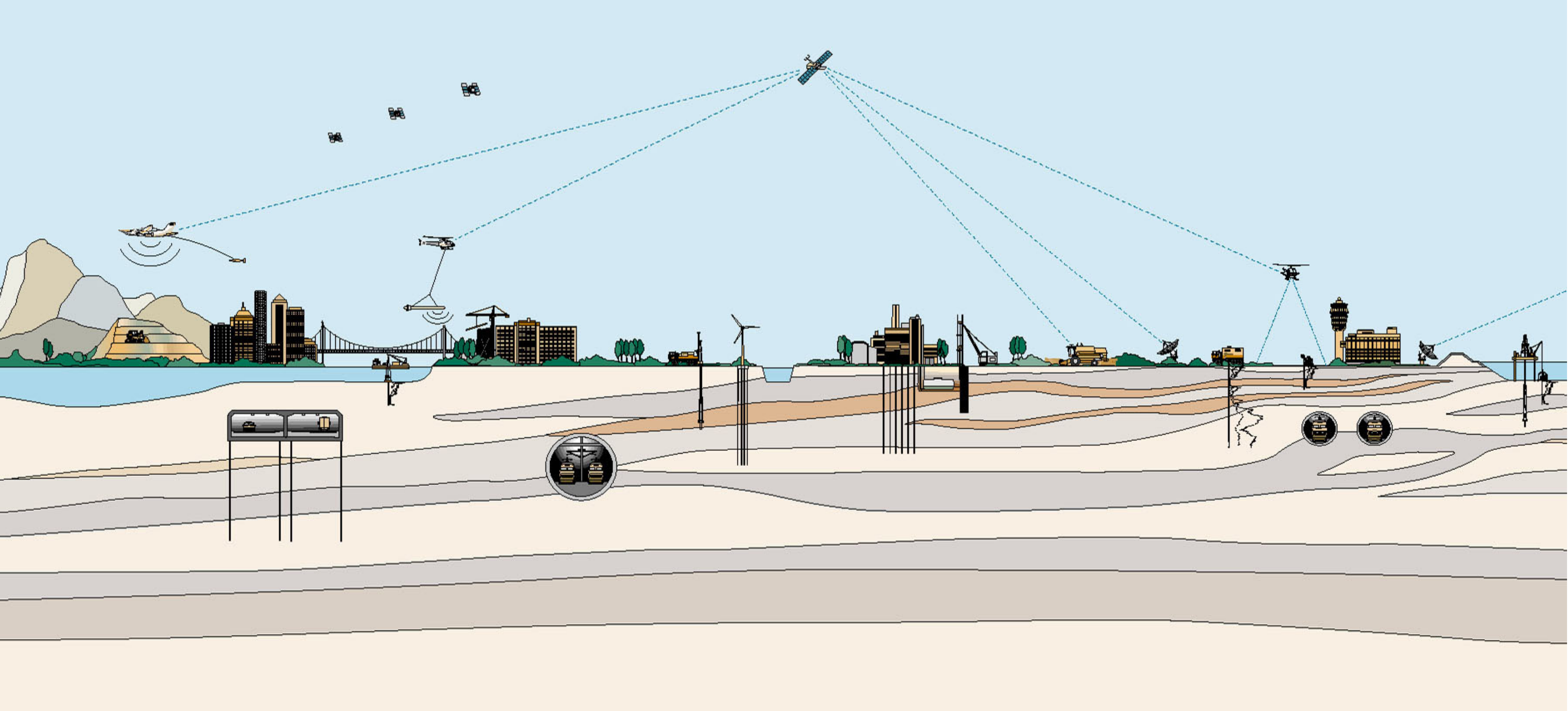
FUGRO CONSULTANTS, INC.

LIMITED GEOTECHNICAL REPORT
SEEPAGE EVALUATION OF THE EXISTING ARROYO GRANDE CREEK NORTH LEVEE
SAN LUIS OBISPO COUNTY, CALIFORNIA

Prepared for:
County of San Luis Obispo
Department of Public Works

April 25, 2012



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April 25, 2012
Project No. 04.6212.0004

County of San Luis Obispo
Public Works Department, Utilities Administration
County Government Center, Room 107
San Luis Obispo, California 93401

Attention: Ms. Jill Ogren

Subject: Limited Geotechnical Report, Seepage Evaluation of the Existing Arroyo Grande Creek North Levee, San Luis Obispo County, California

Dear Ms. Ogren:

Fugro is pleased to submit this Limited Geotechnical Report for the Seepage Evaluation of the Existing Arroyo Grande Creek North Levee in San Luis Obispo County, California. This report was prepared in accordance with our proposal dated December 27, 2011, and authorized under County Purchase Order No. 22007455, dated January 4, 2012.

This report presents the results of our evaluation of the seepage conditions along the existing north levee of Arroyo Grande Creek. Our evaluation was based on site-specific exploration, our previous study and other geotechnical studies in the site vicinity, review of published geologic information, project information provided by the County of San Luis Obispo, and hydraulic and stream flow information provided Waterways Consulting. This report is a supplement to the Fugro (2009) Preliminary Geotechnical Report that was focused on evaluating liquefaction and other seismic related hazards that could impact the levee.

The purpose of this report is to evaluate seepage conditions along the north levee of Arroyo Grande Creek, evaluate the potential for underseepage within the levee foundation soils to cause boils where seepage exits the ground surface beyond the levee, evaluate the potential for seepage through the levee (which could cause piping and erosion of the levee soils), and to discuss alternatives to mitigate seepage conditions for the design flood event, if needed. This report includes a summary of the results of our seepage and stability evaluations, field and laboratory data collected, graphics showing the locations of explorations, a discussion of mitigation concepts, and supporting data from the slope stability and seepage analyses.

We appreciate the opportunity to provide our services on this project. Please contact the undersigned if you have questions regarding this report, or require additional information.

Sincerely,

FUGRO CONSULTANTS, INC.

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Project Engineer/Geologist

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Copies: 4 – Addressee (1 – pdf on CD ROM)

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1.0 SITE AND PROJECT DESCRIPTION

The project was performed to evaluate the seepage and stability conditions for the existing north levee of Arroyo Grande Creek as input to the County's Arroyo Grande Creek Waterways Management Program (WMP). The Arroyo Grande Creek Waterways Management Program consists of flood protection improvements along Arroyo Grande Creek, from the city limits of Arroyo Grande and the confluence with Los Berros Creek to the upper edge of the Arroyo Grande Creek lagoon at the Pacific Ocean. The location of the site and proposed levee improvement limits are shown on Plate 1, Site Map. The proposed levee improvements will extend along the lower approximately 3½ miles of Arroyo Grande Creek and the lower approximately 1,700 feet of Los Berros Creek (a total of about 7 miles of levee). Arroyo Grande Creek is mainly confined by levees west of Highway 1, and intermittently confined by levees east of Highway 1.

1.1 PROJECT DESCRIPTION

The project consists of evaluating the seepage conditions along the north levee on Arroyo Grande Creek, and whether or not there is a potential for sand boils or piping to impact the levee, especially in areas where existing residences border the north levee. We understand from the County that the existing north levee provides flood protection for a flood event with about a 5-year recurrence interval. The north levee is considered the main flood protection for residences that border the north side of Arroyo Grande Creek, particularly east of 22nd Street, between about Station 72+00 and 102+00, where existing homes are located in close proximity or encroach upon the levee, and in the vicinity of the Oceano wastewater treatment plant site near Station 20+00.

The County has given priority to the north levee because of the high density residential areas, and the north levee is maintained at a slightly higher elevation than the south levee to encourage creek flows to breach the south levee before the water level in the creek would overtop the north levee. As part of that effort, we understand that the County recently raised sections of the north levee with about 1 foot or less of fill material between Stations 15+50 and 145+00, and placed temporary flood protection on sections of the south levee. The temporary flood protection consists of visqueen covering both interior and exterior slopes, and sand bags along the levee crest. According to 2011 topographic data provided by the County (2012), levee crest elevations on the north and south levees range from 20.88 feet to 62.09 feet and 20.68 feet to 59.36 feet, respectively. All the elevations noted herein are relative to the NAVD88 datum.

Waterways Consulting (2011) performed hydraulic modeling of a 5,070-cubic feet per second (cfs) peak flow, which corresponds to a storm event with a recurrence interval of between 5 and 10 years. According to Waterways Consulting (2012), the water surface elevation (el.) for the estimated 5,070-cfs flow would be near the top of the existing north levee in the vicinity of Station 80+00, at about el. 34.5 feet. Additionally, the water surface elevations for the estimated 5,070-cfs flow would be about el. 24.1 feet and el. 20.2 feet at Station 40+00 and Station 23+00 (near the Oceano Airport and Wastewater Treatment Plant), respectively.

We understand that the creek would likely not overtop the north levee downstream of Highway 1 during the 5,070-cfs flow event because the south levee would likely breach, and water surfaces downstream of the breach would drop as a result. Based on discussions with the County, we understand the north levee would likely breach upstream of 22nd Street before the levee downstream of 22nd Street would be overtopped during a flood event greater than 5,070 cfs.

The design storm events for Arroyo Grande Creek are generally considered to be relatively short duration (flashy) type floods that peak and recede below the base of the levee within 24 hours. Peak water surface elevations are anticipated to remain stable for only a few hours before either the south levee would overtop in a storm event greater than the design storm event, or waters would eventually recede. We understand the County has monitored and observed the latter phenomenon during past flood events. The duration of the storm event considered in the seepage evaluation corresponds to the estimated time for steady-state seepage conditions to develop through the levee and exit on the exterior levee slopes.

1.2 EXISTING SITE

Los Berros Creek flows west into Arroyo Grande Creek at the eastern terminus of the project. Arroyo Grande Creek then flows westerly to the Pacific Ocean, about 3½ miles downstream of Los Berros Creek. Based on site observations, concrete weirs and check dams are located within the Los Berros Creek channel, and rip-rap boulders associated with construction and maintenance of existing levees were observed along sections of variable length within the Arroyo Grande Creek channel. Bridges span Arroyo Grande Creek at Highway 1/Cienega Street, 22nd Street, and along the Union Pacific Railroad (UPRR) alignment. We understand that the County performs periodic tree trimming and vegetation management of the channel as part of the levee system maintenance.

The site topography, exploration locations, cross section locations, and project stationing are shown on Plate 2, Field Exploration Plan. Existing site grades range from approximately elevation 11 feet (SH+G, 2008), at the west end of the project reach, to approximately elevation 65 feet, near the city limits of Arroyo Grande. The existing channel bottom consists mostly of gravel with vegetated banks and levee slopes. Sand and gravel bars have built up within the channel between the slopes of the levees. The existing land use adjacent to the southern levee is predominantly agricultural land planted in irrigated row crops. There is also the Cardoza (horse) Ranch west of Creek Road. The existing land use adjacent to the northern levee is a combination of the Oceano airport, South County Waste Water Treatment Plant, and residential and agricultural plots. Beyond the down stream limits of the project, the south levee is bordered by active sand dunes within the Oceano Vehicle Recreation Area operated by State Parks.

The levees and channelized Arroyo Grande Creek were constructed in the late 1950s as a U.S. Department of Agriculture, Soil Conservation Service project (USDA 1956). Portions of the creek were relocated as part of the construction of the levee system. Downstream of Highway 1, the levees consist of earthen berms. Review of the USDA (1956) plans show the levee embankments designed with 15-foot wide crests, with 1½h:1v to 2h:1v exterior slope inclinations, and 3h:1v interior slope inclinations. As-built plans provided by the County and cross sections developed with SH+G (2008) and San Luis Obispo County (2012) topographic data show that the interior slopes were constructed as steep as about 2h:1v. The interior height of the channel slopes indicated on the plans ranges from about 11 to 14 feet. The exterior slope height appears to have been designed about 5 to 12 feet above the adjacent grades downstream of Highway 1. However, upstream of Highway 1, the existing levee is less pronounced and more intermittent, with a design height generally less than about 3 feet above adjacent grades.

1.3 FUTURE FLOOD CONTROL IMPROVEMENTS

In the project area, the Arroyo Grande Creek channel is managed through Zones 1 and 1A of the San Luis Obispo County Flood Control and Water Conservation District (Morro Group, 2008). We understand the Arroyo Grande Creek Waterways Management Program will involve flood control improvements along the northern and southern levees of the Arroyo Grande and Los Berros Creeks. The project is intended to provide increased flood control benefits and riparian enhancement through vegetation management and sediment control within Arroyo Grande Creek channel. The preliminary designs under consideration for the project are described as Alternatives 3a, 3b and 3c in a memorandum prepared by Swanson Hydrology + Geomorphology (SH+G, 2008).

We understand that the improvements shown on the conceptual plans prepared by Waterways Consulting (2009) for Alternative 3a are being designed to provide 2 feet of freeboard and flood protection for an estimated 10-year flood event, which corresponds to a peak flow of 5,400 cubic feet per second (cfs).

2.0 WORK PERFORMED

2.1 PURPOSE

The purpose of this report is to evaluate seepage and slope stability conditions along the existing north levee of Arroyo Grande Creek. The main geotechnical considerations that we have evaluated for this project are:

- Characterization of the subsurface conditions along the alignment of the levee, particularly the hydraulic conductivity and strength properties of levee fill material and underlying alluvium;
- An evaluation of the seepage vulnerability and stability of the existing levee relative to full flood steady-state and rapid drawdown conditions; and
- An evaluation of alternatives to mitigate seepage conditions for the 5,070-cfs storm event, and construction considerations relative to mitigation alternatives.

2.2 SCOPE

To evaluate the geotechnical considerations for the project, we have executed the following scope of work:

- Meeting and consulting with the County regarding our approach to providing geotechnical services for the project and to review the project objectives;
- Reviewing selected published geologic maps and reports, previous geotechnical studies performed along the levee and for bridges that span the creek channel, and as-built plans for the existing levee;
- Performing site visits to observe the general site conditions and coordinate the field exploration program;
- Field exploration consisting of drilling three (3) borings drilled to depths of approximately 31½ to 41½ below the ground surface at selected locations along the north levee to characterize subsurface conditions and obtain samples for testing;
- Laboratory testing of selected samples obtained from the site to assist in characterizing the material properties of the levee fill and alluvium encountered;
- Preparing this Limited Geotechnical Report that provides our opinions and recommendations regarding:
  - Geologic setting;
  - Soil and groundwater conditions encountered;
  - General condition, history, and material composition of the existing levees relative to seepage;
  - Potential for steady-state flow conditions to result in seepage through the levee, instability of the levee slopes, or critical state underseepage conditions (sand boils or piping on the downstream side of the levee) for the 5,070-cfs flood event;
  - The need for mitigation to address seepage conditions; and
  - Construction considerations relative to existing residences and land uses along the levees, and suitability for the site conditions encountered;

During the course of the project, the County also requested that we review the conceptual plans for project Alternative 3a, and discuss our results relative to the proposed north levee raise.

2.3 FIELD EXPLORATION

The drilling subcontractor for exploratory borings was S/G Drilling Company of Lompoc, California. Field exploration consisted of drilling and sampling three (3) hollow-stem-auger borings on January 12, 2012. The logs for the field data collected are presented in Appendix A.

Based on discussions with the County, the boring locations selected are considered critical areas due to high density residential areas and community facilities. The approximate locations of the borings and historical explorations are shown on Plate 2, Field Exploration Plan.

S/G Drilling operated a CME85, truck-mounted drill rig to advance three (3) hollow-stem auger borings using 8-inch diameter hollow stem augers. The hollow-stem auger borings were advanced to depths of approximately 31½ to 41½ feet below the existing ground surface. The borings were sampled at selected depths using an unlined 2-inch outside diameter standard penetration test (SPT) split spoon sampler, and a 3-inch outside diameter modified California split spoon sampler with brass liners. The split spoon samplers were driven into the material at the bottom of the drill hole using a 140-pound automatic trip hammer with a 30-inch drop. The blow count (N-value) is the number of blows from the hammer that were needed to drive the sampler 1 foot, after the sampler had been seated approximately 6 inches into the material at the bottom of the hole. Bulk samples were collected as drill cuttings retrieved from the auger flights.

2.4 LABORATORY TESTING

Laboratory tests for grain size distribution, permeability, direct shear strength, and triaxial compressive strength were performed on selected samples recovered from the field exploration program. The tests were performed in general accordance with the applicable standards of ASTM. The results of the tests are presented in Appendix B.

2.5 PREVIOUS STUDIES

Fugro (2009) conducted a preliminary geotechnical investigation of the north and south levees. The investigation evaluated the potential for the site to be impacted by geologic hazards, analyzed static and seismic stability of levee slopes, and discussed geotechnical considerations for proposed levee raise alternatives. Field exploration activities consisted of advancing six (6) electric cone penetration test (CPT) soundings, collecting hand samples from the creek, and excavating a hand auger boring adjacent to the levee. The logs of the CPT soundings and hand auger boring are presented in the Fugro (2009) report, and the approximate locations of the explorations are shown on Plate 2. In addition, subsurface profiles summarizing Fugro's interpretation of the soil conditions encountered along the alignment of Arroyo Grande Creek within the project limits are shown in Fugro (2009).

The U.S. Geological Survey (Holzer et al., 2004) previously performed a geotechnical study in the project vicinity. The study focused on liquefaction and liquefaction-induced lateral spreading that occurred in Oceano in response to the 2003 San Simeon Earthquake. As part of that study, the USGS performed three CPT soundings (SOC 036, 035 and 037) on the Arroyo Grande Creek Levee within the project limits. The soundings were performed in this area of the levee because the USGS observed evidence of levee instability and liquefaction adjacent to the levee. The data from those CPT soundings were used to assist in our characterization of the subsurface conditions for this report. The logs of those CPT soundings performed by the USGS are included with the Fugro (2009) report. The approximate locations of the CPT soundings performed by the USGS are shown on Plate 2.

We reviewed logs of test borings from Caltrans (1956, 1984) and San Luis Obispo County (1984) as part of geotechnical investigations for the State Route 1 Bridge and 22nd Street Bridge, respectively. This boring information was used to help characterize the subsurface conditions at the site. The approximate locations of the bridge borings are shown on Plate 2.

2.6 GENERAL CONDITIONS

Fugro prepared the conclusions and professional opinions presented in this report in accordance with generally accepted geotechnical engineering principals and practices at the time and location this report was prepared. This statement is in lieu of all warranties, expressed or implied.

This report has been prepared for San Luis Obispo County and their authorized agents only. It may not contain sufficient information for the purposes of other parties or other uses. If any changes are made in the project as described in this report, the conclusions and recommendations contained in this report should not be considered valid unless Fugro reviews the changes and modifies and approves, in writing, the conclusions and recommendations of this report. The report and drawings contained in this report are intended for design-input purposes; they are not intended to act as construction drawings or specifications.

Soil and rock deposits will vary in type, strength, and other geotechnical properties between points of observation and exploration. Additionally, groundwater and soil moisture conditions can also vary seasonally or for other reasons. Therefore, we do not and cannot have complete knowledge of the subsurface conditions underlying the site. The conclusions and recommendations presented in this report are based upon the findings at the points of exploration, and interpolation and extrapolation of information between and beyond the points of observation, and are subject to confirmation based on the conditions revealed during construction.

The scope of services did not include any environmental assessments for the presence or absence of hazardous/toxic materials in the soil, surface water, groundwater, or atmosphere. Any statements or absence of statements, in this report or data presented herein regarding odors, unusual or suspicious items, or conditions observed are strictly for descriptive purposes and are not intended to convey engineering judgment regarding potential hazardous/toxic assessment. Site conditions

3.0 SITE CONDITIONS

3.1 GEOLOGIC SETTING

The project is located in the Arroyo Grande and Cienega Valleys and within the Coast Ranges geologic and geomorphic province. That province consists of north-northwest-trending sedimentary, volcanic, and igneous rocks extending from the Transverse ranges to the south into northern California. Rocks of the Coast Ranges province are predominantly of Jurassic and Cretaceous age; however, some pre-Jurassic, along with Paleocene-age to recent rocks are present. The surficial geology in the project vicinity, as mapped by Hall et al. (1973), is shown on Plate 3, Regional Geologic Map.

The Arroyo Grande and Cienega Valleys and adjacent eolian (windblown) dune sand deposits are the dominant geomorphic features within the project vicinity. The valleys were formed during a period of low sea level (the Wisconsin glacial stage), as coastal streams adjusted to the drop in sea level by carving into the landscape. A subsequent rise in sea level produced a dynamic depositional environment reflected in the discontinuous and variable subsurface stratigraphy. Approximately 800 feet of interlayered and unconsolidated sediments have been deposited within the valleys, dip gently to the west, and are underlain by bedrock consisting of Pismo Sandstone or similar sedimentary rocks.

As shown on Plates 2 and 3, the predominant geologic units mapped in the study area are surficial sediments composed of dune sand deposits (Qs), older-stabilized dune sand deposits (Qos), and alluvium (Qal). Hall identified older dune sands as eolian deposits that have been stabilized and subsequently covered by vegetation. The alluvium is associated with sediment that has been deposited along Arroyo Grande Creek and Los Berros Creek, and on the floor of the Arroyo Grande and Cienega Valleys. Surficial sediments are primarily underlain by weakly consolidated units of the age-equivalent of Paso Robles Formation and Careaga Sandstone.

Also depicted on Plate 2, a portion of the site along the creek was previously occupied by dune sand and an extensive pre-settlement Estero, according to an 1873-1874 map produced by the U.S. Coast Survey (Holzer et al., 2004). According to the USGS (2004) report, this area was subsequently "subdivided and turned into developable lots by leveling dunes and filling in swamp areas with dune sand in March 1927." Presumably, the creek alignment was altered as a consequence of this development. The approximate limits of the Pre-Existing Estero reported by Holzer et al. (2004) are noted on Plate 2.

3.2 SUBSURFACE CONDITIONS

The subsurface conditions encountered generally consisted of artificial fill (Af) materials overlying alluvium deposits (Qal). Logs of the borings for this investigation are presented in Appendix A. The locations of the borings are shown on Plate 2. A discussion of the geologic units encountered is provided below. Cross sections showing our interpretation of subsurface conditions at Stations 23+30, 40+00, and 80+00 are shown on Plates 4a to 4c. Our interpretation of subsurface conditions is based on boring logs, and is generally supplemented by logs of previous explorations (Fugro, 2009; USGS, 2004; Caltrans, 1956, 1984; San Luis Obispo County, 1984). Refer to Fugro (2009) for additional subsurface data and a profile interpretation of the subsurface conditions along the levee alignment.

Artificial Fill (Af). Each of the borings, advanced through the top of the existing levee, encountered artificial fill materials. The thickness of the fill materials encountered ranged from approximately 5 to 8½ feet. The artificial fill consisted of medium dense silty sand (SM), medium dense silty sand with gravel (SM) and clayey sand (SC), and medium dense to dense poorly graded sand with silt and gravel (SP-SM). For the purposes of seepage and stability analyses, the artificial fill was modeled as a uniform levee fill material.

In-situ moisture contents of the levee fill samples ranged from 6 to 18 percent and unit dry weights ranged from 94 to 104 pounds per cubic foot (pcf). Based on the results of laboratory tests, selected samples of the levee fill had hydraulic conductivities that ranged from approximately 8.6×10^{-7} centimeters per second (cm/s) in clayey soils to 1.5×10^{-3} cm/s in sandy soils. The friction angle of the levee fill was estimated to range from 33 to 44 degrees based on the results of laboratory shear tests.

