moncarz P, Rau, C. Structural analysis of the Coal Loadout Gallery at the Poplar River Mine. February 1985.

Moncarz P, Wolf, J. Investigation of General Electric Supply Company building collapse, March 1984, Anchorage, Alaska. January 1985.

Moncarz P. Side effects in structural performance. James Chinn Memorial Session of the American Society of Civil Engineers Conference, Denver, CO, April 30, 1985.

Moncarz P. Structural failures: Distribution and investigation. Structural Engineers Association of Central California, Sacramento, CA, January 8, 1985.

Moncarz P, Osteraas J. Major considerations in scale modeling of reinforced containment structures. Specialty Conference on Structural Engineering in Operating Nuclear Facilities, North Carolina State University, Raleigh, NC, September 1984.

Moncarz P, Osteraas J. Structural aspects of leakage in reinforced concrete containments—Experimental approach. 2nd Sandia National Laboratories Workshop on Containment Integrity, June 1984.

Moncarz P. Civil engineering failures. American Society of Civil Engineers, Marysville Branch, May 22, 1984.

Moncarz P, Johnston P, Shusto L, Thomas J. Model studies of gravity drydocks. May 1984.

Moncarz P. Long span structures. Architect's Licensing Examination seminar, American Institute of Architects, Santa Clara Valley Chapter, Santa Clara, CA, April 1984 and April 1985.

Moncarz P. Investigation of the deterioration of coal silos at Buckskin Coal Mine, Gillette, Wyoming. March 1984.

Moncarz P, Osteraas J, Curzon A. Experimental modeling techniques for reinforced concrete containment structures. December 1983.

Moncarz P. Structural failures—Their causes and lessons learned. American Society of Military Engineers, San Diego Chapter, San Diego, CA, December 6, 1983.

Moncarz P. Structural failure—Anatomy, impact, investigation. California Department of Transportation, Engineering Staff Meeting, Sacramento, CA, November 10, 1983.

Moncarz P, Rau, C. Investigation of failure of the coal loadout gallery at the Poplar River Mine. October 1983.

Moncarz P, Kadlex R. Failure investigation of the Kilroy Industries Building at 901 East Ball Road, Anaheim, California. August 1983.

Moncarz P, Thomas J, Taylor R, Paulling J. Stability of the Alexander Platform under conditions of the accident of May 1983.

Moncarz P, Osteraas J. Impact of calcium chloride addition to Portland cement concrete mix on the corrosion potential of post-tensioning tendons. February 1983.

Moncarz P, Osteraas J. Failure investigation of the California fabrics roof. November 1982.

Moncarz P, Nelson E. Experimental investigation of shear capacity of anchorage bolts. July 1982.

Moncarz P, Tolles E. Study of the cause of the February 13, 1980, roof collapse at 919 Branston Road, San Carlos, California. July 1982.

Moncarz P, Hopkins. Study of the cause of slab cracking along the western wall of Tektronics Building, 3200 Coronado Drive, Santa Clara, California. November 1981.

Moncarz P, Thomas J, Rau C. Comments on the Norwegian inquiry commission report on the Alexander L. Kielland accident. June 1981.

Moncarz P, Krawinkler H. Theory and application of experimental model analysis in earthquake engineering. John A. Blume Earthquake Engineering Center, Report 50, Stanford University, Palo Alto, CA, June 1981.

Moncarz P. Effects of non-linear connections in steel frames. University of British Columbia, Department of Civil Engineering, Vancouver, British Columbia, March 1980.

Moncarz P. Effects of non-linear connections in steel frames. Report, Department of Civil, Environmental and Architectural Engineering, University of Colorado to American Iron and Steel Institute, December 1976.

Professional Affiliations

American Society of Civil Engineers (fellow); Structural Engineering Association of Northern California (member); American Concrete Institute (member); American Concrete Institute Committee for Concrete Structures for Refrigerated Liquefied Gas Containment (LNG) (member); International Committee on Industrial Chimneys (CICIND) (member); American Water Works Association (member); Prestressed Concrete Institute (member); Earthquake Engineering Research Institute (member); Association of Energy Engineers (member); American Management Association (member); Institute for Energy Law (member); Institute for Energy Law Oil & Gas Committee (member); California Universities for Research in Earthquake Engineering (member); Polish Academy of Science (foreign member); Academy of Technological Sciences of the Russian Federation (foreign member); International Concrete Repair Institute (member); United States Industry Coalition (member); Deep Foundation Institute (member); The Center for Liquefied Natural Gas (LNG) (member); The International Society of Offshore and Polar Engineers (member)

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Principal Engineer

Professional Profile

Dr. Subodh Medhekar is a Principal Engineer in Exponent's Engineering Management Consulting practice. Dr. Medhekar's practice focuses on addressing risk and reliability issues. Dr. Medhekar specializes in evaluating technologies and manufacturing operations, and reviewing process/product designs for the purpose of proactive reduction of failures and hazards. He conducts FMEA, PHA, HAZOP, MTBF, reliability, root cause, fault tree, event tree, and uncertainty analyses.

Over the last 10 years, Dr. Medhekar has provided risk assessment and management consulting services to various Automotive OEM's and Tier 1 suppliers, Semiconductor, Medical and Biomedical, Chemical/Petrochemical, Nuclear Power, and various other Manufacturing facilities. He has authored or coauthored more than 50 technical publications/reports and presented a number of papers and short courses with topics ranging from performing complex reliability investigations, identifying and managing risks under PSM/OSHA Act, practical FMEAs for product design, performing risk and reliability assessments for automotive, semiconductor, biomedical, and process industries, pipeline risk assessments, fault tree analysis, source term modeling, and Bayesian uncertainty analysis.

Dr. Medhekar also uses his expertise as a chemical engineer in the investigation and prevention of accidents, with particular emphasis on safety and risk. He provides consulting services to the chemical and petrochemical process (LNG/NG and Refinery sector) industries, specializing in the safety/risk-based evaluation/investigation of process failures, such as process upsets/explosion/fire incidents, at chemical processing and petroleum refining facilities. Dr. Medhekar's projects have involved a wide range of equipment including chemical reactors and separation systems; pressure vessels, piping, pumps and compressors; furnaces and heat exchangers; railcars and tanker trucks; and pressure relief valves and emergency relief systems.

Prior to joining Exponent, Dr. Medhekar held a variety of consulting and engineering positions with companies that include PLG, Inc. in Newport Beach, California; the Center for Risk Studies and Safety in Santa Barbara, California; Indian Oil Refinery in Baroda, India; and Union Carbide in Thane, India.

Academic Credentials and Professional Honors

Ph.D., Chemical Engineering, University of California, Santa Barbara, 1991
M.S., Chemical Engineering, University of California, Santa Barbara, 1988
B.Tech., Chemical Engineering, Indian Institute of Technology, New Delhi, 1984

Outstanding Achievement Award, PLG, Inc.; UC Regents Scholarship; Tata Endowment Scholarship; Aryabhatta Science Talent Award; Ramanujam Math Talent Award; Best Paper Award, Society of Plastics Engineers, Inc.

Licenses and Registrations

Registered Professional Chemical Engineer, California, #CH6087
Certified Reliability Engineer, American Society for Quality, Certificate #5469

40-Hour OSHA Certification, Hazardous Waste Operations and Emergency Response
Reliability Centered Maintenance Analyst Course, Naval Air Systems Command, Jan 2001
RAM-W Certification, Sandia National Labs, AWWA, Haestad Methods, June 2002
SIL-LOPA Certification, March 2005

Publications

Roy C, Fessler J, Medhekar SR. Managing post-production change, materials and processes for medical devices conference. St. Paul, MN, August 25–27, 2004.

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Presentations

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Professional Affiliations

- American Institute of Chemical Engineers (member)
- Southern California Society for Risk Analysis (Councilor)
- Computational Project, NSF Supercomputer, San Diego, California (Principal Investigator)
- Graduate Student Association, UCSB (Administrative Vice President)
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Professional Profile

Dr. Philip Shaller is a Senior Managing Scientist and head of the Geo Group within Exponent's Civil Engineering practice. He has worked for 20 years as an engineering geology consultant. His expertise includes geological and geotechnical site investigations, slope stability analysis, landslide and debris flow identification and mitigation, rheological modeling of debris flows, evaluation of debris flow recurrence intervals, potential travel pathways and protective structures, geologic field mapping, analysis of aerial photographs and remote sensing images including InSAR and synthetic aperture radar imagery, sub-surface characterization by means of small diameter borings, rock coring and large diameter borings (downhole logging), assessment of bedrock permeability by means of downhole packer testing, well construction and development, fluvial geomorphology, assessment of alluvial fan flooding patterns, field and aerial photo analysis of historic flood patterns, assessment of future flood pathways, investigation of fire-flood-erosion processes, investigation of dam failure, foundation construction and earthwork observation, rock mass characterization for tunneling and dam construction, seismic hazard characterization, assessment of aggregate resources for use as railroad ballast, expansive and collapsible soils hazards, coastal geomorphology, and karst geomorphology.

Dr. Shaller's specialty is in the field investigation and mechanics of large-scale landslides and debris flows. He also holds bachelors and masters degrees in geochemistry, with a specialty in the chemistry of liquid sulfur and aqueous- and vapor-phase sulfur compounds.

Academic Credentials and Professional Honors

Ph.D., Geology, California Institute of Technology, 1991
M.S., Geochemistry, Montana College of Mineral Science and Technology, 1985
A.B., Geochemistry, Occidental College, 1983

Robert P. Sharp Graduate Teaching Award, California Institute of Technology, Division of Geological and Planetary Sciences, 1990

Moderator (with MW Hart), Symposium on Long-Runout Landslides and Rock Avalanches, 52nd Annual Meeting of Association of Engineering Geologists, Lake Tahoe, CA, September 23, 2009.

Licenses and Registrations

Professional Geologist, California, #6132; Certified Engineering Geologist, California, #1912
Registered Geologist, Idaho, #1010; Registered Geologist, Washington, #261
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Association of Engineering Geologists, Portland, OR, October 1997, and in Geological Society of America, Abstracts with Programs, Vol. 29, p. 64, May 1997.

