GEOTECHNICAL LOGS AND DATA FROM PERMANENTLY INSTRUMENTED FIELD SITES: GARNER VALLEY DOWNHOLE ARRAY (GVDA) AND WILDLIFE LIQUEFACTION ARRAY (WLA)

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Report to

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1. Introduction

The George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES) is an organization of 15 equipment sites dedicated to advancing earthquake research through open access to newly developed laboratory facilities and cooperation between broad groups of investigators. The NEES Charter states that its purpose is to provide a national, networked, simulation resource "that includes geographically-distributed, shared-use, next-generation experimental research Equipment Sites built and operated to advance earthquake engineering research and education through collaborative and integrated experimentation, theory, data archiving, and model-based simulation. The goal is to accelerate progress in earthquake engineering research and to improve the seismic design and performance of civil and mechanical infrastructure systems through the integration of people, ideas, and tools in a collaboratory environment. Open access to and use of NEES research facilities and data by all elements of the earthquake engineering community, including researchers, educators, students, practitioners, and IT experts, is a key element of this goal" (http://www.NEES.org/NCI/purpose.html)."

Two field sites, the Wildlife Liquefaction Array (WLA) and the Garner Valley Downhole Array (GVDA), were developed by Principal Investigators from Brigham Young University (T. Leslie Youd), the University of California at Santa Barbara (Jamison H. Steidl) and the University of Southern California (Robert L. Nigbor) as NEES Equipment sites. These sites have been upgraded, re-instrumented, and integrated into the NEES system. Youd et al. state that these sites are "key elements in the NEES system" and that they "will provide data from monitored responses generated by earthquakes and by active experiments using shakers. These sites will also provide beds for testing of new in-situ characterization techniques and for development of new sensor technologies. The telepresence and teleparticipation capabilities of the sites will provide opportunities for collaborative research and educational interaction. The continuous streaming of data to the NEES data repository and the Advanced Network of Seismic Stations (ANSS) repository will provide ready access to the collected data" (Youd et al., 2004).

1.1 Scope

In this report, we introduce the two NEES field sites, WLA and GVDA, describe field and laboratory geotechnical investigations, document the results of those investigations, and provide guidance for retrieving the test data and results. The data and results are embedded in interactive ArcView maps for each site with internal hyperlinks to CPT logs, borehole logs with test results and diagrams of installed instrument casings, photographs of the sites and retrieved split spoon samples, laboratory test data, permeability test data, and P- and S-wave velocity data and profiles. These field and laboratory test results and data are also organized in separate folders in an appendix, which is contained on a CD in the back of this report. Each document can be accessed either through the links on the GIS maps or through retrieval of folders from the Appendix. Field and laboratory data from previous investigations have been collected and published from these two sites (Bennett et al, 1984; Steidl, et al., 1998); this information is not reproduced here. The reader is referred to the published references for that data.

Several software programs are required to access the geotechnical data that is embedded in the GIS maps and stored in the Appendix, including ArcView 9.0, Microsoft Word, Microsoft Excel, Adobe Reader 6.0, and software that will open jpeg picture files.

2. Site Histories and Lessons Learned from GVDA and WLA

2.1 GVDA

The Garner Valley Downhole Array (GVDA) is located in southern California at a latitude of 33^{o} 40.127’ north, and a longitude of 116^{o} 40.427’ west. The instrument site is located in a narrow valley within the Peninsular Ranges Batholith 23 km east of Hemet and 20km southwest of Palm Springs, California. GVDA is located in a seismically active region of California that is within 7 km of the San Jacinto fault and within 35 km of the San Andreas fault. Historically, the San Jacinto is the most active strike-slip fault system in southern California, with a fault slip rate of 10 mm/yr and an absence of large earthquakes since at least 1890. The San Jacinto fault has a relatively high probability for magnitude 6.0 or larger earthquake in the near future (Youd et al, 2004).

The near-surface stratigraphy beneath GVDA consists of 18-25 m of lake-bed alluvium overlying approximately 70 m of weathered granite which transitions into unweathered granitic bedrock. Sediments in the upper 18-25 m consist of alternating layers of sand, silty sand, clayey sand, and silty gravel. The alluvium gradually transitions into decomposed granite in the depth interval between 18 m to 25m. The decomposed granite classifies as gravely sand (Steidl et al., 1998; Youd et al. 2004). Analyses of CPT and SPT data indicate the much of the granular sediment in the alluvium and upper decomposed granite is liquefiable if shaken by a magnitude 7 or greater earthquake with peak acceleration of 0.4 g or greater.

Instrumentation of the GVDA site began in 1989. By the beginning of the NEES project in November 2002, the seismic array consisted of six downhole accelerometers at depths of 6 m, 15 m, 22 m, 50 m, 220 m and 500 m and five surface accelerometers placed in a linear array 250 m long which is bisected by the downhole array. Two accelerometers were also placed at a remote rock site, one at ground surface and the other in a borehole at 30 m depth. One additional accelerometer, at a depth of 150 m, was placed in 2004 as part of the NEES equipment augmentation. All of these instruments are operational and have been incorporated into the NEES field laboratory (Youd et al, 2004; Steidl et al., 1998; Archuleta and Steidl 1998).

Several electronic piezometers were installed in the lake-bed alluvium and weathered granite prior to 2002, but those instruments failed either due to water seepage into the electronics or from electrical overload during lightning strikes.

Important findings reported by Archuleta and Steidl from ground motions recorded at GVDA include: (1) “One of the simplest, yet demanding, tests for the accuracy of our knowledge of the subsurface [geologic] structure is to compare theoretical accelerograms with records from small earthquakes” (1998). At GVDA, good matching has been achieved between the measured accelerations caused by small quakes and the calculated theoretical accelerations. (2) Concerning the applicability of borehole recordings at GVDA to other sites, Archuleta and Steidl (1998) note that the general applicability of these recordings is good except near frequencies where destructive interference occurs between the incoming wave field and the surface reflections. As long as amplifications near these frequencies are considered with skepticism, the borehole records provide excellent input motion for the studies of site effects. The frequencies at which destructive interference occurs can be computed from the equation $f = V_s / 4H$ where V_s is the shear wave velocity between the surface and depth H, and H is the depth of the sensor.

2.2 WLA

The Wildlife Liquefaction Array (WLA) was instrumented in 1982 by US Geological Survey personnel (Bennett et al., 1984; Youd and Holzer, 1994). This research site is located in the Imperial Wildlife Area, a California State game refuge, at latitude of 33^o 05.843' north, and a longitude of 115^o 31.827' west. The site is approximately 13 km due north of Brawley, California and 160 km due east of San Diego. WLA is in a highly active seismic area, where 6 earthquakes with the past 75 years generated observed liquefaction effects within 10 km of the instrumental array.

The 1982 instrumentation consisted of one surface and one downhole force-balance accelerometer (FBA) and six electrically transduced piezometers. The downhole accelerometer, at a depth of 7 m is immediately below a 4-m thick liquefiable layer. Five of the six piezometers placed at the site were set within the liquefiable layer (Bennett et al., 1984; Youd and Holzer, 1994).

The WLA instruments recorded accelerations above and below the liquefied layer, and pore water pressures within that layer during the 1987 Superstition Hills earthquake (Holzer et al, 1987). Youd et al. (2004) note four major lessons learned from the Wildlife site and its recordings: (1) soil softening led to lengthening of period of transmitted ground motions; (2) soil softening also led to attenuation of short-period spectral accelerations (< 0.7 sec); (3) amplification of long period motions (> 0.7 sec) occurred due to liquefaction-induced ground oscillation; and (4) ground oscillation led to a continued rise of pore water pressures after strong ground shaking ceased" (Youd et al. 2004).

Youd et al. (2004) note that "since 1987, the piezometers installed in 1982 have failed and the site has been disturbed by additional investigations. Because of this deterioration, the decision was made to reestablish WLA for the NEES project at a new locality about 65 m down river (northward) from the 1982 USGS site." The new site provides a large clear area within rather dense tamarisk brush for placement of instruments and a site in closer proximity to the incised Alamo River to enhance potential for lateral ground deformation during liquefaction events.

3. Geotechnical Investigations

The following subsurface investigations were performed at GVDA and WLA to define the subsurface stratigraphy at each site and measure soil properties. Five CPT soundings were placed at GVDA and 24 CPT soundings were placed at WLA to define the stratigraphy. Seismic velocity tests were conducted in one CPT sounding at GVDA and two soundings at WLA to measure P- and S-wave velocities. Depths of the soundings for seismic velocity measurements were about 18 m. The other soundings reached depths of 8 m to 12 m. Thirteen boreholes were drilled at GVDA and 24 boreholes were drilled at WLA for placement of casings. SPT tests were conducted in many of these holes and Shelby tube samples were taken from one hole at each site. One additional hole solely for SPT testing (SPT1) was drilled at GVDA. Split-spoon samples were retrieved from each SPT test for laboratory index testing and soil classification. An OYO suspension seismic velocity probe was lowered to 100 m in the deep accelerometer hole at WLA (before it was cased) to log P- and S-wave velocities. Results from these investigations are discussed in later sections of this report.

4. New instruments Placed at GVDA and WLA

The Garner Valley site is primarily a ground motion research site. However, some of the lake-bed and weathered granite sediments are liquefiable. Thus, four electrically transduced piezometers were placed in those layers to measure pore-water response during future earthquakes. Also, a new accelerometer was placed at a depth of 150 m in a cased borehole to supplement the existing downhole array. A one-story soil-foundation-structure-interaction (SFSI) structure was constructed at the site for the study of dynamic response of this structure during earthquakes and during excitation of the site with mechanical shakers. In summary this site now incorporates seven downhole accelerometers at depths of 6m, 15 m, 22 m, 50m, 150 m (new NEES instrument), 220 m, and 500 m. Four piezometers at depths of 4.0 m, 6.0 m, 8.5 m, 12.3 m. Casings for one standpipe piezometer, one deep bench mark, and six slope inclinometer tubes were also placed at the site.

WLA is a ground motion monitoring and liquefaction research site. New infrastructure at this site includes cased drill holes for (1) five downhole strong ground motion accelerometers at depths of 2.4 m, 4.8 m, 7.2 m, 30 m and 97 m; (2) eight electrical piezometers at depths ranging from 2.7 m to 6.3 m; (3) two standpipe piezometers to depths of 4.5 m; (4) five slope inclinometer casings to depths of 10 m; and (5) three flexible casings set at depths of 10 m for measurement of permanent lateral ground displacement.

5. GIS Map with Inserted Links to Geotechnical Test Data and Appendix Navigation

Proctor (2004) created the base GIS maps and the links to CPT and borehole logs. Bartholomew (2004) added links to the geotechnical test data. Proctor's report includes simple instructions to navigate the features on the GIS maps. One feature for which reader understanding is vital to access the geotechnical data is the hyperlink feature. The following section, reproduced from Proctor's report, contains directions for accessing hyperlinks embedded in the map document.

The first step in accessing the hyperlinked documents is to choose the hyperlink tool form the Tools toolbar. This is the lighting bolt tool (fig. 1). When pressed, this button displays in blue all points, lines, and polygons that have linked documents. To access these links one places the curser above the blue item of interest and waits for the lightning bolt to change to a hand (fig. 2). A left click of the mouse will then bring up whatever document is linked to that item or, if there are multiple documents linked, a menu will appear from which the desired document can be selected from the complete list of documents attached to the feature. A screen shot of this window is shown in figure 3. Choosing the button "Jump" will open whichever document is currently highlighted.

