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report

VOLUME 1

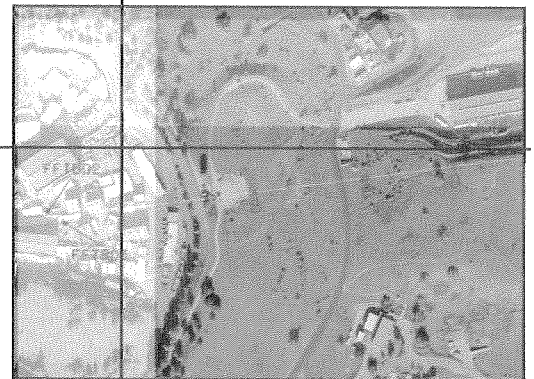
GEOTECHNICAL DATA AND INVESTIGATION REPORT

**Linac Coherent Light Source (LCLS) Project
Stanford Linear Accelerator Center
Menlo Park, California**

Prepared for
Stanford Linear Accelerator Center

21 January 2005

By
Rutherford & Chekene
427 Thirteenth Street
Oakland, CA 94612





RUTHERFORD & CHEKENE

Consulting Engineers
Geotechnical Structural Civil

427 Thirteenth Street
Oakland, CA 94612
TEL 510 740 3200
FAX 510 740 3340

www.ruthchek.com



RUTHERFORD & CHEKENE Consulting Engineers • Structural Civil Geotechnical
San Francisco & Oakland • 427 Thirteenth Street Oakland CA 94612 • TEL 510 740 3200 FAX 510 740 3340

21 January 2005

Ms. Jo Beth Folger, Project Manager
Stanford Linear Accelerator Center
2575 Sandhill Road
Menlo Park, California 94025

#2003-060G2

Subject: **VOLUME 1- GEOTECHNICAL DATA & INVESTIGATION REPORT
LINAC COHERENT LIGHT SOURCE (LCLS) PROJECT
STANFORD LINEAR ACCELERATOR CENTER
MENLO PARK, CALIFORNIA**

Dear Ms. Folger:

We are pleased to transmit herewith six copies of Volume 1 of our two-volume report covering the subject project. Volume 1 of the report contains the summary of all of the methods employed as well as results obtained during our field exploration and laboratory testing programs. The Volume 2 report contains a summary of geotechnical recommendations for use in design.

The field exploration program involved the drilling and logging of seven borings, logging of seismic wave velocity in two of the seven borings, and performance of pressuremeter tests in two other borings. Environmental samples were obtained from five of the seven borings. The environmental samples were transferred to the SLAC for subsequent characterization. Testing of geotechnical samples was our responsibility.

The logs of our borings as well as detailed results of the seismic velocity logging, pressuremeter testing, and laboratory testing are presented in the appendices of Volume 1 of the report. The logs of borings and laboratory test results from our 2003 geotechnical study of the site are also contained in the appendices of Volume 1 of the report.

We greatly appreciate the opportunity to be of service to you on this project. If you have questions or comments regarding this report, please contact us.

Sincerely,

RUTHERFORD & CHEKENE

Gyimah Kasali, Ph.D., G.E.
Principal

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EXECUTIVE SUMMARY

General

Geotechnical studies, involving both field and laboratory components, for the LCLS Project to be located at SLAC in Menlo Park, California were conducted by Rutherford & Chekene. This report constitutes the geotechnical investigation report (GIR), which presents the findings as well as geotechnical recommendations for the design of the proposed project. The project site is shown in Figure 1, Site Vicinity Map, and Figure 2, Site Aerial Photograph.

Details regarding the topics summarized below as well as other topics covered by this report are contained in the body of this Volume 1 of the report. The accompanying Volume 2 of the report contains design recommendations derived from the data in Volume 1 of the report.

Previous Geotechnical Study

We had performed an initial geotechnical study for this project based on a scope that was defined by SLAC. The results of our findings were summarized in the Geotechnical Data Report (GDR), dated 1 August 2003. Some of the pieces of information and laboratory tests required for the development of geotechnical recommendations were established during that study. In general, the laboratory tests that were performed during that study were not repeated during this investigation other than for the purposes of confirming the results of the previous tests on similar-looking samples.

As part of the initial geotechnical study, we also issued a tunneling memorandum, dated 1 August 2003.

Geology and Seismicity

Geologically, the site is located in an area characterized by moderate folding and faulting of underlying rock. The earth materials underlying the site within the depth of construction fall under three main categories:

1. Artificial fills, which were derived from nearby project sites at SLAC. The artificial fill consists primarily of moist, medium dense, silty sand (SM) and sandy lean clay (CL).
2. Santa Clara Formation, which caps some of the hills on the east side of the tunnel alignment. The Santa Clara Formation consists primarily of low-to-moderately weathered, poorly-to-moderately cemented, coarse sand, gravel, and chert cobbles.
3. Ladera Formation, which will constitute the bulk of the materials excavated during the tunneling operations. The Ladera Formation consists primarily of weak-to-moderately strong, median-to-coarse grained, moderately-to-well cemented sandstone.

There are no known major faults traversing the site, the closest major fault is the Peninsula segment of the San Andreas Fault, which is located about 2.5 miles to the southwest of the site. There are minor faults in the vicinity, but none of them is known to traverse the site. Like most sites in the San Francisco bay area, the site is susceptible to strong ground shaking.

Field Exploration Program

A new field exploration program was performed within the footprint of the proposed construction from July 19 to August 18, 2004. This exploration involved the drilling of seven borings, the collection of environmental samples in five of the borings as well as the collection of geotechnical samples in all of the borings for subsequent testing. The environmental samples were transferred to SLAC for subsequent characterization.

In addition to the drilling, logging and sampling of borings, the field exploration program also included seismic velocity logging in two of the seven borings and pressuremeter tests in two other borings that had not been subjected to seismic velocity logging. The logs of borings are contained in Appendix A of this report. The geologist's handwritten field logs are presented in Appendix C. The results of the seismic velocity logging and the pressuremeter tests are contained in Appendix F and Appendix G of this report, respectively.

Laboratory Test Program

A laboratory test program involving index and strength tests on selected samples obtained from the field exploration program was performed. The tests included moisture-density-porosity tests, particle size analysis with hydrometer, unconfined compressive strength tests with and without moduli, triaxial tests, slake durability index tests, shrink-swell/expansion pressure tests, Cerchar abrasion tests, creep tests, Resistance value (R-value) tests, and corrosion potential tests. The test results are summarized in this report. Detailed laboratory test results are presented in Appendix D of this report.

Subsurface Conditions

The subsurface conditions that we encountered are similar to the conditions described in our 2003 Geotechnical Data Report. The description is virtually repeated here for ease of reference.

The project site is underlain by Quaternary and Tertiary sedimentary deposits that are covered by a thin mantle of residual soil and artificial fill locally. The thickest section of the artificial fill, mostly silty sand, was encountered to a depth of 18.5 feet at the location where boring SB-B was drilled in 2003. Fill was also present to a depth of about three feet in borings SB-C and LCLS-3, and to a depth of five feet in boring LCLS-3A. Below the fill at LCLS-3 and LCLS-3A, residual soils in the form of sandy silt and lean clay were encountered to a depth of about 9 feet. Near the east end of the site, a layer of the Plio-Pleistocene Santa Clara Formation, which is moderately consolidated, is present to depths of about 15 feet and 33 feet below grade in borings SB-D and

SB-E, respectively. In boring LCLS-5, evidence of the Santa Clara Formation was found in the upper 5 feet.