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Shaller P, Rapp L. Folds, faults and fills: The geology and geotechnical engineering of the Getty Center, Brentwood, California. Presented at Monthly Meeting of Association of Engineering Geologists, Southern California Section, Los Angeles, CA, June 1996.

Shaller P. Mechanics of long-runout landslides. Presented at Monthly Meeting of Association of Engineering Geologists, Southern California Section, Los Angeles, CA, February 1996.

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Shaller P. Long-runout landslides on Mars. Presented at U.S.S.R. Academy of Sciences, O. Yu. Schmidt Institute of Earth Physics, Moscow, October 1990.

Shaller P, Murray B, Albee A, Shelton J. A large composite landslide/debris flow, Lost River Range, Idaho. Geological Society of America, Abstracts with Programs, Vol. 21, p. 344, October 1989.

Shaller P, Muray B, Albee A. Subaqueous landslides on Mars? Presented at 20th Lunar and Planetary Science Conference, pp. 990–991, October 1988.

Prior Experience

Senior Staff Geologist to Project Geologist, Woodward-Clyde Consultants, 1991–1999
Project Geologist, Bing Yen and Associates, 1999–2000

Project Experience

Evaluated cause and origin of distress to single-family residence in La Mirada, California and possible relationships to underlying fill character and adjacent buried CMP storm drain line.

Led team that carried out post-earthquake reconnaissance of damaged infrastructure and ground deformation following the Mexicali Earthquake, April 4, 2010. Developed web site material based on findings of the reconnaissance.

Evaluated the engineering geologic feasibility of installing a pipeline system through the Niger Delta and contributed to the development of a preliminary risk assessment to assist the government and operator in quantifying potential risks and in making a go or no go decision on the project.

Evaluated geomorphic effects of early 2005 storm runoff on the Santa Clara River system in northern Los Angeles County, California. Documented areas of bank erosion by means of aerial photo analysis and field inspection.

Performed geologic and geomorphic investigations for 100-year flood hazard evaluations for sites located on active alluvial fan surfaces in Rosamond, Tujunga, North Fontana, Desert Hot Springs, Palm Springs, Thousand Palms, Indio, Oasis and Thermal, California, and Phoenix, Arizona. Combined field observations with aerial photo interpretation to document active and inactive portions of the alluvial fans. Used findings to document the geologic and geomorphic history of the sites, including the role of active tectonics and climate change on fan processes. Provided oversight for hydrologic modeling of peak 100-year stormwater flows on active portions of fans.

Conducted soils and geologic investigations for construction of temporary and permanent flood control levees in the Whitewater River spreading grounds and in the central Coachella Valley, California. Performed field investigations, including field mapping, drilling, logging and sampling of soils along levee alignments. Participated in development of recommendations for temporary and permanent levee construction.

Project engineering geologist for flood control-related investigations and design of detention dam, pipeline, and open channels at the Sunrise Mountain landfill, Las Vegas, Nevada. Performed or directed geologic mapping, aerial photo interpretation, mapping and characterization of late Quaternary faulting and seismic sources, rock coring, down-hole packer testing, test pits, aggregate sampling, and logging of fault trenches. Participated in preparation of design geotechnical report and provided geologic input for design plans.

Project manager for the geotechnical investigation of the Agua Caliente Cultural Museum, near Palm Springs, California. Conducted boulder mapping, directed test pit excavations, conducted an in-situ load test for collapsible soil, and prepared a summary geotechnical report. Also conducted an investigation of the debris flow flood hazard using aerial photos and field mapping and provided recommendations for mitigation of the hazard. Participated in discussions of footing design options with the project architect and structural engineer.

Project manager for the Lowden Fire investigation, Lewiston, California. Managed a six-member team evaluating the geologic, hydrologic and ecologic effects of a 1999 wildfire. The project entailed aerial photo analysis, engineering geologic evaluation of slope stability and mass wasting issues, storm water runoff and sediment yield analysis, as well as evaluation of the intensity of the burn and the level of recovery from the fire.

Project manager for investigation of alleged wall distress and out-of-tolerance residential slab tilts at a 1,300-home residential development in Las Vegas, Nevada. These claims were investigated by combining field observations and manometer measurements with In-SAR remote sensing techniques, historical aerial photographs of the development, geologic mapping, and available construction plans and documents.

Observed and documented field load testing for collapsible soils, Hamaca Refinery, Venezuela. Also performed geologic field mapping, logged test pits and trenches, developed geologic maps and cross sections, and participated in construction of project database.

Served as geology representative from Exponent in EERI-sponsored visit to site of January 2001 (magnitude 7.7) Gujarat, India, earthquake. Conducted 10-day field reconnaissance in epicentral region with team of seismologists seeking evidence of coseismic ground rupture.

Observed CPT-LIF testing at the Kinder-Morgan Mission Valley tank farm, San Diego, California. Developed geologic cross sections derived from the CPT data and developed maps and cross sections depicting the subsurface distribution of hydrocarbons beneath the facility.

Performed visual inspections and destructive testing for single-family residences and apartment complexes at various locations in Fontana, Huntington Beach, Laguna Niguel, Santa Monica, Van Nuys and Hollister, California, to investigate claims of slab distress, moisture intrusion and/or earthquake damage.

Performed historic air photo analysis for the Ocean Trails Golf Course, Rancho Palos Verdes, California. Documented intersections of construction haul roads and buried sewer pipeline in area of major slope failure.

Directed an investigation of a potentially life-threatening landslide complex at Lukes Farm, Matahina Reservoir, New Zealand, and a reconnaissance slope stability hazard investigation along the Pacific Coast Highway from Santa Monica to Malibu, California.

Assisted in the development of an emergency response and remediation of a landslide threatening a residential development in Diamond Bar, California, and performed an emergency evaluation and geotechnical investigation of a landslide at the Getty Villa museum complex in Pacific Palisades, California.

Performed a variety of geotechnical site investigation activities, including logging bucket auger borings for a proposed dam near Graybull, Wyoming; mapping stream scour above a heated oil pipeline in Santa Barbara, California; directing a CPT investigation of a bridge crossing of the San Gabriel River in Pico Rivera, California; and investigating and developing cross sections for the proposed expansion of a flood control channel in San Clemente, California. The latter included observing the installation of two slope inclinometers in large fill slopes along the banks of the channel.

Served as a project geologist during construction of The Getty Center museum complex in Brentwood, California, and is the geologist of record for the site's funicular tramway. Developed cross sections, performed computer-aided slope stability evaluations, and logged a combined total of more than 100 test pits, bucket auger borings, drilled pier shafts, drilled slope drains, mass grading cuts, and spread footing excavations at the museum site.

Directed the engineering geologic investigation for a 115-mile railway alignment on the Tongue River, Montana. The project called for the excavation of major cuts and fills in areas underlain by soft sedimentary rock, coal deposits and burned coal.

Performed construction observation tasks, including the documentation of an approximately 1,000-foot long retaining wall footing in Chino Hills, California, and observed the over-excavation for a water pump plant in San Diego, California. Performed geologic mapping in mass grading cuts at a landslide overexcavation in Diamond Bar, California.

Performed investigations of landslide-related problems for home sites in Malibu, California, and an apartment complex in El Sereno, California.

Investigated vibration issues at a condominium complex in Anaheim, California, and construction defects case for a condominium complex in Lemon Grove, California.

Performed geotechnical and seismic investigations for city agencies. These projects include the revision of seismic safety elements for the City of Monterey Park, California, and the City of West Hollywood, California, as well as the reconstruction of an elementary school in Glendale, California, and the development of a sports park for the City of Chino Hills, California. The latter project included the construction of three groundwater monitoring wells in an area of historically high groundwater.

Served as an instructor at Ranch Santiago Community College in Santa Ana, California, and as a teaching assistant at the California Institute of Technology in Pasadena, California.

Professional Affiliations

- Geological Society of America (member)
- Association of Engineering Geologists (member)
- Seismological Society of America (member)

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Eric R. Ahlberg, Ph.D., P.E.

Senior Engineer

Professional Profile

Dr. Eric R. Ahlberg is a licensed Civil Engineer in the State of California and is in Exponent's Buildings and Structures practice. He received a Ph.D. in Civil Engineering at the University of California, Los Angeles. Dr. Ahlberg's primary area of research is in soil-structure interaction of foundation elements. He is involved in drilled shaft and abutment wall research, including lateral performance of drilled shafts and passive pressure development for wall-type foundations. He has assessed damage to structures due to earthquake, storm surge, wind, fire, ground settlement, and soil pressure. He also has experience in earthquake engineering, reinforced concrete, steel, wood and masonry design, as well as geotechnical designs for retaining walls, tiebacks, and deep foundations.

Academic Credentials and Professional Honors

Ph.D., Civil Engineering, University of California, Los Angeles, 2008
M.S., Civil Engineering, University of California, Los Angeles, 2005
B.S., Architectural Engineering, California Polytechnic State University, 2001

SEAOSC Scholarship, Civil Engineering Department, UCLA, 2003

Licenses and Certifications

Registered Professional Engineer, California, #C73736

Publications

Ahlberg E. Interaction between soil and full scale drilled shafts under cyclic lateral loads. Doctoral Dissertation, Civil Engineering, Department of Civil and Environmental Engineering, University of California, Los Angeles, CA, Spring 2008.

Stewart JP, Wallace JW, Taciroglu E, Ahlberg E, Lemnitzer A, Rha C, Tehrani P, Keowen S, Nigbor RL, Salamanca A. Full scale cyclic testing of foundation support systems for highway bridges. Part II: Abutment backwalls. Report No. UCLA-SGEL 2007/02, Structural and Geotechnical Engineering Laboratory, University of California, Los Angeles, October 2007.

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Ahlberg E, Stewart JP, Wallace JW, Rha C, Taciroglu E. Response of a reinforced concrete embedded pile under lateral loading. Part I: Field testing. Caltrans Bridge Conference, Sacramento, CA, November 1, 2005.

