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Failure Analysis Associates

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

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Contents

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.

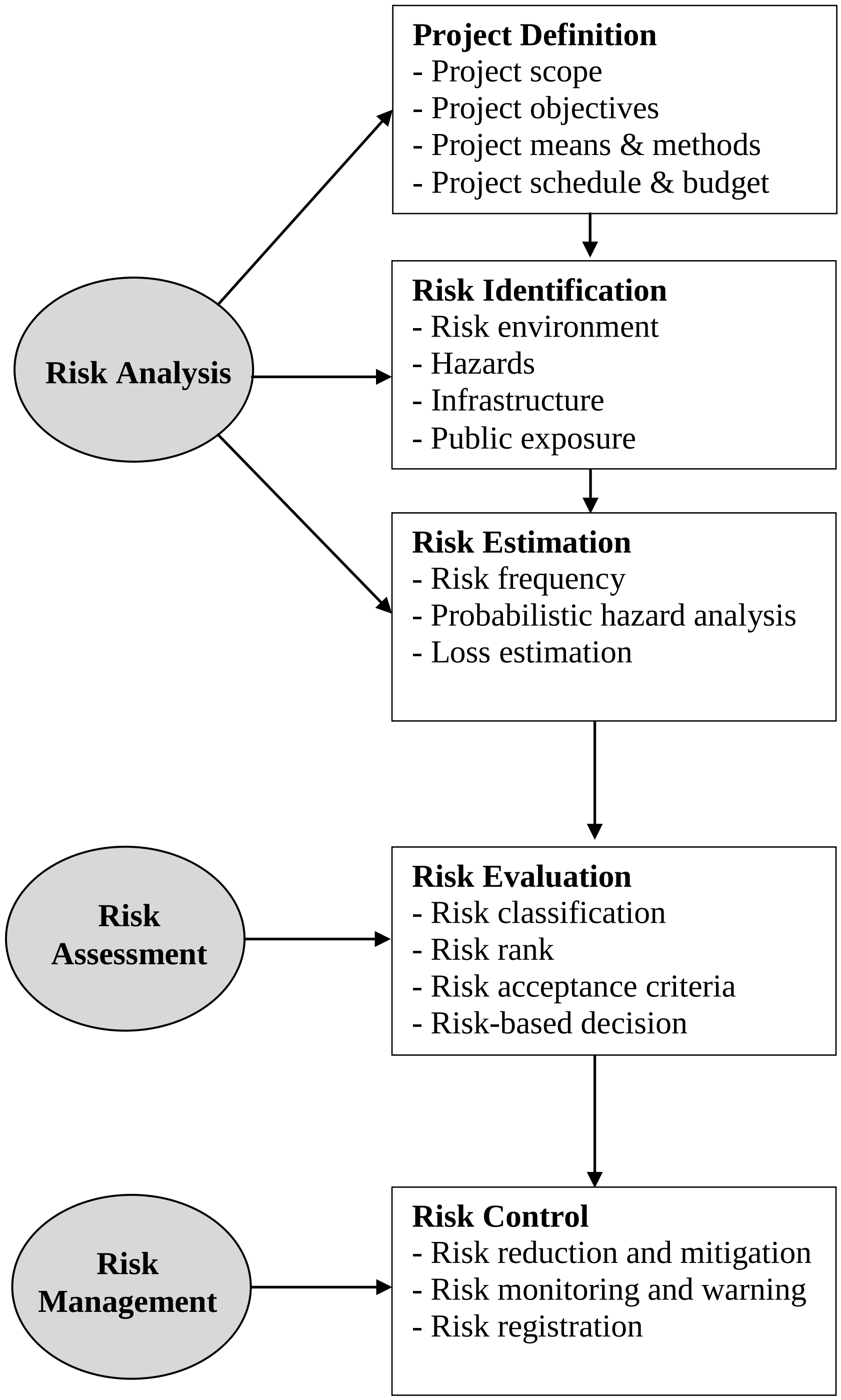

Figure 1. Risk management methodology and flowchart, adopted from Hu *et al*. (2007).