Figure 1
Main toolbar
(Proctor, 2004)

To illustrate this procedure, the following steps bring up the document highlighted in figure 3, which is a picture file with results from an analysis of liquefaction susceptibility for various peak accelerations. The directions to find liquefaction

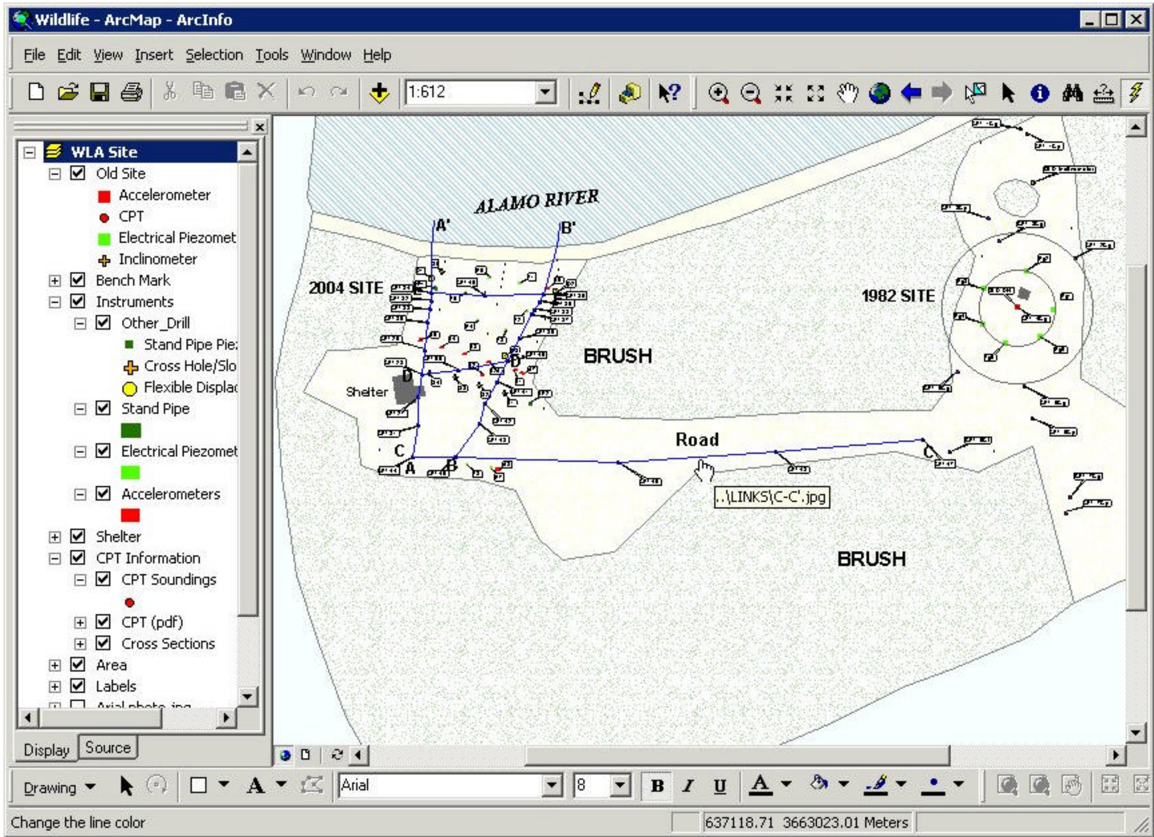

Figure 2 Allow the cursor symbol to rest over the desired element; when the symbol changes to a hand left click the mouse to access the linked files (Proctor, 2004)

susceptibility results read as follows. Open the WLA map with ArcView 9.0, choose the hyperlink lighting bolt tool from the “Tools” toolbar (fig. 1), find the CPT point which is labeled “CPT 49,” left click on this point, choose the document titled “CPT 49.jpg.” A shorter notation of these directions is:

- WLA (map); CPT 49 (point); CPT 49.jpg (document)

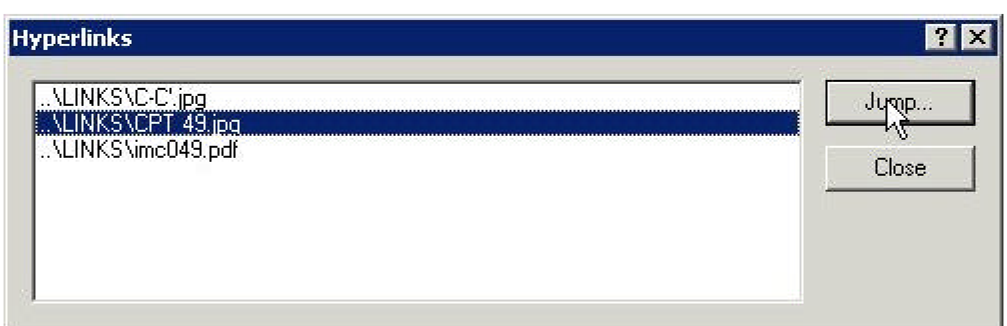

Figure 3 Multiple hyperlink window (Proctor, 2004)

Caution: all of the themes for one GIS layer type must be turned on for all of the linked documents to be available. Note in figure 2 that all of the “CPT Information” themes, “CPT Soundings,” “CPT (pdf),” and “Cross sections,” are turned on with check marks next to their names. If one of these themes were turned off (no checkmark next to the name), then only two of the three links associated with this CPT point would be accessible.

Names of the linked documents are recorded as an entry in the Attribute Table for the point, line, or area to which they are linked. The attribute table can be accessed as shown in figure 4 by right clicking on the feature’s theme and choosing “Open Attribute Table” from the menu that appears. The name of the linked documents will appear in those fields with the word link in their name. Once the name of the desired document is known, the document itself can be accessed in the folder named “Links” with a file explorer. Because the WLA and GVDA have separate maps, the folder of linked documents is also separate. These folders are accessed through path addresses (listed below). Figure 5, which displays the Appendix folder structure, demonstrates the use of a path address.

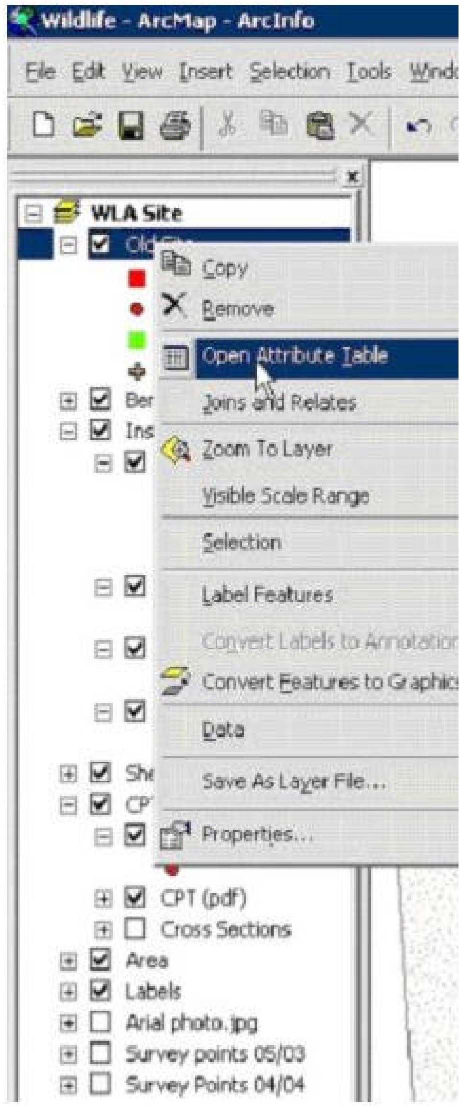

Figure 4 Opening the attribute table (Proctor, 2004)

- …\Appendix\GIS Maps\Garner Valley\Links
- …\Appendix\GIS Maps\Wildlife\LINKS

Every geotechnical document that is linked to either WLA or GVDA maps is also collected and organized separately in the Appendix. The appendix folder structure is shown in figure 5. Path names are given in each section for accessing the particular data discussed in that section and their process can be seen in this diagram. For example the path name "…\Appendix(a)\SPT Data(b)\GVDA(c)\Borehole Logs(d)" is demonstrated in figure 5.

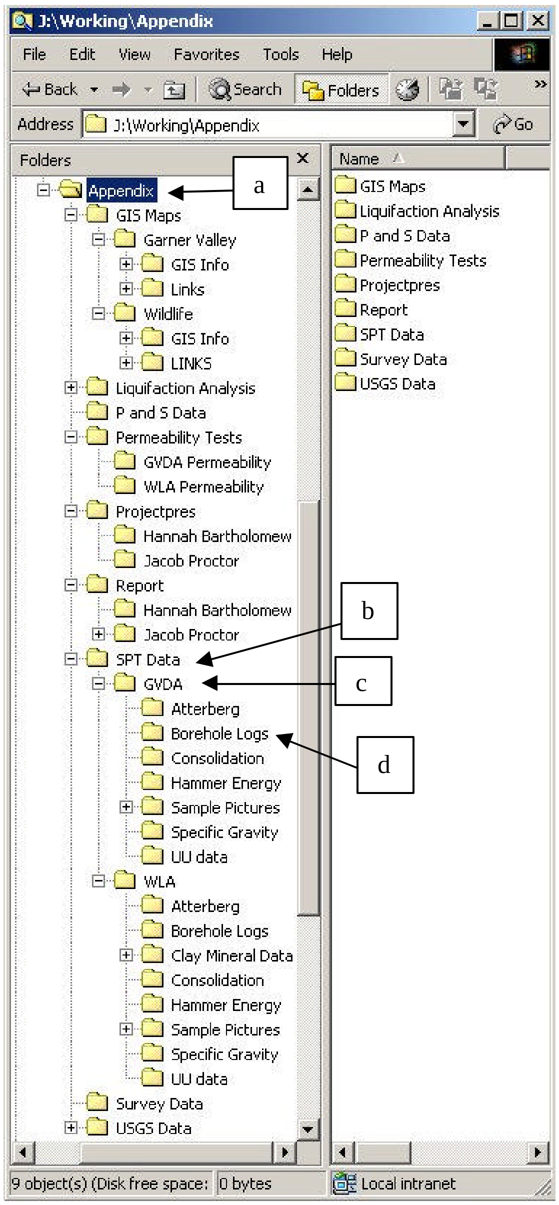

Figure 5 Appendix file structure

6. Field and Laboratory Test Data

The previous sections have introduced the two NEES sites, their improvements, and the navigation of the Appendix that is on the CD that is attached to the back cover of this document. Specific instructions for retrieving data from the WLA and GVDA geotechnical investigations are given in the following sections describing the field and laboratory tests conducted. Some of the details of the tests are applicable to both sites. These details and an outline of the tests conducted are discussed in following sections.