Alluvium Deposits (Qal). The alluvium encountered was composed of undifferentiated units of floodplain, fluvial, and estuarine sediments deposited along Arroyo Grande Creek. The alluvium was encountered below the artificial fill materials to the maximum depth explored, approximately 31½ to 41½ feet below the existing ground surface. The alluvium encountered during the Fugro (2009) field exploration program was characterized as two predominant units of sandy alluvium (Qal_1, Qal_2), and three predominant units of fine-grained alluvium that were encountered at various depths within and below the sandy alluvium (Qal_3, Qal_4 and Qal_5). With the exception of Qal_5, the alluvium units noted above were encountered in the borings drilled as part of this study, and are characterized below in a manner consistent with Fugro (2009).

For the purposes of seepage and stability analyses, the sandy alluvium units (Qal_1, Qal_2) were modeled as a uniform pervious foundation material. Additionally, the fine-grained alluvium units (Qal_3, Qal_4) were modeled as a uniform impervious foundation material.

Qal_1. This unit consisted of sandy material encountered below the levee fill in borings B-1 and B-2 from an elevation at or near the creek invert to depths of approximately 4 to 17½ feet below the creek invert. This upper sand unit consisted of medium dense poorly-graded sand (SP), very loose poorly-graded sand with gravel (SP), loose to dense poorly-graded sand with silt (SP-SM), and very loose silty sand (SM).

Qal_2. This unit consisted of sandy alluvium encountered immediately below the levee fill in boring B-2 at a depth of approximately 8½ feet below the ground surface, and just below the Qal_1 unit in boring B-3 at a depth of approximately 15 feet. This lower sand unit consisted of very loose to dense sand with silt (SP-SM), medium dense sand with silt and gravel (SP-SM), very loose to medium dense silty sand (SM), and dense clayey gravel with sand (GC). The unit was encountered to the maximum depth explored in borings B-2 and B-3, approximately 31½ to 41½ feet below the existing ground surface, respectively.

Moisture contents of pervious foundation (Qal_1, Qal_2) samples ranged from 9 to 36 percent and unit dry weights ranged from 82 to 105 pcf. Based on the results of laboratory tests, selected samples of the pervious foundation material had hydraulic conductivities that were approximately 2×10^{-4} and 4.4×10^{-3} cm/s. The friction angle of the pervious foundation material was estimated to range from 32 to 34 degrees, based on the results of laboratory shear tests.

Qal_3. This unit of fine-grained alluvium consisted of relatively shallow strata composed of soft to stiff lean clay (CL), sandy lean clay, and very stiff sandy silt (ML) that were encountered near or just below the levee fill in all three (3) borings. The thickness of this unit ranged from approximately 1½ to 2 feet.

Qal_4. This unit consisted of medium stiff to stiff fat clay (CH) and stiff fat clay with sand (CH) encountered in borings B-1 and B-2. The 2- to 4½-foot-thick strata are interbedded at various depths within the sandy Qal_1 and Qal_2 units. The Qal_4 unit was encountered to the maximum depth explored in boring B-1, approximately 31½ feet below the existing ground surface.

Based on laboratory tests, selected samples of the impervious foundation material (Qal_3, Qal_4) had hydraulic conductivities that were approximately $7.4x10^{-7}$ and $1.6x10^{-6}$ cm/s.

3.3 GROUNDWATER CONDITIONS

Groundwater was encountered in all three (3) borings drilled during our January 2012 field exploration program at depths of approximately 12 feet (B-1 and B-2) and approximately 13 feet (B-3) below the ground surface. Groundwater was typically encountered at approximately the same elevation as the water elevation in Arroyo Grande Creek. During our field exploration program, the water in Arroyo Grande Creek was observed to be approximately ½ to 2½ feet deep. Variations in groundwater levels and soil moisture conditions will occur depending on changes in precipitation, runoff, tidal fluctuations, irrigation schedules, and other factors.

4.0 CROSS SECTIONS FOR ANALYSES

As part of our limited geotechnical investigation, two (2) cross sections were analyzed for seepage and slope stability. The locations of the cross sections, shown on Plate 2, correspond to the locations of borings B-1 and B-2 at Stations 80+00 and 40+00, respectively.

Based on our field exploration, the subsurface conditions encountered in boring B-3 are generally similar to those encountered in borings B-1 and B-2. However, it is our opinion that the cross section at Station 23+00 is less susceptible to seepage than the cross sections we evaluated. Our opinion is based on boring logs, topography data provided by SH+G (2008) and San Luis Obispo County (2012), and water surface elevations estimated for the 5,070-cfs storm event (Waterways Consulting, 2012).

The ground surface profiles used in the stability analyses were estimated from SH+G (2008) and San Luis Obispo County (2012) topography data. For the purposes of our analyses, the subsurface conditions were generally modeled as levee fill overlying impervious foundation material and pervious foundation material. The ground surface profile across the levee was estimated to be a uniformly graded embankment with a trapezoidal cross section.

5.0 GEOTECHNICAL ANALYSIS

5.1 SEEPAGE EVALUATION

Seepage analyses were performed for the two (2) cross sections with the numerical modeling program GeoStudio (GEO-SLOPE, 2010). Analyses were performed for steady-state seepage conditions corresponding to the water surface elevations estimated by Waterways Consulting (2012) for the 5,070-cfs event within Arroyo Grande Creek. Steady-state seepage is defined as a stabilized water surface elevation in the creek channel, and stabilized seepage flow paths below and through the levee.

Foundation underseepage refers to hydraulic flow beneath the levee that results when a higher water level (high gradient) in the creek infiltrates the creek bed, and then flows beneath the levee to the lower water level outside the levee (low gradient).

As input to the seepage analyses, hydraulic conductivity values were selected based on a comparison of laboratory hydraulic conductivity test results, values estimated by the empirical grain size correlations presented in Chapuis (2004), and limited sensitivity analyses. Plates C-1 and C-2 show the estimated hydraulic conductivity values for the levee fill and foundation material, respectively. Both horizontal (k_h) and vertical hydraulic conductivity (k_v) values are required for modeling in GeoStudio. Permeability values are assigned by inputting the saturated permeability in the horizontal direction and inputting the vertical to horizontal permeability ratio (k_v/k_h). Estimated k_v/k_h ratios and additional material properties are presented with the results of our seepage and stability analyses in Appendix D. It should be noted that the saturated hydraulic conductivity (k-saturation) values shown in Appendix D are presented in units of feet per second.

In addition, curves representing the variation of permeability (unsaturated permeability) versus matric suction were estimated for our seepage analyses. Without direct measurements, generalized curves based on soil type correlations were selected in GeoStudio to estimate the unsaturated permeability of each material.

For the full flood steady-state seepage analyses, the landside extent of our models was defined by a distance of 2,000 feet from the creek centerline. To simulate the general hydrogeologic conditions we anticipate during a steady-state flood event, the phreatic surface was modeled at the landside ground surface.

To evaluate the potential for through-seepage to impact the north levee at Stations 40+00 and 80+00, we approximated the time for the phreatic surfaces estimated in our steady-state seepage analyses to develop and emerge on the levee exterior slopes. Based on our assumption that the levee embankment is uniform in composition, our estimate compared the horizontal hydraulic conductivity (seepage velocity) of the levee fill and the length of an approximate through-seepage path within the embankment.

Seepage daylighting on an unconfined exterior soil slope could potentially decrease the stability of the slope as a result of sloughing or internal, localized erosion of the embankment material. Sustained through-seepage and erosion can lead to piping, which typically consists of a tunnel-like void that forms within the embankment when uncontrolled seepage daylights on the face of the levee exterior slope.

5.1.1 Seepage Criteria

The factor of safety for underseepage is defined as the critical gradient (i_{cr}) divided by the exit gradient (i_e). The critical gradient is defined as the effective unit weight (the difference between the saturated unit weight of soil at the landside toe and the unit weight of water) divided by the unit weight of water. The exit gradient is a measure of upward seepage force defined as the difference in hydraulic head at the top and bottom of a landside soil stratum, divided by the thickness of the soil stratum. Critical seepage conditions exist when the exit gradient equals the critical gradient. Piping of the subsurface can erode foundation materials and potentially destabilize the embankment if the exit gradient exceeds the critical gradient.

Typical performance criteria specify that underseepage beneath an existing levee is acceptable if the exit gradient is 0.5 or less, which would provide a factor of safety against underseepage-related failures of at least about 1.5 for a soil with a minimum submerged unit weight of 110 pcf. However, it should be noted that new levees are typically designed to provide a minimum factor of safety of about 5 or 6 to further reduce the potential for underseepage failure, as the consequences of piping and daylighting seepage adversely and severely impact the stability of a levee slope or foundation.

5.1.2 Results

The results of our seepage analyses for the two (2) cross sections are tabulated below, and presented graphically in Appendix D.

Table 5-1. Results of Steady-State Seepage Analyses

Section	5,070-cfs Event Water Surface Elevation (feet)	Exit Gradient at Landside Toe	Factor of Safety	Estimated Time for Phreatic Surface to Emerge on Exterior Slope (hours)
40+00	**24.1**	**0.37**	**2.6**	**±97**
80+00	**34.5**	**0.38**	**2.5**	**±100**

5.2 SLOPE STABILITY

Slope stability analyses were performed for the two (2) cross sections using the numerical modeling program GeoStudio (GEO-SLOPE, 2010). As input to the stability analyses, parameters including soil unit weight, and drained and undrained shear strength parameters (friction angle [phi] and cohesion) were estimated based on laboratory test results, and a review of the subsurface data and stability analyses included in Fugro (2009).

We performed stability analyses of the exterior slope for full flood conditions, with water surface elevations corresponding to the 5,070-cfs flood event. Additionally, we performed stability analyses of the interior slope for rapid drawdown conditions, which we anticipate would arise as flood water recedes following the 5,070-cfs flood event. The conditions evaluated and the results of our slope stability analyses are presented in Appendix D.

For our stability analyses of full flood and rapid drawdown conditions, drained shear strength parameters were assigned to the subsurface materials. As noted above, consolidated drained direct shear and consolidated, undrained triaxial strength testing was performed on relatively undisturbed samples collected during our field exploration program. The results of our direct shear and triaxial testing are presented in Appendix B. Phreatic surfaces and pore pressures modeled in our stability analyses of full flood and rapid drawdown conditions were based on the results of our steady-state seepage analyses.

5.2.1 Slope Stability Criteria

For the purpose of evaluating analysis results, the San Luis Obispo County (2005) Guidelines for Engineering Geology Reports considers slopes stable when the estimated factor of safety from slope stability analyses is at least 1.5 under static loading conditions. These values are consistent with local practice and California Geologic Survey (CGS 2008) guidelines for slope stability evaluations.

It should be noted that these publications do not specifically address slope stability analyses of full flood and rapid drawdown conditions. We therefore considered a minimum factor of safety equal to 1.4, as specified by the U.S. Army Corps of Engineers [USACE] (2000) for levee slope stability under long-term, steady seepage conditions. For rapid drawdown stability analyses, a minimum factor of safety equal to 1.0 is specified by the USACE (2000) for conditions where elevated water levels are unlikely to persist for long periods preceding drawdown.

In any case, a factor of safety of 1.0 represents the theoretical boundary below which a slope is no longer stable and experiences failure. Minimum factors of safety greater than 1.0, such as those stated above, are typically used to define stable slope conditions in practice to help account for uncertainties in characterizing subsurface conditions and limitations of analyses used to evaluate slope stability.

5.2.2 Results

The results of our slope stability analyses for the two (2) cross sections are tabulated below, and presented graphically in Appendix D.

Table 5-2. Results of Slope Stability Analyses

Section	Levee Slope	Steady-State Seepage During Full Flood Event (5,070 cfs)	Rapid Drawdown
40+00	Interior	-----	1.3
	Exterior	2.0	-----
80+00	Interior	-----	1.3
	Exterior	1.4	-----

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY OF FINDINGS

- Soils encountered within the north levee consisted of the existing levee fill material founded on alluvial sediment that has been deposited along Arroyo Grande Creek. The alluvium was encountered to the maximum depths explored, approximately 41½ feet below the ground surface, and consists of interbedded very loose to very dense sandy soils and soft to very stiff fine-grained materials (see Plates 4a to 4c). Water was flowing in the creek at the time of our January 2012 field exploration program. Groundwater was encountered as shallow as approximately 12 feet below the existing top of levee and about 4½ feet below the exterior toe of the levee in borings drilled for this investigation, suggesting that the foundation soils beneath levee are always saturated.

- The levee was designed and constructed by the Soil Conservation Service (USDA 1956), and based on blow count data and existing CPT data recorded in our explorations (present study, Fugro 2009), the levee fill consisted of predominantly medium dense to dense granular soil that appears to have been constructed as an "engineered" compacted fill material. Varying degrees of rodent burrows, vegetation, and loose surface soil were commonly observed along the interior and exterior of the existing levee slopes. We understand the County actively manages vegetation and rodent activity on the levee, which is a common practice to maintain hydraulic earth structures.

- Our evaluation of the existing north levee suggests that there is a low potential for seepage to exit on the levee slopes or result in underseepage failure (piping or sand boils) relative to the flow capacity and flood protection of the existing Arroyo Grande Creek channel. As the water level in the creek rises, there is a greater head of water pushing seepage through the soil and a greater potential for seepage to exit on the slope or destabilize the levee. Relative to the 5,070-cfs storm event, water surfaces corresponding to that amount of flow would either recede before there was time for the seepage to exit on the levee slopes, or the south levee would overtop before water surfaces became high enough for critical seepage conditions to develop. The conclusions appear consistent with our field observations, which did not include any evidence of historical underseepage impacts (e.g. piping or sand boils). Additionally, the conclusions appear consistent with the County's observation that the levee has performed adequately during storm events with elevated creek water levels near those water levels considered by our analyses.

Based on limited sensitivity analyses, the susceptibility of the north levee to underseepage during a flood event is potentially influenced by the depth of the impervious foundation unit characterized as Qal_3 in this report and assumed to be present within the extent of the entire north levee. This unit of fine-grained alluvium was encountered near or just below the levee fill in all three (3) borings and helps to reduce the seepage pressures that can pass beneath the levee. In general, estimated exit gradients may rise or exceed the typical performance criteria if the Qal_3 unit is present above the elevation of the levee exterior toe, or if the Qal_3 unit is not present (between our explorations) below the levee fill. Further exploration, design-level studies, and construction monitoring activities should consider the presence of this unit, and whether or not there are localized areas where the seepage conditions may be more critical than those analyzed. If the Qal_3 unit is not present in certain areas, additional seepage analysis or mitigation should be performed to evaluate those areas.

- As discussed in the Fugro (2009) report, alluvium encountered beneath the levee is vulnerable to being impacted by seismic hazards that could result in settlement and instability of the levee slopes. The levees were damaged by liquefaction of the alluvium in the vicinity of Stations 30+00 to 35+00 during the 2003 San Simeon Earthquake. Consideration of these seismic hazards was not a part of the seepage evaluation, and we understand from the County that the current design considerations of the Alternative 3a improvements are to improve the levee relative to flood control only.

6.2 EXISTING LEVEE

For our seepage and stability analyses of existing conditions, we considered the estimated flood event with a 5,070 cfs peak flow, which corresponds to a recurrence interval between 5 and 10 years (Waterways Consulting, 2009). We understand historical flood events with peak flows approximately equal to 5,070 cfs have occurred since the construction of the Arroyo Grande Creek levee system, and that there have been no reports of seepage daylighting on the exterior levee slopes or sand boils having developed beyond the exterior toe of the levee.

The groundwater conditions encountered suggest that the foundation soils beneath the levee embankments are saturated to some extent by the normal dry-season water flow within the creek. As a result, it is possible that rising water levels within the channel may increase the rate of seepage beneath the embankment relatively quickly. Two general cases were evaluated: whether or not seepage through the existing levee embankment could occur on the north side of Arroyo Grande Creek, and whether or not underseepage would reduce the north levee's stability due to piping, seepage, or sand boils developing near or beyond the exterior toe of the levee.

Underseepage analyses of Stations 40+00 and 80+00 estimated exit gradients of 0.37 and 0.38, respectively, which correspond to factors of safety equal to about 2.6 and 2.5. These values are consistent with our field observations, which did not include any evidence of historical underseepage impacts (e.g. piping or sand boils). These factors of safety exceed typical performance criteria for existing levees, and susceptibility to underseepage during the 5,070-cfs event is generally not considered a potential deficiency of the existing north levee. However, if the County prefers to further reduce the potential for underseepage failure, seepage mitigation concepts are discussed below.

Based on limited sensitivity analyses, the susceptibility of the north levee to underseepage during a flood event is potentially influenced by the depth of the impervious foundation unit characterized as Qal_3 in this report and assumed to be present within the extent of the entire north levee. This unit of fine-grained alluvium was encountered near or just below the levee fill in all three (3) borings and helps to reduce the seepage pressures that can pass beneath the levee. In general, estimated exit gradients may rise or exceed the typical performance criteria if the Qal_3 unit is present above the elevation of the levee exterior toe or if the Qal_3 unit is not present (between our explorations) below the levee fill. Further exploration, design-level studies, and construction monitoring activities should consider the presence of this unit, and whether or not there are localized areas where the seepage conditions may be more critical than those analyzed. If the Qal_3 unit is not present in certain areas, additional seepage analysis or mitigation should be performed to evaluate those areas.

Through-seepage analyses estimated the time for steady-state seepage conditions to potentially develop and phreatic surfaces to emerge on the exterior slopes at Stations 40+00 and 80+00 to be approximately 97 and 100 hours, respectively. We understand the anticipated duration of the 5,070-cfs event is much less than the times noted above. Therefore, susceptibility to through-seepage during that event is not considered a potential deficiency of the existing north levee. These findings are consistent with our field observations, which did not include any evidence of erosion of the existing embankment material. However, we expect the potential for through-seepage would increase for longer duration storm events.

The slope of the north levee appears to be stable relative to the anticipated flow conditions. The exterior levee slope at Stations 40+00 and 80+00 had estimated factors of safety of 2.0 and 1.4, respectively, for full flood conditions. In addition, the interior slopes at Stations 40+00 and 80+00 had estimated factors of safety equal to about 1.3 for both slopes, assuming rapid drawdown conditions. These factors of safety meet or exceed typical performance criteria for existing levees; therefore, slope instability during the 5,070-cfs event, and instability as water recedes immediately following that event (rapid drawdown), is not considered a potential deficiency of the existing north levee. As part of their inspection efforts, the County should consider checking the levee slopes following major storm events to evaluate if there has been scour or erosion of the slopes that could impact embankment stability.

6.3 CONSIDERATIONS FOR PROPOSED ALTERNATIVE 3A

We understand the improvements shown on the conceptual plans prepared by Waterways Consulting (2009) for Alternative 3a are designed to provide 2 feet of freeboard and flood protection for the 10-year flood event, which corresponds to a peak flow of 5,400 cubic feet per second (cfs). According to the plans, the levee raise will be up to about 2½ feet for the north levee and up to about 3 feet for the south levee. Based on our preliminary, qualitative evaluation of the design, we anticipate the seepage conditions of the proposed north levee would be generally similar to, or slightly less favorable than those of the existing levee. At a minimum, for design of the proposed north and south levee improvements, we recommend seepage and slope stability evaluations, which should consider the water surface elevations and the duration of the 10-year flood event. It should be noted, however, that the standard of practice for design of new levees or levee improvements typically involves seepage mitigation measures, which are discussed below.

6.4 SEEPAGE MITIGATION CONCEPTS

Based on our evaluation, the existing Arroyo Grande Creek North Levee is not susceptible to seepage-related failure, and in our opinion, mitigation measures for the existing levee are not necessary. Therefore, a detailed evaluation of mitigation concepts, including estimated material quantities and construction cost is not included in this report. However, if the County prefers to further reduce the potential for seepage-related failure of the existing levee, or plans to include seepage mitigation concepts in the design of levee improvements, a discussion of potential mitigation concepts is provided below. General considerations for each concept relative to construction and land use are included.

Typical mitigation measures to control foundation underseepage below the levee include cutoff trenches or sheet pile cutoff walls, landside seepage berms, pervious toe trenches, and pressure relief wells. Typical mitigation measures to control seepage through the levee embankment include cutoff trenches or sheet pile cutoff walls, landside seepage berms, and toe drains.

The concepts presented are not intended to be all-inclusive; it may be that a combination, modification or alternative concept is more appropriate for design, based on additional considerations and input from the design team. Generalized illustrations and further discussion of the mitigation alternatives discussed herein are presented in USACE (2000).

6.4.1 Cutoffs

Cutoffs reduce the potential for underseepage failure by blocking seepage paths through the pervious foundation material. Cutoffs may consist of excavated trenches, backfilled with low-permeability soil or slurry, located within the levee footprint or along the levee toe. Alternatively, a steel sheet pile cutoff wall may be driven through the pervious foundation. Although sheet piling is not entirely watertight, it will likely reduce the possibility of piping of sand strata in the foundation. Cutoff walls located within the levee footprint may also serve as mitigation for through-seepage, as potential through-seepage paths could be blocked by the cutoff.

To maximize effectiveness, cutoffs are typically designed to penetrate approximately 95-percent or more of the thickness of the pervious foundation material. Based on our review of boring logs for this investigation and historical subsurface data, the thickness of the pervious foundation unit may be up to about 30 feet thick in some sections of the levee alignment. As a result, cutoff trench excavations for low-permeability earth backfill would likely extend below the water table and require a dewatering system. However, slurry cutoff trenches and sheet pile cutoff walls could be constructed without dewatering.

6.4.2 Landside Seepage Berms

Landside berms are constructed on the landward side of embankments to reduce the potential for underseepage failure by lengthening seepage paths to reduce hydraulic head, and providing additional weight to counteract upward seepage forces. Berms may also mitigate through-seepage by lengthening seepage paths and providing protection against sloughing of the levee exterior slope. In addition, berms may serve as a source of borrow material for emergency repairs to the levee.

Berms may be composed of impervious or semi-pervious material, sand, or free-draining gravel. However, the configuration (thickness and width) of berms should be designed for site-specific conditions, and may require an impractical amount of space.

6.4.3 Pervious Toe Trenches

Pervious toe trenches are constructed along the levee exterior toe to improve seepage conditions by allowing controlled drainage of excess seepage forces at the levee toe. Trenches are typically excavated with dimensions suited to site-specific seepage conditions and space limitations. Excavations extending below the water table may require a dewatering system. Trench backfill should consist of graded-granular material that will help to retain foundation material where the seepage exits. Trenches are typically provided with a perforated pipe to collect and convey seepage to a suitable collection point.

It should be noted that the effectiveness of a pervious toe trench may be limited by the thickness of pervious foundation material, as seepage paths may bypass the trench and generate excess seepage forces beyond the limits of the trench. Therefore, the primary purpose of a pervious toe trench would be to control shallow underseepage and protect the area in the vicinity of the levee toe.

6.4.4 Pressure Relief Wells

Pressure relief wells are installed along the landside toe of levees to reduce uplift pressure by intercepting and providing controlled outlets for seepage. Well systems are usually effective where pervious foundation material is too thick to be penetrated by cutoffs or toe drains, or where space for landside berms is limited. Wells must offer little resistance to the discharge of water and prevent the loss of any soil, although the discharge capacity of wells can be temporarily increased by pumping if necessary.

Well spacing, size, and penetration depth should be evaluated relative to site-specific conditions; individual wells should be designed by an experienced professional and suited to subsurface materials encountered at the site. Pressure relief wells require periodic maintenance, and frequently lose efficiency with time due to clogging of well screens, bacteria growth, or carbonate incrustation.