The Miocene Ladera Sandstone, which underlies the Santa Clara Formation, is encountered along the entire alignment of the tunnel. Tunneling, if used, will occur entirely in this sandstone unit. The Ladera Sandstone is generally a fine- to medium-grained silty sandstone with minor interbeds of siltstone. Results of sieve and hydrometer analysis on two samples of the rock indicate that 17 to 21 percent of the materials passing the U.S. No. 200 sieve is silt compared to about 4 percent clay. The sandstone is typically very soft and very weak and thinly bedded to massive. Thin to moderately thick beds strongly cemented with calcium carbonate are present locally. Minor occurrences of thin calcite-filled fractures are also present.

Bedding exposed in the Research Yard strikes northeast and dips shallowly toward the southeast (N29E, 25E; N30E, 9E and N50E, 12E). The contact between the Santa Clara Formation and the Ladera Sandstone was characterized in the core samples and outcrop by an abrupt increase in soil strength and a lack of chert fragments with depth.

Groundwater Conditions

Groundwater was not encountered in any of our borings to the maximum depths of exploration because the drilling mud was used, and the borings were not converted to wells. Historical groundwater data collected over a period of 35 years indicate that the groundwater level on the project site would range from elevation 190 to 240 feet, approximately.

Seismic Velocities of Ladera Sandstone

Seismic velocity logging was performed in boring numbers LCLS-3 and LCLS-5. The results show that the average shear wave velocity of the materials encountered at LCLS-3 and at LCLS-5 to a depth of about 45 feet and 130 feet, respectively, is approximately 1,800 feet per second. The corresponding average value for compression wave velocity is 4,100 feet second.

Deformation Parameter of Ladera Sandstone

Mernard pressuremeter tests were performed in boring numbers LCLS-3A and LCLS-6. Six pressuremeter tests were performed in LCLS-3A, starting at a depth of about 15 feet, and 15 tests were performed in LCLS-6, starting at a depth of 39 feet. Tests were performed at approximately 5-foot depth intervals. The tests were performed in accordance with ASTM D-4719.

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The deformation parameter is the initial modulus or the slope of the elastic portion of the pressure-volume curve. Based on the test results, the initial modulus at LCLS-3A is almost constant at 1,900 bars until elevation 243 feet after which the modulus increases dramatically to 12,000 bars at elevation 237 feet. The initial modulus for LCLS-6, on the other hand ranges from 1,000 bars to about 12,500 bars between elevations 315 and 245 feet in a zig-zag fashion, indicating that there were interbedded layers of soft and hard rock.

**SECTION 1
INTRODUCTION**

INTRODUCTION

General

This report summarizes the findings from our geotechnical investigation program for the proposed Linac Coherent Light Source (LCLS) Project, to be located at the Stanford Linear Accelerator Center (SLAC) at 2575 Sand Hill Road in Menlo Park, California. The project site is shown in Figures 1, 2, 3 and 4.

The geotechnical investigation program consists of the following two components:

1. Obtain Geotechnical Data from Field Exploration and Laboratory Test Programs. The findings from this component of the investigation are presented in Volume 1 of the report.
2. Develop Geotechnical Recommendations from the Analysis of Geotechnical Data. The results of this component of the investigation are presented in Volume 2 of the report.

Purpose

The purpose of the geotechnical investigation program was to gather and present the factual test and other data that were collected during the field exploration and laboratory testing programs as well as to develop design recommendations derived from the field and laboratory test data.

Existing Site Conditions

The SLAC is located on 426 acres of low, rolling hills and swales with low to moderate relief. The proposed project site is located in the eastern part of SLAC. The surface elevations are variable within the project site. They vary from elevation 245 feet at the Research Yard, where an approximately 75-foot cut with a gradient of 1:1 (horizontal:vertical) was made as part of the construction of the existing LINAC, to elevation 323 feet at boring location SB-A, elevation 276.1 feet at boring location SB-C, elevation 295.5 feet at boring location LCLS-4, elevation 354.1 at LCLS-5, and elevation 341.8 feet at LCLS-6.

The site is mostly undeveloped except for a few above- and below-grade improvements that either traverse or are located in the immediate vicinity of the site. The above-grade improvements, shown in Figures 2 and 3, include an existing antenna and a one-lane roadway near boring location SB-A, a two-lane roadway near boring location SB-C and LCLS-3, and the existing SLC Experimental Hall to the north of boring locations LCLS-4, SB-D and SB-E. The existing SLAC Research Yard, which has several structures, is located to the west of boring location SB-A and in the area where LCLS-1 and LCLS-2 were drilled. Existing below-grade improvements, shown in Figure 4, include the Positron Electron Project (PEP) tunnel and the

Stanford Linear Collider (SLC) tunnel. The PEP tunnel, which was constructed in 1978, traverses the site between boring locations SB-C and SB-D whereas the SLC tunnel, which was built in 1985, traverses the site between boring location SB-D and SB-E.

Project Description

SLAC is a national research facility operated by Stanford University for the United States Department of Energy (USDOE). Research at the facility centers around experimental and theoretical particle physics using accelerated electron beams. Other research programs at the facility involve using synchrotron radiation from accelerated electron beams.

We understand that the proposed LCLS facility is aimed at creating a new type of x-ray light source from a single pass free electron laser (FEL). The FEL would have a peak brightness ten orders of magnitude greater and with faster pulses than the most intense synchrotrons currently available. The higher peak brightness would make it possible to examine much smaller particles, and the faster pulses would make it possible to evaluate changes within a very short time frame.

The new LCLS facility would make use of key existing structures. For example, the LCLS will use the last one-third of the LINAC, which will be modified by adding two magnetic bunch compressors. Most of the LINAC and its infrastructure will however remain unchanged. The existing components in the FFTB tunnel will be removed and replaced by a new 426-foot (130-meter) undulator and associated equipment.

The key elements of the new construction will include the following:

1. **SLAC Research Yard Modifications** – The Beam Transport Hall (BTH) will be built in the research yard. To facilitate this construction, a number of existing buildings and underground utilities will be modified and the Final Focus Test Beam (FFTB) Facility will be demolished and removed. A north-south overpass roadway will be constructed on top of the cut slope on the east side of the research yard to allow vehicular access to the north and south sides of the research yard.
2. **Beam Transport Hall (BTH)** – A tunnel-like structure crossing the research yard that will house the LCLS electron beam line.
3. **Undulator Hall (UH)** – the UH is a tunnel-like section designed to house about thirty-three specially-designed undulator magnets, which extends from the BTH to the Front End Enclosure (FEE). The Undulator Hall has tight alignment constraints, which places stringent requirements on its foundation and temperature stability.
4. **Front End Enclosure (FEE)** – The FEE will house varied optics and electron beam separation components and is located immediately downstream of the Undulator Hall.

The FEE is 131 feet (40 meters) in length and has environmental requirements similar to those for the Undulator Hall.