7. CPT And SPT Penetration Resistance Measurements

CPT tests were preformed according to ASTM D 3441-86 (Standard Test Method for Performing Electronic Friction Cone and Piezocone Penetration Testing of Soils). The tests were performed by Thomas Noce, USGS, using the USGS CPT rig. The CPT devices used were subtraction cones, one with capability for pore-water pressure and another with capability for seismic wave velocity measurements. Pore pressure measurements were made in two soundings at WLA (CPT32 and CPT40). P- and S-wave velocity measurements were made in two soundings at WLA (CPT31 and CPT38) and one sounding at GVDA (CPT1).

SPT tests were preformed according to ASTM D 1586-84 procedures. Liners were used in the split-spoon sampler for all of the tests. The liners were 1-3/8 in internal diameter tubes that were capped in the field with the sediment inside and then transported to the Soil Mechanics Laboratory at Brigham Young University where the samples were later extruded, photographed and tested.

The hammer used in the SPT was a Longyear auto safety hammer. This hammer is characterized by an average energy ratio of about 90 percent. This energy ratio is much higher than the average of 60 percent for typical rope and cat-head driven hammers used in the US. The energy ratio of 60 also forms the basis for the energy correction for calculation of the corrected and normalized blow counts, $(N_1)_{60}$. To generate an energy ratio near 60 percent and to increase the sensitivity of the SPT test in low blow-count sediments, the drop height for the SPT tests was reduced to 25 inches by the inclusion of a five-inch sleeve in the safety hammer mechanism. This reduction in drop height led to an equivalent hammer energy ratio very near 60 percent. All of the SPT tests at GVDA and WLA were made with a 25 in drop height, except a few tests in Borehole X2 at WLA, where the height was varied to calibrate the hammer energy for versus drop heights as discussed below.

The data acquisition system used for the hammer energy tests at GVDA was manufactured by Northwood Instruments. The hammer energy was measured for nearly all of the hammer drops in one borehole (SPT 1) on November 13, 2003. The operator of the equipment, Tim Boyd, Pitcher Drilling Co., reported "some difficulty with the performance of the SPT energy calibration equipment (specifically pre-triggering of the equipment and difficulty in balancing the load cell)" (…\Appendix\SPT Data, this report; Boyd, 2004). Rain fell throughout the day of the calibration test, which also may have adversely affected the energy measurements. Although the measured energies appeared reasonable (50 to 60 percent), to assure accurate results Mr. Boyd requested that additional energy measurements be made at WLA with a Model PAK Pile Driving Analyzer (SPT energy calibration data acquisition system manufactured by PDI, Inc.) operated by personnel from GRL Engineers. The additional hammer energy measurements were made in borehole X2 at WLA on November 21, 2003 (Alvarez and Berger, 2003). The reports and data from these tests are contained in the appendix.

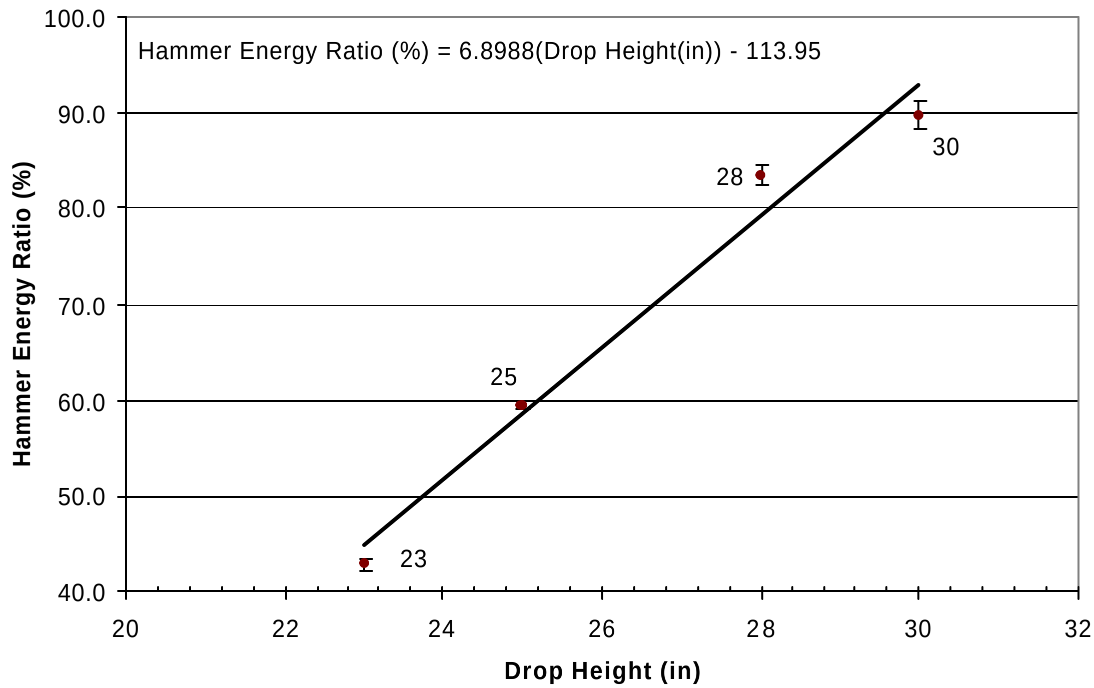

Figure 6 Hammer energy ratio (based on 30-in drop) versus drop height

The drop height for energy measurements at WLA was initially set at 25 in, and energy measurements collected during SPT tests at depths of 9 ft, 12 ft, 15 ft and 18 ft. Twenty-one consistent energy ratios between 58 percent and 63 percent were obtained from the hammer drops for the SPT test between 18.5 ft and 19.5 ft depth. (Seating blows and blows from tests less than 18 ft deep generally had smaller energy ratios and were not used in the comparisons noted below.) The borehole was then drilled to a 21 ft depth and cleaned. The drop height for hammer blows was adjusted to drop heights of 23 in, 28 in, and 30 in, respectively, with several blows at each during the SPT test between 21 ft and 22.5 ft. Energy ratios measured during these tests varied with drop height as plotted on figure 6. During an additional SPT test between 24 and 25.5 ft the drop height was reset to 25 in; measured energy ratios during this SPT test ranged from 59 to 61 percent. From these experiments, a plot was made of calculated hammer energy ratio (based on a 30-in drop) versus drop height (fig. 6). This plot indicates a roughly linear relationship, with a drop of 25 in producing an average hammer energy ratio of 59-60 percent (fig. 1, \Appendix\SPT Data\WLA\Hammer Energy\X2_Hammer_E.rtf, this report).

8. P- And S-Wave Velocity Measurements

In addition to the downhole seismic CPT velocity, an OYO suspension logger, operated by Mr. Rob Steller, GeoVision, Inc., was used to seismically log the deep accelerometer borehole (A5) at WLA prior to installing the PVC casing. A description of this instrument is given on the GeoVision, Inc web site: http://www.geovision.com/borehole.html. No ASTM standard applies to downhole or suspension logging for P- and S-wave velocity, but conventional procedures applied in engineering practice were used for the seismic CPT and OYO suspension logging tests.

9. Permeability Tests

Field permeability tests were conducted in all of the casings for piezometers, except P7 at WLA and P4 at GVDA. The casings for piezometers at both GVDA and WLA consisted of 2-in diameter PVC pipe with 1-ft long slotted sections at the lower end of each casing. The slotted section allows water to enter of leave the casing as water pressures change either within the ground or within the casing. These casings were later equipped with pore pressure transducers to continuously measure ground water pressures, including pressures during future earthquakes. For the permeability tests, the pressure transducers were lowered to a position about 1.5 ft (0.5 m) above the bottom of the casing. The casing was then filled to the top with clean water and the water level allowed to fall as water seeped into the soil through the slotted sections of casing. Pressure versus time records were electronically recorded for tests in each piezometer casing. A minimum of 15 min of record was collected for each test. The static water level in each casing was measured with a tape prior to the tests to provide initial or static water level data.

The lengths of slotted sections of piezometer casing were the same for all installations. During the installation of the casings, as described later in the field installation section, 0.15 m diameter and 0.4 m to 0.6 m long sand packs of Monterey sand (particle diameters between 4.74 and 0.85 mm with mean of 1.00 mm) were placed around the slotted sections of casing. The length and diameter of this sand pack is taken as the length and diameter of the calculation of hydraulic conductivity, k. The following equation was used for this calculation (Cedergren, 1989):

$$k(cm/s) = \frac{r^2}{2 * L * (t_2 - t_1)} * \ln\left(\frac{L}{R}\right) * \ln\left(\frac{H_1}{H_2}\right) * 100 \qquad \text{Eq (1)}$$

where r is the radius of the casing, R is the radius of the sand pack, L is the length of the sand pack, t_1 and t_2 are times at the beginning and end of the interval of record used in the calculation, and H_1 and H_2 are water heights above the static water level corresponding to t_1 and t_2.

Equation (1) was programmed into an Excel Spreadsheet. These sheets and the derived plots of hydraulic conductivity versus time are contained in a file in the Appendix entitled “Permeability Tests” (…\Appendix\Permeability Tests). An example plot is reproduced in figure 7. Calculations of hydraulic conductivity were made from head changes during both 15 sec and 60 sec time intervals across the entire time record.

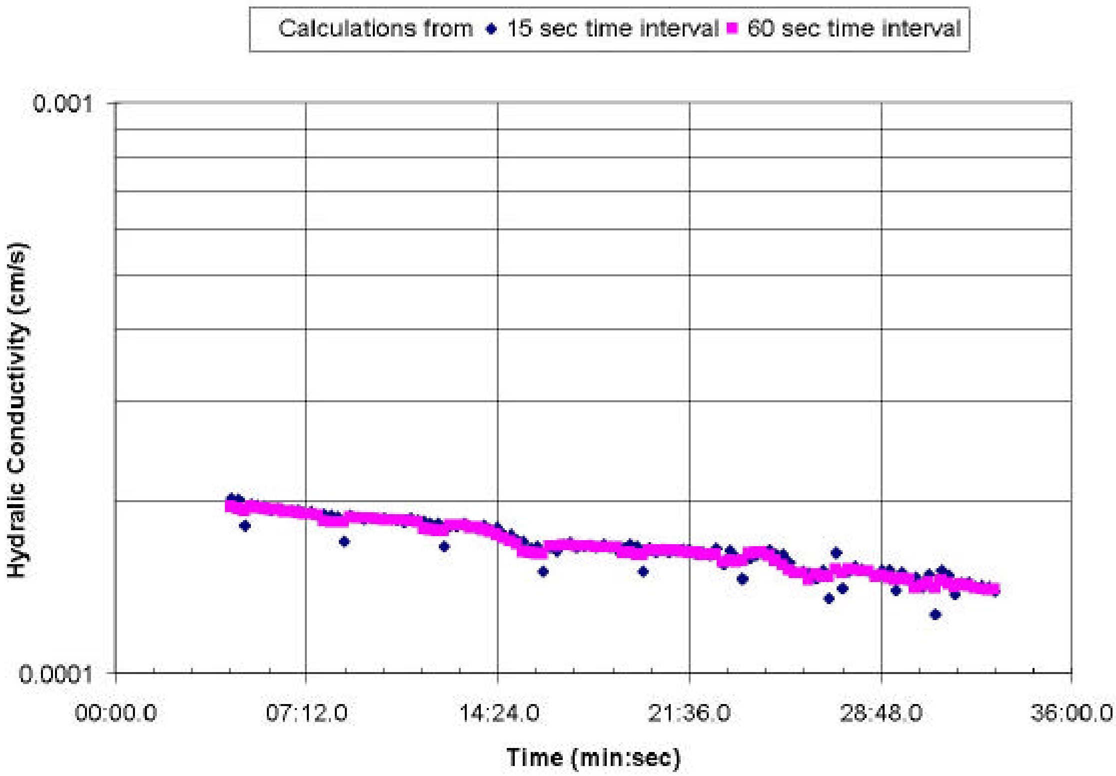

Figure 7 Calculated hydraulic conductivity from test in piezometer casing P4 at WLA

Theoretically, the calculated hydraulic conductivities should be constant with head and time, but most of the plots indicate slight decreases of hydraulic conductivity with decreasing head. At the end of the tests, when head differences were small (in the millimeter range), the calculated hydraulic conductivities tend to become erratic. Cedergren (1989) suggests that only the first approximately one-third of the time record be used in the calculations. Using this suggestion, the plots provide hydraulic conductivity values consistent with the general accuracy of field or laboratory tests. As a further check, the calculated hydraulic conductivities were compared with tabulated hydraulic conductivity values in textbooks for various soil textures. For example, the calculated hydraulic conductivity for WLA P4, plotted on figure 7, is about $2x10^{-3}$ cm/sec; this value is typical for "very fine sands, organic and inorganic silts, and mixtures of sand silt an clay, (Terzaghi and Peck, 1967), which is the type of soil (ML) at the bottom of the hole into which the casing was placed.