6.4.5 Pervious Toe Drain

Pervious drainage material placed along the exterior levee toe would provide a controlled exit for seepage passing through the embankment and lower the phreatic surface to reduce the potential for seepage to emerge on the exterior levee slope. Drainage material should consist of graded-granular material that will help to retain levee fill material where the seepage exits. A pervious toe drain could likely be combined with the pervious toe trench discussed above.

6.5 GEOTECHNICAL CONSIDERATIONS FOR DESIGN

This limited evaluation identified geotechnical considerations relating to seepage conditions of the existing north levee that should be considered in the design of the project. The design-level geotechnical study will likely involve additional exploration, and slope stability and seepage analyses to provide specific recommendations relative to the design grade raises and levee configurations, and to confirm the preliminary slope inclinations provided in Fugro (2009). The report would also provide material requirements for compacted fill and drainage as needed for the improvements, based on the results of additional analyses.

7.0 REFERENCES

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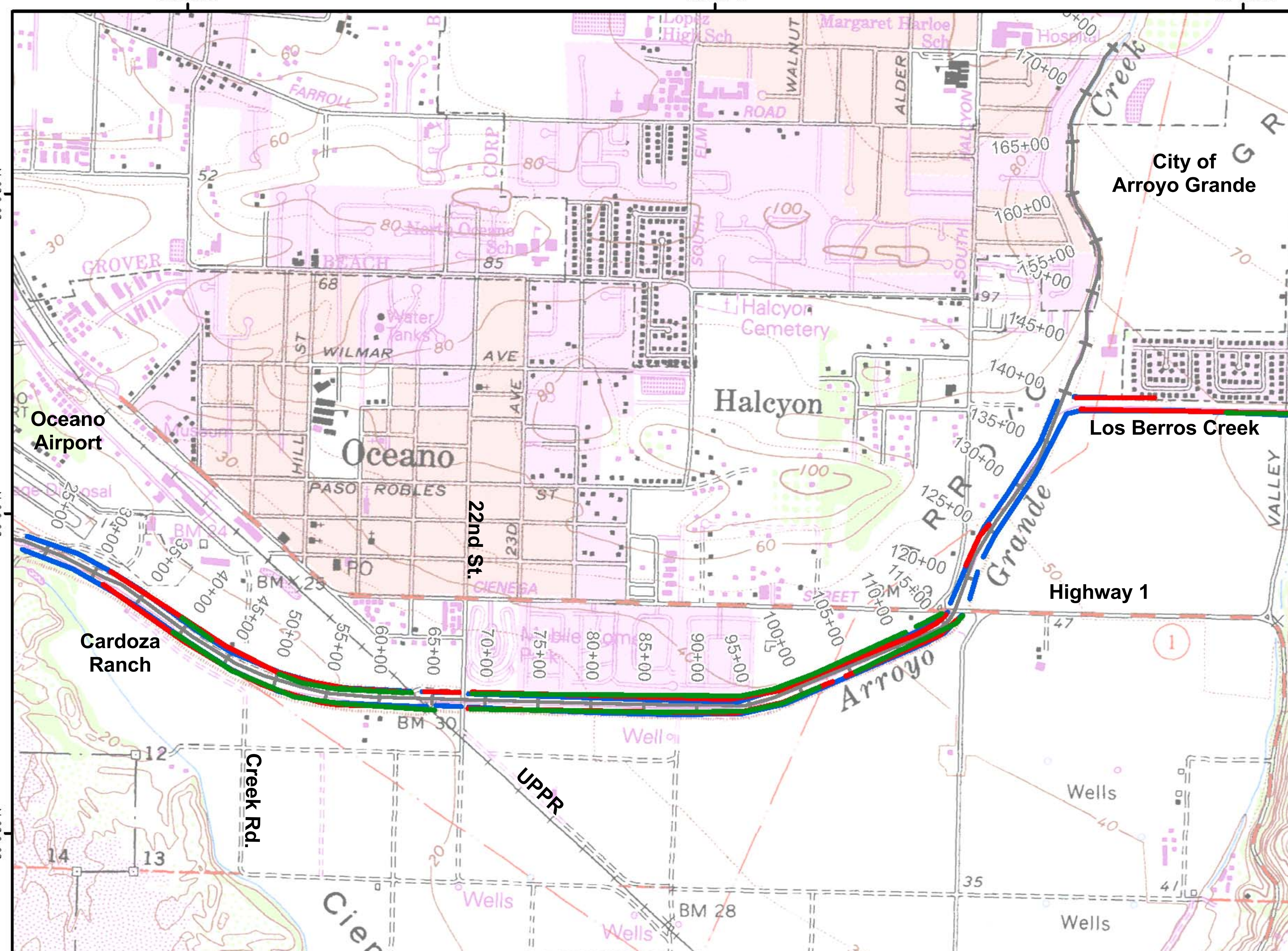
PLATES



Legend

- Alt-3a Proposed levees
- Alt-3b Proposed levees
- Alt-3c Proposed levees
- Centerline Along Levee with Stationing

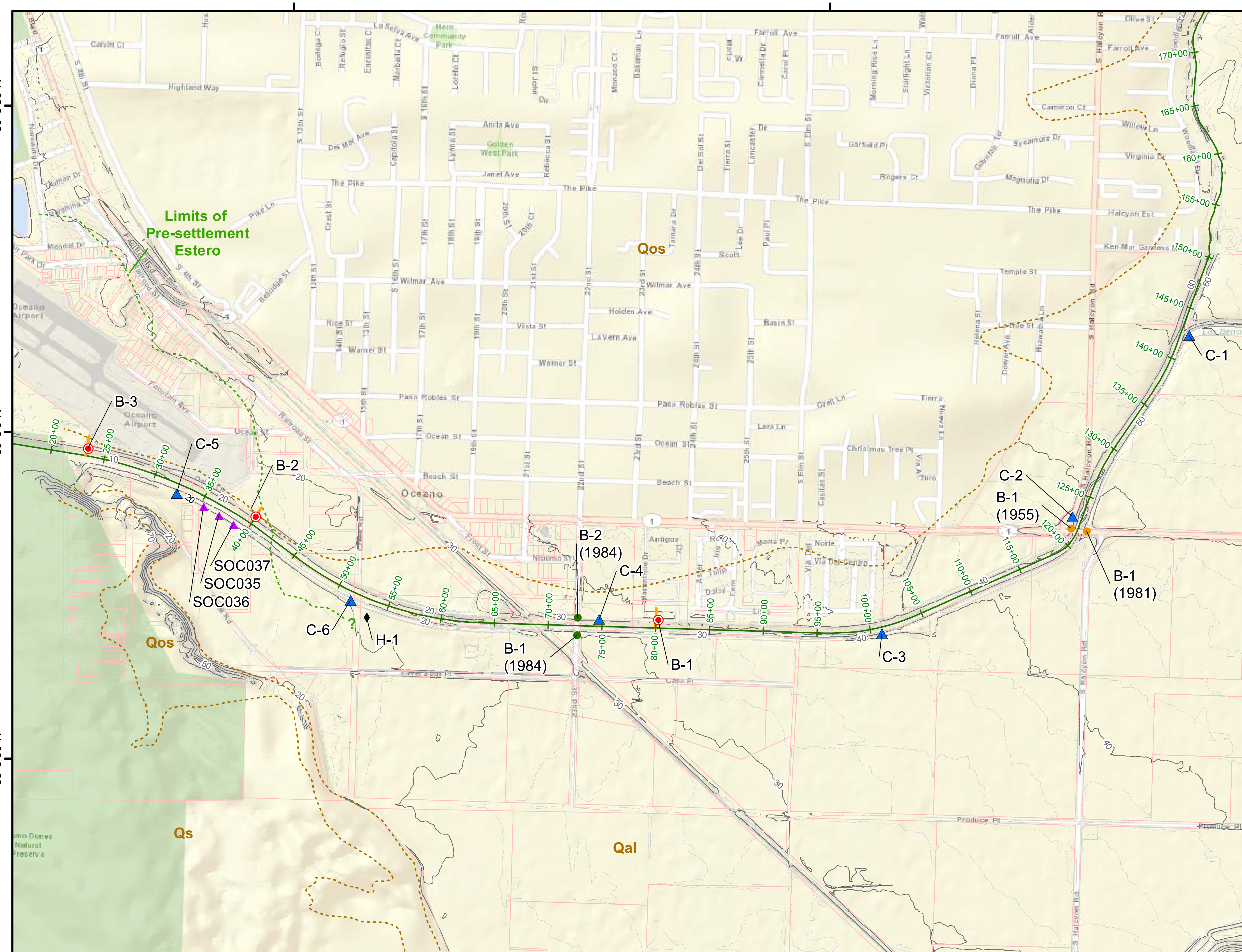
Horizontal Scale: 1:12,000

0 500 1,000 2,000 Feet

SITE MAP

Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

N:\Projects\3014_SLOcounty\3014-029_Arroyo_Grande_Creek\Outputs\Working\mxd\Plate1-SiteMap.mxd, 09/23/08, vengis



Legend

Approximate Exploration Locations

- 2012 Fugro Boring
- 2008 Fugro CPT
- 2003 USGS SCPT
- Caltrans Boring (Year of Study)
- SLO County Boring (Year of Study)
- 2008 Fugro Hand Auger Boring
- 4000 Cross Section Line
- Centerline Along Levee with Stationing
- 10 foot contour
- 2 foot contour
- Parcels within Zones 1 and 1a

Geology

- Qal Alluvial Deposits
- Qs Sand Dune Deposits
- Qos Older Sand Dune Deposits
- Contact
- Limits of Pre-settlement Estero

N

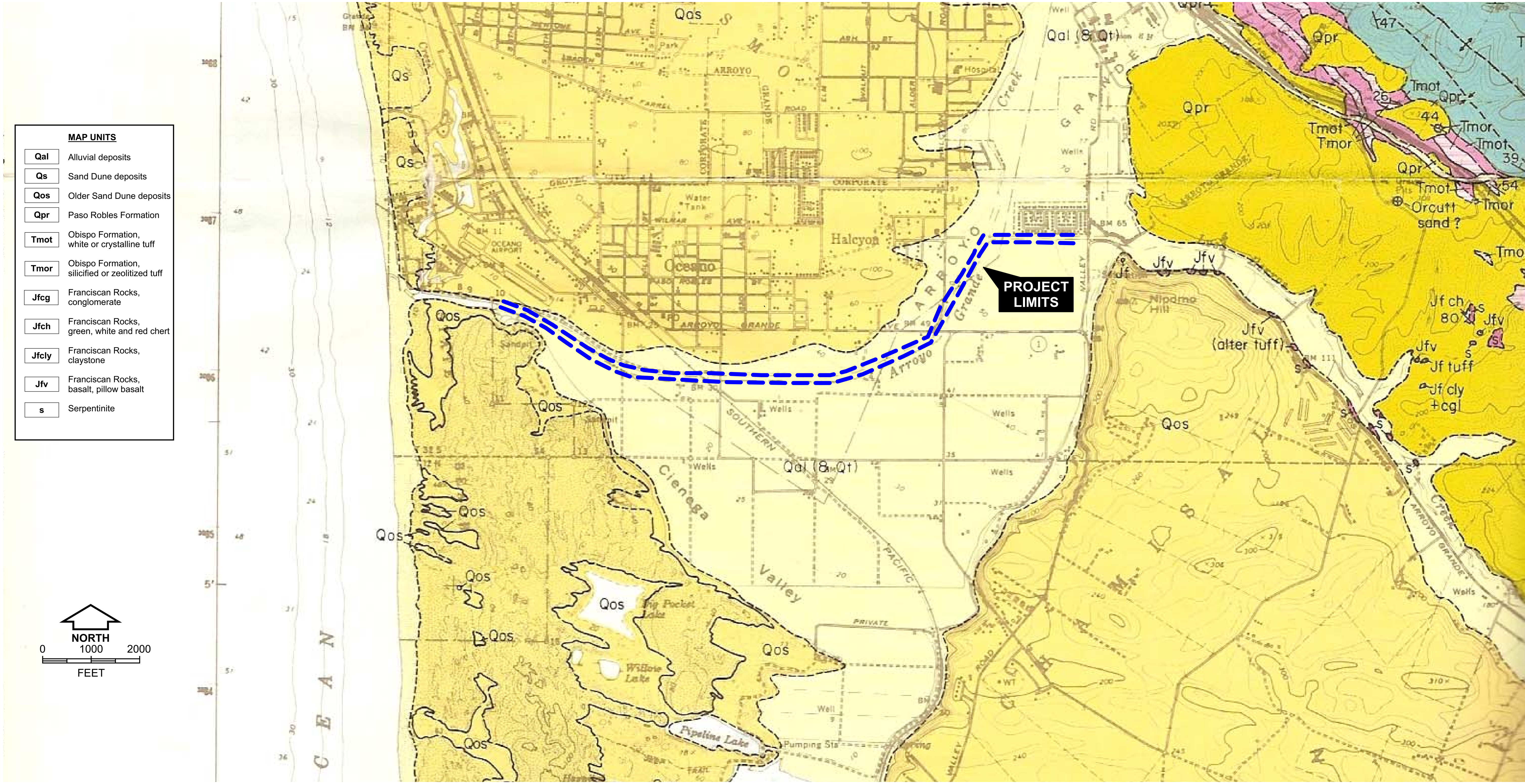
Horizontal Scale: 1:12,000

1,000 500 0 1,000 Feet

FIELD EXPLORATION PLAN

Arroyo Grande Creek Levee
Seepage Evaluation
San Luis Obispo County, California

County of San Luis Obispo
Project No. 04.6212.0004



BASE MAP SOURCE: Geology of the Arroyo Grande 15' Quadrangle, San Luis Obispo County (Hall, 1973).

LEGEND

Contact - Dashed where approximately located or inferred; queried where doubtful; dotted where concealed

High-angle fault - Dashed where approximately located or inferred; dotted where concealed and inferred; queried where uncertain. Arrows show relative direction of movement on cross sections when known; queried where uncertain.

Thrust or reverse fault - Dashed where approximately located or inferred, dotted where concealed and inferred; queried where concealed or doubtful. Sawteeth on upper plate. Dip of fault plane between 30° and 80°

Photo lineament - Queried where uncertain

Synform - Trace of axis at surface. Dashed where approximately located. Flanks coverate downward in folds and in rocks whose stratigraphic sequence is unknown.

Antiform - Trace of axis at surface. Dashed where approximately located. Flanks diverge downward in folds and in rocks whose stratigraphic sequence is unknown.

Strike and dip of beds uncertain

Marker beds

Conglomerate or gravel bed

Sandstone

Siltstone or diatomaceous siltstone

Tuff

Breccia

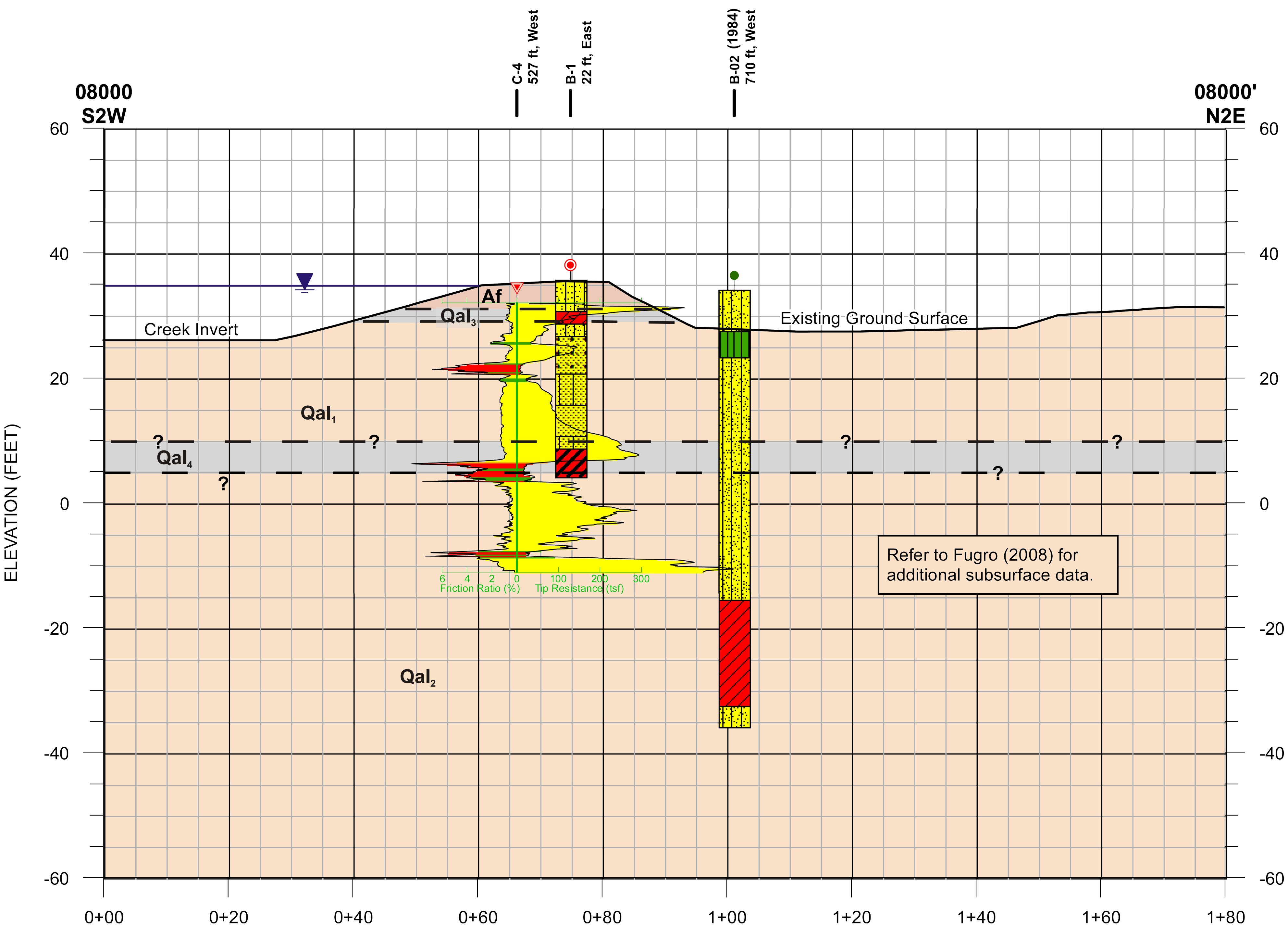
30 Strike and dip of flow banding

x 6193 Megafossil locality - U.C.L.A. locality number

Vollmer Ranch name/property owner

REGIONAL GEOLOGIC MAP
Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

PLATE 3



20 ft

20 ft

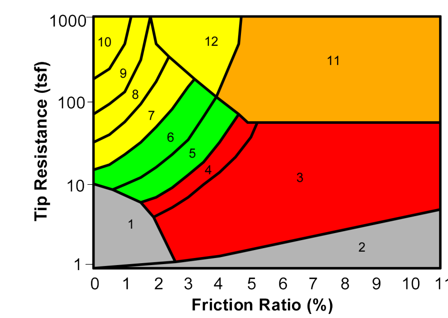
Vertical Exaggeration = 1.0X

LEGEND

Af	**Artificial Fill**
Qal	**Sandy Alluvium**
Qal	**Fine-grained Alluvium**

CPT Legend

CPT CORRELATION CHART
(Robertson and Campanella, 1988)



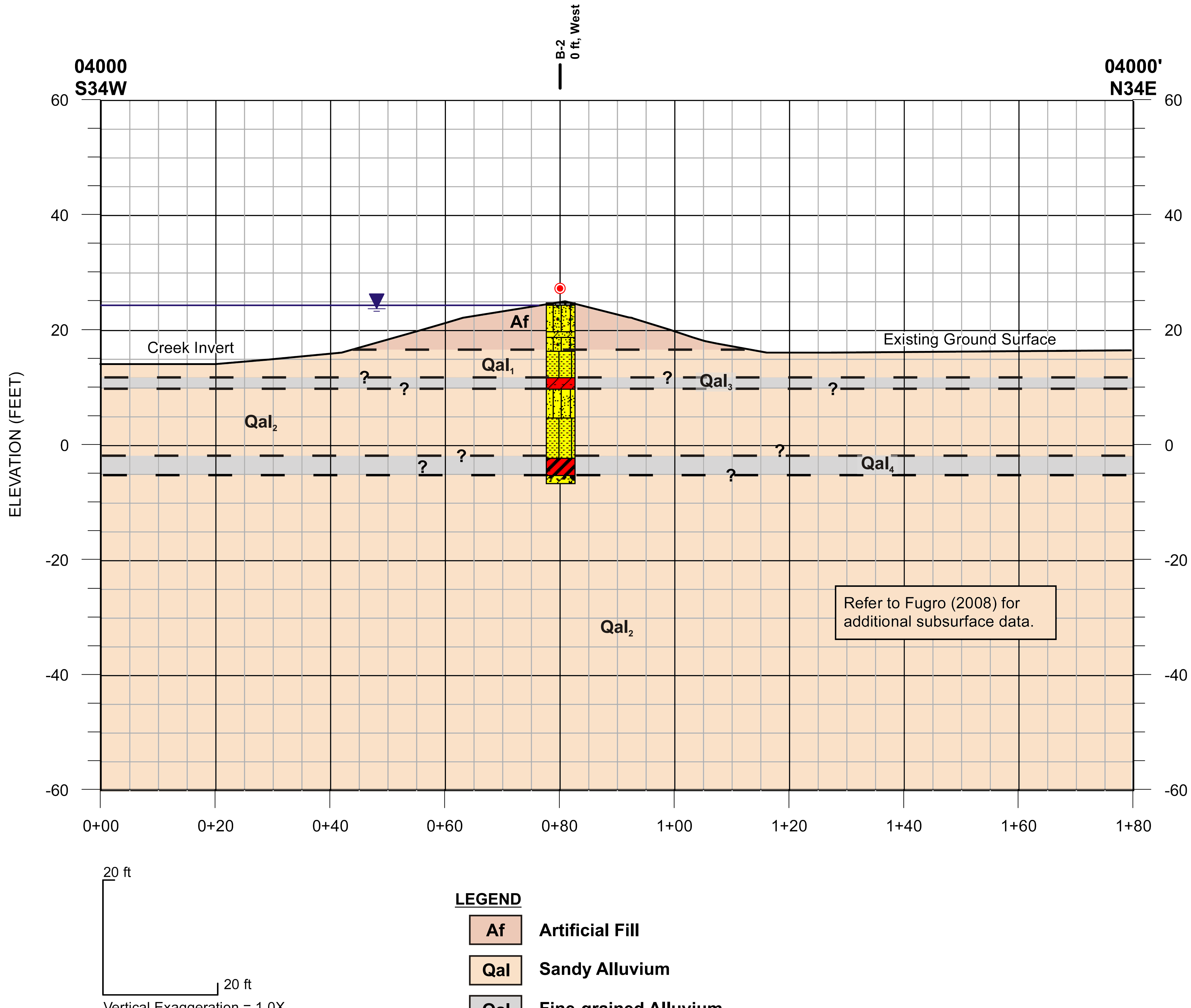
Zone	Soil Behavior Type	U.S.C.S.
1	Sensitive Fine-grained	OL-CH
2	Organic Material	OL-OH
3	Clay	CH
4	Silty Clay to Clay	CL-CH
5	Clayey Silt to Silty Clay	MH-CL
6	Sandy Silt to Clayey Silt	ML-MH
7	Silty Sand to Sandy Silt	SM-ML
8	Sand to Silty Sand	SM-SP
9	Sand	SW-SP
10	Gravelly Sand to Sand	SW-GW
11	Very Stiff Fine-grained *	CH-CL
12	Sand to Clayey Sand *	SC-SM