Rha C, Taciroglu E, Ahlberg E, Stewart JP, Wallace JW. Response of a reinforced concrete embedded pile under lateral loading. Part II: Numerical simulations. Caltrans Bridge Conference, Sacramento, CA, November 1, 2005.

Presentations and Published Abstracts

Ahlberg E, Rha C, Stewart JP, Nigbor RL, Wallace JW, Taciroglu E. Field testing and analytical modeling of reinforced concrete foundation systems under lateral loading. George E. Brown Network for Earthquake Engineering Simulation (NEES) Annual Meeting, Snowbird, UT, June 19, 2007.

Reviewer

- Peer Reviewer, American Society of Civil Engineers, *Journal of Geotechnical and Geoenvironmental Engineering*

Professional Affiliations

- Structural Engineers Association of Southern California (Associate Member)
- American Society of Civil Engineers (Associate Member)

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Jeffrey P. Hunt, Ph.D., P.E.
Engineer

Professional Profile

Dr. Jeffrey Hunt is an Engineer in Exponent's Buildings and Structures practice, where he specializes in engineering analysis of complex structures, performance-based earthquake engineering, and evaluation of the safety associated with architectural components in buildings such as curtain walls and window systems. He also has experience with structural reliability theory and its application to nonstructural components.

Dr. Hunt's educational background includes study of structural analysis, design of steel, concrete and timber structures, and earthquake engineering. He was a visiting researcher at the Institute for Lightweight Structures and Conceptual Design at the University of Stuttgart, Germany, where he studied the analysis and design of lightweight and spatial structures.

Prior to joining Exponent, Dr. Hunt was a researcher at the University of California, Berkeley, where he focused on the seismic response of precast concrete cladding systems, including how cladding systems and facades can influence the global seismic response of multistory buildings. He developed fragility curves for the damage states of various cladding components, and performed repair cost analysis of the cladding systems using a probabilistic performance-based approach.

Academic Credentials and Professional Honors

Ph.D., Civil and Environmental Engineering, University of California, Berkeley, 2010
M.S., Civil and Environmental Engineering, University of California, Berkeley, 2005
B.S., Architectural Engineering, University of Texas, Austin (high honors), 2004

Fulbright Scholar, Universität Stuttgart, Germany, 2006–2007
IASS Hangai Prize, 2008

Licenses and Certifications

Registered Professional Civil Engineer, California, #C79454

Languages

German – Conversational

Publications

Hunt J, Stojadinovic B. Seismic performance assessment and probabilistic repair cost analysis of precast concrete cladding systems for multistory buildings. PEER Report No. 2010/110, Pacific Earthquake Engineering Research Center (PEER), University of California, Berkeley, November 2010.

Hunt J, Stojadinovic B. Repair cost analysis of multistory buildings with precast concrete cladding. Proceedings, 9th US National and 10th Canadian Conference on Earthquake Engineering, Toronto, Canada, July 25–29, 2010.

Hunt J. Seismic performance assessment and probabilistic repair cost analysis of precast concrete cladding systems for multistory buildings. Doctoral Dissertation, Structural Engineering, Mechanics and Materials, Department of Civil and Environmental Engineering, University of California, Berkeley, CA, Spring 2010.

Hunt J, Haase W, Sobek W. A design tool for spatial tree structures. Journal of the International Association for Shell and Spatial Structures 2009; 50(1):3–10.

Hunt J, Haase W, Sobek W. Designing adaptive spatial structures. Journal of the International Association for Shell and Spatial Structures 2008; 49(3):167–173.

Hunt J, Stojadinovic B. Nonlinear dynamic model for seismic analysis of non-structural cladding. Proceedings, 14th World Conference on Earthquake Engineering, Beijing, China, October 12–17, 2008.

Hunt J, Stojadinovic B, McMullin K. Modeling the effect of non-structural cladding in buildings. Proceedings, 6th Annual NEES Meeting, The Value of Earthquake Engineering Research, Portland, OR, June 18–20, 2008.

Presentations

Hunt J. Seismic performance assessment of three precast cladding designs using the PEER PBEE repair cost methodology. SEMM Seminar, Department of Civil and Environmental Engineering, UC Berkeley, Berkeley, CA, September 20, 2010.

Hunt J. Repair cost analysis of multistory buildings with precast concrete cladding. 9th US National and 10th Canadian Conference on Earthquake Engineering, Toronto, Canada, July 25–29, 2010.

Hunt J. Designing adaptive spatial structures. Symposium IASS-2008, Shell and Spatial Structures: New Materials and Technologies, New Designs and Innovations – A Sustainable Approach to Architectural and Structural Design, Acapulco, Mexico, October 27–31.

Hunt J. Nonlinear dynamic model for seismic analysis of non-structural cladding. 14th World Conference on Earthquake Engineering, Beijing, China, October 12–17, 2008.

Hunt J. Modeling the effect of non-structural cladding in buildings. 6th Annual NEES Meeting, The Value of Earthquake Engineering Research, Portland, OR, June 18–20, 2008.

Professional Affiliations

- Structural Engineers Association of Northern California (associate member)
- Earthquake Engineering Research Institute (member)

Preliminary Review Comments
of Century City Area
Fault Investigation Report
Westside Subway Extension Project
Century City and Beverly Hills, CA

March 8, 2012

SHANNON & WILSON, INC.

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51-1-10024-003

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PRELIMINARY REVIEW COMMENTS OF CENTURY CITY AREA FAULT INVESTIGATION REPORT, WESTSIDE SUBWAY EXTENSION PROJECT, CENTURY CITY AND BEVERLY HILLS, CALIFORNIA

1.0 EXECUTIVE SUMMARY

This report presents the results of our review of the Century City Area Fault Investigation (Fault Report) and Century City Area Tunneling Safety Report (Tunnel Report) for the Westside Subway Extension (WSE) project. The reports were prepared by Parsons Brinkerhoff (PB) in October 2011 for the Los Angeles County Metropolitan Transportation Authority (Metro). The report also includes our observations of fault tunneling on the campus of the Beverly Hills High School (BHHS) completed by BHHS geotechnical consultant. The following summarizes our review opinions of PB's studies as requested by the City of Beverly Hills (City). Details of our report reviews used to develop our opinions are provided in the following sections.

Constellation Station Studies –When compared with the studies completed at the Santa Monica Station, the relatively sparse exploration data presented for the Constellation Station does not indicate, nor fully negate, the presence of faulting. It is our opinion that the current studies for this station are not as thorough as for the Santa Monica Station. Therefore, we recommend that comparable geological and geotechnical explorations be carried out for the Constellation Station.

Santa Monica Station Relocation – Relocating the station further south or east along Santa Monica Boulevard, including the gap (see Figure 2) between the Santa Monica Fault Zone (SMFZ) and West Beverly Hills Lineament/Newport Inglewood Fault Zone (WBHL), has risks similar to the current proposed Santa Monica Station owing to high probability of ground deformation stemming from earthquakes originating from the SMFZ or by previously unmapped fault splays. Data collected at the recent fault trenching performed at BHHS, does not appear to indicate that the WBHL is an active fault. Relocating the Santa Monica Station further east as shown in Figure 2 could be feasible if the WBHL is also shown to be inactive where it crosses Santa Monica Boulevard, and if the SMFZ terminates west of the Beverly Hills City Limits. We recommended fault trenching occur at the station location.

Tunneling Beneath Beverly Hills High School – The proposed tunnel crown is approximately 50 to 70 feet below the existing ground surface along the BHHS campus. The tunnel is therefore not likely to directly impact the campus facilities (as we understand their current use). The proposed BHHS underground parking garage could be constructed above the tunnel to a maximum depth of about 30 to 50 feet below grade, leaving at least 20 feet of undisturbed soil above the tunnels. Risks associated with ground loss during construction, vibrations during construction and operation, and hazards from methane and other gasses should be mitigated by the design and plans and specifications for the project.

Precedents for Stations on Fault Zones – While there are case histories of tunnels surviving earthquakes in relatively good condition, damage has been noted in references we reviewed for stations subjected to strong ground shaking. The California Geological Survey could designate the SMFZ as "active," and thus place it into the category of an Alquist-Priolo Earthquake Hazard Fault Zone (AP Act). Since enactment of the AP Act in 1972, no underground transit stations in California have been knowingly sited across regulatory-defined active faults. Accordingly, if the SMFZ is defined as active the Santa Monica Station should not be located underground where the SMFZ is mapped. The WBHL does not appear to be active based on the trenching completed at BHHS, but as discussed above, should be confirmed with additional trenching along Santa Monica Boulevard.

2.0 INTRODUCTION

The proposed WSE will be a heavy-rail subway connecting to the existing Wilshire/Western station at the Purple Line. The proposed alignment travels west along Wilshire Boulevard through Beverly Hills and westward into the Century City and Westwood areas of Los Angeles. The proposed subway alignment in the study area is shown in Figure 1. A proposed station is located on Santa Monica Boulevard (Santa Monica Station) with an alternate at Constellation Boulevard (Constellation Station). The tunnel alignment for the Constellation Station passes beneath residential and commercial buildings, including the BHHS campus. The draft environmental impact report (DEIR) cites that one of the reasons to consider the Constellation Station as an alternative site is the possibility that active faults might cross the Santa Monica Station. The active SMFZ and the likely inactive WBHL, are shown in Figure 2.

We previously prepared a DEIR Summary Letter dated October 14, 2010 for the City of Beverly Hills (City). In our DEIR Summary Letter, we provided the following recommendation to the City about faults potentially impacting the proposed WSE in Century City:

> “Given the uncertainty of the Santa Monica Fault and West Beverly Hills Lineament, further evaluation to identify fault traces should be completed prior to final location of the Santa Monica base station. The Santa Monica Fault could have one or more distinct fault traces that could impact the station location. The trace(s) would be identified during the geotechnical investigation of the project using a combination of geophysical

techniques, subsurface explorations, and/or trenching (where possible). If a trace is discovered passing through the proposed station, then the station would likely need to be relocated."