10. Field Installations

10.1 Piezometer Casings

The procedure for installation of piezometer casings was as follows: A hole was drilled to the desired depth with a rotary bit and drilling fluid composed of a mixture of water and Revert (Revert breaks down with time leaving clear water in the borehole). In all of the holes at WLA, SPT tests were conducted in the hole as it was drilled at 3 ft (0.9 m) intervals. (SPT tests were not conducted in the piezometer boreholes at GVDA.) In particular, an SPT test was conducted at the depth at which the slotted section of casing was placed to sample the sediment at the slots and sand pack level. Following the SPT test at the slotted-casing level in each hole, the hole was deepened by 6 in (15 cm), cleaned, and prepared for installation of the casing.

After the drill rod and tools were removed from the hole, the casing was assembled by attaching a 0.3 m section of slotted casing to the bottom of the needed length of PVC casing and a pointed tip or plug attached to the bottom of the slotted casing (fig. 8). The pointed tip provides about a 10-cm long cavity below the slots in the casing. The casing assembly was then lowered into the borehole until the tip rested on the bottom. The depth of the hole was carefully measured from the length of casing in the borehole below ground surface.

No. 3 Monterey sand was then poured down the hole around the casing until a 0.4-m to 0.6-m thick sand pack was developed. The height of the sand pack was measured by lowering a tape with a weight on the end until the weight contacted the sand. Once the required thickness of sand pack had been placed, a charge of bentonite chips was poured down the hole to cover the sand pack and form a thick seal above the sand. Typically, the thicknesses of the bentonite-chip packs were between 0.6 m and 0.9 m. The purposes of these bentonite chips were to provide an impermeable seal immediately above the sand packs and a non-erodable layer that would not be disturbed as the hole above the bentonite-chip pack was filled with grout by pumping a water-bentonite-cement mixture into the borehole though a tremie pipe.

A diagram showing the casings, sand packs, and bentonite-chip plug and grouted borehole is plotted in the far left column of each borehole log. A legend explains the colorized symbols on the log (fig. 9). These logs are contained in the appendix in the SPT Log subsections of the WLA and GVDA SPT and Laboratory Sections.

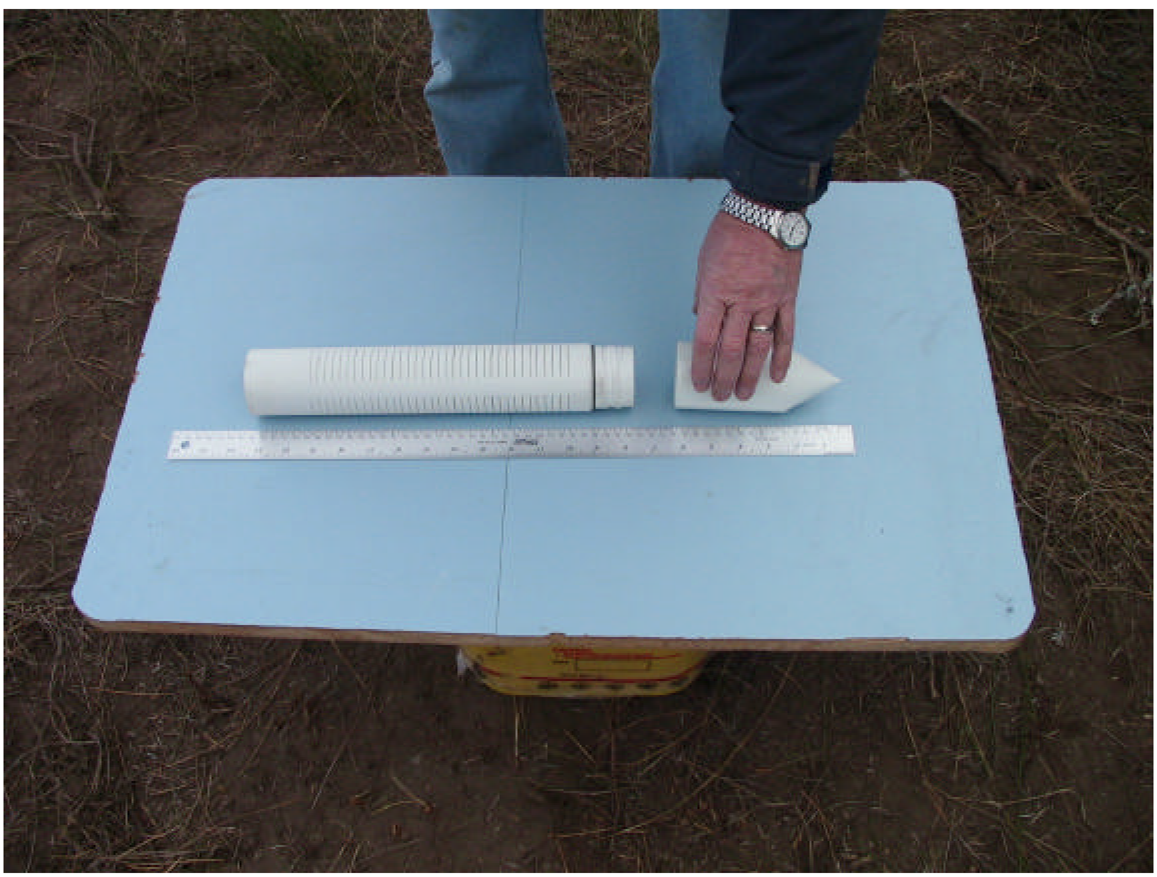

Figure 8 Slotted casing section and pointed end plug installed in piezometer boreholes

An example legend is circled in the log for WLA P4 (fig. 9). This example shows the sand pack around the bottom of the casing, the solid bentonite seal constructed by pouring bentonite chips down the borehole and allowing them to expand. The heights of the sand pack and bentonite pellet seal was checked by lowering a weighted tape measure down the borehole after each element was placed to measure the height of the element. Some time after the bentonite-chip seals were placed, the boreholes were backfilled bentonite-cement grout.

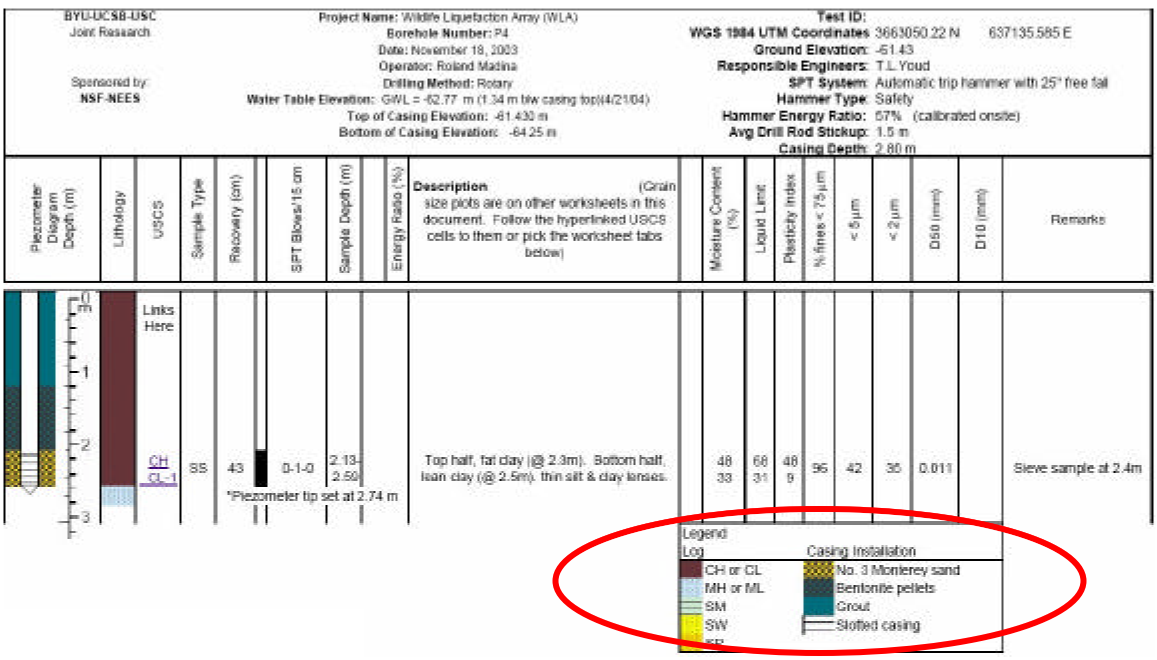

Figure 9 WLA P4 borehole with diagram at left showing the components in the piezometer installation

Some uncertainty exists as to the material into which the piezometer in Casing P4 at WLA is placed. The split-spoon sample taken from the depth of the slotted casing section (2.13-2.59 m) was fat clay (CH) at the top of the sample and lean clay at the bottom (CL-1). However, when the borehole was drilled 0.15 m deeper and cleaned, the hole may have penetrated into the upper strata of the silty sand layer. This possibility means that the slotted section of casing and the Monterey sand pack most likely is in contact with the SM material below the clay. To test this possibility, the hydraulic conductivity calculated from the permeability test in this casing was compared with tables of hydraulic conductivity versus material type. The calculated hydraulic conductivity of $2x10^{-3}$ cm/sec for casing P4 indicates a silt or silty sand sediment, further indicating that the hole did indeed penetrate a few centimeters into the silty sand layer.