*overconsolidated or cemented

Boring Legend

- Lean CLAY (CL)
- Sandy Lean Clay (CL)
- Fat CLAY (CH)
- Fat CLAY with SAND (CH)
- Silt (ML)
- Sandy SILT (ML)
- Poorly-Graded SAND (SP)
- Poorly-Graded SAND with Silt (SP-SM)
- Gravelly Poorly-Graded SAND (SP)
- Clayey SAND (SC)
- Silty SAND (SM)
- Gravelly Silty SAND (SM)
- Sandy, Clayey GRAVEL (GC)
- Base Material

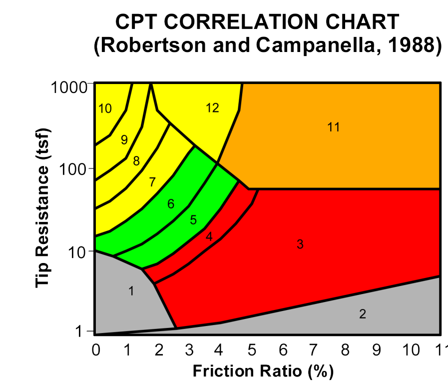
CROSS SECTION 80+00
Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California



LEGEND

- **Af** — **Artificial Fill**
- **Qal** — **Sandy Alluvium**
- **Qal** — **Fine-grained Alluvium**

CPT Legend



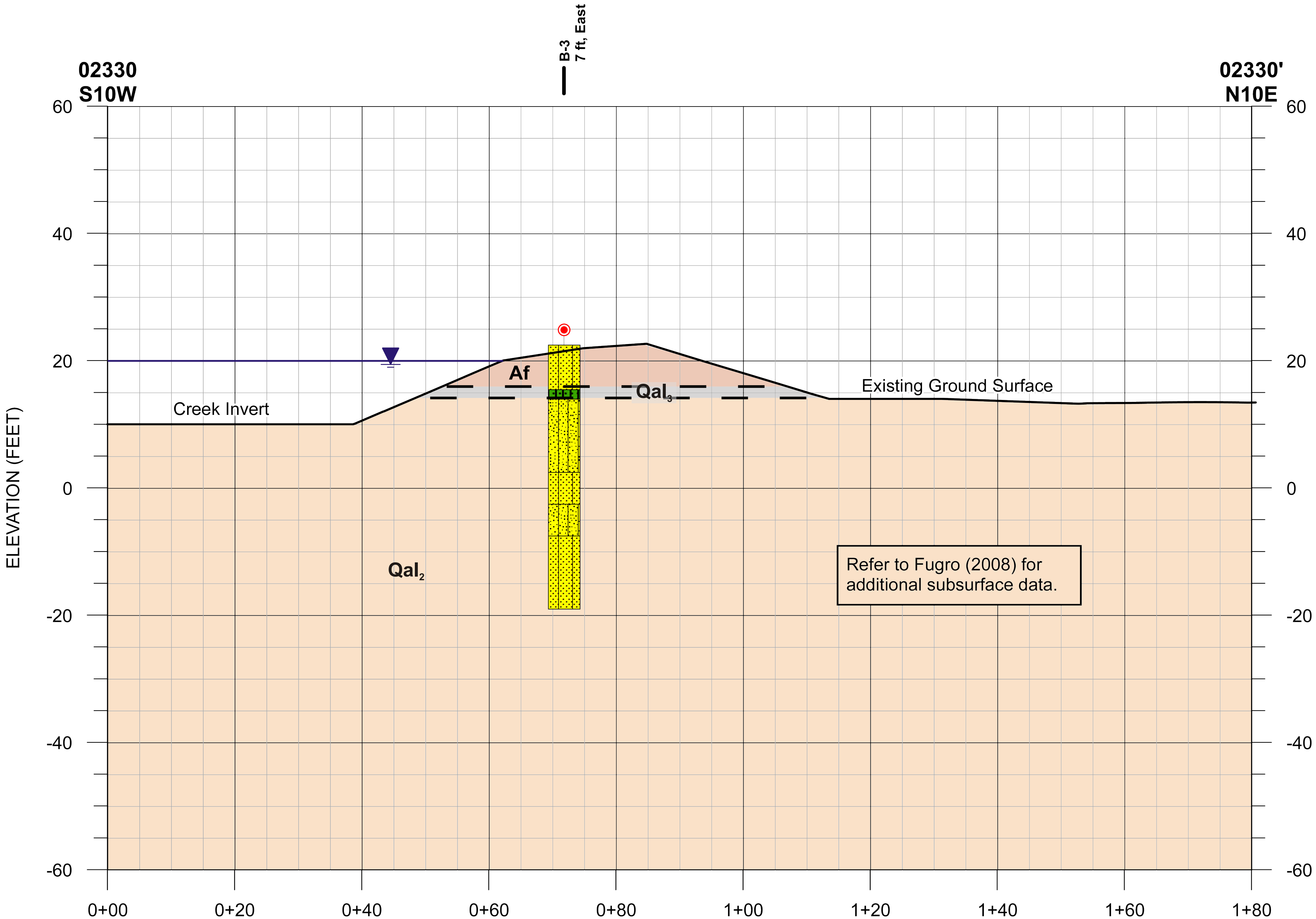
Zone	Soil Behavior Type	U.S.C.S.
1	Sensitive Fine-grained	OL-CH
2	Organic Material	OL-OH
3	Clay	CH
4	Silty Clay to Clay	CL-CH
5	Clayey Silt to Silty Clay	MH-CL
6	Sandy Silt to Clayey Silt	ML-MH
7	Silty Sand to Sandy Silt	SM-ML
8	Sand to Silty Sand	SM-SP
9	Sand	SW-SP
10	Gravelly Sand to Sand	SW-GW
11	Very Stiff Fine-grained *	CH-CL
12	Sand to Clayey Sand *	SC-SM

*overconsolidated or cemented

Boring Legend

- Lean CLAY (CL)
- Sandy Lean Clay (CL)
- Fat CLAY (CH)
- Fat CLAY with SAND (CH)
- Silt (ML)
- Sandy SILT (ML)
- Poorly-Graded SAND (SP)
- Poorly-Graded SAND with Silt (SP-SM)
- Gravelly Poorly-Graded SAND (SP)
- Clayey SAND (SC)
- Silty SAND (SM)
- Gravelly Silty SAND (SM)
- Sandy, Clayey GRAVEL (GC)
- Base Material

CROSS SECTION 40+00
Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California



20 ft

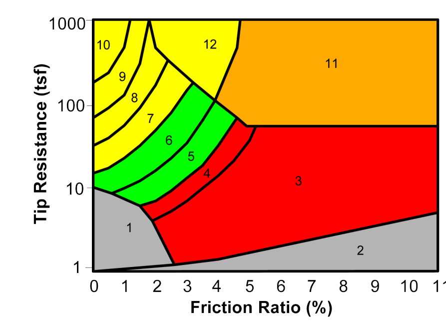
20 ft

Vertical Exaggeration = 1.0X

LEGEND

Af	Artificial Fill
Qal	Sandy Alluvium
Qal	Fine-grained Alluvium

CPT Legend



Zone	Soil Behavior Type	U.S.C.S.
1	Sensitive Fine-grained	OL-CH
2	Organic Material	OL-OH
3	Clay	CH
4	Silty Clay to Clay	CL-CH
5	Clayey Silt to Silty Clay	MH-CL
6	Sandy Silt to Clayey Silt	ML-MH
7	Silty Sand to Sandy Silt	SM-ML
8	Sand to Silty Sand	SM-SP
9	Sand	SW-SP
10	Gravelly Sand to Sand	SW-GW
11	Very Stiff Fine-grained *	CH-CL
12	Sand to Clayey Sand *	SC-SM

*overconsolidated or cemented

Boring Legend

- Lean CLAY (CL)
- Sandy Lean Clay (CL)
- Fat CLAY (CH)
- Fat CLAY with SAND (CH)
- Silt (ML)
- Sandy SILT (ML)
- Poorly-Graded SAND (SP)
- Poorly-Graded SAND with Silt (SP-SM)
- Gravelly Poorly-Graded SAND (SP)
- Clayey SAND (SC)
- Silty SAND (SM)
- Gravelly Silty SAND (SM)
- Sandy, Clayey GRAVEL (GC)
- Base Material

CROSS SECTION 23+30

Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

APPENDIX A

ELEVATION, ft	DEPTH, ft	MATERIAL SYMBOL	SAMPLE NO.	SAMPLES	BLOW COUNT / REC"/DRIVE"	LOCATION: The drill hole location referencing local landmarks or coordinates SURFACE EL: Using local, MSL, MLLW or other datum MATERIAL DESCRIPTION	
			1		25	Well graded GRAVEL (GW)	COARSE GRAINED
-12	2		2		(25)	Poorly graded GRAVEL (GP)	COARSE GRAINED
-14	4					Well graded SAND (SW)	COARSE GRAINED
-16	6		3		(25)	Poorly graded SAND (SP)	COARSE GRAINED
-18	8		4		(25)	Silty SAND (SM)	COARSE GRAINED
-20	10		5		18"/ 30"	Clayey SAND (SC)	COARSE GRAINED
-22	12					Silty, Clayey SAND (SC-SM)	COARSE GRAINED
-24	14		6			Elastic SILT (MH)	FINE GRAINED
-26	16		7			SILT (ML)	FINE GRAINED
-28	18		8		20"/ 24"	Silty CLAY (CL-ML)	FINE GRAINED
-30	20		9		(25)	Fat CLAY (CH)	FINE GRAINED
-32	22					Lean CLAY (CL)	FINE GRAINED
-34	24		10		30"/ 30"	CONGLOMERATE	ROCK
-36	26		11		20"/ 24"	SANDSTONE	ROCK
-38	28		12			SILTSTONE	ROCK
-40	30		13			MUDSTONE	ROCK
-42	32					CLAYSTONE	ROCK
-44	34					BASALT	ROCK
-46	36					ANDESITE BRECCIA	ROCK
-48	38					Paving and/or Base Materials	

General Notes

Soil Texture Symbol

Sloped line in symbol column indicates transitional boundary

Samplers and sampler dimensions (unless otherwise noted in report text) are as follows:

Symbol for:	
1	SPT Sampler, driven 1-3/8" ID, 2" OD
2	CA Liner Sampler, driven 2-3/8" ID, 3" OD
3	CA Liner Sampler, disturbed 2-3/8" ID, 3" OD
4	Thin-walled Tube, pushed 2-7/8" ID, 3" OD
5	Bulk Bag Sample (from cuttings)
6	CA Liner Sampler, Bagged
7	Hand Auger Sample
8	CME Core Sample
9	Pitcher Sample
10	Lexan Sample
11	Vibracore Sample
12	No Sample Recovered
13	Sonic Soil Core Sample

Sampler Driving Resistance

Number of blows with 140 lb. hammer, falling 30" to drive sampler 1 ft. after seating sampler 6"; for example,

Blows/ft	Description
25	25 blows drove sampler 12" after initial 6" of seating
86/11"	After driving sampler the initial 6" of seating, 36 blows drove sampler through the second 6" interval, and 50 blows drove the sampler 5" into the third interval
50/6"	50 blows drove sampler 6" after initial 6" of seating
Ref/3"	50 blows drove sampler 3" during initial 6" seating interval

Blow counts for California Liner Sampler shown in ( )

Length of sample symbol approximates recovery length

Classification of Soils per ASTM D2487 or D2488

Geologic Formation noted in bold font at the top of interpreted interval

Strength Legend

Q = Unconfined Compression
u = Unconsolidated Undrained Triaxial
t = Torvane
p = Pocket Penetrometer
m = Miniature Vane

Water Level Symbols

- Initial or perched water level
- Final ground water level
- Seepages encountered

Rock Quality Designation (RQD) is the sum of recovered core pieces greater than 4 inches divided by the length of the cored interval.

KEY TO TERMS & SYMBOLS USED ON LOGS

PLATE A-1

LOCATION: North levee, Station 80+00

SURFACE EL: 35.8 ft +/- (rel. NAVD88 datum)

ELEVATION, ft	DEPTH, ft	SAMPLE NO.	SAMPLER BLOW COUNT	MATERIAL DESCRIPTION	UNIT WET WEIGHT, pcf	UNIT DRY WEIGHT, pcf	WATER CONTENT, %	% PASSING #200 SIEVE	LIQUID LIMIT, %	PLASTICITY INDEX, %	UNDRAINED SHEAR STRENGTH, S_u, ksf
				ARTIFICIAL FILL (af) Approximately 2.5" of base material							
34	2	A, 1A, 1B	(23)	Silty SAND (SM): medium dense, brown matrix, moist, angular gravel	105	99	6	27			
		2	11								
32	4										
		3	(5)	**ALLUVIUM (Qal_3)** Lean CLAY (CL): soft to stiff, brown to dark brown, wet, fine sand	109	81	35				p 1.5
30	6	4A, 4B	4								p 0.8
28	8	5	(6)	**Qal_1** Silty SAND (SM): very loose, brown to light reddish brown, moist							
26	10			Poorly graded SAND with gravel (SP): very loose, brown matrix, well-rounded gravel				3			
24	12										
22	14										
20	16	6A, 6B	(13)	Poorly graded SAND with silt (SP-SM): loose, brown, wet, fine sand	125	101	24	10			
18	18										
16	20	7A, 7B	(39)	Poorly graded SAND (SP): medium dense, light brown, wet	125	100	26	3			
14	22										
12	24										
10	26	8A, 8B	(63)	Poorly graded SAND with silt (SP-SM): dense, light yellowish brown, wet	128	105	21	8			
8	28			**Qal_4** Fat CLAY (CH): medium stiff to stiff, brown, wet, mottled light brown, oxidation staining							
6	30	9A, 9B	(12)								p 1.0 p 1.5 p 0.5
4											

The log and data presented are a simplification of actual conditions encountered at the time of drilling at the drilled location. Subsurface conditions may differ at other locations and with the passage of time.

COMPLETION DEPTH: 31.5 ft
DEPTH TO WATER: 12.0 ft
BACKFILLED WITH: 2 Sack Slurry
DRILLING DATE: January 12, 2012

DRILLING METHOD: 8-inch-dia. Hollow Stem Auger
HAMMER TYPE: Automatic Trip
DRILLED BY: S/G Drilling Company
LOGGED BY: G Eckrich
CHECKED BY: J Blanchard

LOG OF BORING NO. B-1

Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

PLATE A-2

LOCATION: North levee, Station 40+00

SURFACE EL: 24.9 ft +/- (rel. NAVD88 datum)

ELEVATION, ft	DEPTH, ft	SAMPLE NO.	SAMPLER BLOW COUNT	MATERIAL DESCRIPTION	UNIT WET WEIGHT, pcf	UNIT DRY WEIGHT, pcf	WATER CONTENT, %	% PASSING #200 SIEVE	LIQUID LIMIT, %	PLASTICITY INDEX, %	UNDRAINED SHEAR STRENGTH, S_u, ksf
24	0			**ARTIFICIAL FILL (af)** Approximately 5" of base material							
		A 1A 1B	(35)	Silty SAND with gravel (SM): medium dense, brown, moist, angular gravel, pockets of fat CLAY (CH), gravel up to 2"	107	98	9	14			
22	2	2	27								
20	4		(45)								
	5	3A 3B		Clayey SAND (SC): medium dense, dark brown, moist, angular gravel	123	104	18	42			
18	6	4	33	Silty SAND with gravel (SM): medium dense, brown, moist							
16	8	5A 5B	(11)	**ALLUVIUM (Qal_1)** Poorly graded SAND with silt (SP-SM): loose, light brown to brown, moist, well-rounded gravel	102	93	9	11			
14	10										
12	12										
	13	B		**Qal_3** Sandy Lean CLAY (CL): brown, wet				66			
10	15	6A 6B	(6)	**Qal_2** Silty SAND (SM): very loose, brown, wet - color change to dark gray at 16.2', fine to coarse sand							
6	18										
4	20	7A 7B	(6)	Poorly graded SAND with silt (SP-SM): very loose, brown, wet	121	94	30	11			
0	25	8	(4)	- driller notes flowing sands at 25'							
-2	27	C		**Qal_4** Fat CLAY (CH): hard, dark gray, wet							p 1.8
-6	30	9A 9B	(51)	**Qal_2** Clayey GRAVEL with sand (GC): dense, brown to dark gray matrix, wet, abundant oxidation staining							

The log and data presented are a simplification of actual conditions encountered at the time of drilling at the drilled location. Subsurface conditions may differ at other locations and with the passage of time.

COMPLETION DEPTH: 31.5 ft
DEPTH TO WATER: 12.0 ft
BACKFILLED WITH: 2 Sack Slurry
DRILLING DATE: January 12, 2012

DRILLING METHOD: 8-inch-dia. Hollow Stem Auger
HAMMER TYPE: Automatic Trip
DRILLED BY: S/G Drilling Company
LOGGED BY: G Eckrich
CHECKED BY: J Blanchard

LOG OF BORING NO. B-2

Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

LOCATION: North levee, Station 23+30

SURFACE EL: 22.5 ft +/- (rel. NAVD88 datum)

SAMPLE NO.	SAMPLER BLOW COUNT	MATERIAL DESCRIPTION	UNIT WET WEIGHT, pcf	UNIT DRY WEIGHT, pcf	WATER CONTENT, %	% PASSING #200 SIEVE	LIQUID LIMIT, %	PLASTICITY INDEX, %	UNDRAINED SHEAR STRENGTH, S_u, ksf
A 1	(46)	**ARTIFICIAL FILL (af)** Poorly graded SAND with silt and gravel (SP-SM): dense, brown, moist, gravel up to approximately 2"	107	94	13	7			
2	22	- medium dense at 3'							
3	(39)		108	98	11	19			
4A	17								
4B		**ALLUVIUM (Qal_3)** Sandy SILT (ML): very stiff, brown, moist				49			
5A	(7)	**Qal_2** Silty SAND (SM): loose, brown, moist, roots and rootlets, pockets of silty clay							
5B			106	92	16	26			
6A 6B	(17)	- medium dense, light yellowish brown to light yellow, wet, well-rounded gravel at 15' - approximately 1" thick layer of lean CLAY (CL) at 15.8'	111	82	36	12			
7	(18)	Poorly graded SAND with gravel (SP): medium dense, light brown to light yellowish brown, wet, well-rounded gravel	124	105	18	2			
8A 8B	(40)	Silty SAND (SM): medium dense, dark gray, wet							
9A 9B	(64)	Poorly graded SAND with silt (SP-SM): dense, dark gray, wet	128	103	24	10			

The log and data presented are a simplification of actual conditions encountered at the time of drilling at the drilled location. Subsurface conditions may differ at other locations and with the passage of time.

COMPLETION DEPTH: 41.5 ft
DEPTH TO WATER: 13.0 ft
BACKFILLED WITH: 2 Sack Slurry
DRILLING DATE: January 12, 2012

DRILLING METHOD: 8-inch-dia. Hollow Stem Auger
HAMMER TYPE: Automatic Trip
DRILLED BY: S/G Drilling Company
LOGGED BY: G Eckrich
CHECKED BY: J Blanchard

LOG OF BORING NO. B-3
Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

PLATE A-4a

ELEVATION, ft	DEPTH, ft	MATERIAL SYMBOL	SAMPLE NO.	SAMPLERS	SAMPLER BLOW COUNT	LOCATION: North levee, Station 23+30 SURFACE EL: 22.5 ft +/- (rel. NAVD88 datum) MATERIAL DESCRIPTION	UNIT WET WEIGHT, pcf	UNIT DRY WEIGHT, pcf	WATER CONTENT, %	% PASSING #200 SIEVE	LIQUID LIMIT, %	PLASTICITY INDEX, %	UNDRAINED SHEAR STRENGTH, S_u, ksf
-10													
-12	34				(26)	- medium dense at 35', abundant shell fragments							
-14	36												
-16	38												
-18	40		10A 10B		(79/10")	- very dense, light gray, wet at 40' - increase in gravel content at 41'							
-20	42												
-22	44												
-24	46												
-26	48												
-28	50												
-30	52												
-32	54												
-34	56												
-36	58												
-38	60												
-40	62												

The log and data presented are a simplification of actual conditions encountered at the time of drilling at the drilled location. Subsurface conditions may differ at other locations and with the passage of time.