5. Electron Beam Dump Enclosure (BDE) – The BDE is a high radiation enclosure that contains a beam dump designed to absorb the energy of the LCLS electron beam. The BDE is immediately downstream of the FEE and is approximately 26 feet (eight meters) square in cross section.
6. Near Experimental Hall (NEH) – The NEH is the first of two experimental facilities, and is located immediately downstream of the BDE. The proposed building site is approximately 108 feet (33 meters) in length with a ground floor level approximately 23 feet (seven meters) below existing grade.
7. X-Ray Transport and Diagnostics Tunnel (XDT) – The XDT is a 951-foot (290-meter) long tunnel section that extends from the NEH to the Far Experimental Hall (FEH), which will house specially-designed optical equipment.
8. Far Experimental Hall (FEH) – The FEH is the second experimental facility, and is located approximately 951 feet (290 meters) downstream from the NEH. The FEH extends approximately 98 feet (30 meters) in the direction of the beam and is approximately 59 feet (18 meters) wide. One of the principal design challenges of the FEH is that its finished floor will be approximately 107 feet (33 meters) below existing grade.
9. Free Electron Laser (FEL) Center – The FEL Center will be constructed to house the research offices and laboratory space for the LCLS users, scientific and support staff. The FEL Center footprint is envisioned to be approximately 180 feet (55 meters) long and 115 feet (35 meters) wide, but is not constrained by LCLS technical requirements. The FEL should be architecturally attractive and moderately landscaped, with parking provided adjacent to FEL. The proposed location of the FEL is on grade and adjacent to the east edge of PEP Ring Road.
10. Central Lab Office Complex (CLOC) – An office complex shaped in the form of a segment of a circle and a northeast-southwest longitudinal axis will be built over the eastern third of the NEH. The CLOC is envisioned to have two floors above grade and one floor below grade. A plaza will be built on the east and west sides of the CLOC. Because of the existing topography, construction of the CLOC will lead to a portion of the building being supported on a cut pad, a portion on the NEH, and the remaining portion on engineered fill.
11. Service Stations – New service stations are to be built at various locations on the site. Service Stations A, B, and C are to be built at the west end, mid-point, and east end of the BTH, respectively. Service Station D will be built near the east end of the UH, at the

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location of borings LCLS-3 and LCLS-3A. Service Station F will be located over the XDT near the location of boring SB-D. Service Station G will be built to the immediate east of the existing SLC Experimental Hall.

12. Access Tunnel – An. access tunnel will be constructed from Service Station G, on the east side of the existing SLC Experimental Hall, to the FEH.
13. Substations – New substations are to be built at various locations on the site. Substations 1, 2, and 3 will be built to the north of CLOC and to the southwest of the existing SLC Experimental Hall. Substation 4 will be built to the immediate north of Service Station G.
14. Sighting Holes – A 24-inch diameter sighting hole, extending from the ground surface to the UH, will be installed to the east of the existing survey tower. Another sighting hole extending to the UH will be located just to the west of Service Station D. The last sighting hole, which will extend from the ground surface to the XDT, is to be located adjacent to Service Station F.

According to information provided by SLAC, based on the proposed invert elevation, the LCLS tunnel will traverse the alignment of the existing PEP tunnel about 34 feet above the invert elevation of 213.9 feet for that tunnel. It will also traverse the alignment of the existing SLC tunnel about 33 feet above that tunnel's invert of elevation 214.89 feet.

Proposed site work includes the following:

1. Crossover Road – A crossover road, which will involve the widening and upgrading of an existing roadway, will be built to the east of the existing survey tower. The Crossover Road will facilitate access to the north and south sides of the new BTH, which will extend above grade in the Research Yard.
2. Parking Areas and Access Roads – New parking areas will be built on the north side of Service Station D and on the west side of the CLOC. Access roads will be provided from the PEP Ring Road to the new parking areas. The section of the existing PEP Ring Road within the projection of the CLOC and the new parking area on the west side of the CLOC will be reconstructed by raising the existing grade along the subject section of the roadway. The raising of the grade of the subject section of the PEP Ring Road will help minimize the gradients of new access roads from the roadway to the new parking area.

Site Elevations

We based the site elevations in this report on a topographic survey, dated 13 May 2003 and prepared by C. Banuelos for SLAC. The elevations in the survey are based on the Mean Sea

Level (MSL) Datum. We have therefore based all elevations in this report on the MSL Datum, unless otherwise noted.

Previous Subsurface Explorations

As part of our preparation for this report, we have reviewed exploratory boring logs from previous geotechnical investigations in the vicinity of the project site. The logs that we reviewed are those from the PEP and SLC tunnel projects. Although most of the borings are outside the footprint of the proposed LCLS tunnel, they provided a general idea of the subsurface conditions in the vicinity of the site. The logs also provided useful information on groundwater conditions.

We also performed a preliminary investigation in 2003, which involved the drilling and logging of five borings along the alignment of the proposed tunnel. The detailed and summary logs of those borings are presented in our report Rutherford & Chekene (2003). Those logs are also presented in this report.

Organization of Report

General: The geotechnical data and investigation report has been organized into two volumes as follows:

Volume 1 of the Report – Constitutes the Geotechnical Data portion of the report.

Volume 2 of the Report – Constitutes the Analysis and Recommendations portion of the report.

Volume 1 of the Report: Volume 1 of the report is divided into the following six sections:

- Section 1: Introduction - Contains background and general information regarding the project.
- Section 2: Geology and Seismicity - Contains both the regional and local geologic conditions encountered at the project site, as well as the seismic setting.
- Section 3: Field Exploration Program – Contains a description of the field exploration activities and a presentation of the results.
- Section 4: Laboratory Testing Program – Contains a summary of the methodologies and the results from laboratory testing on geotechnical samples.
- Section 5: Subsurface Conditions – Describes the subsurface conditions based on information gathered from literature review and data from the field exploration and laboratory test programs.

Volume 1 of the report contains the following appendices:

- Appendix A: Contains logs of borings (LCLS-1 to LCLS-6) from our current geotechnical investigation as well as photographs of core samples obtained from those borings.
- Appendix B: Contains logs of borings (SB-A to SB-E) from our 2003 geotechnical study, and photographs of core samples obtained from those borings.
- Appendix C: Contains the geologist's field logs from the current investigation program.
- Appendix D: Contains detailed results of laboratory tests performed by Cooper Testing Laboratory, Cerco Analytical and Geo Test Unlimited on geotechnical samples.
- Appendix E: Contains detailed results of laboratory tests, including the summary, from our 2003 geotechnical study as well as the mineralogy analysis performed by John Wakabayashi on geotechnical samples during that study.
- Appendix F: Contains detailed results from the seismic velocity logging performed by GEOVision.
- Appendix G: Contains detailed results from pressuremeter tests performed by Fugro Geosciences.
- Appendix H: Contains miscellaneous information, including the description of the scope of services and information relating to the drilling permit.

Volume 2 of the Report: Volume 2 of the report contains design recommendations for surface structures, retaining walls, tunnels and caverns, and pavements. It also includes a summary of the site response analysis performed as a means of establishing various tunnel design parameters. This volume of the report is under a separate cover.

Limitations

1. This report has been prepared for the exclusive use of the Stanford Linear Accelerator Center and its consultants for specific application to the LCLS Project as described herein. In the event that there are any changes in ownership, nature, location or design of the project, the information contained in this report shall not be considered valid unless the project changes are reviewed by Rutherford & Chekene.
2. Any conclusions contained in this report are based in part upon the data obtained from exploratory borings and laboratory testing performed as part of this investigation. The nature and extent of variations between the borings may not become evident until construction. If variations are discovered, it will be necessary to re-evaluate any conclusions contained in this report.

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3. We cannot be responsible for the impacts of any changes in geotechnical or geologic standards, practices, or regulations subsequent to the performance of our services if we are not consulted subsequent to the changes.
4. We can neither vouch for the accuracy of information supplied by others, nor accept consequences for use of segregated portions of this report without consultation with our office.