The WSE project owner (Metro) commissioned the Fault and Tunnel Reports to address selection of the Century City area station location. The Fault Report presents conclusions regarding the potential for fault rupture at the station locations. The Tunnel Report presents safety concerns regarding tunneling below occupied structures, specifically the BHHS.

3.0 SCOPE OF SERVICES

The primary purpose of our services is to evaluate the geotechnical reports produced for the Final Environmental Impact Report (FEIR) in order to form an opinion on the potential impacts to the City from project construction. A secondary purpose was to provide observation of the fault trenches completed at BHHS. The City authorized our services on September 27, 2011.

4.0 PROJECT TEAM

To provide opinions to the questions above, we have retained a paleoseismologist or fault specialist as part of our team to evaluate the Fault and Tunnel Reports. Dr. Roy Shlemon is a recognized expert for evaluating activity on Quaternary-age faults in southern California and his qualifications are attached to this letter as Appendix A. Dr. Shlemon's report is attached as Appendix B. In addition to Dr. Shlemon, our team consists of our Director of Underground Services, Robert Robinson; engineering geologist, Dean Francuch; and geotechnical engineer, Travis Deane. Resumes of the project team are also provided in Appendix A. Note that Dr. Shlemon was invited by BHHS representatives to view the fault trenching completed at BHHS by their geotechnical consultant, Leighton & Associates. His observations are included in his report.

5.0 CONSTELLATION STATION STUDIES

5.1 General

We reviewed the fault studies performed at the proposed Constellation Station and compared them to fault studies completed at the Santa Monica Station. The intent of our review was to assess that a reasonable investigation had been undertaken to confirm that fault strands were not present in the proposed Constellation Station site, nor that the possible presence of faults in the vicinity do not impact the Constellation Station. The next section references the relevant pages in the Constellation Station studies in the Fault and Tunnel Reports followed by our review and opinion.

5.2 Century City Reports

5.2.1 Fault Report

The following pages of the Fault Report discuss or depict the studies completed for the Constellation Station:

- Pages 1 and 2
- Figure 8
- Page 23
- Page 28

5.2.2 Tunnel Report

The focus of the Tunnel Report is on the safety of tunneling for the Constellation Boulevard alignment and refers to the Fault Report for the fault studies. Therefore, the Tunnel Report does not comment on active faults crossing the Constellation Station.

5.3 Technical Review

Based on the findings near the Santa Monica Station alternative location, the proposed location of the Constellation Station alternative appears to show less probability of active faulting. Page 2 of the Fault Report states that *"…no faulting was found passing through or in close proximity to the proposed Constellation Boulevard Station*." This assertion that Constellation Station is not within a fault zone and that it is a viable option is premature based on the level of study presented in the Fault Report. Note that the WBHL fault trenching completed on the BHHS campus is east of the Fault Report studies.

In our opinion, the study at Constellation Station was not as thorough as that completed for the Santa Monica Station. Transects in the vicinity of the SMFZ and WBHL generally included closely-spaced CPTs and borings as well as seismic reflection profiles. However, along the Constellation Boulevard alignment, the evaluation was limited to a northeast-southwest oriented subsurface profile drawn using existing explorations of variable quality, age, and marginal depth, and a few widely-spaced new CPTs and borings performed for the Fault Report. One transect was also drawn perpendicular to the station (northwest-southeast); this transect was fairly well studied to a similar level of effort to the SMFZ and WBHL areas.

The profile provided along the Constellation Boulevard alignment in the Fault Report interprets lateral continuity of strata, and therefore no obvious signs of faulting. We reviewed the boring logs along the Constellation Boulevard alignment and generally agree with their interpretations with the following exceptions. The interpretation of lateral continuity relies on the identification of marker beds (e.g., discrete gravel beds). Since their interpretation is based largely on existing logs from several different sources, those marker beds are potentially more difficult to correlate than if they were identified in a series of explorations performed in a new, single study, such as that completed for the Santa Monica Station.

Furthermore, the soil profiles shown on Figures 4 and 5 of the Tunnel Report interpreted three fault strands, with the western-most strand based on only two borings, spaced about 500 feet apart. As a result of the wide borehole spacing, the strand is interpreted to lie midway between two borings (69-036-1 and G-168B), about 350 feet east of the station/crossover (see Figure 2). This fault strand could occur anywhere within this 500-foot interval, and consequently might be located as close as 100 feet from the east end of the station/crossover. Also to the west of this western-most fault strand, the boundaries between the San Pedro Formation (Qsp) and the overlying Lakewood Formation (Qlw), and between the Qlw and the overlying older alluvium (Qalo) are shown inclined upward, rather than horizontal, as interpreted within the fault strand-bounded block to the east that show uplifted and depressed blocks along interpreted fault strands. An alternate interpretation, in the absence of available data from additional borings, might be to interpret yet another fault strand within the east end of the station/crossover structure. The report states that the fault line locations are also interpreted from seismic reflection surveys, but this particular strand does not appear to be crossed by a seismic reflection line performed for the fault study. Additional borings and possibly trench explorations, and geophysical studies should be completed in this area to determine the absence or presence and locations of potential fault strands crossing the proposed station.

Several shallow borings were drilled at the Constellation Station, but their primary purpose appears to have been for gas testing, as identified on Figure 5 of the Tunnel Report. It is not clear if soil samples were obtained that might be used for age-dating. Detailed logs of these borings were not provided in the Fault and Tunnel Reports. Groundwater levels are not noted on these borings (M-19, B-1, B-2, B-3, B-4, and B-7). These borings also do not extend down to the station invert, and none extend to 40 or 50 feet below station bottom, as might normally be required for design. We believe that a seismic profile and deeper borings with piezometers should be considered for the station. The deeper borings would be required for station design in order to analyze the station excavation bottom stability, dewatering requirements, presence of methane and hydrogen sulfide gas, temporary shoring depths and support, and other design elements.

It is our opinion that the Fault Report authors should provide justification that the profile drawn from the existing explorations along the Constellation Boulevard alignment is sufficient, or label it as preliminary, warranting a much greater level of study as was undertaken in other areas (even in some areas where faults were not previously mapped).

In summary, we agree with the conclusions of the Fault Report that the Constellation Station location appears to be more favorable than the Santa Monica Boulevard location based on the exploration data that is interpreted to show no faulting in the station area. However, in our opinion, additional explorations at Constellation Station are warranted based on the questions we discussed above regarding the Fault Report studies, coupled with the directive for these studies. The directive on Page 1 of the Fault Report states that *"…Metro staff was directed to fully investigate the nature and location of faults in the Century City area and their potential impact on the proposed station locations*." Based on this directive, we do not believe the WBHL and the Constellation Station were fully investigated particularly when compared with the studies performed at the Santa Monica Station.

6.0 RELOCATION OF SANTA MONICA STATION

6.1 General

We reviewed the potential for relocating the Santa Monica Station along Santa Monica Boulevard to avoid the SMFZ and WBHL. The next section highlights possible relocation of the Santa Monica Station in the Fault and Tunnel Reports followed by our review and opinion.

6.2 Century City Reports

6.2.1 Fault Report

The following pages of the Fault Report discuss relocation of the Santa Monica Station:

- Pages 1 through 5
- Page 8
- Page 10 Pages 12 through 14
- Page 28

6.2.2 Tunnel Report

The focus of the Tunnel Report is on the Constellation Boulevard alignment. Therefore, this report does not comment on relocating the Santa Monica Station.

6.3 Technical Review

6.3.1 General

We generally agree that placing a station along the Santa Monica Boulevard alignment will be more risky than at Constellation Boulevard due to increasing likelihood of faults to the north, along the SMFZ. Based on the results of the fault trenches recently completed at the BHHS, it is our opinion that the WBHL may not be considered active, contrary to what was asserted in the Fault Report. Specifically, we recommend trenching be performed within the WBHL zone in the median of Santa Monica Boulevard near Moreno Drive to confirm the findings of the BHHS studies. If it is confirmed that the SMFZ and WBHL are not present, or determined to be inactive, if present, then a station could be considered feasible at this location from a fault hazards perspective.

From our review of the Fault Report and from our knowledge of regional and site-specific tectonics, we recognize that many more faults may underlie the upper plate (north side) of the SMFZ. The most recent and highest rate of slip is topographically expressed by a generally east-west, pre-urbanization en-echelon series of escarpments along Santa Monica Blvd. and within the Los Angeles Country Club. South of this alignment, fault presence and relative activity is likely less, but additional studies are warranted. The SMFZ is more active towards the north side with more recent topographic expression, but less active towards the south with less topographic expression, though fault traces are identified to the south.

There are three possible adjustments or modifications to the proposed Santa Monica Station location that should be assessed: 1) moving the station to the “gap” between the SMFZ and WBHL, or eastward over the WBHL if it is demonstrated to be inactive, 2) moving the station to the southern margin of Santa Monica Boulevard, and 3) placing this section of the alignment at grade.

6.3.2 Station in the “Gap”

As shown in Figure 2, traces of the SMFZ are interpreted to curve northeast near the intersection with the WBHL, leaving a gap between the two faults along Santa Monica Boulevard. However, the apparent curves of the fault traces may be due to topographic variations and could be misleading. Also, fault rupture is not the only potential issue associated with displacement of the SMFZ. Ground deformation due to complex fault movements could increase stresses on the buried walls at the station. However, based on the recent BHHS trench investigations, the WBHL may not be present or active in this area. Consequently additional studies may be warranted to assess if moving the station into this apparent "gap", or even further to the east, is a viable alternative.