COMPLETION DEPTH: 41.5 ft
DEPTH TO WATER: 13.0 ft
BACKFILLED WITH: 2 Sack Slurry
DRILLING DATE: January 12, 2012

DRILLING METHOD: 8-inch-dia. Hollow Stem Auger
HAMMER TYPE: Automatic Trip
DRILLED BY: S/G Drilling Company
LOGGED BY: G Eckrich
CHECKED BY: J Blanchard

LOG OF BORING NO. B-3

Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

PLATE A-4b

APPENDIX B

LAB SUMMARY TABLE VENTURA _F:\FUGRO SLO GEOTECH DOCUMENTS\GINT\GINT PROJECTS\04.6212.0004.GPJ_ 3/8/12 11:56 AM-cab

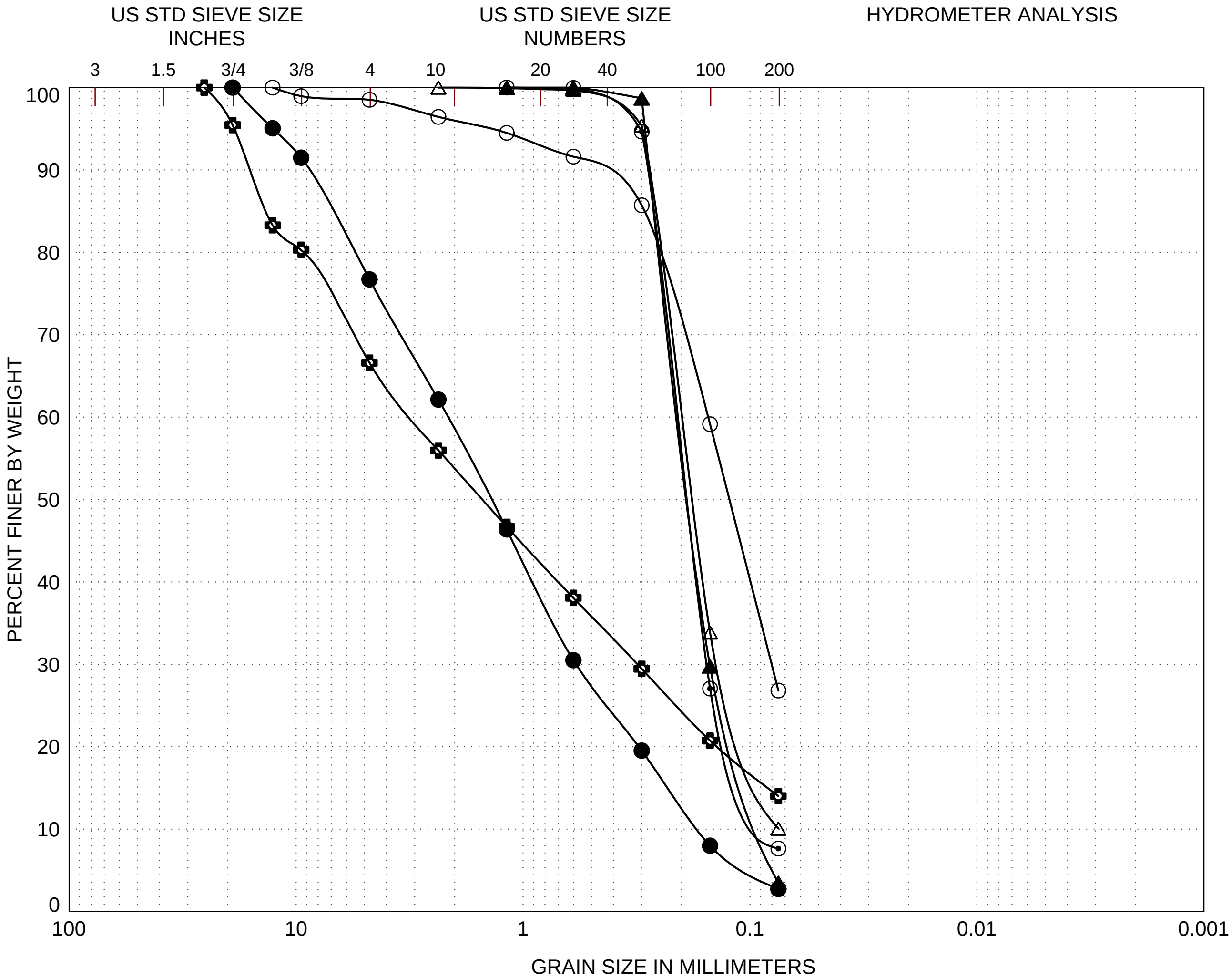
County of San Luis Obispo
Project No. 04.6212.0004

DRILL HOLE	DEPTH, ft	SAMPLE NUMBER	MATERIAL DESCRIPTION	UWW pcf	UDW pcf	MC %	FINES %	ATTERBERG LIMITS		COMPACTION TEST		DIRECT SHEAR		COMPRESSIVE STRENGTH TESTS		CORROSIVITY TESTS				R-VALUE	EXPANSION INDEX	SAND EQUIVALENT (SE)	SPECIFIC GRAVITY
								LL	PI	MAX DD pcf	OPT MC %	C ksf	PHI deg	Qu, ksf	S_u (Cell Prs.) ksf	R	pH	Cl	So_4 (%)				
B-1	2.0	1B	Silty SAND (SM)	105	99	6	27																
B-1	5.5		Lean CLAY (CL)	109	81	35																	
B-1	9.5		Poorly graded SAND with gravel (SP)				3																
B-1	15.5	6A	Poorly graded SAND with silt (SP-SM)	125	101	24	10																
B-1	20.5	7A	Poorly graded SAND (SP)	125	100	26	3																
B-1	26.0	8B	Poorly graded SAND with silt (SP-SM)	128	105	21	8																
B-2	2.0	1B	Silty SAND with gravel (SM)	107	98	9	14																
B-2	5.5	3B	Clayey SAND (SC)	123	104	18	42																
B-2	9.5	5B	Poorly graded SAND with silt (SP-SM)	102	93	9	11																
B-2	13.0	B	Sandy Lean CLAY (CL)				66																
B-2	21.0	7B	Poorly graded SAND with silt (SP-SM)	121	94	30	11																
B-3	1.0	1	Poorly graded SAND with silt and gravel (SP-SM)	107	94	13	7																
B-3	4.5	3	Poorly graded SAND with silt and gravel (SP-SM)	108	98	11	19																
B-3	7.0	4B	Sandy SILT (ML)				49																
B-3	9.5	5B	Silty SAND (SM)	106	92	16	26																
B-3	15.5	6A	Silty SAND (SM)	111	82	36	12																
B-3	20.0	7	Poorly graded SAND with gravel (SP)	124	105	18	2																
B-3	30.5	9A	Poorly graded SAND with silt (SP-SM)	128	103	24	10																

SUMMARY OF LABORATORY TEST RESULTS

Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

PLATE B-1

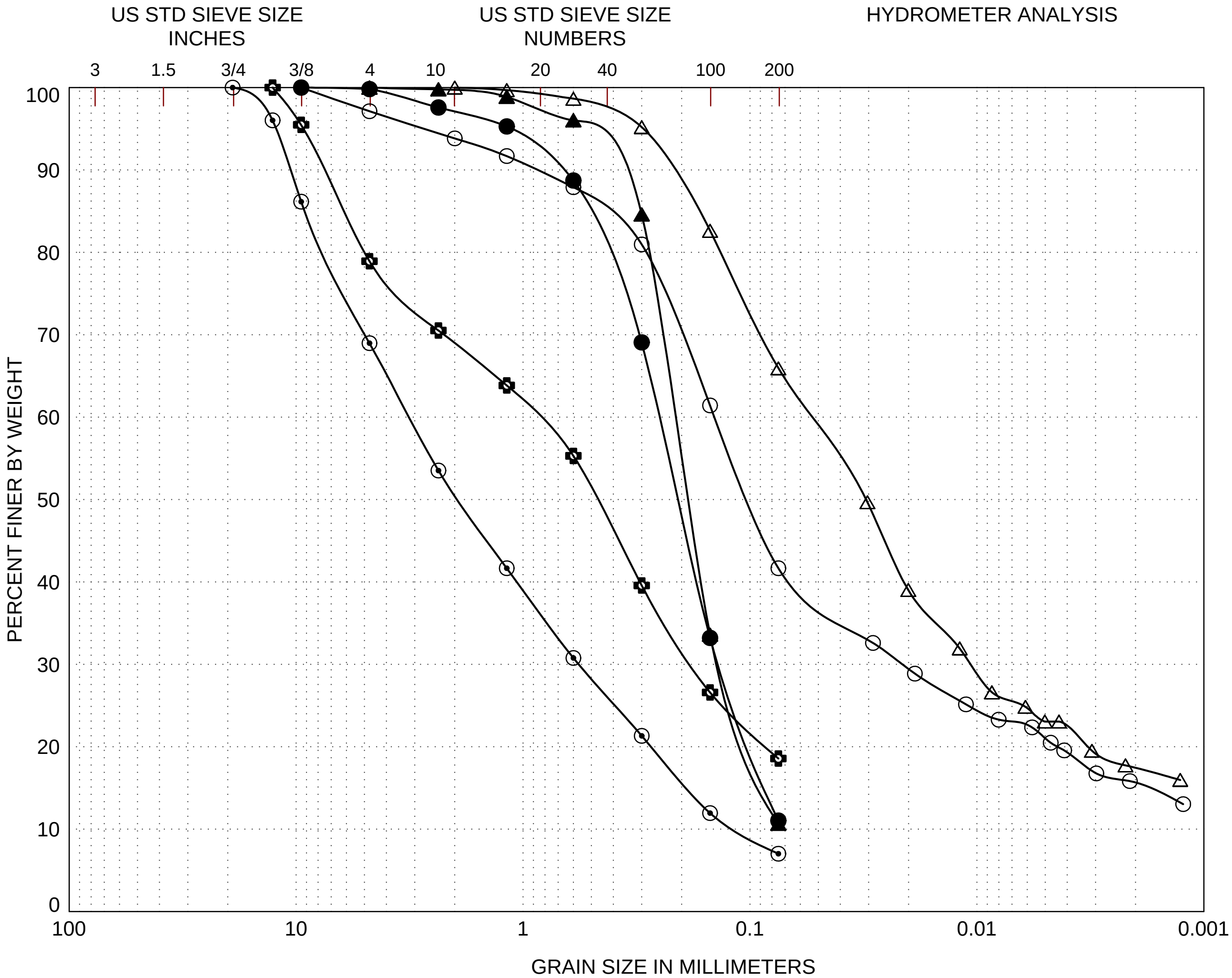


GRAVEL		SAND			SILT or CLAY
Coarse	Fine	Coarse	Medium	Fine	

LEGEND (location)	(depth,ft)	CLASSIFICATION	Cc	Cu
○ B-1	2.0	Silty SAND (SM)		
● B-1	9.5	Poorly graded SAND with gravel (SP)	0.9	12.7
△ B-1	15.5	Poorly graded SAND with silt (SP-SM)	1.2	2.7
▲ B-1	20.5	Poorly graded SAND (SP)	1.2	2.3
⊙ B-1	26.0	Poorly graded SAND with silt (SP-SM)	1.4	2.6
✤ B-2	2.0	Silty SAND with gravel (SM)		

GRAIN SIZE CURVES
Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

PLATE B-2a

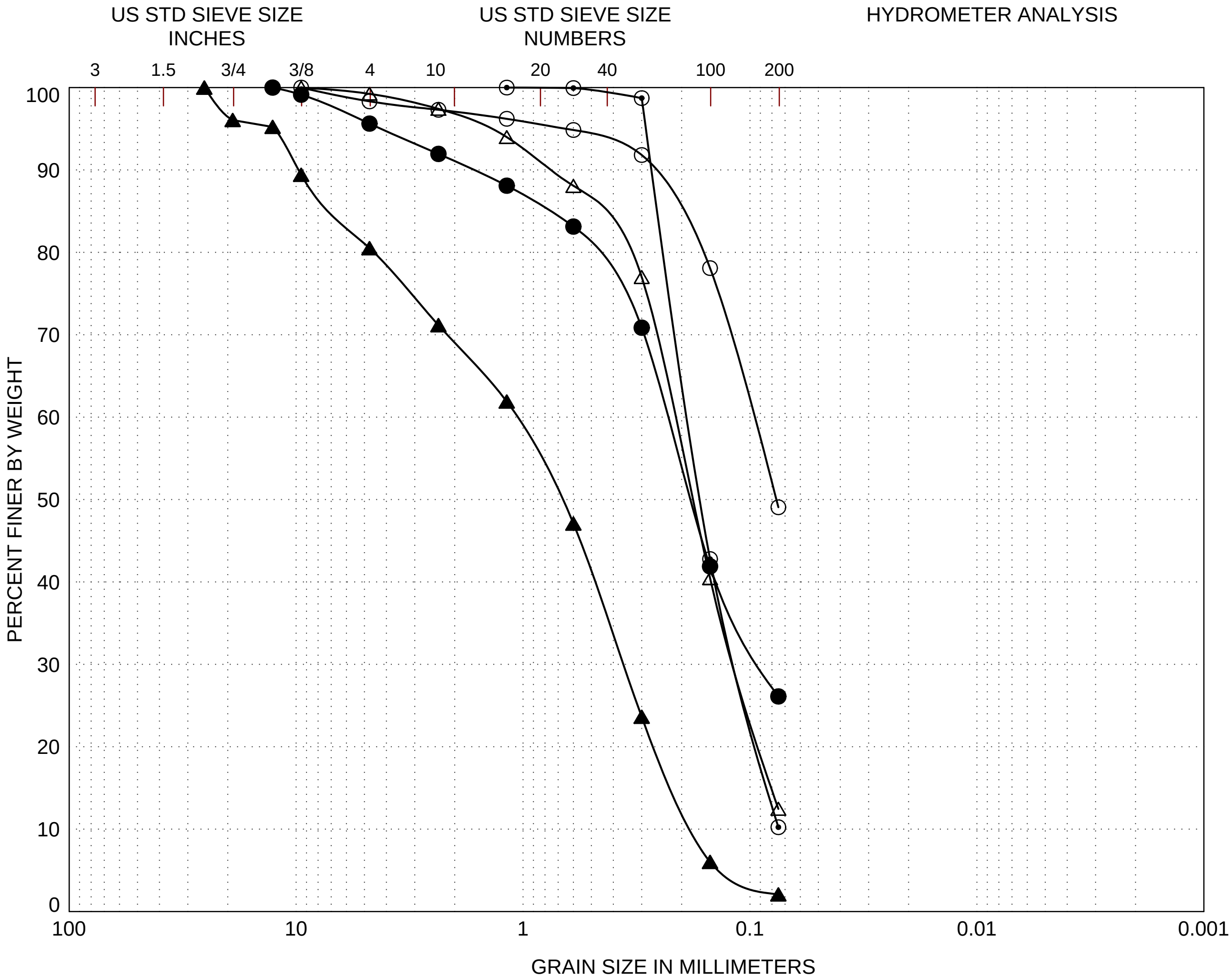


GRAVEL		SAND			SILT or CLAY
Coarse	Fine	Coarse	Medium	Fine	

LEGEND	(location)	(depth,ft)	CLASSIFICATION	Cc	Cu
○	B-2	5.5	Clayey SAND (SC)		
●	B-2	9.5	Poorly graded SAND with silt (SP-SM)	1.0	3.5
△	B-2	13.0	Sandy Lean CLAY (CL)		
▲	B-2	21.0	Poorly graded SAND with silt (SP-SM)	1.1	2.9
⊙	B-3	1.0	Poorly graded SAND with silt and gravel (SP-SM)	0.9	27.7
✿	B-3	4.5	Poorly graded SAND with silt and gravel (SP-SM)		

GRAIN SIZE CURVES
Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

PLATE B-2b



GRAVEL		SAND			SILT or CLAY
Coarse	Fine	Coarse	Medium	Fine	

LEGEND	(location)	(depth,ft)	CLASSIFICATION	Cc	Cu
○	B-3	7.0	Sandy SILT (ML)		
●	B-3	9.5	Silty SAND (SM)		
△	B-3	15.5	Silty SAND (SM)	0.9	3.1
▲	B-3	20.0	Poorly graded SAND with gravel (SP)	0.7	6.2
⊙	B-3	30.5	Poorly graded SAND with silt (SP-SM)	0.9	2.5

GRAIN SIZE CURVES
Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

PLATE B-2c

SAMPLE ID

Boring Number	B-01
Sample Number	1B
Sample Depth, ft	2.0
Classification	Silty SAND (SM): pale brown, moist

CLASSIFICATION

Sieve Size	% Passing
3/8-in. (9.5mm)	99
#4 (4.75mm)	98
#16 (1.18mm)	94
#30 (0.6mm)	92
#100 (0.150mm)	59
#200 (0.075mm)	27

Other Parameters	
Liquid Limit	---
Plastic Limit	---
Plasticity Index	---
Estimated Gs	2.7

SAMPLE PROPERTIES

	Intial	Final
Mass, g	631.13	---
Water Content, %	5.5%	---
Dry Density, pcf	99.1	---
Saturation, %	21%	---
Void Ratio	0.70	---
Diameter, in	2.42	---
Height, in	5.00	---
Area, in^2	4.60	---
Volume, in^3	23.00	---

TEST SUMMARY

Sample Type	MCA
Permeant	Deaired Tap-Water
Pipette Area, cm^2	0.971
k_{avg} 20ºC, cm/s	1.5E-03
Tested By	JC

REMARKS

Test Method: ASTM D5084 (Method C)
Specimen was tested in triaxial compression following permeation
Final Sample Properties not provided due to testing sequence

PERMEATION DATA

Trial	Date	Time, sec	$Temp_{Avg}$, ºC	σ', ksf	μ, ksf	i_o	i_f	k_t, cm/s
1	1/19/12	282	23.4	0.3	14.4	0.2	0.1	1.7E-03
2	1/19/12	284	23.4	0.3	14.4	0.2	0.1	1.7E-03
3	1/19/12	277	23.4	0.3	14.4	0.2	0.1	1.7E-03
4	1/19/12	287	23.4	0.3	14.4	0.2	0.1	1.6E-03
5								
6								

SAMPLE IMAGES

HYDRAULIC CONDUCTIVITY
Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

SAMPLE ID

Boring Number	B-01
Sample Number	3
Sample Depth, ft	4.5
Classification	Lean CLAY (CL): dark yellowish brown, moist, w/fine sand pockets

SAMPLE PROPERTIES

	Intial	Final
Mass, g	132.34	135.26
Water Content, %	35.3%	38.3%
Dry Density, pcf	80.5	82.8
Saturation, %	87%	100%
Void Ratio	1.09	1.04
Diameter, in	2.42	2.38
Height, in	1.01	1.02
Area, in^2	4.60	4.43
Volume, in^3	4.63	4.50

CLASSIFICATION

Sieve Size	% Passing
3/8-in. (9.5mm)	---
#4 (4.75mm)	---
#16 (1.18mm)	---
#30 (0.6mm)	---
#100 (0.150mm)	---
#200 (0.075mm)	---

Other Parameters	
Liquid Limit	---
Plastic Limit	---
Plasticity Index	---
Estimated Gs	2.7

TEST SUMMARY

Sample Type	Cal
Permeant	Deaired Tap-Water
Pipette Area, cm^2	0.0314
Annulus Area, cm^2	0.7671
k_{avg} 20ºC, cm/s	7.4E-07
Tested By	JC

REMARKS

Test Method: ASTM D5084 (Method F)

Estimated Gs provides final saturation of 100%.

PERMEATION DATA

Trial	Date	Time, sec	$Temp_{Avg}$, ºC	σ', ksf	μ, ksf	i_o	i_f	k_t, cm/s
1	1/19/12	392	20.6	0.3	10.1	19.8	5.1	7.6E-07
2	1/19/12	391	20.6	0.3	10.1	19.8	5.1	7.6E-07
3	1/19/12	394	20.6	0.3	10.1	19.8	5.1	7.5E-07
4	1/19/12	396	20.6	0.3	10.1	19.8	5.1	7.5E-07
5								
6								

SAMPLE IMAGES

HYDRAULIC CONDUCTIVITY

Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

SAMPLE ID		
Boring Number	B-01	
Sample Number	7A	
Sample Depth, ft	20.5	
Classification	Poorly-graded SAND (SP): brown, moist	

SAMPLE PROPERTIES	Intial	Final
Mass, g	455.25	446.41
Water Content, %	25.7%	23.3%
Dry Density, pcf	99.6	103.5
Saturation, %	100%	100%
Void Ratio	0.69	0.63
Diameter, in	2.42	2.49
Height, in	3.01	2.75
Area, in^2	4.60	4.86
Volume, in^3	13.84	13.33

CLASSIFICATION

Sieve Size	% Passing
3/8-in. (9.5mm)	100
#4 (4.75mm)	100
#16 (1.18mm)	100
#30 (0.6mm)	100
#100 (0.150mm)	30
#200 (0.075mm)	4

Other Parameters	
Liquid Limit	---
Plastic Limit	---
Plasticity Index	---
Estimated Gs	2.7

TEST SUMMARY

Sample Type	MCA
Permeant	Deaired Tap-Water
Pipette Area, cm^2	0.971
k_{avg} 20ºC, cm/s	4.4E-03
Tested By	JC

REMARKS

Test Method: ASTM D5084 (Method C)
Estimated Gs provides final saturation of 100%.

PERMEATION DATA

Trial	Date	Time, sec	$Temp_{Avg}$, ºC	σ', ksf	μ, ksf	i_o	i_f	k_t, cm/s
1	1/18/12	58	21.1	1.0	10.1	0.4	0.1	4.2E-03
2	1/18/12	56	21.1	1.0	10.1	0.4	0.1	4.4E-03
3	1/18/12	53	21.1	1.0	10.1	0.4	0.1	4.6E-03
4	1/18/12	53	21.1	1.0	10.1	0.4	0.1	4.6E-03
5	1/18/12	53	21.1	1.0	10.1	0.4	0.1	4.6E-03
6	1/18/12	55	21.1	1.0	10.1	0.4	0.1	4.4E-03

SAMPLE IMAGES

HYDRAULIC CONDUCTIVITY
Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

SAMPLE ID

Boring Number	B-02
Sample Number	1B
Sample Depth, ft	2.0
Classification	Silty SAND with gravel (SM): dark yellowish brown, moist

CLASSIFICATION

Sieve Size	% Passing
3/8-in. (9.5mm)	80
#4 (4.75mm)	67
#16 (1.18mm)	47
#30 (0.6mm)	30
#100 (0.150mm)	21
#200 (0.075mm)	14

Other Parameters	
Liquid Limit	---
Plastic Limit	---
Plasticity Index	---
Estimated Gs	2.7

SAMPLE PROPERTIES

	Intial	Final
Mass, g	371.60	413.64
Water Content, %	9.4%	21.7%
Dry Density, pcf	97.5	106.2
Saturation, %	35%	100%
Void Ratio	0.73	0.59
Diameter, in	2.38	2.38
Height, in	3.00	2.74
Area, in^2	4.43	4.45
Volume, in^3	13.28	12.19

TEST SUMMARY

Sample Type	Remold
Permeant	Deaired Tap-Water
Pipette Area, cm^2	0.971
k_{avg} 20ºC, cm/s	1.3E-03
Tested By	JC

REMARKS

Test Method: ASTM D5084 (Method C)
Estimated Gs provides final saturation of 100%.
Gravel removed for hydraulic conductivity testing.

PERMEATION DATA

Trial	Date	Time, sec	$Temp_{Avg}$, ºC	σ', ksf	μ, ksf	i_o	i_f	k_t, cm/s
1	1/24/12	188	22.6	0.3	10.1	0.4	0.1	1.4E-03
2	1/24/12	190	22.6	0.3	10.1	0.4	0.1	1.4E-03
3	1/24/12	185	22.6	0.3	10.1	0.4	0.1	1.4E-03
4	1/24/12	188	22.6	0.3	10.1	0.4	0.1	1.4E-03
5								
6								

SAMPLE IMAGES

HYDRAULIC CONDUCTIVITY
Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

SAMPLE ID

Boring Number	B-02
Sample Number	3B
Sample Depth, ft	5.5
Classification	Clayey SAND (SC): dark olive brown mottled w/dark gray & brownish yellow, moist

CLASSIFICATION

Sieve Size	% Passing
3/8-in. (9.5mm)	100
#4 (4.75mm)	97
#16 (1.18mm)	92
#30 (0.6mm)	88
#100 (0.150mm)	61
#200 (0.075mm)	42

Other Parameters	
Liquid Limit	---
Plastic Limit	---
Plasticity Index	---
Estimated Gs	2.7

SAMPLE PROPERTIES

	Intial	Final
Mass, g	148.36	151.92
Water Content, %	18.1%	20.9%
Dry Density, pcf	104.3	107.5
Saturation, %	79%	100%
Void Ratio	0.62	0.57
Diameter, in	2.42	2.42
Height, in	1.00	0.97
Area, in^2	4.60	4.58
Volume, in^3	4.59	4.45

TEST SUMMARY

Sample Type	MCA
Permeant	Deaired Tap-Water
Pipette Area, cm^2	0.0314
Annulus Area, cm^2	0.7671
k_{avg} 20ºC, cm/s	8.6E-07
Tested By	JC

REMARKS

Test Method: ASTM D5084 (Method F)
Estimated Gs provides final saturation of 100%.

PERMEATION DATA

Trial	Date	Time, sec	$Temp_{Avg}$, ºC	σ', ksf	μ, ksf	i_o	i_f	k_t, cm/s
1	1/18/12	318	21.2	0.3	10.1	10.6	2.7	9.0E-07
2	1/18/12	321	21.2	0.3	10.1	10.6	2.7	8.9E-07
3	1/18/12	331	21.2	0.3	10.1	10.6	2.7	8.7E-07
4	1/18/12	325	21.2	0.3	10.1	10.6	2.7	8.8E-07
5								
6								

SAMPLE IMAGES

HYDRAULIC CONDUCTIVITY
Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

SAMPLE ID

Boring Number	B-02
Sample Number	7B
Sample Depth, ft	21.0
Classification	Poorly-graded SAND with silt (SP-SM): dark bluish gray, wet

SAMPLE PROPERTIES

	Intial	Final
Mass, g	439.75	429.63
Water Content, %	29.5%	26.5%
Dry Density, pcf	93.7	98.2
Saturation, %	100%	100%
Void Ratio	0.80	0.71
Diameter, in	2.42	2.42
Height, in	3.00	2.86
Area, in^2	4.60	4.60
Volume, in^3	13.80	13.17

CLASSIFICATION

Sieve Size	% Passing
3/8-in. (9.5mm)	100
#4 (4.75mm)	100
#16 (1.18mm)	99
#30 (0.6mm)	96
#100 (0.150mm)	34
#200 (0.075mm)	11

Other Parameters	
Liquid Limit	---
Plastic Limit	---
Plasticity Index	---
Estimated Gs	2.7

TEST SUMMARY

Sample Type	MCA
Permeant	Deaired Tap-Water
Pipette Area, cm^2	0.971
k_{avg} 20ºC, cm/s	2.0E-04
Tested By	JC

REMARKS

Test Method: ASTM D5084 (Method C)

Estimated Gs provides final saturation of 100%.