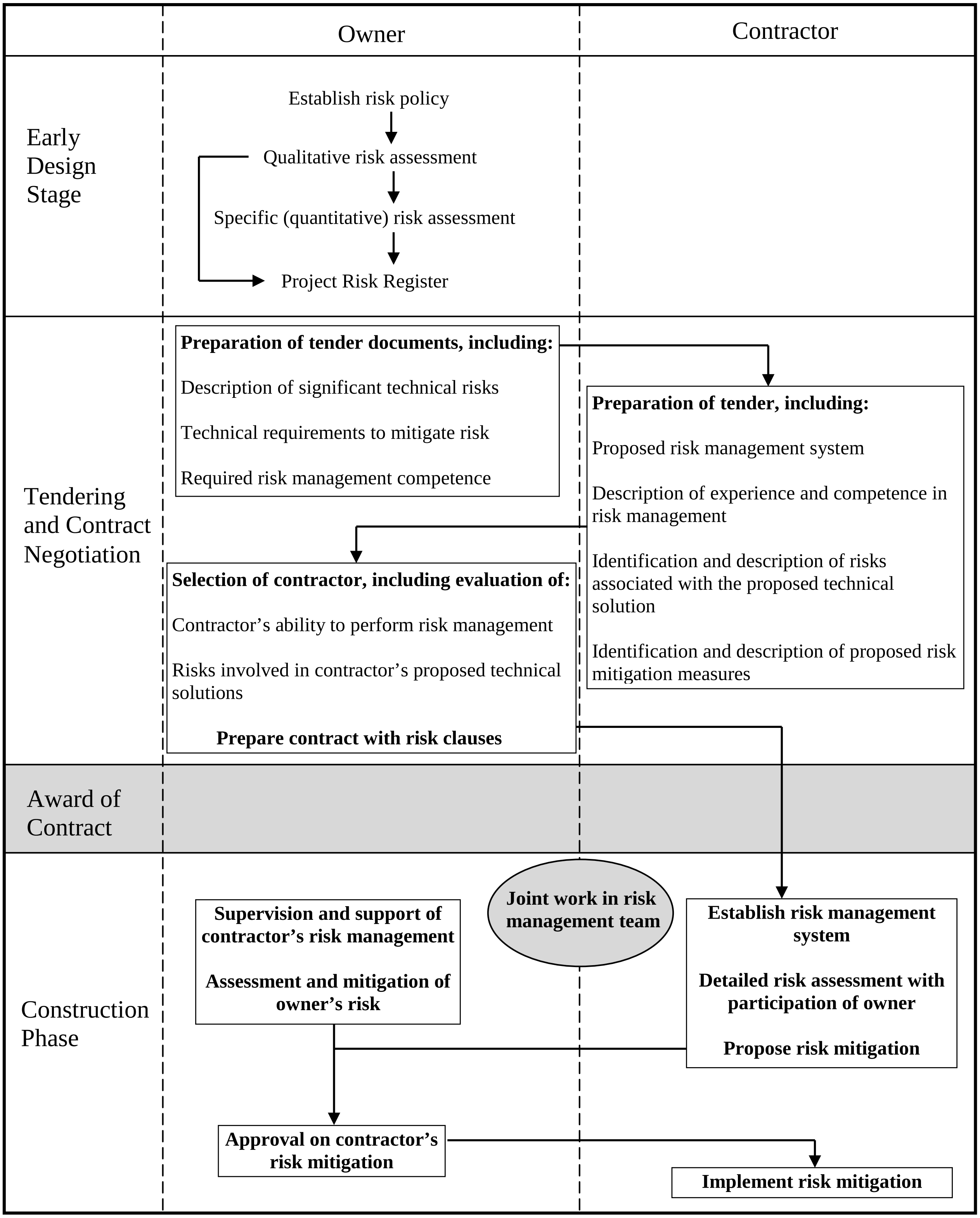

Figure 2. Risk management activity flow for owner and contractor (Eskesen *et al*., 2004).

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" (0, 10', 20', 40')

HORIZONTAL SCALE: 1" = 40'-0" (0, 20', 40', 80')

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

Exponent™
Failure Analysis Associates®

Figure 1.