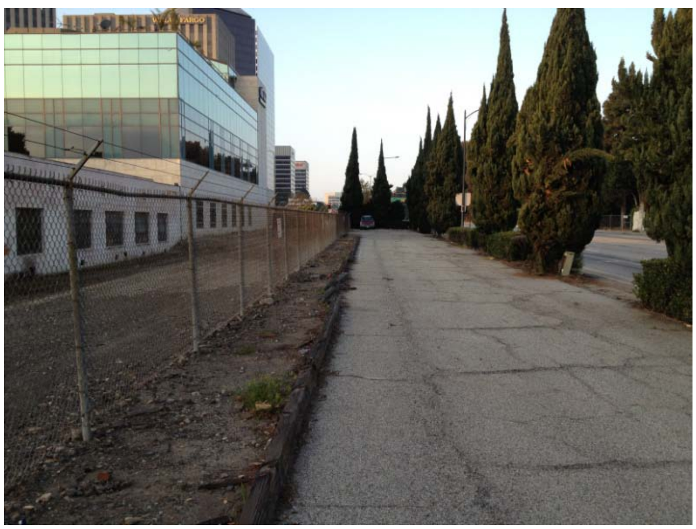
It is uncertain if the main trace of the SMFZ, or a fault splay, lies within the gap, even though maps presented in the Fault Report indicate otherwise. The Fault Report notes that the portion of the SMFZ that bends away from Santa Monica Boulevard is within an area that may have been modified by stream activity. The erosion could have modified the topographic expression of the SMFZ to make it appear that the fault curves to the north, when in actuality it could follow Santa Monica Boulevard in a more straight-line fashion until it intersects with the WBHL. As a result, there is a reasonable chance that the SMFZ crosses the gap.

Moving the station further northeast into the WBHL could be a feasible option based on our interpretation of the Fault Report data and trenching at BHHS. The Fault Report concludes that the WBHL is structurally connected to the active Newport-Inglewood Fault zone to the southeast, and therefore is also considered active. However, the recent trench mapping at the BHHS contradicts this conclusion. Also, the Fault Report geologic sections showing displacements of geologic units by the WBHL (Plate 4 of Fault Report) terminate in the Older Alluvium Sand Deposits (geologic symbol: Qfo). The unit is identified as late Pleistocene (Table 1 of Fault Report), which makes it too old to be an indicator of Holocene fault activity. This is an important issue in deciding if a fault is "active", which relies on movement within the recent Holocene Epoch (the last 10,000 to 12,000 years).

The BHHS excavated several fault trenches on campus which are detailed in Dr. Shlemon's report (Appendix B). Based on the observations presented in Dr. Shlemon's report and our discussions with him, the probability of the WBHL being active at the BHHS study area is low (see Section 8.0 below for discussion on defining faults as "active"). Therefore, we recommend that considerations should be given to excavating a confirming trench along Santa Monica Blvd, across the WBHL. If similar conclusions are derived regarding the absence of active faults along the WBHL, or that the ages of any such offset precede the state's cutoff date for active faulting, then the potentially active fault zones shown in Figure 2 from the Fault Report that pass through the BHHS study area should be deleted.

With tentative reclassification of the WBHL fault splays and zone through the BHHS study area as “in-active”, the extrapolated WBHL features crossing Santa Monica Boulevard to the northwest of the BHHS campus should be further explored to confirm absence or inactivity of fault splays at this location. While the faulting observed at the BHHS trenches is now considered inactive, this does not negate activity in the area of Santa Monica Boulevard due to the presence of the SMFZ. The possible intersection of the likely active SMFZ at Santa Monica Boulevard complicates WHBL activity at this location. Furthermore, fault traces east of the Beverly Hills city limits could be present and/or active as they are further east of the BHHS campus (and thus unexplored by the BHHS fault trenches).

As discussed above, we recommend that additional studies be considered to determine fault activity of the WBHL in the vicinity of Santa Monica Boulevard. An east-west fault trench could be excavated in the old railroad right-of-way on the south side of “Big” Santa Monica Boulevard as shown in Figure 2 and Photograph 1 below, to confirm the WBHL findings at the BHHS. A north-south fault trench perpendicular to the trace of the SMFZ should also be considered at the west end of the proposed station in this area to confirm the termination of the SMFZ at the WBHL. Depending on the results of these additional studies, locating the station within the currently denoted WBHL may be feasible.



Photograph 1 – South Side of “Big” Santa Monica Boulevard looking southwest along the old railroad right-of-way.

6.3.3 Santa Monica Boulevard Right-of-Way (ROW)

One option could be to locate the station on the south edge of Santa Monica Boulevard rather than at the current center of the ROW. Santa Monica Boulevard is approximately 300 feet wide from the edge of the golf course to the buildings of Century City. However, while fault activity could be less along the south side of Santa Monica Boulevard, the Fault Report (p. 12) indicates that the SMFZ may be up to 300 feet wide.

We also suggest consideration be given to placing the Santa Monica Station at grade. While the WSE is proposed underground throughout the alignment using an electrified third rail, an above-grade, third rail "subway" has precedence on several transit systems both domestic and international. Examples include Long Island (Photograph 2 below), New York, Chicago, Tokyo, and Berlin transit systems.

Photograph 2 – Long Island Railroad Third Rail

An at-grade platform for the Santa Monica Station would still be subject to the potential of fault rupture; however, it is our opinion that the threat to life safety would be significantly less than a below grade station. Such a station location would likely require reassessment by Metro of federal and state regulations regarding above ground transit station locations relative to active faults. An at-grade alignment could run along the existing busway along Santa Monica Boulevard as shown in Photograph 3 below.

Photograph 3 – Santa Monica Boulevard Busway looking northeast

An at-grade station would require approaches of the track out of the tunnels that could be constructed using cut-and-cover excavations. Traffic access along lanes of Santa Monica Boulevard would require modifications, including the possibility of at-grade crossings such as shown in Photograph 4 below. However, these challenges should be weighed against cost savings from elimination of a below grade station and potential impacts to project schedule and budget from potential conflicts with the BHHS and other parties along the proposed Constellation Boulevard alignment.

Photograph 4 – Third Rail Grade Crossing in Tokyo

7.0 TUNNELING BENEATH BHHS

7.1 General

We reviewed the Tunnel Report regarding the safety of constructing the Constellation Boulevard alignment below the BHHS and other occupied structures. The intent of our review was to comment on assertions made in the Tunnel Report regarding the practicality and safety of tunneling and present our opinions regarding stated and unstated tunneling risks based on our experience on several similar tunneling projects. The next section highlights tunneling studies in the Fault and Tunnel Reports followed by our review and opinion.

7.2 Century City Reports

7.2.1 Fault Report

The focus of the Fault Report is on the fault studies for Santa Monica and Constellation Stations while the safety of tunneling for the Constellation Boulevard alignment is described in the Tunnel Report. Therefore, this report does not comment on safety of tunneling below structures such as BHHS, and consequently is not relevant to this section of our report.

7.2.2 Tunnel Report

The following pages of the Tunnel Report discuss risks associated with tunneling below the BHHS campus:

- Pages ES-1 through ES-3
- Pages 2-7 and 2-8
- Page 3-4
- Page 4-1
- Pages 4-4 and 4-5
- Page 5-4
- Page 8-1
- Page 8-4
- Page 8-6
- Page 8-10

7.3 Technical Review

7.3.1 General

The Tunnel Report provides a generalized review of relevant case history data and an optimistic perspective on likely behavior and approaches to construction of the WSE in the

Beverly Hills and Century City areas. Nevertheless, the conclusions that construction of tunnels, using state-of-the-practice closed-face Tunnel Boring Machines (TBMs) can result in negligible to minor settlements, and little to no impacts from gas, groundwater, and soil variability is a generally realistic assessment. The details of the specifications developed by Metro, the procurement of the appropriate TBMs, and construction implemented by an experienced contractor will be essential to complete a quality tunnel project with little or no impacts on overlying and adjacent buildings.

The information provided in the Tunnel Report does not provide detailed information on the correct operation of a closed-face TBM to preclude or minimize surface settlement. Typically, TBM operational requirements are provided in the contract documents (plans and specifications) that guide the contractor's selection and design of the TBM, his operation of the TBM including allowable minimum face pressure, means of monitoring muck weights or volumes, maximum allowable settlements, and settlement monitoring instrumentation and surveying. Ground improvement techniques and settlement compensation techniques that might be used to minimize surface settlements and compensate for excessive ground losses (if they occur) should also be included in the Contract Documents.

7.3.2 Ground Settlement

We agree that closed-face TBMs provide the best means, methods and opportunities to achieve negligible ground losses and small to unmeasurable settlements (p. 4-4). Overall, our experience with closed-face TBMs has been good, although there has been much more experience with earth pressure balance machines (EPBM) than slurry-pressure balance machines (SPBM) in the United States. Ground losses of 0.5% or less and resulting settlements of fractions of an inch are typical of most closed-faced TBM projects. However, large ground losses and surface settlements have occurred on a small percentage of international projects, and over a small percentage of the length of these projects. Isolated large ground losses have more frequently occurred where the TBM exits and enters the stations or shafts, where mixed-face conditions occur (e.g., flowing cohesionless soils in contact with cohesive and hard soils or rock), or where face pressures have not been maintained equal to or greater than the ambient soil and groundwater pressures. Ground losses can occur due to excessive intake of soil into the cutterhead, an enclosed excavation cross section due to poor TBM alignment control (particularly on curves), inadequate grout filling behind the gasketed concrete segmental lining, and lowered face pressure during extended maintenance.

These settlement and ground control issues should be identified during the normal risk assessment process undertaken during preliminary and final design phases and mitigated through the specification of appropriate construction methods and safeguards in the Construction Documents and with the selection of an experienced contractor, who brings experienced staff to the project, a TBM with characteristics that promote a small overcut, continuous monitoring and real-time reporting and review of critical machine parameters (e.g., face pressures, conditioner usage, muck volumes or weights, and cutter tool wear), constant review of TBM operational data, frequent monitoring of deep ground movements around the advancing TBM and surface settlements, and daily collaboration between the construction management staff and contractor.