PERMEATION DATA

Trial	Date	Time, sec	$Temp_{Avg}$, ºC	σ', ksf	μ, ksf	i_o	i_f	k_t, cm/s
1	1/19/12	1514	20.3	1.0	10.1	0.4	0.1	1.8E-04
2	1/19/12	1260	20.3	1.0	10.1	0.4	0.1	2.1E-04
3	1/19/12	1279	20.2	1.0	10.1	0.4	0.1	2.1E-04
4	1/19/12	1386	20.2	1.0	10.1	0.4	0.1	1.9E-04
5								
6								

SAMPLE IMAGES

HYDRAULIC CONDUCTIVITY

Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

SAMPLE ID

Boring Number	B-03
Sample Number	1
Sample Depth, ft	1.0
Classification	Poorly-graded SAND with silt and gravel (SP-SM): yellowish brown, moist

SAMPLE PROPERTIES

	Intial	Final
Mass, g	257.77	278.61
Water Content, %	13.0%	22.2%
Dry Density, pcf	94.4	105.3
Saturation, %	45%	100%
Void Ratio	0.78	0.60
Diameter, in	2.42	2.38
Height, in	2.00	1.86
Area, in^2	4.60	4.45
Volume, in^3	9.20	8.25

CLASSIFICATION

Sieve Size	% Passing
3/8-in. (9.5mm)	86
#4 (4.75mm)	69
#16 (1.18mm)	42
#30 (0.6mm)	21
#100 (0.150mm)	12
#200 (0.075mm)	7

Other Parameters	
Liquid Limit	---
Plastic Limit	---
Plasticity Index	---
Estimated Gs	2.7

TEST SUMMARY

Sample Type	MCA
Permeant	Deaired Tap-Water
Pipette Area, cm^2	0.971
k_{avg} 20ºC, cm/s	1.2E-03
Tested By	JC

REMARKS

Test Method: ASTM D5084 (Method C)

Estimated Gs provides final saturation of 100%.

PERMEATION DATA

Trial	Date	Time, sec	$Temp_{Avg}$, ºC	σ', ksf	μ, ksf	i_o	i_f	k_t, cm/s
1	1/20/12	145	22.9	0.3	10.1	0.6	0.2	1.2E-03
2	1/20/12	143	22.9	0.3	10.1	0.6	0.2	1.3E-03
3	1/20/12	146	22.9	0.3	10.1	0.6	0.2	1.2E-03
4	1/20/12	145	22.9	0.3	10.1	0.6	0.2	1.2E-03
5								
6								

SAMPLE IMAGES

HYDRAULIC CONDUCTIVITY

Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

SAMPLE ID

Boring Number	B-03
Sample Number	6A
Sample Depth, ft	15.5
Classification	Silty SAND (SM) and fat CLAY (CH): gray, wet

CLASSIFICATION

Sieve Size	% Passing
3/8-in. (9.5mm)	100
#4 (4.75mm)	99
#16 (1.18mm)	94
#30 (0.6mm)	88
#100 (0.150mm)	40
#200 (0.075mm)	12

Other Parameters	
Liquid Limit	---
Plastic Limit	---
Plasticity Index	---
Estimated Gs	2.7

SAMPLE PROPERTIES

	Intial	Final
Mass, g	403.88	395.45
Water Content, %	36.3%	33.5%
Dry Density, pcf	81.8	88.3
Saturation, %	93%	100%
Void Ratio	1.06	0.91
Diameter, in	2.42	2.41
Height, in	3.00	2.81
Area, in^2	4.60	4.55
Volume, in^3	13.80	12.78

TEST SUMMARY

Sample Type	MCA
Permeant	Deaired Tap-Water
Pipette Area, cm^2	0.0314
Annulus Area, cm^2	0.7671
k_{avg} 20ºC, cm/s	1.6E-06
Tested By	JC

REMARKS

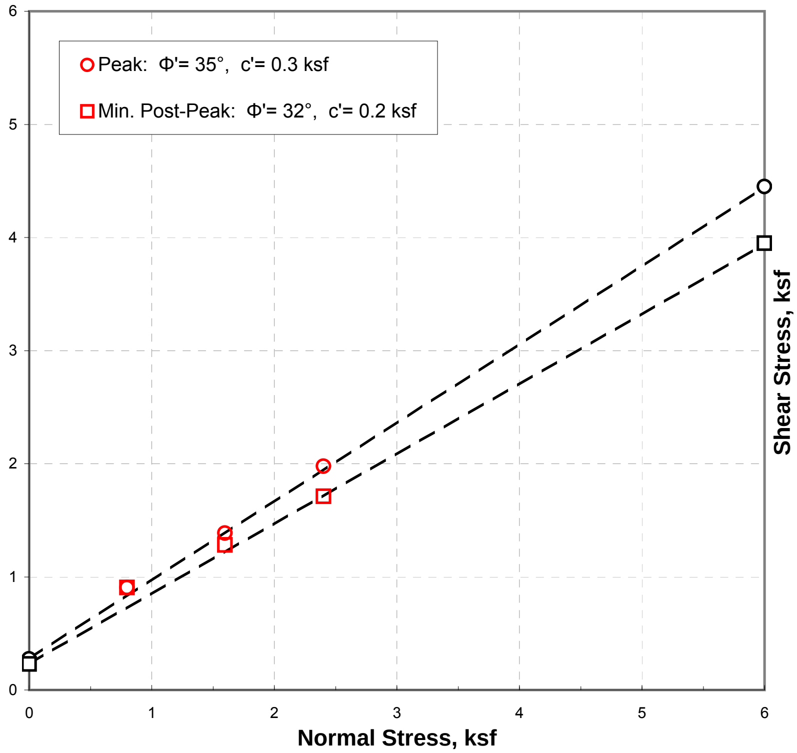
Test Method: ASTM D5084 (Method F)
Estimated Gs provides final saturation of 100%.

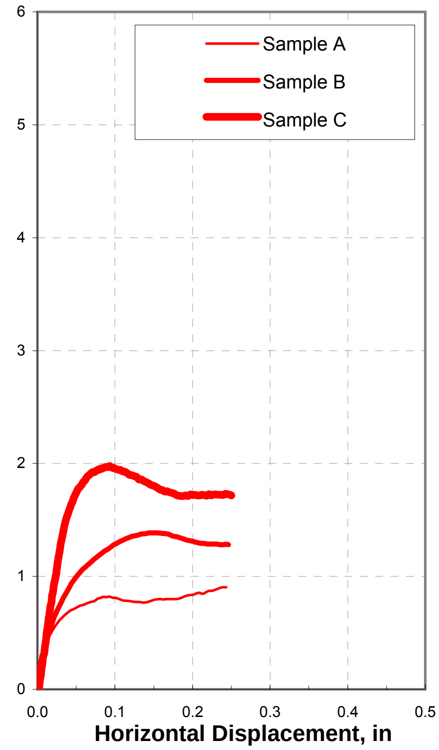
PERMEATION DATA

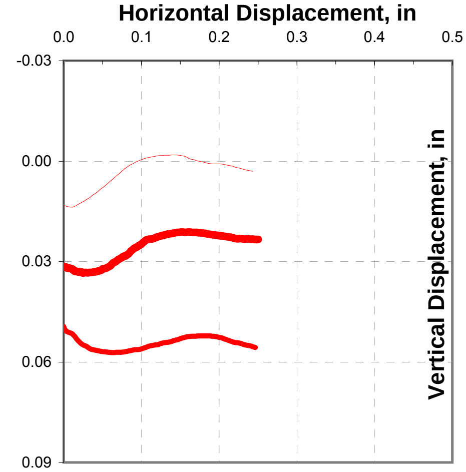
Trial	Date	Time, sec	$Temp_{Avg}$, ºC	σ', ksf	μ, ksf	i_o	i_f	k_t, cm/s
1	1/24/12	120	22.8	0.8	10.1	9.2	6.4	1.7E-06
2	1/24/12	119	22.8	0.8	10.1	9.2	6.4	1.7E-06
3	1/24/12	125	22.8	0.8	10.1	9.2	6.4	1.7E-06
4	1/24/12	122	22.8	0.8	10.1	9.2	6.4	1.7E-06
5								
6								

SAMPLE IMAGES

HYDRAULIC CONDUCTIVITY
Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California







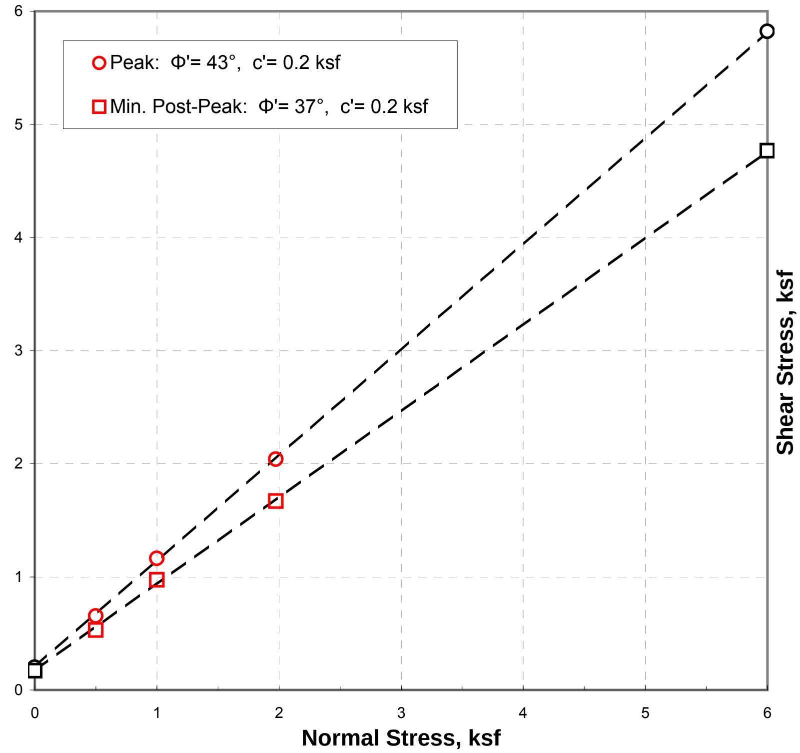
SAMPLE ID	Boring Number:	B-01
	Sample Number:	6A
	Sample Depth:	15.5 ft
	USCS Classification:	Poorly-graded SAND with silt (SP-SM): brown, wet

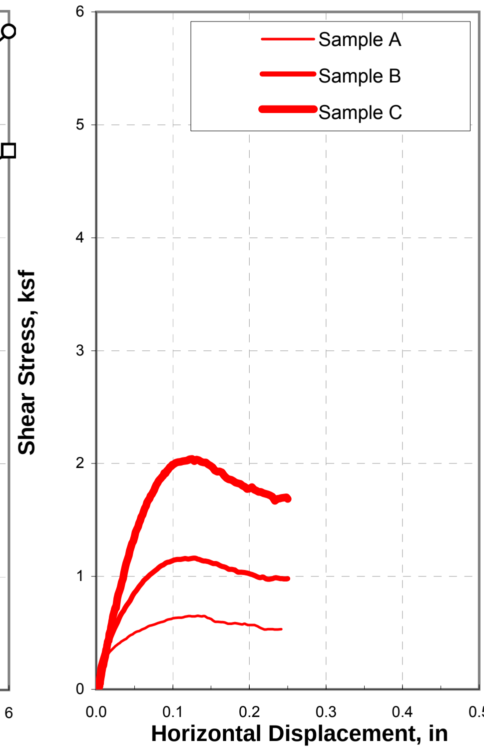
	Sample No.	A	B	C	D
INITIAL	Water Content, %	23.9%	23.9%	23.9%	
	Dry Unit Weight, pcf	102.0	101.0	102.9	
	Saturation, %	98%	96%	100%	
	Void Ratio	0.66	0.67	0.64	
	Diameter, in	2.42	2.42	2.42	
	Height, in	1.00	1.00	1.00	
FINAL	Water Content, %	22.8%	23.9%	22.6%	
	Dry Unit Weight, pcf	102.7	101.3	103.0	
	Void Ratio	0.65	0.67	0.64	
TEST SUMMARY	Deformation at Peak, %	0.24	0.15	0.09	
	Displacement Rate, in/min	0.004	0.004	0.004	
	Normal Stress, ksf	0.80	1.6	2.4	
	Peak Shear Stress, ksf	0.90	1.39	1.98	
	Min. Post-Peak Stress, ksf	0.90	1.28	1.71	
REMARKS	Test Method: ASTM D3080				

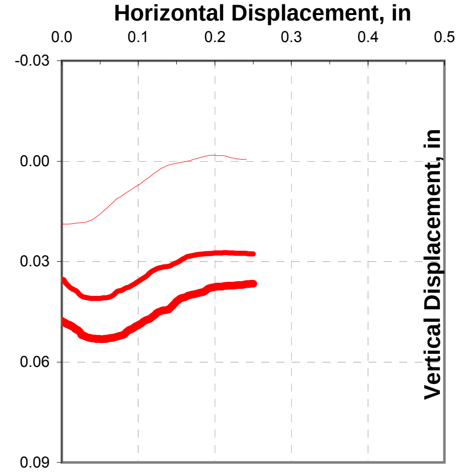
CLASSIFICATION	Sieve Size	% Passing
	3/8-in. (9.5mm)	100
	#4 (4.75mm)	100
	#16 (1.18mm)	100
	#30 (0.6mm)	100
	#100 (0.150mm)	34
	#200 (0.075mm)	10
	Atterberg Limits	
	Liquid Limit, %	---
	Plastic Limit, %	---
	Plasticity Index, %	---
	Estimated Gs	2.71
	k_{avg} 20°C, cm/sec	---

DIRECT SHEAR TEST RESULTS

Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California







SAMPLE ID		
	Boring Number:	B-02
	Sample Number:	1B
	Sample Depth:	2.0 ft
	USCS Classification:	Silty SAND with gravel (SM): dark yellowish brown, moist

	Sample No.	A	B	C	D
INITIAL	Water Content, %	21.7%	21.7%	21.7%	
	Dry Unit Weight, pcf	101.6	102.4	102.2	
	Saturation, %	89%	90%	90%	
	Void Ratio	0.66	0.65	0.66	
	Diameter, in	2.42	2.42	2.42	
	Height, in	1.00	1.00	1.00	
FINAL	Water Content, %	19.6%	18.6%	18.3%	
	Dry Unit Weight, pcf	108.0	109.5	110.1	
	Void Ratio	0.57	0.54	0.54	
TEST SUMMARY	Deformation at Peak, %	0.13	0.13	0.13	
	Displacement Rate, in/min	0.004	0.004	0.004	
	Normal Stress, ksf	0.50	1.0	2.0	
	Peak Shear Stress, ksf	0.65	1.16	2.04	
	Min. Post-Peak Stress, ksf	0.53	0.97	1.67	

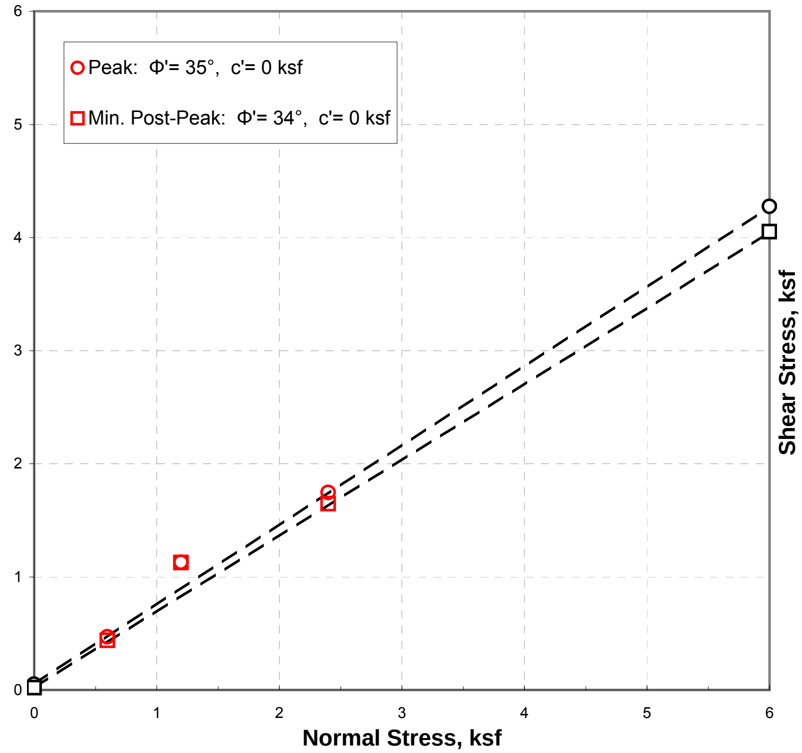
REMARKS

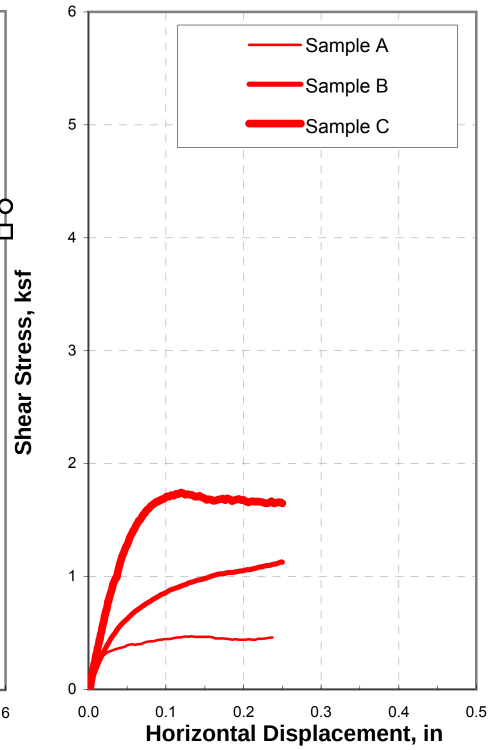
Test Method: ASTM D3080
Specimens remolded from material tested for hydraulic conductivity
Gravel removed from specimens prior to testing

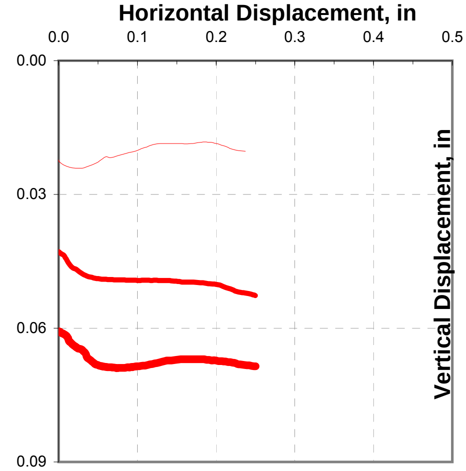
CLASSIFICATION

Sieve Size	% Passing
3/8-in. (9.5mm)	80
#4 (4.75mm)	67
#16 (1.18mm)	47
#30 (0.6mm)	38
#100 (0.150mm)	21
#200 (0.075mm)	14
Atterberg Limits	
Liquid Limit, %	---
Plastic Limit, %	---
Plasticity Index, %	---
Estimated Gs	2.71
k_{avg} 20ºC, cm/sec	---

DIRECT SHEAR TEST RESULTS
Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California







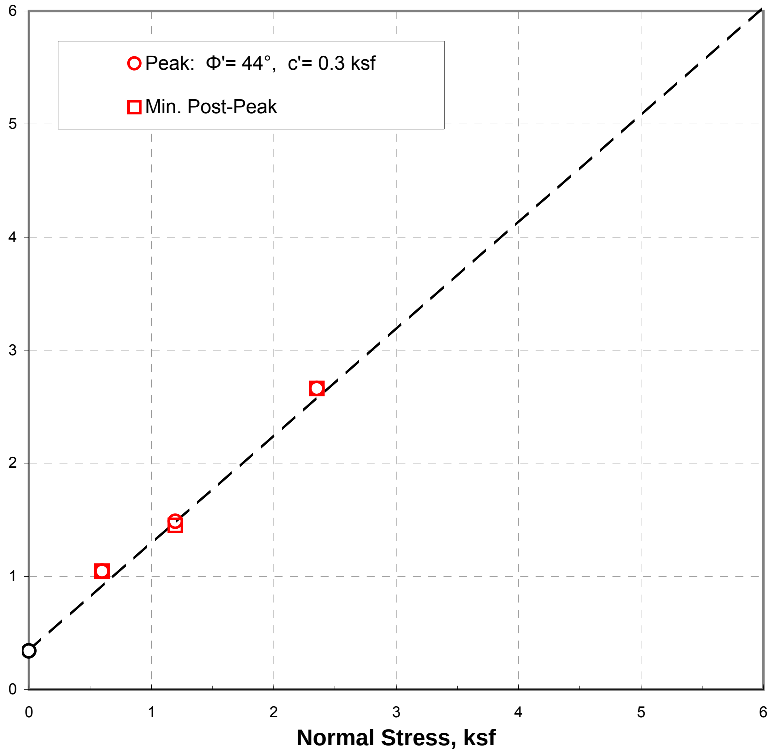
SAMPLE ID	Boring Number:	B-02			
	Sample Number:	5B			
	Sample Depth:	9.5 ft			
	USCS Classification:	Poorly-graded SAND with silt (SP-SM): pale brown, moist			
INITIAL	Sample No.	A	B	C	D
	Water Content, %	9.3%	9.3%	9.3%	
	Dry Unit Weight, pcf	91.3	93.4	92.7	
	Saturation, %	30%	32%	32%	
	Void Ratio	0.81	0.77	0.78	
	Diameter, in	2.42	2.42	2.42	
	Height, in	1.00	1.00	1.00	
FINAL	Water Content, %	24.0%	24.2%	21.3%	
	Dry Unit Weight, pcf	101.0	100.5	105.6	
	Void Ratio	0.64	0.65	0.57	
TEST SUMMARY	Deformation at Peak, %	0.13	0.25	0.12	
	Displacement Rate, in/min	0.004	0.004	0.004	
	Normal Stress, ksf	0.60	1.2	2.4	
	Peak Shear Stress, ksf	0.47	1.13	1.74	
	Min. Post-Peak Stress, ksf	0.44	1.13	1.65	
REMARKS	Test Method: ASTM D3080				