**SECTION 2
GEOLOGY AND SEISMICITY**

GEOLOGY, SEISMICITY AND POTENTIAL HAZARDS

Regional and Local Geologic Setting

The SLAC is located in the central part of the Coast Range's physiographic province of California. This province consists of a moderately high mountain range in western California that extends northwestward some 600 miles from the Transverse Ranges to a point beyond the California-Oregon Border. The geology of the Coast Ranges is extremely complex in the variety of rock formations as well as structure. The ridges and valleys in the region are primarily controlled by the structure and follow the structural grain of the faults or folds.

The major structural feature of the area is the active northwest-trending San Andreas Fault zone, located about 2.5 miles southwest of the SLAC. Compressional forces have caused repeated movement on this fault and produced the northwest-trending structural grain of the San Francisco Peninsula. The few minor folds transecting the SLAC area follow this grain and trend northeast to northwest. The geologic structure of the area is characterized by moderate folding and faulting of the pre-Quaternary rocks. Axes of broad folds trend northwesterly over much of the area.

The project site lies in the eastern foothills of the Santa Cruz Mountains in an area underlain mainly by Tertiary marine sedimentary rocks and Mesozoic sedimentary, volcanic, and metamorphic rocks of the Franciscan Complex. The Tertiary sedimentary rocks are covered in places by younger formations, such as the Plio-Pleistocene Santa Clara Formation and Quaternary alluvial and terrace deposits. Depositional contacts between these various units are generally angular unconformities resulting from periods of erosion, folding, and faulting. A geologic map, prepared by Kenn Ehman et al. (2004), and presented in Figure 5 shows the distribution of the various geologic units on the site as well as the locations of the borings drilled during both the 2003 study and the current investigation. A subsurface profile prepared from the subsurface information obtained from our field exploration programs is shown in Figure 4.

Seismicity

Faulting: Although numerous minor shear zones cut the Tertiary rocks, no major faults have been discovered or mapped previously on the SLAC site nor have any active faults been located (Dibblee, 1966; Page and Tabor, 1967; Dames & Moore, 1981; Pampeyan, 1993). Known active faults that are considered capable of causing strong ground shaking at the site include the San Andreas and Monte Vista-Shannon faults. The nearest of these, the peninsula-section of the San Andreas fault, passes approximately 2.5 miles southwest of the site and has the potential to generate a maximum earthquake of $M_w = 7.1$. The location of this segment of the San Andreas fault relative to the site is shown in Figure 6.

Several minor faults were mapped in the SLAC and PEP excavations and in the cuts for Alpine Road east of the site (Earth Sciences Associates, 1982). The faults are commonly oriented

northeasterly but range from east- to northwest-trending and dip from 35° to near vertical. Observed slickensides indicate strike-slip movement on some faults near the LINAC junction; elsewhere apparent dip-slip displacement has been observed. None of the faults is accompanied by unusually thick shear zones and all gouge and evidence of displacement are commonly dissipated within four feet of the fault. The site is not located within an Earthquake Fault Hazard Zone.

Ground Shaking: The site is located within the Uniform Building Code (UBC) Zone 4, in the seismically active San Francisco Bay region. During a major earthquake on any one of the nearby active faults, the site may experience strong ground shaking. The intensity of the earthquake ground motion at the site will depend on the characteristics of the generating fault, the distance to the earthquake epicenter, the magnitude and duration of the earthquake, and specific site geologic conditions.

A number of historical earthquakes have affected the area, including the 1906 earthquake and the more recent Loma Prieta earthquake. According to Rose (1990), during the October 17, 1989 Loma Prieta earthquake, movements of more than 0.4 inch vertically and about a 0.2 inch horizontally occurred in the LINAC concrete housing near its junction with the SLC tunnel. During that earthquake, accelerations at SLAC were reported to have reached 30 percent of gravity.

Future Earthquakes: The likelihood of a major earthquake in California was recently completed by USGS (2003). USGS estimated the chance of one or more major (M6.7 or larger) earthquakes on the San Andreas Fault between 2003 and 2032 to be 21 percent. The corresponding probability for major faults in the whole San Francisco Bay region within the same time period is estimated to be about 62 percent.

Potential Hazards

In this section, we have briefly reviewed the geologic hazards that would potentially affect the site; we have stated the likelihood of occurrence of each hazard in qualitative terms. The geologic hazards considered for this project are: faulting, groundshaking, liquefaction and differential settlement, flooding, and slope stability.

Faulting and Ground Shaking: Based on the preceding discussion regarding faulting and ground shaking, we estimate the potential for faulting on the site to be low and the potential for strong ground shaking to be high.

Liquefaction and Differential Settlement: Liquefaction is defined as the loss of soil strength due to an increase in soil porewater pressure that results from seismic ground shaking. In order for liquefaction to occur, three general geotechnical conditions need to occur: (1) groundwater is present within the potentially liquefiable material; (2) the soil is granular and meets a specific range of grain sizes; and (3) the soil is in a loose state of low relative density below the water table and within 50 feet of the ground surface. If those conditions are present and strong ground

motion occurs, portions of the soil could liquefy and cause lateral spreading and differential compaction (settlement) of affected soils, depending upon the intensity and duration of the strong ground motion.

The site is underlain at depth by Ladera sandstone, which consists of very coarse grains and intact rocks below the groundwater table. The potential for liquefaction is therefore low.

Slope Instability: Except for some relatively steep cut slopes, the overall ground surface gradients at the site and surrounding area are relatively low and/or consist of Ladera Sandstone. Accordingly, the potential for slope instability is low, except for three areas: (1) the artificial fill slope to the east of boring SB-B, (2) the west-facing cut slope to the west of SB-A, and (3) the existing cut slope around the SLC Experimental Hall. In these three areas, the potential for slope instability, in the form of slumps, is moderate to high during a major earthquake. The potential for minor localized slumps is also moderate to high during the rainy season when saturation within the artificial fill slope or zones of weak rock in the cut slopes could occur.

Flooding: The nearest body of water to the site is Felt Lake. The lake is located about 1 mile to the south of the site at its closest point. If the lake should overtop, based on the general topography of this area, the floodwater will flow into the San Francisquito Creek, which is located to the east of the site. We conclude therefore that the potential for floodwater reaching the site is negligible.

Erosion: In general, most of the site is covered with vegetation and paving. Portions of the faces of the existing cut slopes mentioned above in the discussion on slope instability are however not vegetated. The potential for erosion of those portions of the cut slopes is moderate to high.

SECTION 3
FIELD EXPLORATION PROGRAM

FIELD EXPLORATION PROGRAM

Scope

We conducted a two-phase geotechnical exploration program involving double mobilization that extended from July 19 to August 18, 2004. The purpose of the exploration was to provide geologic and geotechnical data for the project. The exploration program consisted of the following elements:

The first phase of the field exploration involved the following activities:

1. Obtaining a permit
2. Mobilization of equipment on July 19, 2004
3. Drilling, logging and sampling
4. Logging of seismic velocity
5. Demobilization of equipment on July 23, 2004
6. Selection of samples for subsequent geotechnical testing
7. Analysis of laboratory test data and preparation of logs of borings.

The second phase of the field exploration involved the following activities:

1. Mobilization of equipment on August 13, 2004
2. Drilling, logging and sampling
3. Performance of pressuremeter tests
4. Demobilization of equipment on August 18, 2004
5. Selection of samples for subsequent geotechnical testing
6. Analysis of laboratory and pressuremeter test data and preparation of logs of borings.

Detailed information regarding the scope of work is contained in Appendix G of this report.