The Tunnel Report does not discuss ground improvement methods in any detail, but ground improvement techniques, appropriate to various soil conditions, are typically specified for most major tunneling projects to stabilize soils and compensate for tunneling induced ground losses before they progress up to ground surface to impact utilities and structures. Ground improvement methods such as jet grouting, soil/cement mixing, permeation grouting, compaction or compensation grouting, dewatering, and freezing, are commonly used on many major tunnel projects and all provide opportunities for stabilizing the soils and reducing ground losses, particularly beneath critical structures, at launching and retrieval pits, and at cross passages. Remedial grouting measures, such as compaction grouting or compensation grouting, and fracture grouting have been used successfully to compensate for known excessive ground losses and prevent adverse surface settlements in real-time as the TBM moves forward through the ground. All of the preventative and remedial measures should be handled in the specifications, and where possible, with incentives to the contractor to optimize the quality of his work product on this project.

From Metro's experiences on the Gold Line project (or MGLEE), where closed-face TBMs were very successful in minimizing settlements to about 0.3 inches (Robinson and Brogard, 2007) , there is a good discussion of "a comprehensive program of instrumentation and surveying conducted to monitor ground movement above the MGLEE tunnels…"(p. 4-4). Similar instrument and survey systems should be included throughout the WSE project, as well as settlement points on buried utilities and buildings, and tilt meters and crack gages on building components. Borehole extensometers should be installed to provide useful information on the location and source of ground losses immediately above the advancing TBM. The collected and plotted deformation data should be shared with BH staff and building owners.

The 0.5 percent ground loss that is noted in the Tunnel Report is a reasonable number particularly given that the MGLEE tunnels resulted in about 0.3 percent ground loss, and has been used on many recent projects in reasonably competent ground such as is present along the alignment (p. 4-5) as a starting point for developing settlement predictions. Actual surface settlements measured over most of the lengths of tunnel alignments constructed by closed-face TBMs in the United States in the last 15 years are generally equivalent less than 0.5 percent ground loss. Consequently, measured settlements along tunnel or project centerline are generally less than 1 inch, and are often less than 0.25 inch, which is about the level of accuracy of most standard surface surveying. Larger ground losses and resulting settlements typically relate to inappropriate operation of the closed-face TBMs, and can be detected with the instrument monitoring systems and corrected at the insistence of the owner, construction manager and contractor.

7.3.3 Noise and Vibration

Construction related vibrations are likely to be transitory, since the tunnel heading will be advancing at the average rate of about 50 to 100 feet per day beneath and beyond any one single property. Perceptible tunnel vibrations due to subway trains are more likely to occur in curves, at cross-overs or switches, and where track is misaligned due to poor construction and/or poor maintenance. However, a Metro test programs had indicated no adverse noise or vibration due to transit tunnel operations along both the Red and Gold Lines.

The Tunnel Report notes that noise and vibration tests have already been performed on the BHHS and indicate that construction and train operation noises and vibration will be below FTA limits. Measurements would be made under BHHS during construction (p. ES-2). However, there is no indication that these would be used as “not to exceed” baselines for construction. There should also be comments, and eventually specification requirements on using sound-damping noise walls, low noise fans, and minimizing trucks entering and leaving staging areas during hours that would disrupt local residents, businesses, and public facilities

Underground construction typically mutes most of the construction related noise and vibration. However, surface activities such as ventilation fans, cranes, muck removal and loading into dump trucks, and bringing construction materials on site could result in noise and vibration impacts to nearby and adjacent homes and businesses. Noise walls, 12 to 20 feet high, erected around the construction site have been effective on other recent tunnel projects in significantly reducing impacts such as noise and dust to neighbors.

7.3.4 Gassy Ground

For gassy ground, the Tunnel Report notes that "volume of gas released from the soil during TBM tunneling is confined to the excavated material chamber because of the closed-face and gas-tight lining that is installed immediately behind the TBM" (p. 5-4). This would be the case if the contractor is required to utilize a SPBM, where the excavated muck and bentonite slurry is pumped to the ground surface for treatment. However, this would only be partially true if the contractor uses an EPBM, in which the excavated soil is brought out of the "chamber" or cutter-head via a cased screw auger and then dumped onto a conveyor belt for conveyance via any of several means (muck trains, extended conveyor or slurry pipeline) to the portal. When the excavated soil is expelled from the screw auger onto the conveyor belt, entrained gas may bleed off into the air. However, the volume of gas will be limited to that which is only entrained in the excavated soil and will be limited by the earth pressure maintained on the face. On many tunnel projects, high ventilation rates have been used effectively to dilute and expel this gas from the tunnel. If the muck is fluidized and carried out by slurry line, then the gas bleeds off from the slurry at the ground surface. There are also options for neutralizing hydrogen sulfide in the ground, or in transit through the tunneling machine, by injecting chemicals such as bleach, hydrogen peroxide and permanganate. We understand that on the Gold Line tunnel construction, a SPBM was required where methane and hydrogen sulfide gas concentrations were anticipated to be high by the designers.

The recent Metro Gold line specifications required the installation of double-gasketed segmental liners coupled with high ventilation rates for either an EPBM or SPBM along with continuous monitoring for gas concentrations. Similar specification requirements should be applied to the WSE to provide sufficient redundancy to prevent methane and hydrogen sulfide buildup in the tunnel during construction and operations. Most longer than 15-foot diameter TBM-excavated soil tunnels in the U.S. are supported with a bolted precast concrete segments with a gasket around each segment that mates with adjacent segments. Metro has implemented the use of double-gasketed, bolted concrete segments for tunnel lining in order to greatly reduce the potential for gas and groundwater entering the tunnels. This double-gasketed lining system was extensively tested for and is unique to Los Angeles tunnel projects. In addition, the double-gasketed, bolted, precast segmental liner will be fully encased in a 4- to 6-inch thick annulus of grout that is pressure injected around the lining as it is installed at the rear of the advancing TBM. The double gaskets and grouted annulus will virtually eliminate the potential for gas to enter the tunnel through the lining. Federal and state required active ventilation implemented during construction and operation of the tunnels will further dilute gas that enters the tunnel.

Lastly, the contractor is required, in potentially-gassy and gassy ground to install gas detection monitoring systems to continuously monitor the tunnel atmosphere for gas. On most tunneling projects the tunnel foreman or safety engineer also carries a portable gas detector to check the tunnel atmosphere for gas levels. This multiple redundancy of sealing, ventilation, and monitoring has precluded gas from being an issue in most tunnels during and following soil tunnel construction with precast concrete gasketed segmental linings during the last 30 to 40 years.

Based on review of the Tunnel Report, only boring C-119B involved gas testing at three elevations at the Santa Monica Station; whereas, six borings were tested for gas concentration at multiple elevations at the Constellation Station. Additional borings should be drilled and tested for gas concentrations, along with groundwater levels along the final tunnel alignment.

7.3.5 Groundwater

The Tunnel Report notes 500-foot spacing for the borings (p. 2-8). In our opinion, this spacing is too wide with regards to the complexity of the faulted geology and variable groundwater levels in the West Beverly Hills/Century City area. The borings do not appear to have been drilled through the faults, which are shown as steeply inclined to vertical features. Ideally borings, possibly angled, should be drilled through the faults to look for clay gouge, soil consistency, ground water levels changes, and other properties that could impact the tunnel construction. The presence of high groundwater levels to the north of the SMFZ and to the east of the WBHL, and substantially lower groundwater levels to the south and west of these features suggests the presence of clay gouge that is impeding groundwater flows.

Subsurface conditions at BHHS were explored with 14 borings; however, only four are deep enough to go below the tunnel horizon. Only three borings have monitoring wells installed, and water levels were measured in three of the borings during drilling. The three borings with monitoring wells show water levels 10 to 40 feet above the proposed tunnel crown, however, without information on screen locations and sealing methods, it is not possible to determine from which soil horizon(s) the water is originating. From our review, it is unclear if a perched water table is present for some of the upper soil units, or possibly a confined artesian condition for some of the lower soil units. Also, it is unclear how the groundwater levels change across the various postulated faults as water levels were measured in only three borings in the three fault strand bounded blocks.

The fault block furthest to the west apparently has no groundwater measurements. A complete discussion on a postulated groundwater barrier to the northwest of the Constellation Station site is lacking (p. 2-7). We recommend that additional borings with wells and piezometers be installed and a map of contoured groundwater levels be developed to help identify the location, orientation, and cause of the "groundwater barrier." Identification of this feature will be important for both the tunnels and stations.

7.3.6 Existing and Future Structures

Beneath the BHHS, the top or crown of the proposed tunnels are 50 to 70 feet below ground surface. This should provide adequate depth for future development of parking garage/basements down about three to four levels or 30 to 50 feet deep. Normally, construction is limited to no closer than one tunnel diameter above the crown or to the sides of a tunnel. However, closer excavation may be permitted by Metro with adequate design evaluation, lateral support, and protection of the transit tunnels.

The Constellation Boulevard alignment passes below significantly more house, commercial buildings and other structures (including the BHHS) than the Santa Monica Boulevard alignment. The number of structure directly above the tunnels increases the challenges of adequate exploration as well as the need for more careful construction methods and additional monitoring of settlements and ground behavior. Agreements with Metro on design and construction limitations and requirements for any new structures built over the tunnels would be needed from at-grade property owners above the tunnels. These agreements would likely include a maximum basement depth, any special tall building support constraints, such as proximity of piers or pile tips, and basements adjacent to the tunnels.

8.0 PRECEDENCE FOR STRUCTURES ON FAULT TRACES

8.1 General

We reviewed the Fault and Tunnel Reports for comments on locating transit structures on or adjacent to fault traces. The intent of our review was to evaluate case histories of transit structures placed along fault zones, and structures that were impacted by fault displacements. The next section highlights similar structures along fault zones in the Fault and Tunnel Reports followed by our review and opinion.

8.2 Century City Reports

8.2.1 Fault Report

The following pages of the Fault Report discuss structures placed on or near fault traces:

- Page 16
- Page 30

8.2.2 Tunnel Report

The following pages of the Tunnel Report discuss structures placed on or near fault traces:

- Page ES-3
- Pages 7-1 and 7-2

8.3 Technical Review

8.3.1 Overview of the Alquist-Priolo Act

This section provides additional history of and use of the AP Act than is discussed in the Fault Report (p. 16). The authors of the Fault Report note that the assumed likely inclusion of the SMFZ and WBHL into the AP Act is a sufficient reason enough to select the Constellation Boulevard alignment. However, if the results of the recent trenching on the BHHS campus are to be believed, then the WBHL should not be classified as "active".