Approximately a year after the casings, sand packs and seals were placed, pressure transducers were installed in the slotted sections of the piezometer casings. The

Figure 10 Photograph of packer (above measuring tape) used to seal pore-pressure transducer and cable in piezometer casings; transducer has yet to be attached to cable; photograph also shows fixtures at top of casing, including concrete pad, stainless steel protective box, piezometer casing, and electrical conduit (small casing through bottom of box) that leads to the instrument shelter

transducers are Special Order 8WD020-I ParoScientific pressure transducers with a pressure range of 0 to 45 psi absolute. The transducers were connected to a waterproof cable several meters long. The cable was threaded through a packer device, specially

Figure 11 Photograph of pressure transducer being saturated in bucket of water with packer attached (at bottom of bucket) in preparation for installing the piezometer assembly in the casing below the bucket

designed and manufactured by Rob Steller, that sealed the casings above the pressure transducer. The packer was constructed to allow the electrical cable to pass through a hole in the center of unit, with o-rings to provide a water-tight seal against the cable, and o-rings in a slot around the circumference of the units that was compressed against the casing by tightening a nut on the top of packer. The packers were installed about 0.5 m above the end plug with the pressure transducer dangling about 0.15 m below the packer. A centering spider-device prevents the pressure transducer from impacting the wall of the casing during earthquake shaking. A photograph of the packer is reproduced in figure 10 with the electrical cable passing through the packer, without a pressure transducer attached. A photograph of an assembled transducer and packer, being saturated in a bucket of water, is reproduced in figure 11. The bucket has an opening in the bottom that is connected to the top of the piezometer casing so that the packer and transducer can be lowered down the casing and sealed in place while the unit remains saturated. Because the slotted casing prevents direct contact of the transducer with the soil, the porus stone end caps supplied with the transducers were not needed and were removed prior to installation to eliminate the possible trapping of air in a porous filter around the sensing element.

10.2 Slope Indicator Casings

Slope Indicator (SI) casings were installed at both GVDA and WLA primarily for conducting of future cross-hole shear wave velocity tests, but they also serve a casings for measurement of permanent ground displacement following future earthquakes. The bottom of the casings at both GVDA and WLA were set at a depth of 10 m. Six SI casings were installed at GVDA in two perpendicular linear arrays of three casings each spaced at 3 m intervals. These casings were placed adjacent to the SFSI structure for measurement of shear-wave velocities of sediments beneath and surrounding that structure. At WLA, a linear array of four SI casings spaced 3 m apart was placed parallel to the downhole accelerometer array for measurement of shear wave velocities at that locality, including measurement of velocities through the liquefiable layer.

A fifth SI casing was installed near the river at WLA to specifically measure permanent ground displacement that should occur during future earthquakes. However, because the SI casing is rather stiff, additional flexible drain-pipe casings were installed to better track deformations through the liquefiable layer.

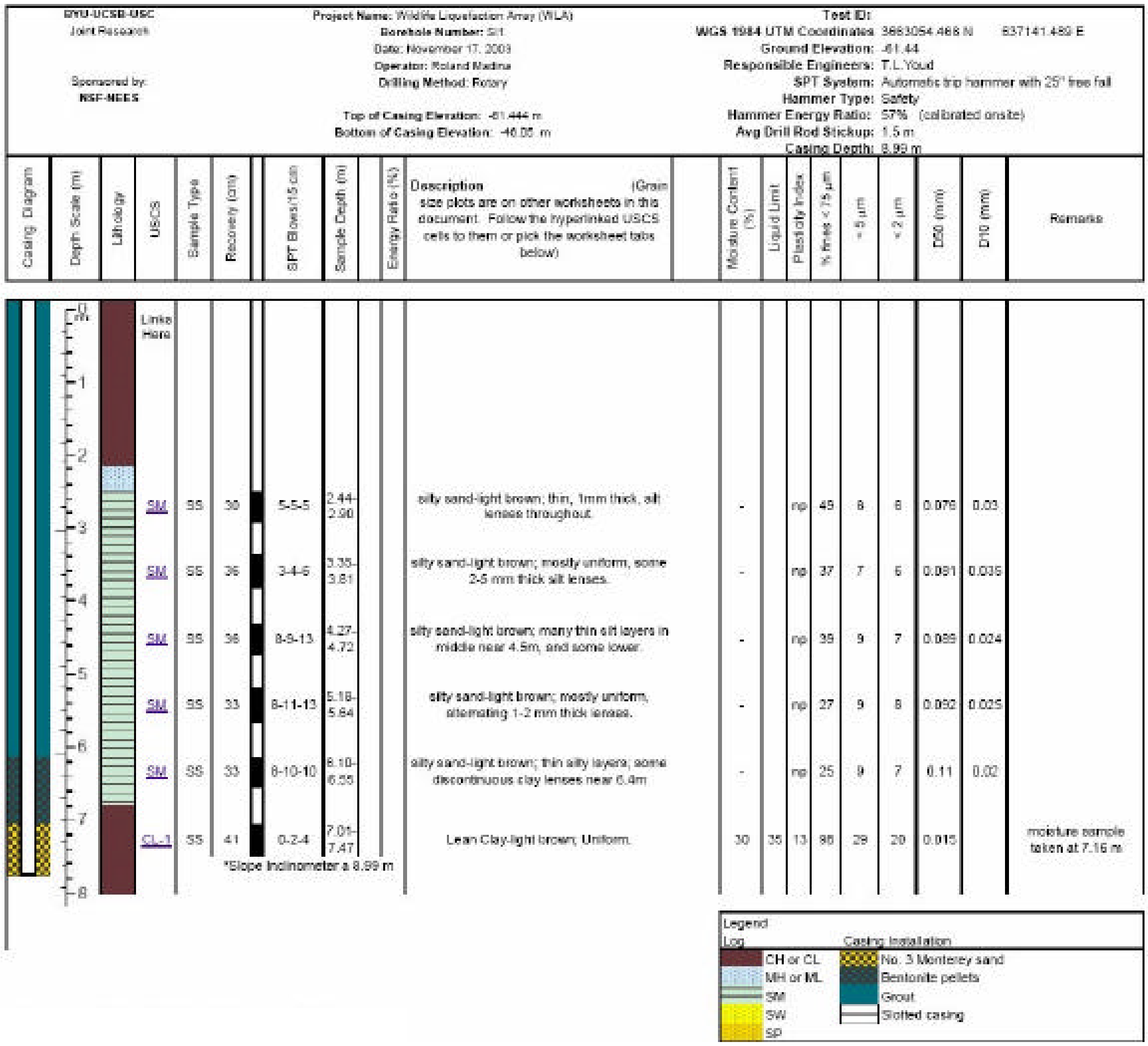

Figure 12 WLA SI1 borehole log with soil properties and diagram of installed SI casing

The following procedure was used to install SI casings. Boreholes were drilled to a 10 m depth using rotary procedures and bentonitic drilling mud. At GVDA, SPT tests were conducted in one of the borehole (SPT2-NS1) and two of the boreholes at WLA (X1 and X2) for measurement of SPT hammer energies at each site. After the holes were drilled and cleaned, SI casings, with water-tight end caps, were lowered to the bottoms of the boreholes. An approximate 0.6-m thick pack of Monterey No. 3 sand was placed around the bottom of each casing to anchor the casing into the surrounding soil and prevent flotation of the casing before bentonite-cement grout was later pumped down the borehole to permanently affix the casing to the surrounding sediment. Finally, the casings were surveyed with a Slope Inclinometer device that was lowered down the casing using grooves in the casing to maintain orientation. The logs of these surveys are on file with the site manager at UCSB.

10.3 Flexible Displacement Casings

Because of the rigidity of the SI casing, three more-flexible casings were installed at WLA, two near the river on either side of the site, and one near the downhole accelerometer array (D1, D2 and D3 on fig. 17). The high flexibility of these casings will allow them to more faithfully deform with the soft sediment in the liquefiable layer than will be the case for the stiffer SI casings. The flexible casings were fabricated from 100-mm diameter, 10-m long sections of Corex drain pipe with non-water tight end caps (fig. 12). To retain a generally straight alignment of the casing, a 10-m long, 75 mm diameter section of PVC pipe was inserted into the flexible casing and then a 10-m long section of drill rod was inserted into the PVC casing. The entire assembly was then raised to the vertical with a winch and lowered to the bottom of a

Figure 13 Rob Steller demonstrating the flexibility of flexibledrain pipe installed at WLA for measurement of earthquake-induced permanent lateral ground deformations

pre-drilled borehole. The inserted PVC casing and drill rod were sufficient stiff and heavy to keep the casing straight and in place while bentonite-cement grout was pumped into the annulus around the casing through a tremie pipe. The grout was allowed to set before the PVC casing and drill rod were extracted from the flexible casing. The casing was later surveyed with a downhole electronic positioning instrument to record the as-built shape of the casing. The results of those surveys are on file with the site manager at UCSB. A log of Borehole D2 with a diagram of the installed casing is included in "…\Appendix\SPT Data\WLA\Borehole Logs" as document WLA_D2.xls.

11. GVDA Geotechnical Investigations

The geotechnical investigations at GVDA for the NEES project consisted of five CPT soundings conducted by Tom Noce, USGS, with USGS equipment in April 2003 and two logged boreholes drilled in November 2004. One of these boreholes was later used for installation of SI casing. The localities of these soundings and casings and other facilities at the site are noted on the GIS map in figure 14.

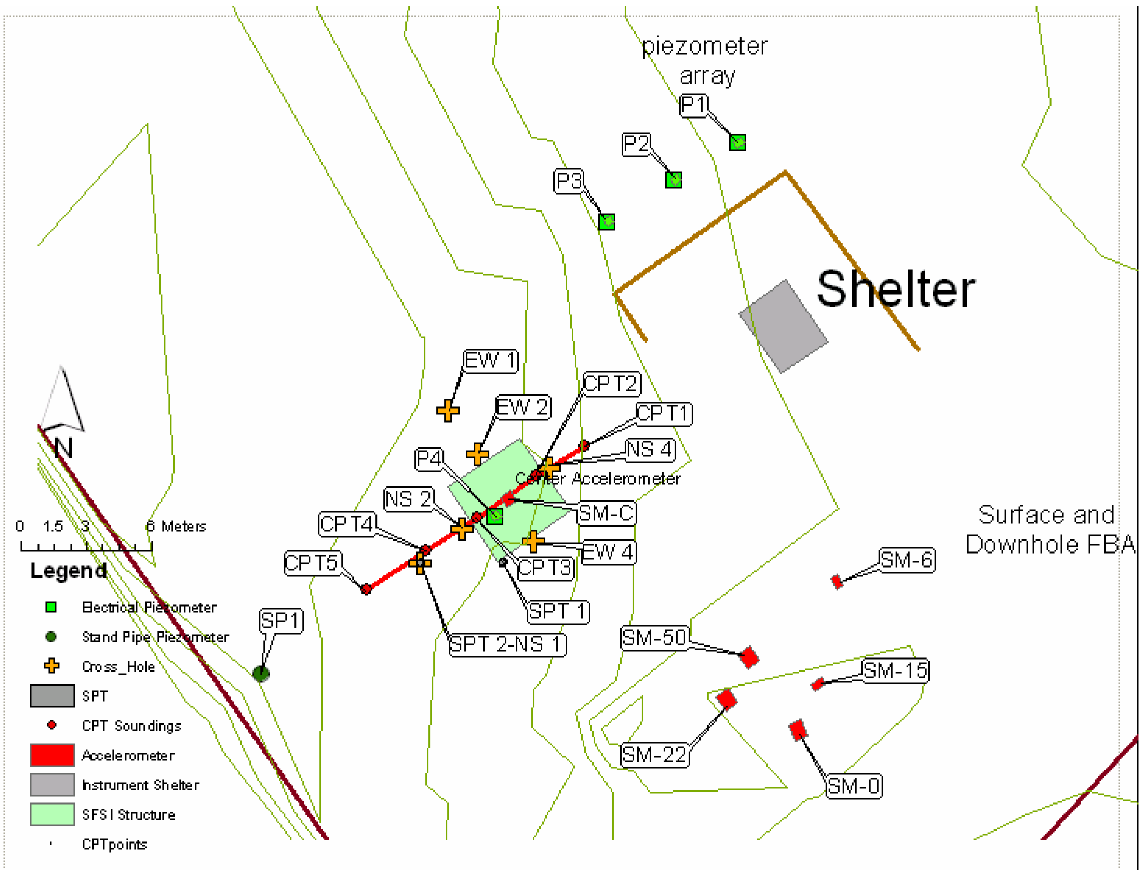

Figure 14 Map of GVDA

11.1 CPT Soundings

The CPT data were organized by Proctor (2004) and are tabulated in the appendix of this report (…\Appendix\USGS Data). A stratigraphic cross section developed from the CPT data is reproduced in figure 15.