Preparatory Activities

Preparation: Staking and utility clearance of the boring locations were performed by SLAC. The boring locations designated as LCLS-1 to LCLS-6 are shown in Figures 2, 3, 4, and 5. The locations were selected above or as near as possible to the surface trace of the tunnel alignment by SLAC. The coordinates of some of the borings, the surface elevations, and the depth of each boring below the existing ground surface are shown in Table 1.

Rutherford & Chekene obtained a permit from the Environmental Health Department of the County of San Mateo in Redwood City for the drilling of the borings. The permit information is contained in Appendix G of this report.

Coordination: We coordinated with SLAC personnel to obtain containers to retain cuttings and bentonite slurry from the drilling operations for subsequent disposal by SLAC. We also coordinated with SLAC to obtain access badges for the drillers and geologist to access the site. Each badge had a dosimeter attached to it.

Field logistics were coordinated by Rutherford & Chekene in conjunction with the geologist from Gilpin Geosciences, working as a subconsultant to Rutherford & Chekene. SLAC's Environmental Safety & Hazard personnel visited the site daily during the drilling operations at LCLS-1 to LCLS-5, excluding LCLS-3A, to coordinate the environmental sampling operations with the geologist.

**Table 1
 Information Relating to Borings**

Identification of Boring	Coordinates		Surface Elevation Mean Sea Level, ft.	Depth of Boring (feet)
	Northing ⁽¹⁾ (feet)	Easting ⁽¹⁾ (feet)		
LCLS-1	-	-	245.0 ⁽²⁾	32.0
LCLS-2	1978833.488	6068173.634	247.57	31.8
LCLS-3	-	-	278.9 ⁽²⁾	60.0
LCLS-3A	-	-	278.0 ⁽²⁾	41.8
LCLS-4	-	-	295.5 ⁽²⁾	61.0
LCLS-5	1979113.339	6070002.774	354.05	136.5
LCLS-6	-	-	341.78	110.9

(1) California Zone 3, NAD 83 Datum
 (2) Approximate Elevation

Phase 1 of the Field Exploration Program

Drilling: Drilling was performed by Taber Consultants of West Sacramento. Taber deployed a track-mounted CME 55 drill rig for the drilling of LCLS-1, LCLS-2, LCLS-3, LCLS-4, and LCLS-5. The upper approximately three feet at LCLS-1 and LCLS-2, 10 feet at LCLS-3, and five feet at LCLS-4 and LCLS-5 were drilled using four-inch diameter continuous flight auger. The remainder of each boring was completed using an HQ core-barrel in order to create a large enough hole to allow a seismic velocity logging probe and a vibration measurement probe to be lowered in LCLS-3 and LCLS-5. This phase of the exploration program was started on July 19, 2004 and was completed on July 22, 2004.

Upon completion of drilling, the borings were backfilled to the ground surface with neat cement grout.

Logging: A Certified Engineering Geologist from Gilpin Geosciences visually classified the soil using the Unified Soil Classification System and the rock samples using the applicable classification system. Generally, core runs of 5 feet were performed, but the actual length of the core varied as a function of rock characteristics such as discontinuities and degree of weathering.

The retrieved rock-core was characterized (i.e., recovery, RQD, rock type, weathering, discontinuities, geological description, etc.), photographed, and stored in cardboard core boxes. The field logs prepared by the geologist are presented in Appendix C of this report.

Sampling: Soil samples were collected for environmental testing at the ground surface, at approximately zero to one foot, and subsequently at one foot intervals below grade through the fill and/or residual soil at each of the five boring locations. The environmental samples were retained in brass liners. The brass liners were cleaned prior to use in a solution of Alconox[®]. The samples collected from the flight auger portion of the boring were collected using a 3-inch O.D. Modified California split-spoon sampler fitted with the cleaned liners. The Modified California sampler was driven using a 140-pound hammer falling and average of 30 inches. The hammer was raised with two wraps around the cat-head. Field blow counts were recorded for each six-inches of penetration.

Brass liner samples were sealed at each end with Teflon[®] sheeting, then capped and labeled. All environmental samples were placed in a cooler chilled with Blue Ice[®] by SLAC personnel. Laboratory analyses data of the environmental samples, made available by SLAC indicate that all the environmental samples were free of contaminants.

Samples were collected for geotechnical testing to evaluate pertinent engineering properties of the material in the zone of the tunnel cross section. A majority of these samples were covered with plastic wrap and labeled.

After the drilling, logging and sampling had been completed at boring LCLS-3 and LCLS-5, those were left open until after seismic velocity logging, described below, had been completed in those borings.

Seismic Velocity Logging and Vibration Measurement: GEOVision Geophysical Services of Corona, California logged exploratory borings LCLS-5 and LCLS-3 on 18 and 19 July 2004, respectively, using P-S Suspension Logging techniques. Geophysical logging allowed us to estimate the P- and S-wave velocities of the various soil strata in the borehole. P-waves, which travel at about twice the speed of S-waves, are compression waves, whereas S-waves are shear waves. The shear wave velocities obtained from geophysical logging were used in the ground motion study and in developing seismic design criteria. The geophysical logging method is briefly described below.

A probe, approximately 25 feet long, is lowered to the bottom of the borehole, which is uncased and filled with drilling fluid. A source, near the base of the probe, creates a pressure wave in the drilling fluid, which produces both P- and S-waves in the surrounding soil. These waves travel through the soil and eventually transmit energy back through the drilling fluid to an upper and lower geophone, located near the top of the probe. Differences in arrival times are used to compute the average P- and S-wave velocities of the soil between the two geophones. The probe is then raised about 1.64 ft and the procedure is repeated for the entire length of the borehole.

The results of our geophysical logging for exploratory borings LCLS-3 and LCLS-5 are presented in GEOVision's report in Appendix F of this report.

After GEOVision completed its work, the Vibration Consultant for SLAC also performed vibration measurements in boring LCLS-3 before the hole was backfilled. Those results are not included in this report.

Phase 2 of the Field Exploration Program

Drilling: Drilling was performed by Fugro Geosciences of Oakland, California. Fugro deployed a truck-mounted CME 75 drill rig to perform the drilling at LCLS-3A and LCLS-6. The upper portion of each of the two borings was drilled with an 8-inch diameter hollow stem auger or a 3-inch tricone rock bit after relatively hard rock was encountered. This phase of the field exploration program was started on August 13, 2004 and was completed on August 18, 2004.

Upon completion of drilling, the borings were backfilled to the ground surface with neat cement grout.

Logging: A Certified Engineering Geologist from Gilpin Geosciences visually classified the soil using the Unified Soil Classification System and the rock samples using the applicable classification system. Generally, core runs of 5 feet were performed, but the actual length of the core varied as a function of rock characteristics such as discontinuities and degree of weathering. The retrieved rock-core was characterized (i.e., recovery, RQD, rock type, weathering, discontinuities, geological description, etc.), photographed, and stored in cardboard core boxes.

Sampling: The samples obtained from the hollow-stem auger portion of boring LCLS-3A were collected using a 2-inch O.D. Standard Penetration Test (SPT) sampler. No samples were taken in that portion of LCLS-6. The SPT samples were driven using a 140-pound hammer falling an average of 30 inches. The hammer was raised with two wraps around the cat-head. Field blow counts were recorded for each six-inches of penetration.

Rock core samples were collected for geotechnical testing to evaluate pertinent engineering properties of the material within the tunnel cross section.