The original name of the AP Act was the Alquist-Priolo Geologic Hazards Zones Act established on December 22, 1972. The State Geologist delineated earthquake fault zones for active traces of the San Andreas, Calaveras, Hayward, and San Jacinto faults. Preliminary review of 175 quadrangle maps occurred between 1973 and 1974. Official maps were issued on July 1, 1974, and Earthquake Fault Zones became effective at that time. The cities and counties were required to implement programs to regulate development within mapped AP Act zones.

Faults were mapped as "active" if they had surface displacement in the last 11,000 years (Holocene). Faults were mapped as "potentially active" if they showed evidence of surface displacement during Quaternary time (last 1.6 million years). "Potentially active" faults are now referred to as "recently active" faults.

The AP Act was renamed the Alquist-Priolo Special Studies Zones Act on May 4, 1975. On January 1, 1976, 81 maps of new zones and five maps of revised zones were implemented.

Beginning in 1977, the State Geologist decided fault zones must meet the criteria of "sufficiently active and well defined." However, the term "potentially active" continued to be used as a descriptive term on map explanations until 1988.

Since 1977, an earthquake fault zone boundary (EFZ) is defined to extend 500 feet to either side of a "major" active fault and about 200 to 300 feet to either side of a well-defined, minor fault. Exceptions exist where faults are locally complex or where faults are not vertical. Within these zones owners of new or rebuilt structures may be required to complete subsurface investigation to delineate faulting on the project boundaries. EFZ maps are typically issued every year or two to delineate additional and revised zones.

The AP Act was again renamed the Alquist-Priolo Earthquake Fault Zoning Act on January 1, 1994. By August 16, 2007, a cumulative total of 547 official maps of active fault locations had been issued. Of these, 148 maps have been revised since their initial issue and four maps have been withdrawn. Additional faults will be zoned as "active" in the future and some will be revised.

Sufficiently Active-This is defined as evidence of Holocene surface displacement along one or more of a fault's segments or branches. Holocene surface displacement may be observable or inferred; it need not be present everywhere along a fault to qualify that fault for zoning. Note that the amount of fault displacement is not specified.

Well-Defined-This is defined as a fault trace that is clearly detectable by a trained geologist as a physical feature at or just below the ground surface. The fault may be identified by direct observation or by indirect methods. The critical consideration is that the fault (or some part of it) can be located in the field with sufficient precision and confidence as to indicate that the required site-specific investigations would meet with some success. Determining if a fault is sufficiently active and well defined is a matter of judgment. Certain faults considered to be active at depth are so poorly defined at the surface that zoning is impractical.

The AP Act is applicable to any project defined under Section 2621.6 of the AP Act. This includes:

- Any subdivision of land which is subject to the Subdivision Map Act, and which contemplates the eventual construction of structures for human occupancy.
- A structure for human occupancy is any structure 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.

- Exemptions for structures with human occupancy include either of the following:
  - A single-family wood-frame or steel-frame dwelling to be build on parcels of land for which geologic reports have been approved
  - A single-family wood-frame or steel-frame dwelling not exceeding two stories when that dwelling is not part of a development of four or more dwellings.

In practice, the minimum setback distance from an active fault trace is typically 50 feet. With respect to building set back, the act simply states that: "No structure for human occupancy shall be permitted to be placed across the trace of an active fault. Furthermore, the area within 50 feet of such active faults shall be presumed to be underlain by active branches of that fault unless proven otherwise by an appropriate geologic investigation and report." (CGS, 2007).

All sections of the AP Act apply to proposed human occupancy structures. When a property pre-dating the AP Act is located within an EFZ, the transferor or agent acting for the transferor must disclose to the prospective transferee the fact that the property is located within a delineated EFZ. The disclosure must include proof and must be disclosed by an appropriate agent as defined by this section.

8.3.2 Stations and Tunnels Subjected to Fault Displacements

We reviewed case histories of fault displacement for several types of structures, including tunnels, subways, stations, buildings, and underground pipelines. We did not find references to stations knowingly placed across an active fault trace. The following discussion highlights tunnels and subways that had been directly subjected to earthquake shaking and fault displacements.

A study of tunnels affected by strong earthquakes revealed multiple cases of tunnels damaged by seismic fault offsets, including the Bolu twin tunnels (Turkey), Wrights Railway Tunnel (California), Kern County Tunnel (California), Balboa Inlet Tunnel (California), and several tunnels in Japan. Research indicates that tunnels may be vulnerable tectonic deformations. Very little or no evidence exists indicating that relatively recent concrete lined tunnels have experienced significant damage or collapse due to seismically induced shaking. There is some evidence that some underground stations have experienced minor damage, particularly at connections with tunnels, and in some of the associated utilities.

The Bolu Tunnels are 50 feet wide and 2 miles long and cross the North Anatolian Fault Zone (strike-slip), along a 500-1000 foot wide shear zone. After a 7.2 Moment Magnitude earthquake in 1999, deformation up to 30 inches was observed in the tunnel and a section of the tunnel, temporarily under construction, collapsed (Kontogianni, V. I. and Stiros, S. C., 2003).

In 1906, the Southern Pacific Railroad's Wrights Tunnel was damaged by a 7.7 Moment Magnitude earthquake occurring in the San Andreas Fault Zone (strike-slip). This 1.2 mile tunnel experienced offsets of between 5 to 6 feet. The tunnel, above which two parallel seismic surface ruptures were observed, collapsed along a 300 foot long section crossing the fault zone (Kontogianni, V. I. and Stiros, S. C., 2003). In this location, the tunnel was timber-supported and considerable crushing of timbers and upward heave of rails occurred (Brown et al., 1981).

The Kern County Tunnel, crossing the White Wolf Fault (reverse strike-slip), was damaged during a 7.5 Moment Magnitude earthquake in 1952. The tunnel, lined with timber and about 1 to 2 feet of reinforced concrete, was located in an area where fault displacements occurred during the earthquake. After the earthquake, both compressive and lateral displacements were detected along the ground surface. The liner was offset just over 4 feet (Kontogianni, V. I. and Stiros, S. C., 2003).

The partially completed Balboa Inlet Tunnel was affected by the San Fernando Magnitude 6.6 earthquake in 1971. The tunnel crossed the Santa Susana Thrust Fault, along which displacement occurred about 1,000 feet from the portal. The reinforced concrete liner was cracked and there was spalling along a 300-foot section at the fault crossing. On each side of the fault, there was also longitudinal cracking in the tunnel liner for about 1,000 feet (Brown et al., 1981).

The San Pablo Tunnel, used to transport water through the Berkley Hills from the San Pablo reservoir, was constructed between 1917 and 1920 and is about 2.5 miles long with a cross-section about 8 feet wide. The tunnel crosses two major fault zones, the Hayward Fault, and the Wildcat Fault, as well as several unnamed faults. In 1969, control points were set up for alignment checks after circumferential and longitudinal cracks were observed. It was not reported whether or not this occurred because of fault rupture or creep (Brown et al., 1981).

During the 7.6 Magnitude Chi-Chi Earthquake in 1999, a portal for water intake tunnels was ruptured for a distance of 30 feet as a result of thrust faulting in Taiwan (Aydan, O., 2003).

Japan has several instances where fault rupture crossed tunnels. The Tanna Railway tunnel on the main line between Tokyo and Kobe was under construction in 1930 when it was damaged by an earthquake with a magnitude estimated at 7.1. Tunneling conditions were very wet and required drainage drifts. Near one of the drainage drifts, a shear zone displaced about 9 feet left lateral and 2 feet vertical. This completely closed the drainage drift. At the surface, about 500 feet above the tunnel invert, fault displacement was less and measured 3 feet left lateral and 1.5 feet vertical (Brown et al., 1981).

The Inatori Tunnel in Japan experienced surface rupture along the Tanna Fault during the 1977 Izu earthquake. With a surface wave magnitude of 6.8, the earthquake caused damage to the 65-foot long railway tunnel with a relative displacement of 40 inches. The railway tunnel crossed the fault at right angles, with a cover of 300 feet. This movement caused extension of the tunnel (Brown et al., 1981).

Similar damages occurred due to the motions of the Rokko, Egeyama, and Koyo faults to the tunnels of Shinkansen and subway lines through the Rokko Mountains. The underground rapid transit subway line in Kobe experienced collapse of 3 of the 10 stations as a result of strong ground shaking during movement of the nearby Egeyama fault (strike-slip). In particular, the Daikai station collapsed after it was subject to torsional failure due to permanent ground displacement from nearby fault displacement (Aydan, O., 2003).

In addition, Shannon & Wilson had staff in San Francisco during and following the 1989 Loma Prieta Earthquake who observed several railroad tunnels immediately after the earthquake and observed no damage other than minor spalling of thin concrete, grout and gunite patches in brick- and concrete-lined tunnel crowns.

We also reviewed highway tunnels and transit tunnels in the Seattle area immediately after the 2001 Nisqually Earthquake in western Washington. None of the four tunnels that were reviewed showed any indications of shaking related damage; however, minor damage was observed in one of the cut and cover stations at the intersections with the running tunnels.

The Tunnel Report indicates that a special tunnel liner design may be required, such as a strong but flexible lining to withstand several feet of movement without collapse (p. 7-2 note above). The use of such a specialized liner would only be required where displacements might occur across an “active” fault, which at this point may only apply to the SMFZ. This could require a localized larger diameter liner, which means that the larger diameter TBM would be needed. The larger diameter tunnel might be on the order of 23 to 26 feet in diameter to accommodate fault offset. Alternately, a flexible lining and a lining backed with crushable grout could be used, but this could also require a larger diameter TBM. The larger diameter TBM might be accommodated with shafts to either side of the SMFZ. It appears that the design team and Metro have not yet settled on a design for the fault crossing.