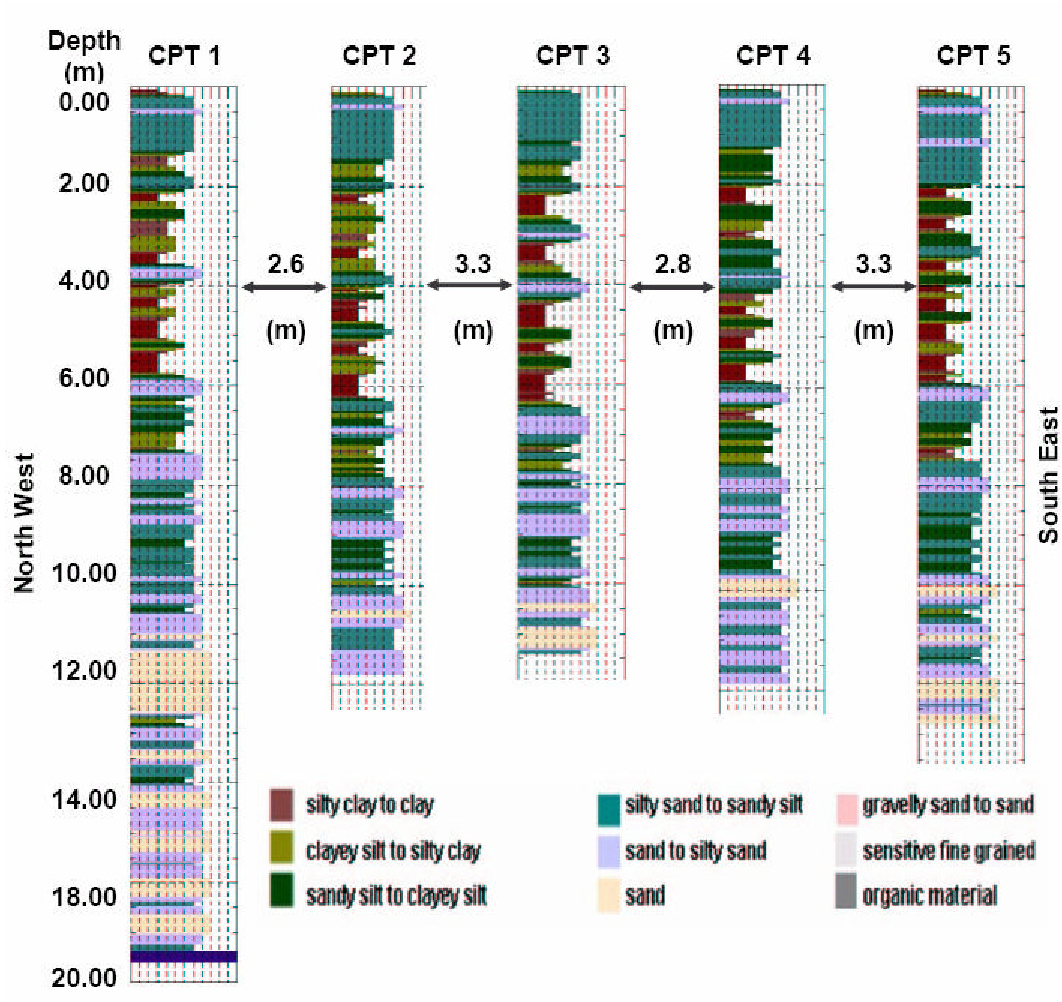

Figure 15 Geotechnical cross section for GVDA developed from CPT data

The appendix of this report (CD attached to back cover) contains a folder labeled USGS Data with a subfolder labeled Riverside, which contains the data from the GVDA CPT tests. The data are in three folders; CPD, PDF2, and Seismic. A description of each of the folders and the information found in them is given in a file entitled "Read me.doc" located in the USGS Data folder.

11.2 SPT Logs, Split-Spoon Samples, Photographs, and Laboratory Tests

At GVDA split-spoon and Shelby tube samples were taken from two boreholes drilled for calibration of the SPT (SPT1 and SPT2-NS1). Borehole SPT 1 was drilled about 3m southeast of SPT2-NS1. A log of that borehole is included in the appendix along with energy measurements made during SPT testing. Those measurements are recorded in an MSWord document summary sheet that is retrievable from either of the following locations.

- GVDA; SPT1; SPT1_Hammer_E.rtf
- …\Appendix\SPT Data\GVDA\Hammer Energy

Field and laboratory test results from the two SPT borings at GVDA are listed on borehole logs in the Appendix. The results on the logs include; measured SPT blow counts; sample recovery lengths; depths of samples; soil descriptions; insitu moisture contents; liquid limits (LL); plastic indices (PI); percentages of soil particles less than 0.075 mm, 0.005 mm, and 0.002 mm diameter; and grain size indices D50 and D10. The log also contains information on casing depth, ground surface elevation, UTM coordinates and water table elevation. The two boreholes logged at GVDA (SPT 1 and SPT 2-NS1) are retrievable form the following addresses:

- GVDA; SPT1; SPT1_Bore.xls
- GVDA; SPT2-NS1; SPT2-NS1_Bore.xls
- …\Appendix\SPT Data\GVDA\Borehole Logs

11.2.1 Soil Testing Procedures and Results

11.2.1.1 Sieve and hydrometer analyses

Gain size distribution tests were conducted on all split spoon samples taken during SPT testing. Both dry sieve and hydrometer tests were conducted on each sample in accordance with ASTM procedure D 422. Hydrometer tests were conducted on the fraction passing the #40 sieve (425 µm). A mechanical stirrer was used to break up clumps of particle and for mixing the sediment with a dispersion agent. Minor alterations to the test procedure included (1) testing in a laboratory with non-constant temperature;

(2) temperature measurements with a thermometer placed in a cylinder of clean water rather than in the test cylinders; (3) one-hour soaking times with the dispersing agent than 16 hr specified in ASTM 422; (4) Exactly 50.0g of sediment was placed in the hydrometers (rather than 115 for sandy or about 65 for silt and clay); (5) the hydrometer sample was used for the mechanical grain size analysis by washing the hydrometer test specimen over a No. 200 sieve, drying the retained sediment, and then sieving the dried sediment in a stack of sieves. The fraction retained on the # 40 sieve was accounted for in the final calculation of the grain-sized distribution.

11.2.1.2 Photographs

Photographs of each extruded split-spoon samples are filed in the Appendix at the addresses listed below. Photographs of the samples were taken in both a moist and dry condition. Notes on the photographs indicate the segments of the samples selected for grain size testing.

- GVDA; SPT2-NS1; SPT2_Samp_pics.pdf
- GVDA; SPT1; SPT1_5-20ft.pdf
- GVDA; SPT1; SPT1_20-36ft.pdf
- GVDA; SPT1; SPT1_36-49ft.pdf
- …\Appendix\SPT Data\GVDA\Sample Pictures
- …\Appendix\SPT Data\GVDA\Sample Pictures\GVDA Sample Pictures

The naming pattern used to identify the photograph files is “location, hole, depth range (in feet), and notes.” For example, “GVDA SPT1 11-12.5_dry.jpg” (fig. 17) is a photograph of the SPT sample taken between 11-12.5 feet from GVDA borehole SPT1.

Figure 16 Photograph of sample GVDA SPT1 11-12.5_dry.jpg

11.2.1.3 Grain size curves

The hydrometer and sieve grain size curves are retrievable from Excel documents which have, for their first worksheet, the log of the borehole from which the split-spoon sample in question was extracted. The borehole logs are located at:

- GVDA; SPT1; SPT1_Bore.xls
- GVDA; SPT2-NS1; SPT2-NS1_Bore.xls
- …\Appendix\SPT Data\GVDA\Borehole Logs

There are two ways to retrieve grain size plots from sieve analyses and hydrometer tests once the borehole log is open. The first option is to follow the hyperlink in the excel document. This hyper link is attached to the cells containing the USCS soil classification. The second option is to navigate through the worksheet tabs located at the bottom of each excel document. The naming convention for these sheets is "special notes, borehole, and depth (in feet)." Examples of these navigating tabs are: SPT1 20-21.5 and Shelby SPT2 15.5-18 where the note "Shelby" means that the tests were performed on a sample from a Shelby tube instead of a split-spoon sample.

11.2.1.4 Atterberg limits

Only two Shelby tube samples from SPT2-NS1 at GVDA had sufficient plasticity to conduct Atterberg limit tests. All of the other samples contained non-plastic sediment. The two apparently plastic samples were tested according to ASTM D 4318-84. These two samples came from the Shelby tube samples collected from SPT2-NS1 at depths of 3.81-4.57 m (12.5-15 ft) and 4.72-5.49 m (15.5-18ft). The results from these tests can be retrieved from the Appendix using the following address:

- GVDA; SPT2-NS1; Atterberg.pdf.
- …\Appendix\SPT Data\GVDA\Atterberg

11.2.1.5 Consolidation tests

Two consolidation tests were preformed on specimens cut from the Shelby tube samples. These tests were conducted under contract by personnel at IGES, Inc., Salt Lake City, using procedures specified in ASTM D 2435. The consolidation test results can be retrieved from the Appendix using the following path:

- GVDA; SPT2-NS1; SPT2_Consol_12.5.pdf
- GVDA; SPT2-NS1; SPT2_Consol_15.5.pdf
- …\Appendix\SPT Data\GVDA\Consolidation

IGES also measured the specific gravities of the sediments for use in consolidation test calculations. The specific gravity results are listed with the consolidation test results noted above. Another report listing just the specific gravity tests results is retrievable from:

- …\Appendix\SPT Data\GVDA\Specific Gravity

Photographs of X-ray images of all of the Shelby tube samples, while still in the tube (prepared by Terratek, Inc., Salt Lake City), are included in the appendix at the following locality:

- GVDA; SPT2-NS1; SPT2-NS1_Scans.pdf
- …\Appendix\SPT Data\GVDA\Sample Pictures\X-ray Scans

The approximate positions in the Shelby-tube sample from which the UU and consolidation test specimens were cut are marked on PDF document with the X-rays photographs taken by Terratek, Inc. This PDF document filed in the appendix at the locality identified by the path noted above.