Pressuremeter Tests: Fugro Geosciences of Oakland, California performed a total of 21 pressuremeter tests in exploratory borings LCLS-3A and LCLS-6 during the time period between 13 August 2004 and 18 August 2004. Six pressuremeter tests were performed in LCLS-3A, starting at a depth of about 15 feet, and 15 tests were performed in LCLS-6, starting at a depth of about 39 feet. Tests were performed at approximately 5-foot depth intervals. The tests were performed in accordance with ASTM D-4719.

The pressuremeter equipment consists of two main elements: a radially expanding cylindrical probe that is placed inside a borehole at the desired test elevation and a monitoring unit that

remains on the ground surface. The probe is made up of three independent cells. Pressure in the outer cells causes the inner measuring cell to exert uniform pressure against the borehole walls. The pressure is increased in equal increments of time and pressure and the resulting borehole expansion is recorded. Pressure is applied to water in the central cell and to the outer cells through the pneumatic control unit and the resulting soil/rock deformations are indicated by volume changes, which are read on a sight tube.

The pressuremeter test is standardized and is usually performed with 4 to 14 (ideally 10) equal loading increments up to the point of failure. Readings and deformations with respect to time are taken for each pressure increment at 15 seconds, 30 seconds and one minute after application of the loading increment. The 30-second and one-minute readings are generally reported.

To obtain as complete a load deformation curve as possible, the measured volume should reach 700 cm³ if the pressure limit (P_L) is less than 8 bars (119 psi) and 600 cm³ if 8 bars < P_L < 15 bars (218 psi). In other cases, the test must be carried up to 20 to 25 bars (290 to 363 psi) in soils and up to 50 to 70 bars (725 to 1015 psi) in rock, as was the case during this investigation.

The results of the pressuremeter tests performed in exploratory borings LCLS-3A and LCLS-6 are presented in Fugro's report in Appendix G of this report.

Logs of Borings

Rock descriptions, including the Rock Quality Designation (RQD), mineralogy, and physical character, weathering, character of fractures have been provided. These descriptions are contained in the detailed logs of borings. These detailed logs, the key to the logs, as well as summary logs are presented in Appendix A. Photographs of the rock cores are also presented in Appendix A.

**SECTION 4
LABORATORY TEST PROGRAM**

SUMMARY

Laboratory Testing

We commissioned Cooper Testing Laboratory (CTL) of Mountain View and Geo Test Unlimited (GTU) to perform laboratory testing aimed at evaluating index and strength characteristics of selected core samples from the borings. We also commissioned Cerco Analytical Inc. to perform corrosion potential analysis of selected core samples. Most of the core samples selected from each boring represents materials between the crown and the invert of the proposed LCLS tunnel.

Laboratory tests, which are summarized in Table 2, were performed on selected samples to characterize the pertinent engineering properties of the earth materials to be encountered along the tunnel alignment.

Table 2
Summary of Laboratory Tests

Type of Test	Applicable Test Method	Purpose	Total No. of Tests
Slake Durability	ASTM 4644-87	Slake durability of soil	2
Dry Density	ASTM D 2937	In-situ soil density	7
Moisture Content	ASTM D 2216	In-situ soil moisture content	7
Unconfined Compression	ASTM D 2166	Unconfined strength of soil	1
Particle Size Analysis with Hydrometer	ASTM D 422	Particle size distribution and clay/silt content of soil	2
Unconsolidated -Undrained Triaxial	ASTM D 2850	Undrained shear strength	8
Creep Test	ASTM D 5202	Creep potential of soil	2
Shrink-Swell/ Expansion Pressure	ASTM D 3877	Shrink and swell potential of soil	4
Cerchar Abrasion	-	Abrasiveness of soil	2
Rock Modulus and Poisson's Ratio	ASTM D 3148	Soil elastic modulus and Poisson's ratio	2
Unconfined Compression of Rock Core	ASTM D 2938	Unconfined strength of soil	2
Resistance Value (R-value)	Caltrans 301	Resistance of soil	3
Corrosion Potential			
Redox Potential	ASTM D 1498	Aerobic or anaerobic soil conditions	6
pH	ASTM D 4972	pH of soils	6
Resistivity	ASTM G 57	Resistance of metallic pipes to corrosion	6
Chloride Ion Concentration	ASTM D 4327	Resistance of steel reinforcement to corrosion	6
Sulfate Ion Concentrations	ASTM D 4327	Resistance of steel reinforcement to corrosion	6
Note: ASTM = American Society for Testing and Materials Caltrans = California Department of Transportation			

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Most of the samples tested can be classified as Ladera Sandstone. The difference, if any, between samples was in the degree of weathering, jointing, and cementing. In general, the sandstone near the ground surface was either uncemented or weakly cemented, while the cementation was weak to moderate as depth increased. Occasionally, highly cemented pockets of sandstone were encountered. The samples that were tested are identified in Table 3.

**Table 3
 Summary of Index and Strength Data**

Sample ID	Sample Depth (ft)	Moisture Density Results					Triaxial & Unconfined Compression Results	
		Dry Unit Weight (pcf)	Water Content (%)	Wet Density (pcf)	ASTM Test	Porosity (%)	σ_1 failure (psi)	σ_3 failure (psi)
LCLS-1	13	104.8	14.8	120.3	D 2937 D 2216	37.9	---	---
LCLS-3A	12.3	114.4	15.9	132.6	D 2937 D 2216	32.2	---	---
LCLS-3A	34	108.3	15.2	124.8	D 3877	---	---	---
LCLS-4	16.8	111.4	18.0	131.5	D 2937 D 2216	33.9	---	---
LCLS-4	33.5	109.5	13.5	124.3	D 2937 D 2216	35.1	---	---
LCLS-4	50.6	111.3	16.0	129.1	D 3877	---	---	---
LCLS-4	51.3	105.9	12.9	119.6	D 3877	---	---	---
LCLS-5	19	95.7	6.8	102.3	D 2937 D 2216	43.2	---	---
LCLS-5	36.5	111.7	8.7	121.4	D 2937 D 2216	33.8	---	---
LCLS-5	87.5	106.9	15.4	123.4	D 2166	---	12.1	---
LCLS-5	96	110.2	10.4	121.7	D 2850	---	202.8	42.4
LCLS-5	109	116.7	15.7	135	D 2850	---	174.3	47.9
LCLS-6	56.5	114.6	7.4	123.1	D 2937 D 2216	32.0	---	---
LCLS-6	83.5	---	---	132.4	D 2166	---	312	---
LCLS-6	87.5	110.9	13.9	126.3	D 2850	---	167.4	38.9
LCLS-6	92.2	120.4	11.1	133.8	D 2850	---	254.2	41.0
LCLS-6	93	---	---	133.1	D 2166	---	198	---
LCLS-6	94.6	122.7	10.6	135.7	D 2850	---	400.7	41.7
LCLS-6	101.5	116.4	14.4	133.2	D 2850	---	277.1	45.1
LCLS-6	107.5	114.6	14.9	131.7	D 2850	---	261.8	47.2
LCLS-6	109	100.6	16.2	115.9	D 3877	---	---	---
LCLS-6	109.4	117.9	12.7	132.9	D 2850	---	302.8	47.9

Results of Laboratory Tests

Summary of Results and Average Values: The results of all the laboratory tests that were performed, except for the slake durability, shrink-swell/ expansion pressure, creep and R-value tests are summarized in Table 3. The average values from the test results in Table 3 are summarized in Table 4.