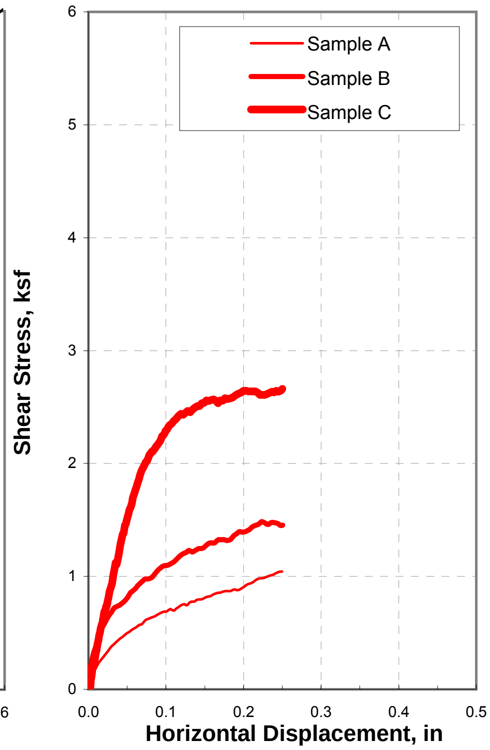
CLASSIFICATION		
	Sieve Size	% Passing
	3/8-in. (9.5mm)	100
	#4 (4.75mm)	100
	#16 (1.18mm)	95
	#30 (0.6mm)	89
	#100 (0.150mm)	33
	#200 (0.075mm)	11
	Atterberg Limits	
	Liquid Limit, %	---
	Plastic Limit, %	---
	Plasticity Index, %	---
	Estimated Gs	2.65
	k_{avg} 20°C, cm/sec	---

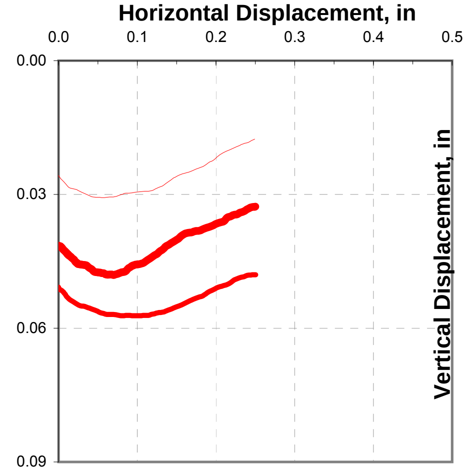
DIRECT SHEAR TEST RESULTS

Arroyo Grande Creek Levee Seepage Evaluation

San Luis Obispo County, California



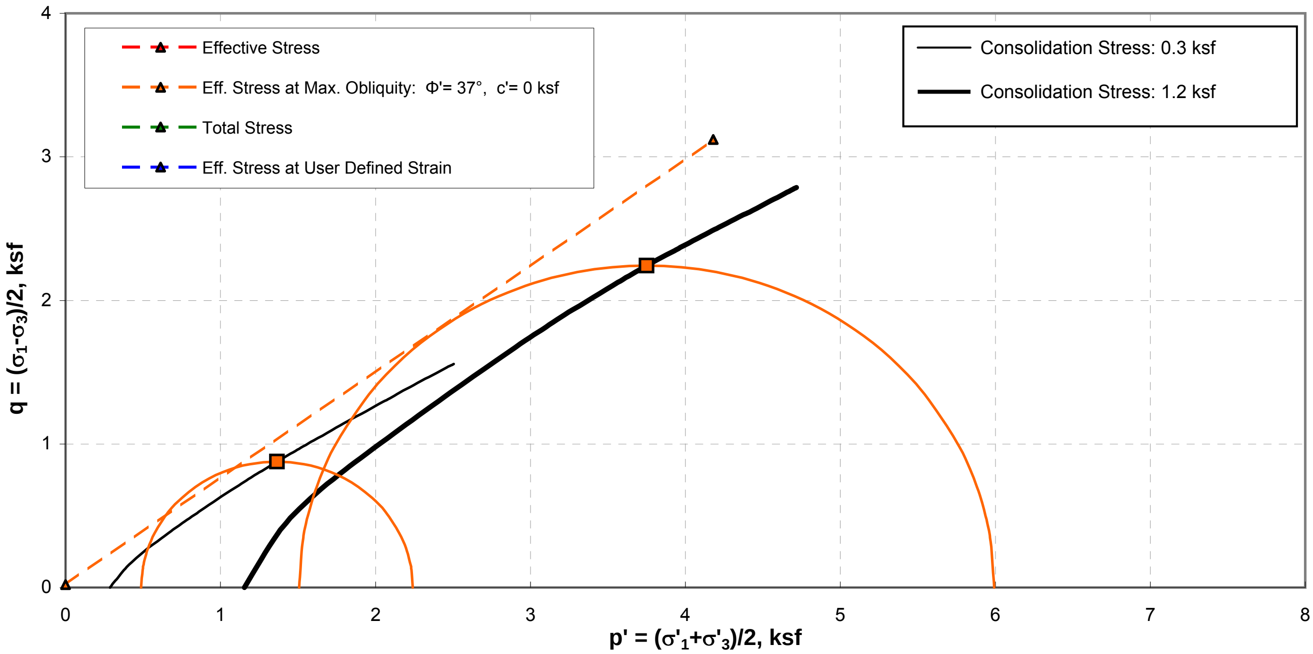




SAMPLE ID	Boring Number:	B-03			
	Sample Number:	3			
	Sample Depth:	4.5 ft			
	USCS Classification:	Silty SAND with gravel (SM): dark yellowish brown, moist			
INITIAL	Sample No.	A	B	C	D
	Water Content, %	10.5%	10.5%	10.5%	
	Dry Unit Weight, pcf	98.6	97.7	101.1	
	Saturation, %	41%	40%	44%	
	Void Ratio	0.68	0.69	0.64	
	Diameter, in	2.42	2.42	2.42	
	Height, in	1.00	1.00	1.03	
FINAL	Water Content, %	18.4%	19.6%	19.6%	
	Dry Unit Weight, pcf	110.7	109.0	108.7	
	Void Ratio	0.49	0.52	0.52	
TEST SUMMARY	Deformation at Peak, %	0.25	0.22	0.25	
	Displacement Rate, in/min	0.004	0.004	0.004	
	Normal Stress, ksf	0.60	1.2	2.4	
	Peak Shear Stress, ksf	1.04	1.49	2.66	
	Min. Post-Peak Stress, ksf	1.04	1.45	2.66	
REMARKS	Test Method: ASTM D3080				
	Gravel removed from specimens prior to testing				

CLASSIFICATION	Sieve Size	% Passing
	3/8-in. (9.5mm)	96
	#4 (4.75mm)	79
	#16 (1.18mm)	64
	#30 (0.6mm)	55
	#100 (0.150mm)	27
	#200 (0.075mm)	19
	Atterberg Limits	
	Liquid Limit, %	---
	Plastic Limit, %	---
	Plasticity Index, %	---
	Estimated Gs	2.65
	k_{avg} 20°C, cm/sec	---

DIRECT SHEAR TEST RESULTS
Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California



SAMPLE ID				
Boring Number.:	B-01	B-01	---	
Sample Number.:	1B	1B	---	
Sample Depth:	2.0 ft	2.0 ft	---	
USCS Classification:	Silty SAND (SM): pale brown, moist	Silty SAND (SM): pale brown, moist	---	

INITIAL	A	B	C
Sample No.	A	B	C
Water Content, %	5.5%	---	---
Dry Unit Weight, pcf	99.1	---	---
Saturation, %	22%	---	---
Void Ratio	0.67	---	---
Diameter, in	2.42	---	---
Height, in	5.00	---	---

PRE-SHEAR			
Water Content, %	---	23.9%	---
Dry Unit Weight, pcf	---	101.2	---
Saturation, %	---	100%	---
Void Ratio	---	0.63	---

REMARKS

Test Method: ASTM 4767 (modified for staged testing)

CLASSIFICATION

Sample No.	A	B	C
Liquid Limit	---	---	---
Plastic Limit	---	---	---
Plastic Index	---	---	---
Passing #4 (4.75 mm)	98%	98%	---
Passing #200 (0.075 mm)	27%	27%	---
Estimated Gs	2.65	2.65	---

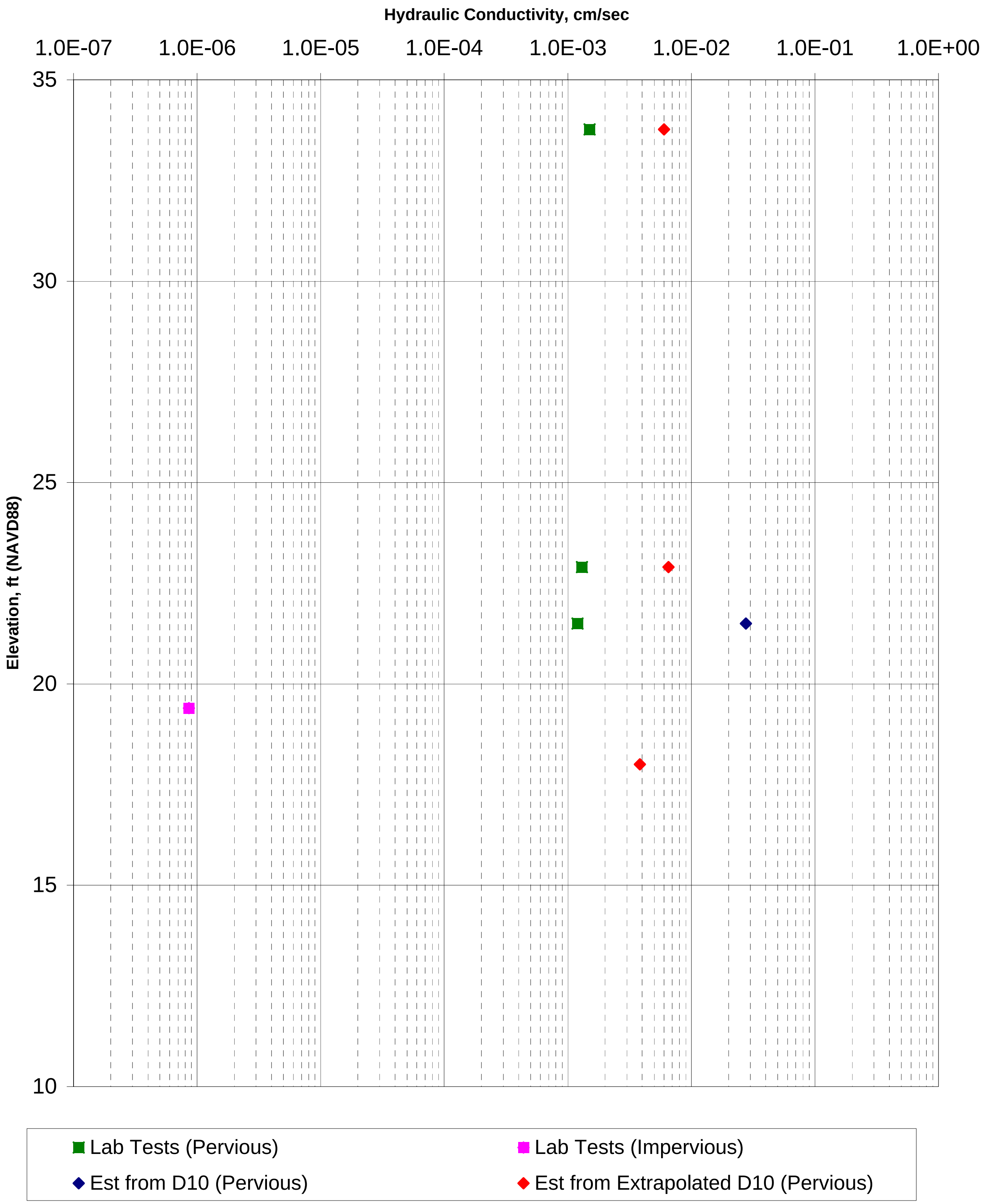
TEST SUMMARY

Sample No.	A	B	C
B-Parameter	0.95	0.95	---
t_{50}, minutes	N/A	N/A	---
Strain Rate, %/min	0.3	0.7	---
Cell Pressure, ksf	14.8	15.7	---
Back Pressure, ksf	14.5	14.5	---
Consolidation Stress, ksf	0.3	1.2	---
Deviator Stress @ Failure, ksf	1.7	4.4	---
Axial Strain @ Failure, %	1.4	3.8	---
σ'_{1F}, ksf	2.2	5.9	---
σ'_{3F}, ksf	0.5	1.5	---
Tested By:	JC	JC	---
Date Tested:	1/19/12	1/19/12	---

ISOTROPICALLY CONSOLIDATED, UNDRAINED TRIAXIAL TEST WITH PORE WATER PRESSURE MEASUREMENTS

Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

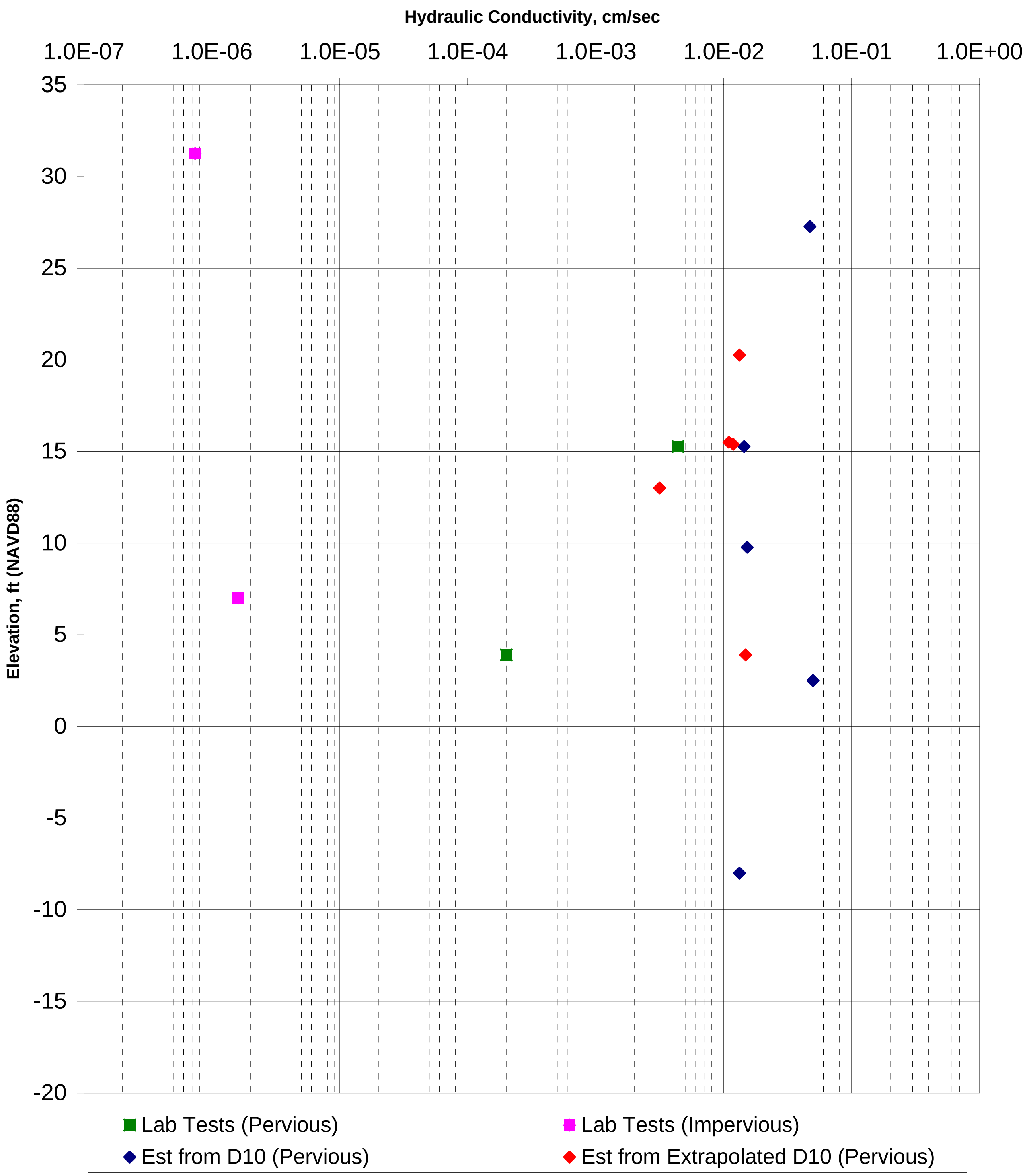
APPENDIX C



LEVEE FILL HYDRAULIC CONDUCTIVITY ESTIMATES

Arroyo Grande Creek Levee Seepage Evaluation

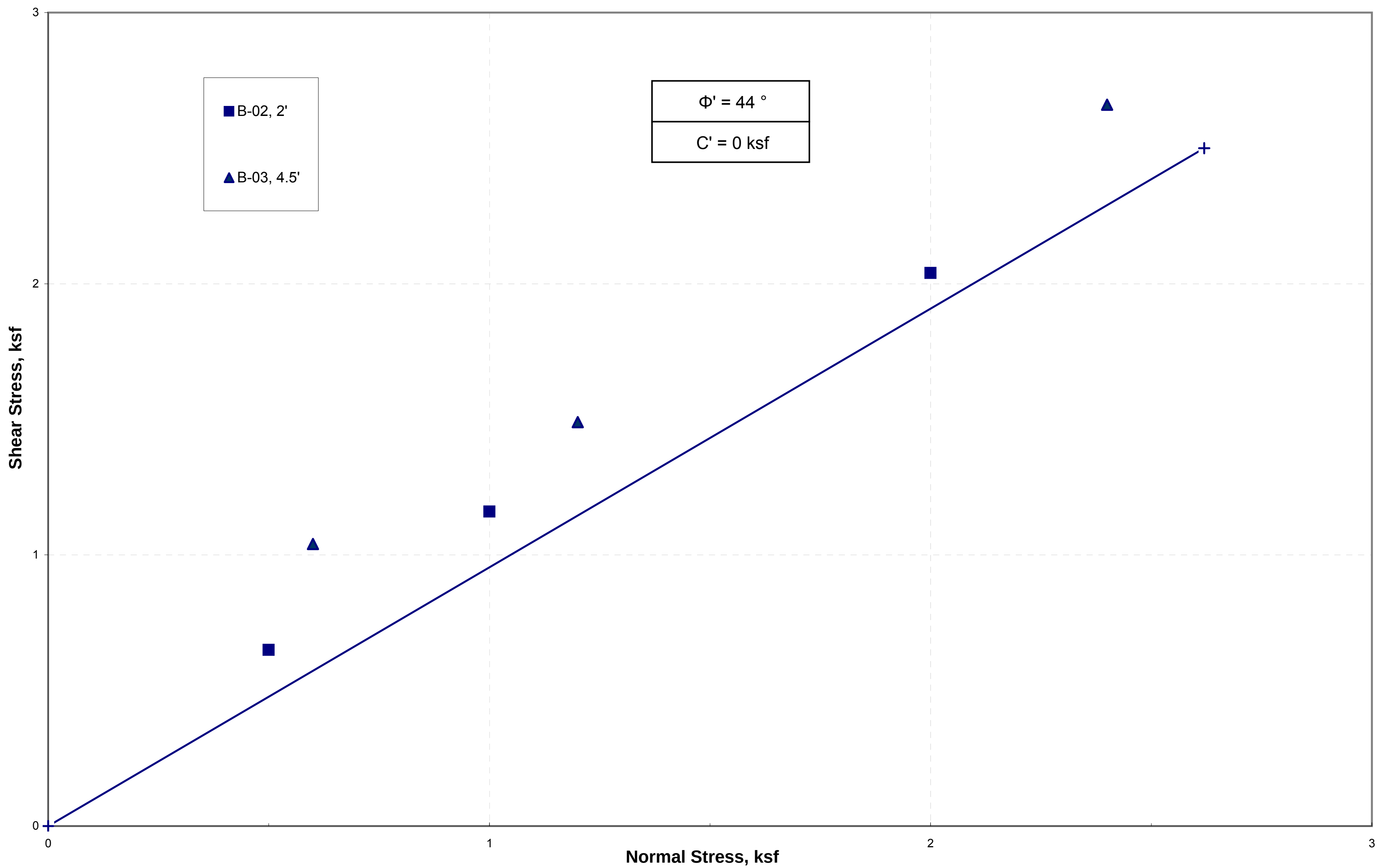
San Luis Obispo County, California



FOUNDATION HYDRAULIC CONDUCTIVITY ESTIMATES

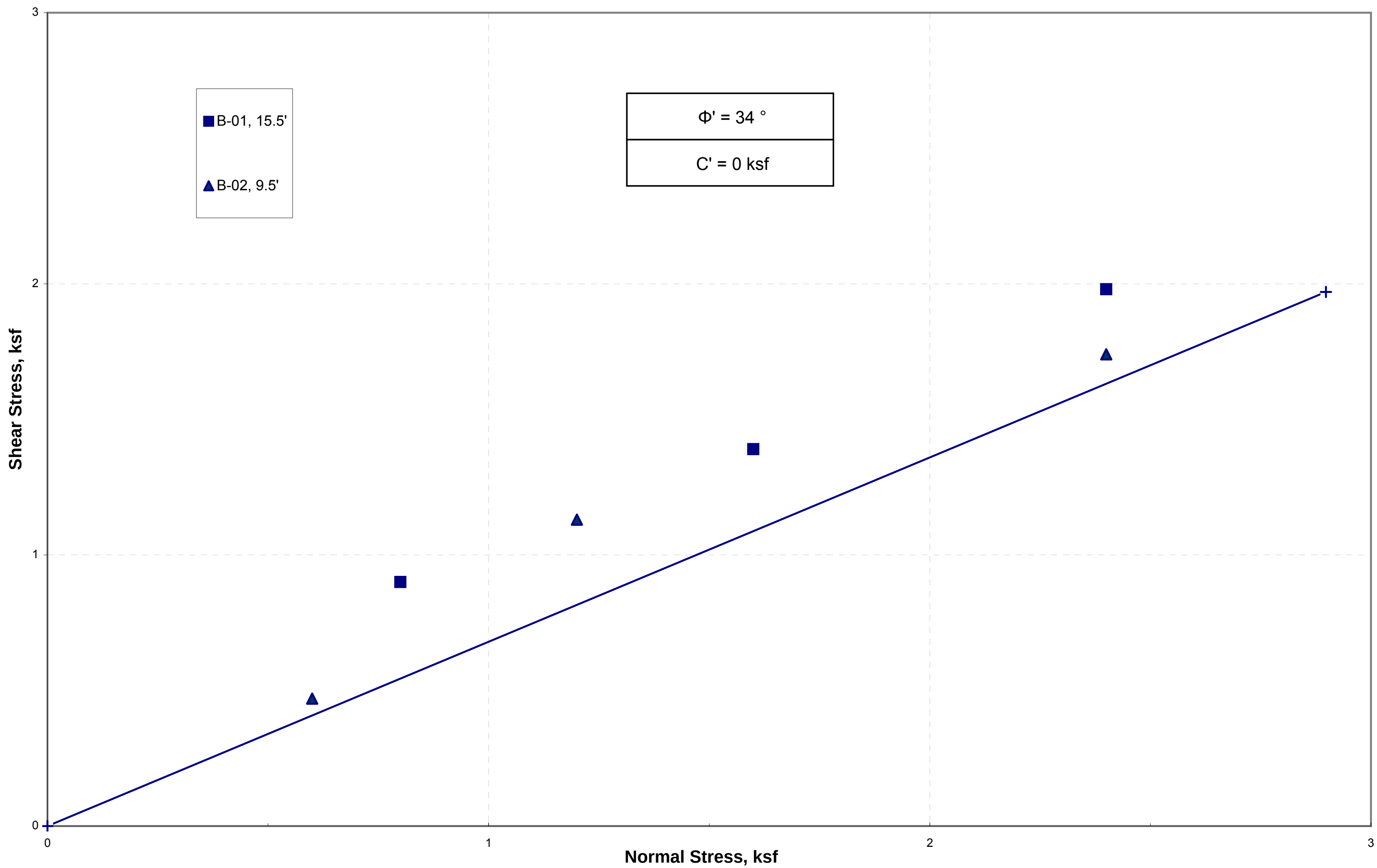
Arroyo Grande Creek Levee Seepage Evaluation