11.21.6 UU tests

Two unconsolidated undrained (UU) strength tests were preformed by technicians at IGES, Inc. in accordance with ASTM D 2850. UU tests were selected rather than unconfined compression test to provide more accurate estimates the undrained shear strengths of the tested specimens. The specimens were cut from the Shelby tube samples retrieved from depths of 3.81-4.57 m (12.5-15 ft) and 4.72-5.49 m (15.5-18ft) in Borehole SPT2-NS1. The results from these tests can be retrieved as directed below.

- GVDA; SPT2-NS1; UU_SPT2_12.5-15.pdf
- GVDA; SPT2-NS1; UU_SPT2_15.5-18.pdf
- …\Appendix\SPT Data\GVDA\UU data

The IGES technicians reported that the part of the sample 15.5-18 ft Shelby tube noted above was too granular to conduct a UU test. The grain size distribution curve and Atterberg limits from a specimen taken from that part of the tube yielded a soil classification of silty sand (SM).

11.2.2 Permeability Tests

Permeability tests were conducted in three of the four piezometer casings installed at GVDA. A test was not conducted in the piezometer casing beneath the SFSI structure. The raw data files from these tests are tabulated in the appendix in the following files:

- …\Appendix\Permeability Tests\GVDA Permeability

The depths, diameters, and other geometric dimensions of the piezometer casings are not recorded in the data files, but are recorded in the Excel files where the hydraulic conductivities are calculated. Reference to these files is made in the discussion of hydraulic conductivity in the section entitled Permeability. The Excel files are stored in the Appendix at the following addresses:

- GVDA; P1; Perm_GVDA P1.xls
- GVDA; P2; Perm_GVDA P2.xls
- GVDA; P3; Perm_GVDA P3.xls
- …\Appendix\Permeability Tests

11.2.3 P- and S- wave Velocity Profiles

P- and S-wave velocities measurements were made with a seismic CPT in one sounding at GVDA. Proctor (2004) prepared profiles of these velocities from the USGS data files. These data and calculated velocity profiles are reproduced in the Appendix at the following location:

- …\Appendix\USGS Data\Riverside\Seismic

12. WLA Geotechnical Investigations

12.1 CPT Soundings

CPT data from 24 soundings placed at WLA in April 2003 by Tom Noce, USGS, was organized by Proctor (2004). A map of WLA is reproduced in figure 17 showing locations of the 24 CPT soundings and a cross section from CPT sounding line B-B' is plotted on figure 18. Figure 19. Cross sections A-A' through E-E' are plotted on diagrams in the Appendix. Figure 19 shows the locations of the instrument casings and boreholes drilled to install those casings.

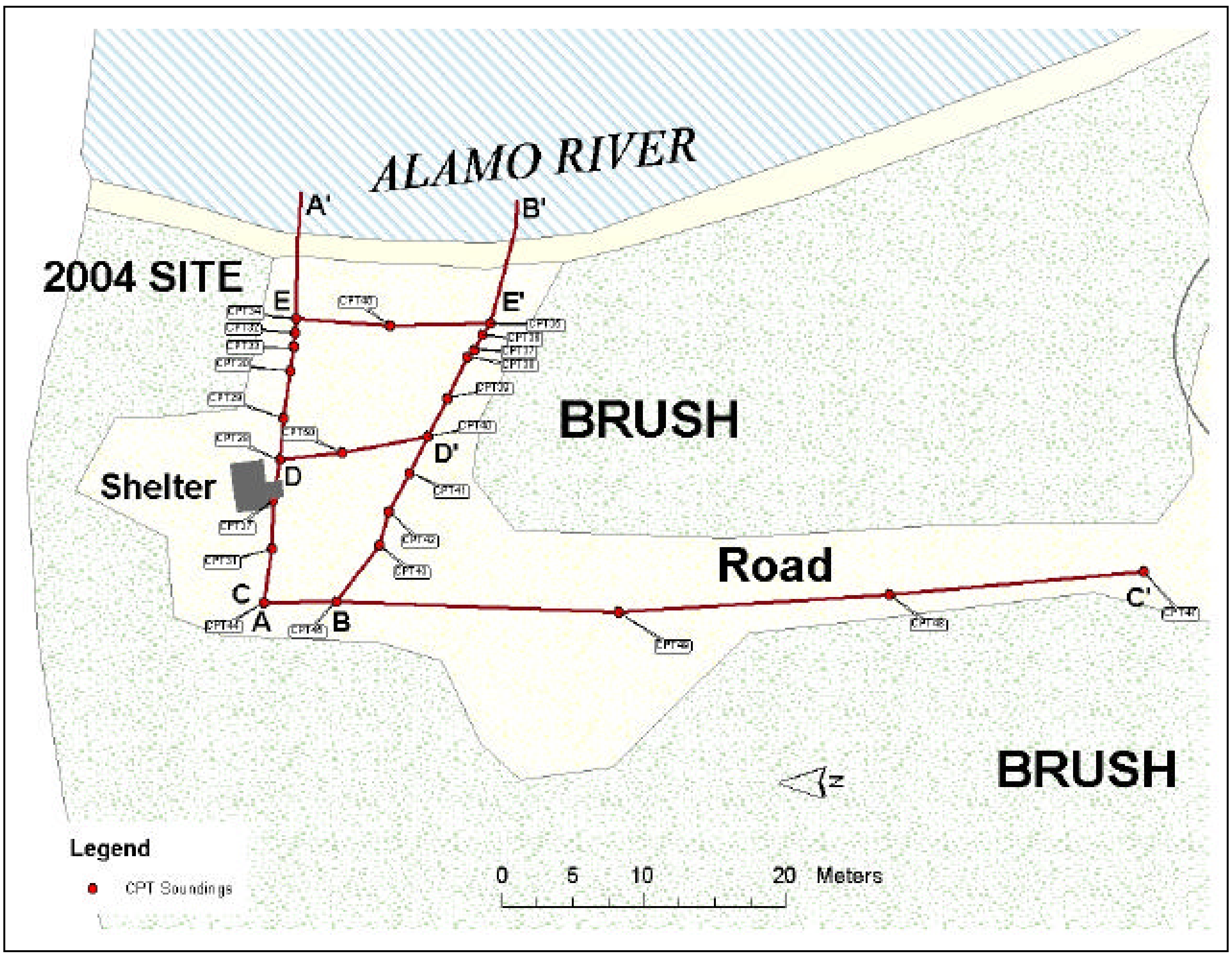

Figure 17 CPT Soundings at the Wildlife Liquefaction Array (Proctor, 2004)

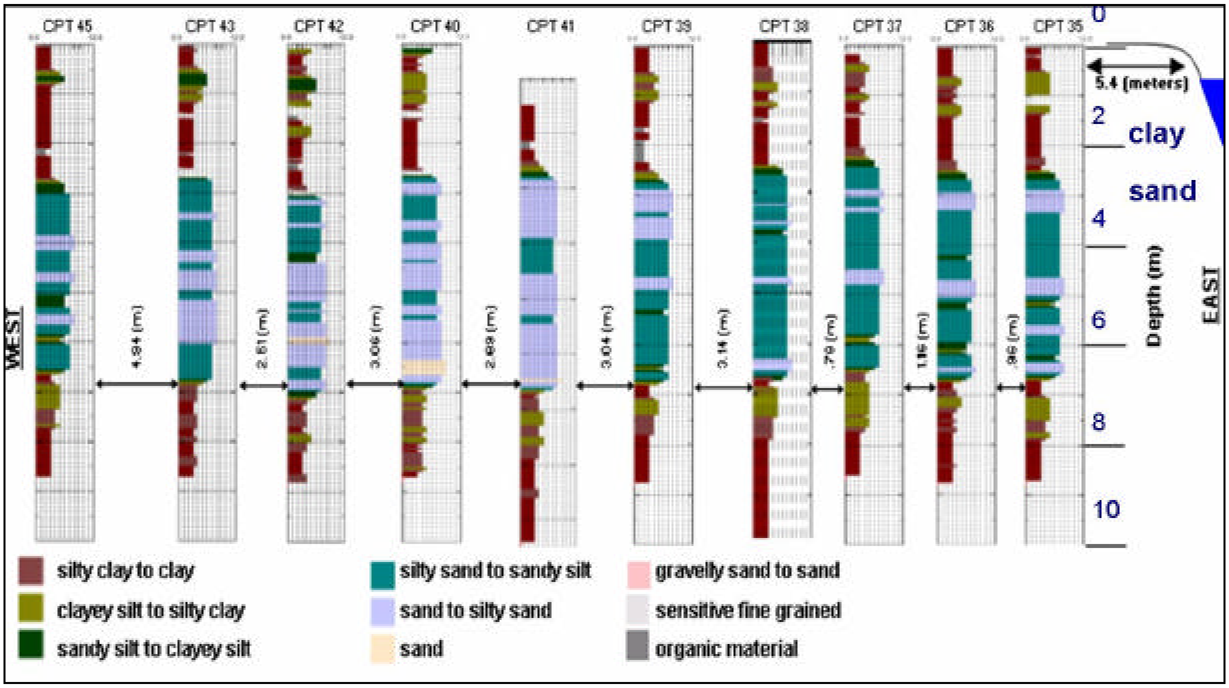

Figure 18 Sediment stratigraphy beneath line B-B' developed from CPT data (Proctor, 2004)

The general stratigraphy at the site is as follows: A 2.5- to 3.0-m thick layer of silty clay to clayey silt caps the site. This layer is underlain by a 3.5- to 4.0-m thick granular layer composed of silt, silty sand, and sandy silt. The granular layer is in turn underlain by a thick layer of silty clay to clay. These layers were analyzed for liquefaction susceptibility using the procedure of Youd et al. (2001) for an expectable earthquake with magnitude 6.5 and peak acceleration at the site of 0.4 g. The results of that analysis for cross section B-B’ indicates that much of the sediment in that part of the site is liquefiable (fig. 20). The high liquefaction susceptibility of this layer was a major reason for selecting this site for instrumentation. Cross sections showing the liquefiability of other cross sections are catalogued in the Appendix.