**Table 4
 Average Values from Laboratory Test Results for Current Investigation**

Average Dry Density, Moisture, Porosity and Wet Density Results				
Property	Dry Density (pcf)	Moisture Content %	Porosity %	Wet Density (pcf)
Average	111.2	13.2	35.4	126.6
Count	20	20	7	22
High	122.7	18.0	43.2	133.1
Low	100.6	6.8	32.0	102.3

Results of Triaxial Compression Testing	
ϕ average (degrees)	34
c average (psi)	0
Count	8

Average Unconfined Compressive Strength	
Compressive Strength (psi)	174.0
Count	3
High (psi)	312
Low (psi)	12.1

A comparison between the average values from the current investigation and the corresponding values from our 2003 investigation indicates that the difference between the two sets of average values is minor.

Table 5
Comparison of Average Values from Current and 2003 Investigations

Engineering Parameter	Average Values of Indicated Parameter	
	Current Investigation	2003 Preliminary Investigation
Dry Density (pcf)	111.2	113.4
Moisture Content (%)	13.2	14.7
Wet Density (pcf)	126.6	129.9
Porosity (%)	35.4	38
Friction Angle (degrees)	34	33
Cohesion (psi)	0	0
Unconfined Compressive Strength (psi)	174	165

The results of the slake durability index tests and shrink-swell/expansion pressure tests are summarized in Table 6 and 7, respectively. The results for the test to determine Rock Modulus and Poisson's Ratio are summarized in Table 8 and the results of the Cerchar Abrasion Tests are shown in Table 9. The results of the R-value tests are shown in Table 10. Detailed results of all the tests performed by CTL and GTU are contained in Appendix D.

Table 6
Summary of Slake Durability Test Results

Sample ID	Sample Depth/Elevation (feet)		Slake Durability Index	Standard Verbal Description and Comments
	Depth	Elevation		
LCLS-4	36.5	259	0	Type III
LCLS-6	88	254	0	Type III

Table 7
Summary of Shrink-Swell/Expansion Pressure Test Results

Sample ID	Sample Depth/Elevation (feet)		Applied Load (psf)	Change in Height (%)	Volume Change (%)	
	Depth	Elev.			Saturated	Air-Dry
LCLS-3A	34	244	350	-0.4	-0.4	-3.6
LCLS-4	50.6	244.9	370	-0.3	-0.3	-2.6
LCLS-4	51.3	244.2	350	-0.5	-0.5	-3.0
LCLS-6	109	233	350	-0.4	-0.4	-1.0

Table 8
Summary of Rock Modulus and Poisson's Ratio Test Results

Sample ID	Sample Depth/Elevation (feet)		Rock Modulus (psi)	Poisson's Ratio
	Depth	Elevation		
LCLS-6	83.5	258	138,000	0.13
LCLS-6	93	249	66,000	0.11

Table 9
Summary of Cerchar Abrasion Test Results

Sample ID	Sample Depth/Elevation (feet)		Cerchar Index	Comments
	Depth	Elevation		
LCLS-3	35	243.9	0.8	Less abrasive than LCLS-6
LCLS-6	99	243.8	2.2	More abrasive than LCLS-3

Table 10
Summary of R-Value Test Results

Sample ID	Sample Location	R-Value	Sample Description
Area 1	Surficial Soil Near Boring LCLS-3	63	Brown silty sand with gravel
Area 2	Surficial Soil Near Boring LCLS-4	18	Brown clayey sand/sandy clay with organics
Area 3	Surficial Soil Near Boring SB-A	50	Brown silty sand, highly organic

Histograms of Test Results: For the purposes of evaluating the scatter of test results or obtaining weighted averages, we have prepared histograms of some of the test results. Figure 30 shows a histogram for the total unit weight test results. A histogram for moisture content test results is shown in Figure 31.

Slake Durability Index: The slake durability test results, summarized in Table 6, indicate that the samples are friable, especially when exposed to water. No materials were retained on the sampler after the first test cycle for each sample.

Shrink-Swell/ Expansion Pressure Test Results: The shrinkage-swell test results, summarized in Table 7, indicate that the samples are susceptible to small volume change when subjected to different moisture contents.

Rock Modulus and Poisson's Ratio Test Results: The rock modulus values, presented in Table 8 for the two samples, are lower than typical values for more indurated and quartz-rich sandstone. The Poisson's ratio values obtained in the lab are also relatively low.

Cerchar Abrasion Test Results: The Cerchar abrasion indices, presented in Table 9 for the two samples, are lower than typical values for more indurated and quartz-rich sandstone. The sample with the higher index is considered more abrasive.

R-Value Test Results: The R-value test results, presented in Table 10 for the three samples, are quite variable because of the difference in material types at the three sample locations.

Creep Test Results: The results of the creep test are presented in Appendix D of this volume of the report. Only two creep tests were performed, making it difficult to determine the creep strength of the sandstone samples. Neither of the two tests reached creep failure. The strains in the samples were levelling off about 7 days after testing started, indicating that creeping of the samples was coming to an end. We therefore stopped the creep tests after about 20 days.

It can be stated in general that the creep test results showed that rock deformation is minimal when considering the long-term effect of an applied load.

Corrosivity Test Results: We commissioned CERCO Analytical of Pleasanton to perform a corrosivity analysis of eight soil samples taken from the exploratory borings using ASTM test methods. Tests were performed to measure the resistivity, pH, chloride and sulfate ion concentrations, and redox potentials of the samples. The results are summarized below in Table 10.

Table 11
Summary of Corrosivity Analysis Results

Sample	Corrosivity Parameters					Material Description
	Resistivity in Ohms-cm	Chloride Ion in mg/kg	Sulfate Ion in mg/kg	pH	Redox in mV	
LCLS-1 5.5'-6'	5,400	N.D.	N.D.	8	450	Silty Ladera Sandstone
LCLS-3A 33.8'-34.3'	920	31	85	8.2	440	Silty Ladera Sandstone
LCLS-4 18.2'-18.8'	400	500	N.D	7.7	46	Silty Ladera Sandstone
LCLS-4 29.2'-29.8'	460	370	N.D	7.8	460	Silty Ladera Sandstone
LCLS-5 98.8'-99.3'	3,100	N.D	N.D	8.3	460	Sandstone
LCLS-6 108'-108.5'	3,600	N.D.	N.D	8.3	460	Silty Ladera Sandstone

CERCO concluded, based on the resistivity measurements, that the third and fourth samples listed above are classified as severely corrosive, the second sample is classified as corrosive, and the remainder of the samples are classified as moderately corrosive. CERCO also concluded that, based on chloride ion concentrations, the third and fourth samples are classified as being able to attack steel embedded in a concrete mortar coating. Based on pH, and sulfate ion

concentrations, and redox potential none of the samples is classified as able to damage reinforced concrete structures, mortar-coated steel, buried iron, steel, etc.

Difficulty Experienced by CTL: CTL had difficulty finding samples that were suitable for the strength tests at the elevations of interest. The primary reason for the difficulty was that the rock cores had zones of weak and poorly cemented material. Samples within these zones were likely to fall apart while attempts were made to cut and trim them for testing.

Limitations of Test Results: The cores selected for laboratory testing represent the rock substance, but not necessarily the rock mass of tunnel material to be excavated and supported. Also, the rock cores selected from the various boring locations are likely the best quality specimens within the locations sampled. Interbedded layers of weakly cemented materials made several core samples fall apart, leaving core samples without layers of weakly cemented materials as they most likely to remain intact for subsequent testing. Thus, laboratory tests may indicate higher strengths and durability than the mean or average values for intact rock pieces within the rock mass.

**SECTION 5
SUBSURFACE CONDITIONS**

SUMMARY

General

A description of the subsurface conditions along the tunnel alignment is provided in this section. The description is based on a combination of pieces of information from historical documents pertaining to the site, field exploration data, and laboratory test data.