San Luis Obispo County, California



LEVEE FILL DRAINED STRENGTH ESTIMATES
Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

PLATE C-3



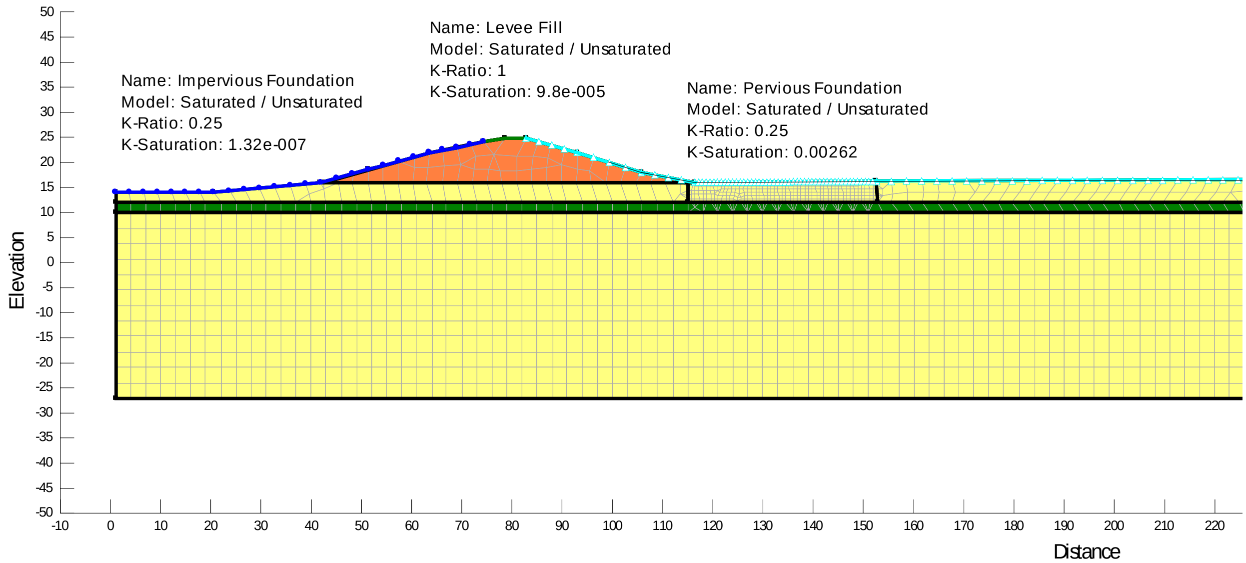
PERVIOUS FOUNDATION DRAINED STRENGTH ESTIMATES
Arroyo Grande Creek Levee Seepage Evaluation
San Luis Obispo County, California

Appendix D

SEEP/W (GRAPHICS) Section 40+00, North Levee, Arroyo Grande Creek Seepage Analysis

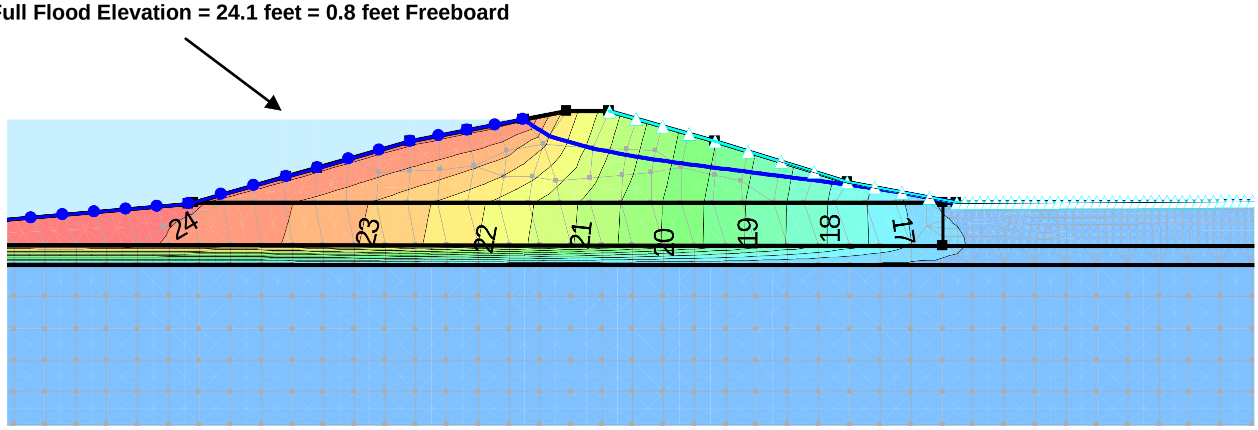
1. Full Flood Stage

Steady State Seepage Model



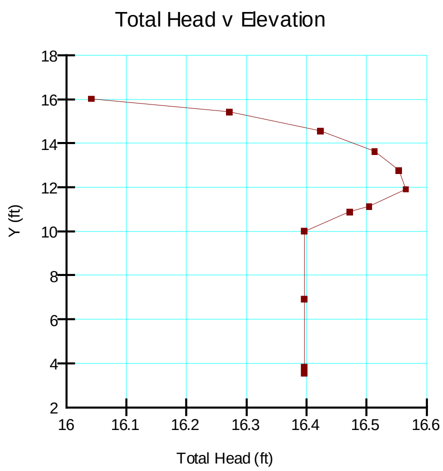
Total Head Contours (in 0.5 foot contours)

Full Flood Elevation = 24.1 feet = 0.8 feet Freeboard

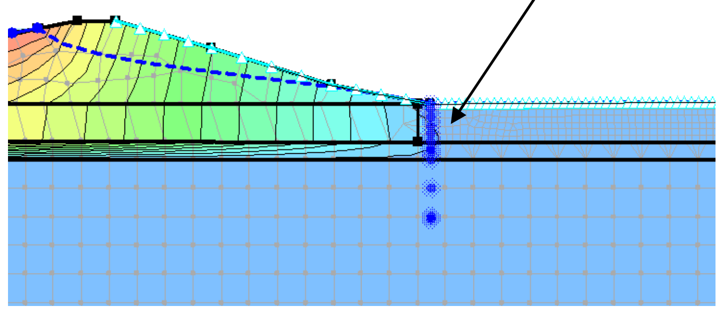


SEEP/W (GRAPHICS) Section 40+00, North Levee, Arroyo Grande Creek Seepage Analysis

Vertical Exit Gradient

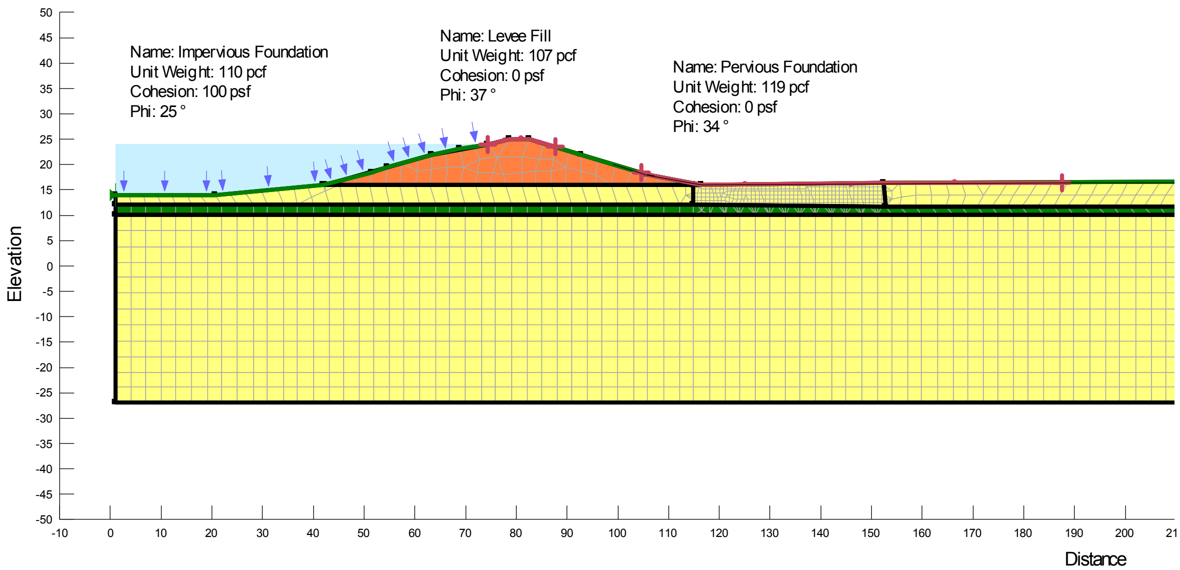


Total Head Data Points (see graph)



SLOPE/W(GRAPHICS) Section 40+00, North Levee, Arroyo Grande Creek Seepage Analysis

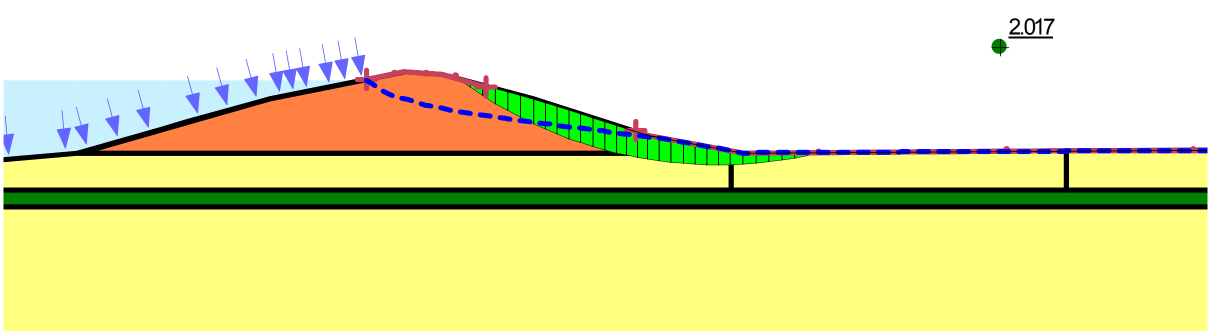
Geometry and Material Parameters



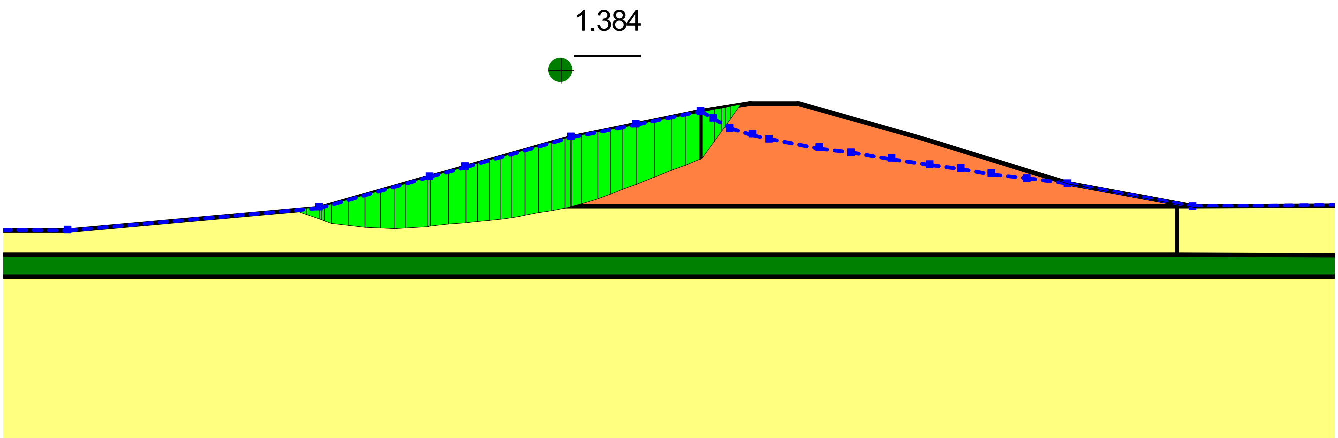
Slope Stability

Note: Pore pressures applied to slope stability analyses were estimated by seepage analyses for full flood elevation and steady-state seepage conditions.

Full Flood Exterior Slope



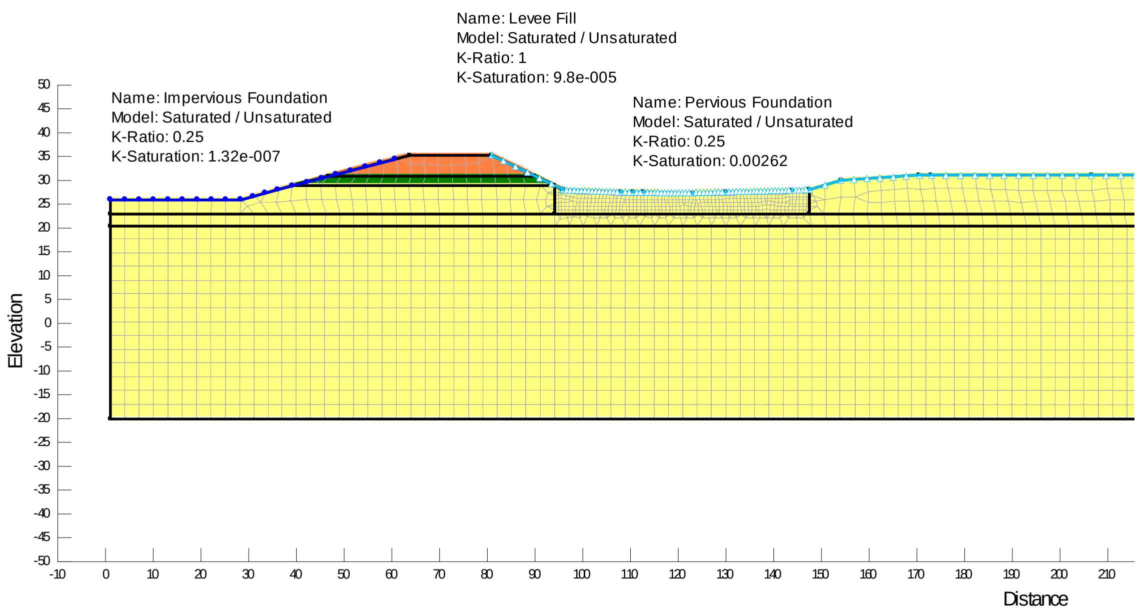
Rapid Drawdown Interior Slope



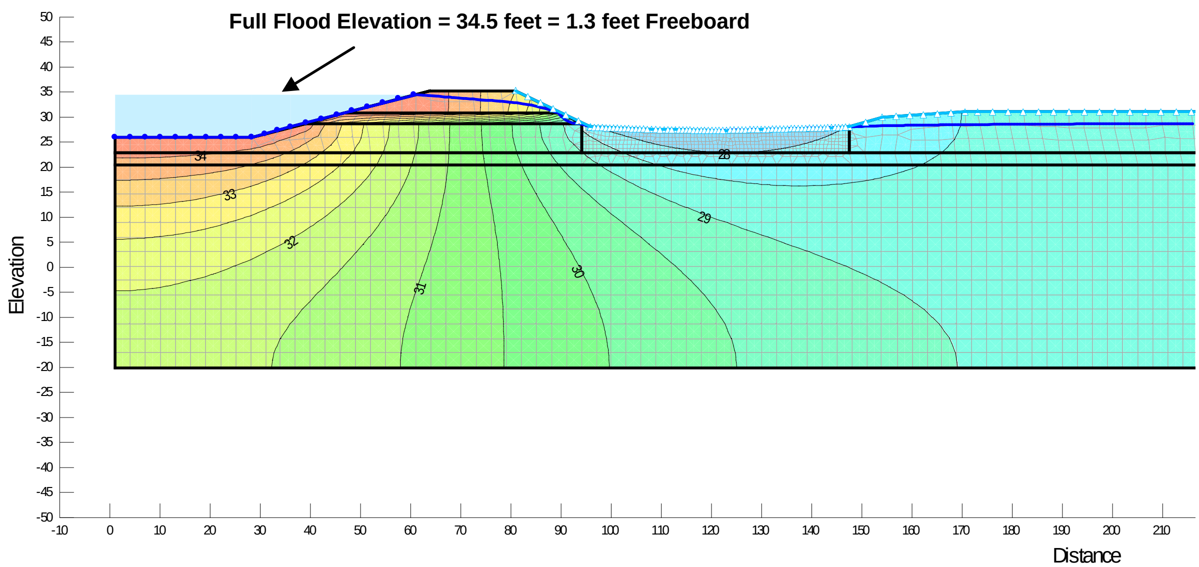
SEEP/W (GRAPHICS) Section 80+00, North Levee, Arroyo Grande Creek Seepage Analysis

1. Full Flood Stage

Steady State Seepage Model

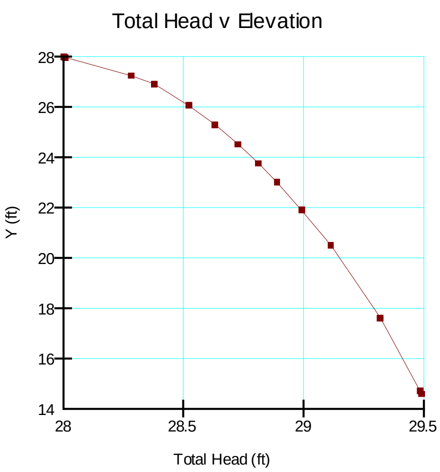


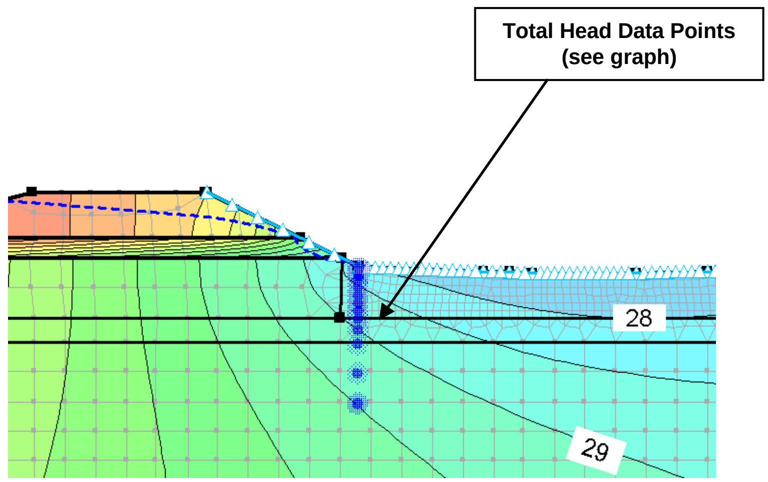
Total Head Contours (in 0.5 foot contours)



SEEP/W (GRAPHICS) Section 80+00, North Levee, Arroyo Grande Creek Seepage Analysis

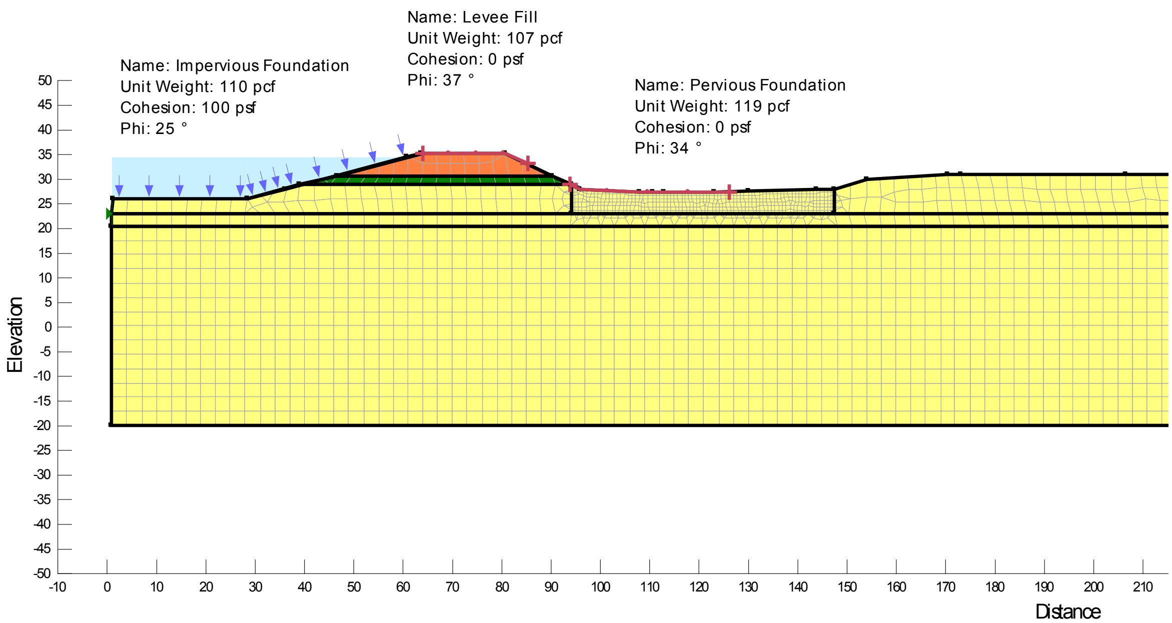
Vertical Exit Gradient





SLOPE/W (GRAPHICS) Section 40+00, North Levee, Arroyo Grande Creek Seepage Analysis

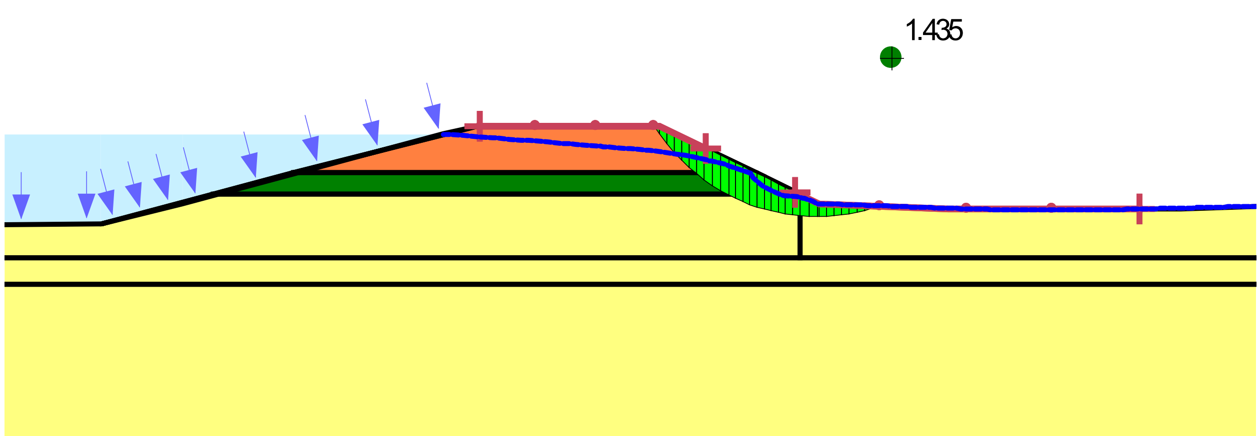
Geometry and Material Parameters



Slope Stability

Note: Pore pressures applied to slope stability analyses were estimated by seepage analyses for full flood elevation and steady-state seepage conditions.

Full Flood Exterior Slope



Rapid Drawdown Interior Slope