9.0 LIMITATIONS

This report was prepared for the exclusive use of the City of Beverly Hills for specific application to this project. This report is a review of information provided in the Century City Reports.

The analyses, conclusions, and recommendations contained in this report are based on information provided in the Metro Reports and our experience in the project vicinity. We assume that the exploratory borings provided in the Metro Reports are representative of the subsurface conditions throughout the project alignment (i.e., the subsurface conditions everywhere are not significantly different from those disclosed by the explorations).

Within the limitations of the scope, schedule, and budget, the analyses, conclusions, and recommendations presented in this report were prepared in accordance with generally accepted professional geotechnical engineering principles and practices in this area at the time this report was prepared. We make no other warranty, either express or implied. These conclusions and recommendations were based on our understanding of the project as described in this report and the site conditions as interpreted from the Metro Reports.

Shannon & Wilson, Inc. has prepared the document, "Important Information About Your Geotechnical/Environmental Report," in Appendix C to assist you and others in understanding the use and limitations of this report.

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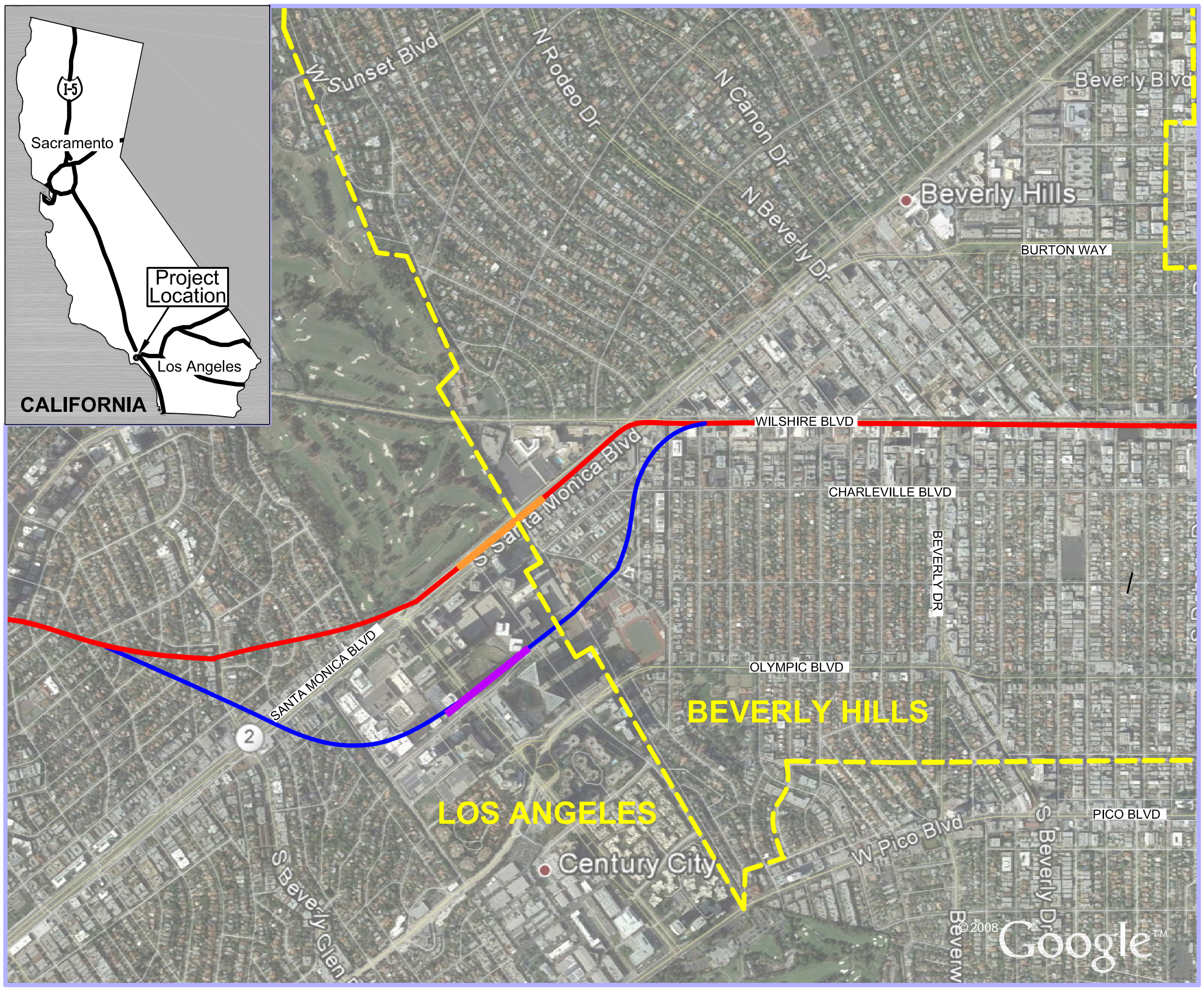

LEGEND

- Proposed Santa Monica Alignment
- Proposed Constellation Alignment
- Proposed Santa Monica Station
- Proposed Constellation Station
- City Boundary

0 1000 2000 4000

SCALE: 1"=2000'

NOTE

Map adapted from aerial imagery provided by Google Earth Pro, reproduced by permission granted by Google Earth ™ Mapping Service.

Westside Subway Extension Review
Beverly Hills, California

VICINITY MAP

March 2012 51-1-10024-003

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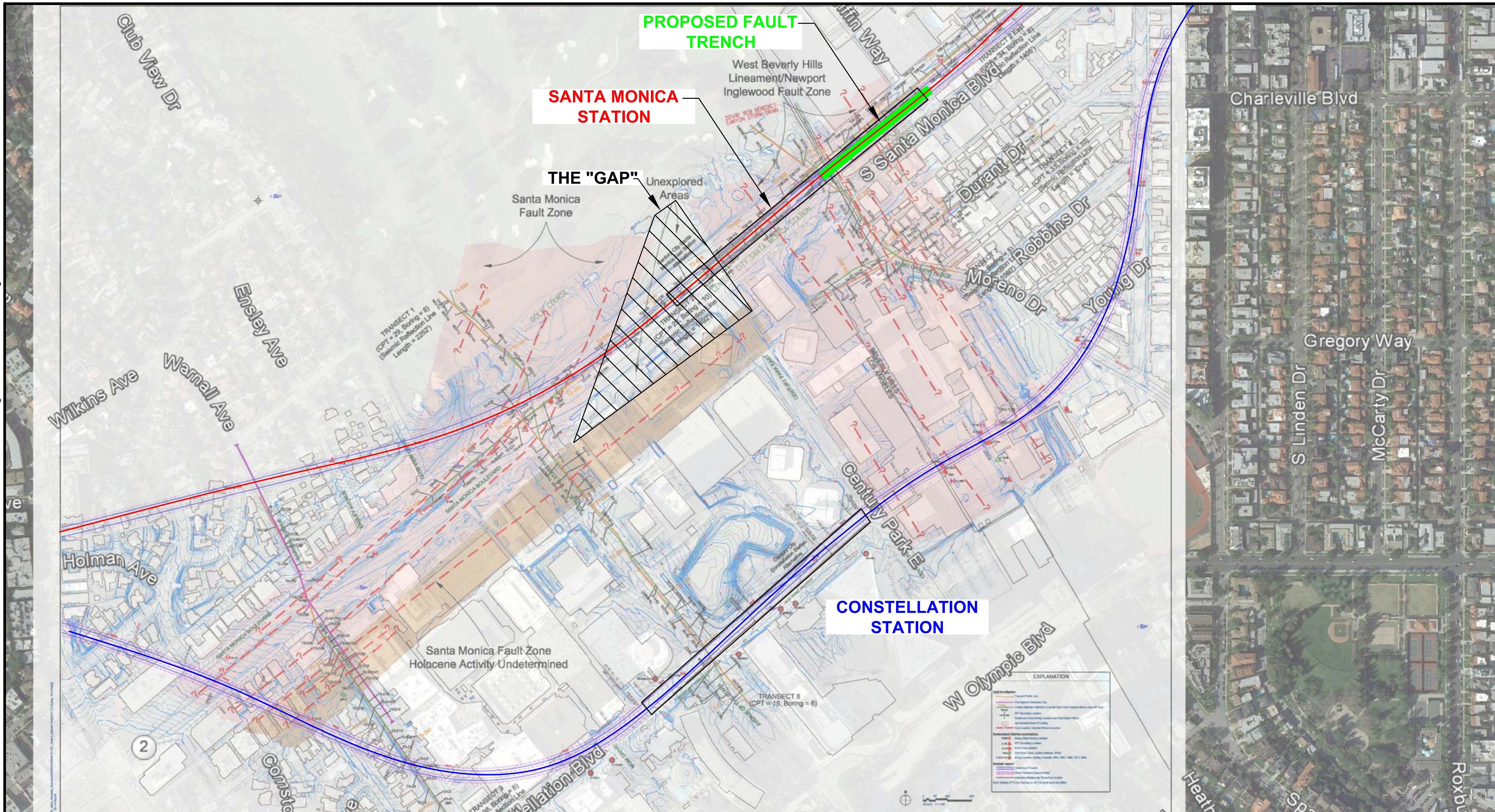
FIG. 1

Filename: I:\PROJECTS\10024 Beverly Hills WSE Review\003 FEIS Review\GRAPHICS\Vicinity Map.dwg Date: 03-08-2012 Login: Louis Larios



Filename: I:\PROJECTS\10024 Beverly Hills WSE Review\003 FEIS Review\GRAPHICS\FIG 2 - ALTERNATE PROPOSED ALIGNMENT.dwg Date: 03-08-2012 Login: Louis Larios

NOTE

Map adapted from Fault Exploration Plan Century City Area, by AMEC, 10-14-2011 .

0 200 400 800

SCALE: 1"=400'

Westside Subway Extension Review
Beverly Hills, California

ALTERNATE ALIGNMENT

March 2012 51-1-10024-003

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FIG. 2