Earth Materials

Residual Soil and Artificial Fill: The proposed LCLS Tunnel alignment is underlain by Quaternary and Tertiary sedimentary deposits covered by a thin mantle of residual soil and artificial fill locally. The soil mantle is derived from a combination of in-place weathering of bedrock and the decay of organic matter near the surface. The greatest thickness of artificial fill was encountered in boring SB-B to a depth of 18.5 feet. Fill was also present to a depth of about five feet in borings LCLS-3A and LCLS-5, three feet in boring LCLS-3 and one foot in SB-C. The fill is from nearby site excavations and generally consists of medium dense to dense, moist silty sand and some lean clay. Residual soil was present to a depth of 8.5 feet in LCLS-3A, six feet in LCLS-3, three feet in SB-C. Also, the upper two feet of materials at LCLS-4 was residual soil.

Santa Clara Formation and Ladera Sandstone: Hillsides near borings SB-D, SB-E, and LCLS-5 are capped by the Plio-Pleistocene Santa Clara Formation. The Formation is moderately consolidated and characterized in exposures immediately north of the alignment by chert pebble and cobble beds. In borings SB-D and SB-E, the Santa Clara Formation is present to about 15 feet and 33 feet below grade, respectively. In boring LCLS-5, on the other hand, the Santa Clara Formation is present to about 5 feet below grade.

The ground surface elevation at the Research Yard located immediately west of boring SB-A is near the proposed tunnel invert elevation of 245 feet. The west-facing slope at the Research Yard, near boring SB-A, is cut at approximately 1H:1V and provides observable exposures of the Ladera Sandstone. Bedding exposed in the Research Yard strikes northeast and dips shallowly toward the southeast (N29E, 25E; N30E, 9E and N50E, 12E). The experimental hall for the SLC, located north of borings SB-D and SB-E, is constructed in a 2H:1V cut area with a maximum slope height of about 80 feet. The Santa Clara Formation and the Ladera Sandstone are exposed in the cut slopes at this building location.

The Miocene Ladera Sandstone underlies the Santa Clara Formation and is the material within which the tunnel will be constructed. The unit consists generally of fine- to medium-grained silty sandstone with minor interbeds of siltstone. The sandstone is typically very soft and very weak and thinly bedded to massive. Thin to moderately thick beds that are strongly cemented with calcium carbonate are present locally. Minor occurrences of thin calcite- and gypsum (?)-filled fractures are present. The contact between the Santa Clara Formation and the Ladera

Sandstone was characterized in the core samples and outcrop by an abrupt increase in soil strength and a lack of chert fragments with depth.

Weathering, Fractures, and Bedding Planes: Weathering in the Quaternary and Tertiary sediments varies from slight to moderate. The Santa Clara Formation is moderately weathered as noted by a discoloration throughout the cores. Three to six-inch zones of completely weathered material are present in the Santa Clara formation above the contact with the Ladera Sandstone. The discoloration of the Ladera Sandstone varies from slight to complete with no distinct relation to depth.

Core recovery from the Ladera Sandstone was very good and typically greater than 90 percent. The rock is generally very slightly fractured (greater than 3.0 feet spacing). Occasionally, fracturing is closely spaced (1-inch to 6-inch). Many fractures are sealed with gypsum (?) or carbonate, or have an oxide coating, especially near the ground surface. Studies performed by Earth Sciences Associates (1982) in connection with some of the existing tunnels indicate that the bedding planes do not typically represent zones of weakness in the Ladera Sandstone.

Cementation: Based on field classification, the rock hardness ranges from very soft to soft and the strength ranges from very weak to moderately weak. As noted in previous explorations and confirmed by this exploration program, the Ladera Sandstone ranges from being uncemented or very poorly cemented with local zones of strongly cemented rock to being well cemented. Where it was tested with dilute hydrochloric acid, the cementing agent appeared to be slightly calcareous. The petrographic analysis however suggests that the primary cementing agent is clay even though the hydrometer analysis indicates that the clay content is lower compared to the silt content.

Relationship Between Tunnel Alignment and Subsurface Conditions: The approximate cross section of the proposed construction in relation to the subsurface conditions is shown in Figure 4 in Appendix A. The figure shows that tunneling excavation will occur exclusively in the Ladera sandstone.

Rock Quality Designation (RQD)

The Rock Quality Designation (RQD) for each core run is presented on the detailed logs (Figures 9-15 in Appendix A) as well as on the summary logs (Figures 23-29 in Appendix A). The RQD is a field observation used to compute a recognized value based on the degree of fracturing or brecciation of the rock mass. The RQD is a single value (percent) for each core run computed by summing the lengths of all intact pieces of core 4 inches or longer and dividing this amount by the total length of the core run. It is inferred in the computation that all cores not recovered consisted of pieces shorter than 4 inches. Pieces longer than 4 inches but split by a vertical fracture were not counted as intact. RQD's best application for assessing rock quality is in hard rock requiring a hammer blow or more to break.

During the 2003 geotechnical study, the hardness or degree of weathering of the soft/weak rock encountered was not considered in the computation of RQD. Thus, the RQD values shown on the logs of borings for the 2003 geotechnical may be misleading and should be ignored. On the other hand, the hardness of the rock was accounted for in the computation of RQD during the current geotechnical investigation. The RQD values on the current logs should therefore be considered as more accurately reflecting the quality of the rock. The minimum and maximum RQD values in the Ladera Formation are 0 and 52, respectively. In most of the tunnel excavation regions, the RQD values are between 0 and 12.

Groundwater Conditions

Based on over 30 years of groundwater monitoring data, collected from monitoring wells at SLAC, groundwater on the site is estimated by ESA Consultants (1994) to be higher than elevation 240 feet near boring SB-A, 230 feet near boring SB-B, about 210 feet near boring SB-C, and about 190 feet near boring SB-D. (SLAC, 2002) reported that groundwater depth in the Research Yard varies from 5 to 10 feet. The groundwater gradients and elevations are believed to have been altered locally to varying degrees by the presence of the LINAC, PEP and SLC tunnels.

We did not encounter groundwater to the maximum depths of exploration in either borings SB-A through SB-E during our 2003 geotechnical study or in borings LCLS-1 to LCLS-6 during our current investigation. It is possible though that the presence of groundwater could have been masked by the use of a rotary method of drilling, which involves the use of a drilling mud.

Minor free groundwater is expected within fractures and some of the cleaner sandstone strata within the Ladera Formation. This assessment is confirmed by reports regarding groundwater discharge from the drainage system installed below the LINAC and PEP tunnels to control groundwater infiltration. The LINAC system was reported to have discharged three gallons per minute from sectors 20 to 30. The system under the PEP tunnel in the area where the tunnel is submerged under groundwater, on the other hand, discharges less than two gallons per minute.

Water quality analyses of samples obtained from the SLAC area indicate fresh to brackish groundwater occurs within the site. The sulfate content in tested groundwater samples is considered corrosive and may affect concrete.

**SECTION 6
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**APPENDIX A
Figures**

**APPENDIX B
Logs Of Borings from 2003 Geotechnical Investigation**

**APPENDIX C
Geologist's Field Logs From Current Investigation**

**APPENDIX D
Results of Laboratory Tests by Cooper, CERCO, and Geo Test**

**APPENDIX E
Results of Laboratory Tests from 2003 Geotechnical Investigation**

APPENDIX F
Seismic Velocity Logging Report by GEOVision