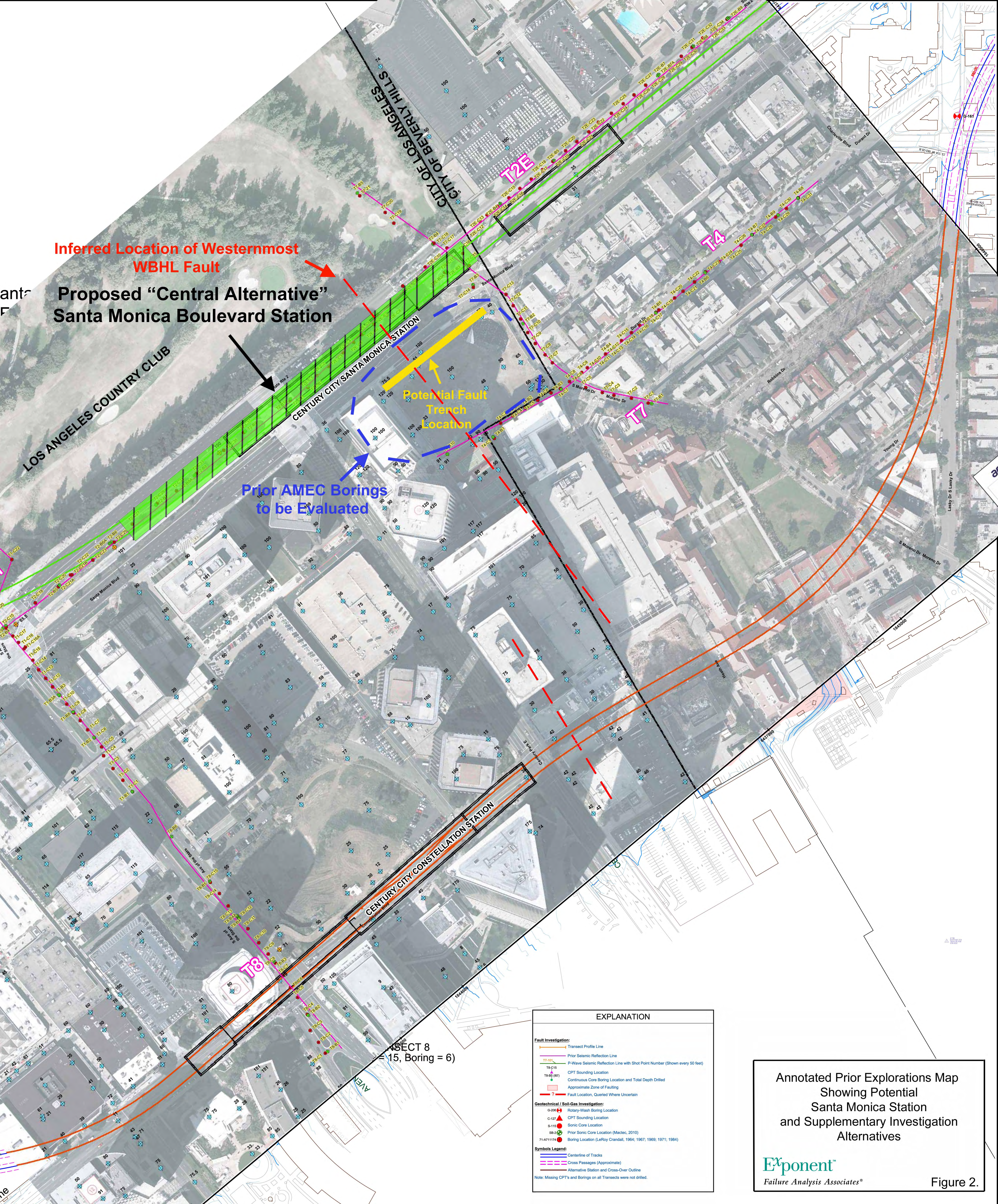
amec
AMEC Environment & Infrastructure
5628 E. Slauson Avenue, Los Angeles, California 90040
Phone (323) 889-5300 Fax (323) 889-5398

Geologic Section

JOB:	4953-10-1561
LT,LNG:	
SCALE:	V: 1" = 20' H: 1"=40'
DRAWN:	V. Nguyen
CHKD:	M. Wickers/M. Farr
PM:	R. Munro
DATE:	10/14/2011

TRANSECT 2 & 2East
Century City, Los Angeles, California

PLATE NO. 5
PROJECT NO. 4953-10-1561



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

Exponent
Failure Analysis Associates®

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

JOB:	4953-10-1561
LT.LNG:	
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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Piotr D. Moncarz, Ph.D., P.E., S.C.P.M.
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

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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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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
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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)
- Chemical Engineering Society, IIT, New Delhi, India (President)

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Senior Managing Scientist

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
40-Hour HAZWOPPER certification

Publications

Shaller P, Shrestha P, Doroudian M, Sykora D, Hamilton D. Numerical modeling of the 2005 La Conchita landslide, Ventura County, California. In: Flood Hazard Identification and Mitigation in Semi- and Arid Climates. French R, Miller J (eds), College Press (London), in press.

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Shaller P. Dig or drill? Weighing options for robotic planetary surface exploration missions. Presented at ASCE Aerospace Division, International Earth and Space Conference, Long Beach, CA, March 3-5, 2008.

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Shaller P, Wren J, Sykora D. New approaches to evaluate and explain recurring geotechnical issues in litigation cases, Part 3: Synthetic Aperture Radar Interferometry (InSAR). Presented at 7th Annual ASCE Forensic Engineering Technical Group Meeting, Los Angeles Section, University of California Irvine, CA, May 10, 2002.

Shaller P, Gupta A, Saraf V. Gujarat Earthquake reconnaissance. Web page developed for Exponent Web Site, Spring, 2001.

Shaller P. Geologic work at the Getty Center, Los Angeles: A study in geologic complexity. Presented at 43 Annual Meeting of Association of Engineering Geologists, San Jose, CA, September 2000.

Shaller P, McSaveney M, Gillon M, Beetham R, Freeman T. Age and failure style of a large landslide complex at Matahina Reservoir, New Zealand. Presented at 40th Annual Meeting of

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. The runaway mountain. Television appearance on documentary program *Horizon*, British Broadcasting Corporation, 1996.

Shaller P, Sabins E. Last motion on the Benedict Canyon Fault, Santa Monica Mountains, California. Geological Society of America, Abstracts with Programs, Vol. 26, p. 185, October 1994.

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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.

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 I: Drilled shaft foundations. Report No. UCLA-SGEL 2007/01, Structural and Geotechnical Engineering Laboratory, University of California, Los Angeles, December 2007.

Ahlberg E, Rha C, Stewart JP, Nigbor RL, Wallace JW, Taciroglu E. Field testing and analytical modeling of a reinforced concrete embedded pile under lateral loading. 5th National Seismic Conference on Bridges and Highways, San Mateo, CA, September 18, 2006.

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)