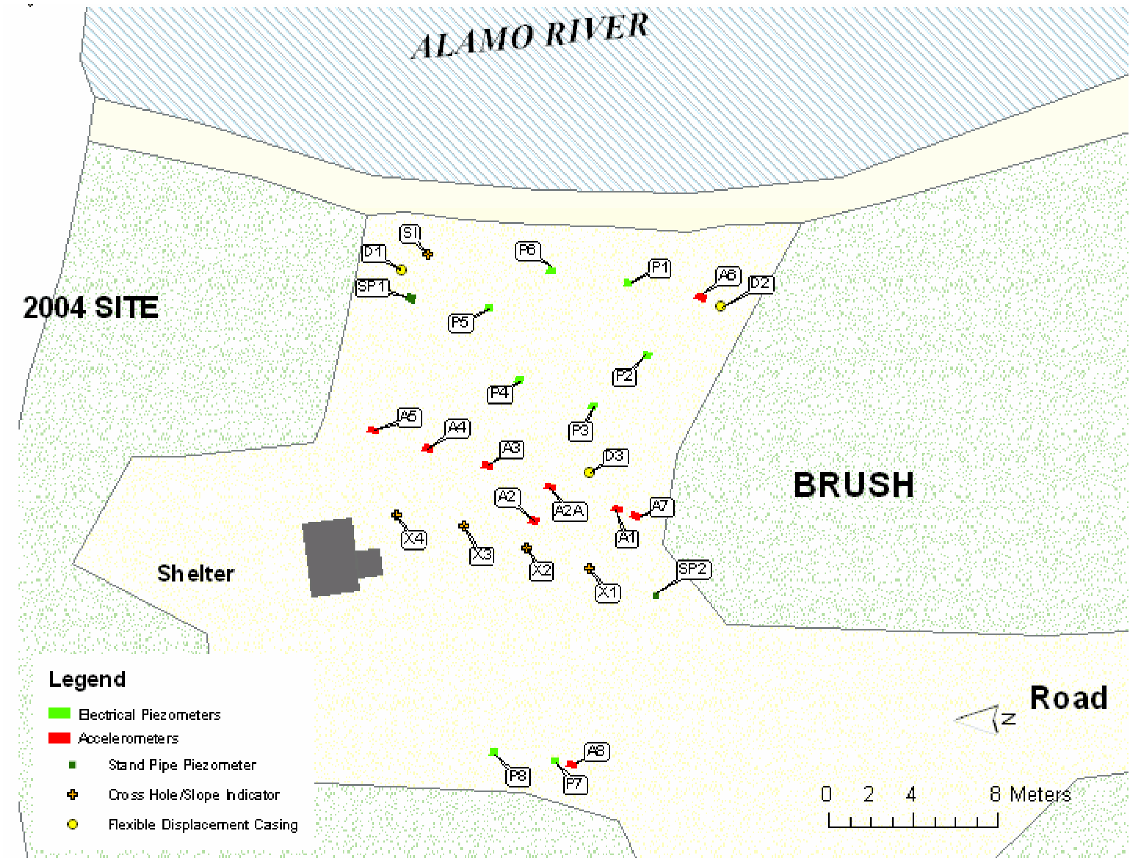

Figure 19 Map of WLA showing localities of casings installed at the site; SPT tests were conducted in several boreholes, including all piezometer holes (P1 through P8) drilled for installation of casings

The appendix of this report (CD in back cover) contains a folder labeled USGS Data with a subfolder labeled Imperial, which contains the data and cross sections developed from the CPT. The results are reported in four folders: CPD, Dissipation, PDF, and Seismic. A description of each of the folders and the information contained in them is listed in a file entitled “Read me.doc” located in the USGS Data folder (Proctor 2004).

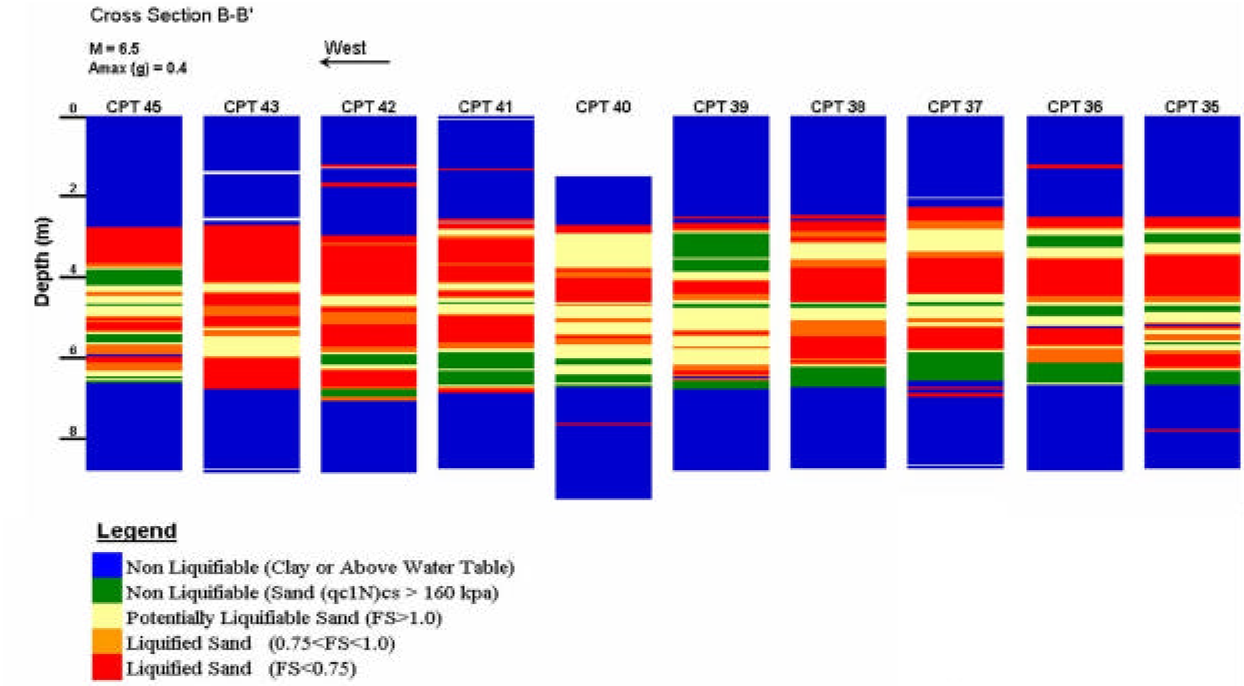

Figure 20 Liquefaction susceptibility of sediments in WLA cross section B-B' for an expectable earthquake with a magnitude of 6.5 and a peak acceleration of 0.4 g (Proctor, 2004; Youd et al., 2004)

12.2 SPT Logs, Split-Spoon Samples, Photographs, and Laboratory Tests

Borehole logs were compiled for each of 12 boreholes where SPT data were collected. Of these boreholes, eight were drilled for piezometer casings (P1-P8), three for Slope Indicator casings (SI1, X1, X2), and one for flexible casing (D2). These logs can be retrieved as directed below. The alphabetical part of the borehole names are abbreviations for the hole's function. P stands for piezometer, SI is for slope inclinometer, X stands for SI casing placed for cross-hole seismic velocity tests, and D stands for flexible casing for measurement of permanent lateral ground deformations.

- WLA; D2; WLA_D2.xls
- WLA; P1; WLA_P1.xls
- WLA; P2; WLA_P2.xls
- WLA; X1; WLA_X1.xls
- Etc….
- …\Appendix\SPT Data\WLA\Borehole Logs

12.2.1 Soil test procedures and results

12.2.1.1 Sieve and hydrometer analyses

Gain size distributions were plotted for all of WLA split-spoon samples taken from SPT tests. The grain size tests were conducted by wet sieve and hydrometer analysis according to ASTM D 422 procedures with the same modifications noted in the discussion of tests at GVDA. For the WLA samples, only a few mica flakes were retained on the #40 sieve (425 μm). Thus the sieve sizes specified in ASTM D2217 (No. 30, 40, 50, 60, 100, and 200) were used for these tests. Again, the samples from the hydrometer tests were washed, dried and sieved in the mechanical sieve test.

12.2.1.2 Photographs

Photographs of the extruded split-spoon samples were taken in a moist and dry condition with notes indicating the parts of the samples selected for testing. The naming pattern used to name this picture files is “location, hole, depth range (in feet), and notes.” For example “WLA SI1 8-9.5 wet2.JPG” is a photograph of the split-spoon sample taken between 8-9.5 feet from WLA borehole SI1. These photographs are compiled in PDF documents in the following files in the Appendix:

- WLA; D2; WLA_D2_Pictures.pdf
- WLA; P1; WLA_P1_Pictures.pdf
- WLA; P2; WLA_P2_Pictures.pdf
- WLA; X1; WLA_X1_Pictures.pdf
- Etc….
- …\Appendix\SPT Data\WLA\Sample Pictures

The photographs can also be retrieved directly from the appendix using the following path (fig. 21 shows and example photograph):

- …\Appendix\SPT Data\WLA\Sample Pictures\WLA Sample Pictures

Figure 21 Photograph of sample Picture named WLA P6 13-15.5 dry2.jpg

12.2.1.3 Grain size curves

The hydrometer and sieve test results and grain size plots are compiled in Excel documents included in the borehole logs documents. The borehole logs can be retrieved as directed below.

- WLA; P3; WLA_P3.xls
- WLA; P4; WLA_P4.xls
- WLA; P5; WLA_P5.xls
- WLA; SI1; WLA_SI1.xls
- Etc….
- …\Appendix\SPT Data\WLA\Borehole Logs

There are two paths to retrieve sieve results, hydrometer results, and the grain size plots once a borehole log is open. The first is to follow the hyperlink in the excel document. This hyper link is attached to the cells containing the USCS soil classifications. The second path is to navigate by the worksheet tabs located at the bottom of every Excel document. The general naming convention for these sheets is “location, borehole, and depth (in feet),” for example “WLA X1 20-21.5.” However, borehole D2 uses the convention “location, sample type, borehole, and depth (in feet)” to differentiate between split-spoon and Shelby samples. An example would be “WLA Shelby D2 5-7.5.”

12.2.1.4 Clay mineral identification

An x-ray spectrometer was used to identity clay minerals present in eight of WLA samples. Two specimens for x-ray testing were taken from each of Boreholes P2, P5 and X1; one sample each was taken from Boreholes P7 and P8. The purpose of the mineral identification tests was to determine the mineral composition of the clay-size particles in the granular layer at WLA. The percentage of clay was relatively high (between 15 % and 25 %) in some of the samples from the layer that was determined to be liquefiable using CPT criteria (fig. 20). No evaluation of the quantitative amounts of the various of clay minerals was attempted from the X-ray tests. The purpose of the tests was to determine whether highly plastic smectite minerals were contained in the clay-size materials in these samples. Samples from X1, which has a low clay content (2-5%) were tested as a control test. The data files for each X-ray scan are retrievable from the path:

- …\Appendix\SPT Data\WLA\Clay Mineral Data\DataFiles

Because smectite was the mineral of interest two scans were necessary. The first scan was preformed on air-dry clay-size particles from the sample of interest. The second scan was preformed after a specimen from the same samples had been sealed in a container with an ethylene glycol solution. If smectite minerals were present, the position of the illite-smectite peak would shift between the first and second scans. In order to evaluate this shift the diffraction plots from the two scans were plotted together. Only a minor shift occurred in one paired plot; no detectable shift was noted in any of the other paired sets. This consistency between paired plots indicates that the clay size minerals in the specimens were not smectites, except for possibly some minerals in the one paired plot that indicated some shifting of the peak. The X-ray scan excel files are retrievable from the following paths:

- WLA; P1; Clay_Min_P2-17.xls
- WLA; P1; Clay_Min_P2-20.xls
- WLA; P7; Clay_Min_P7-09.xls
- WLA; X1; Clay_Min_X1-17.xls
- Etc….
- …\Appendix\SPT Data\WLA\Clay Mineral Data

12.2.1.5 Atterberg limits

Atterberg limit tests were conducted according to ASTM Standards D 4318-84. Seven Atterberg limit tests were conducted on specimens taken from split-spoon samples and three specimens were tested from Shelby tube samples. All of these specimens were either from the upper clay or the lower clay layers at WLA. Two tests were made specimens collected from cuttings from the deep acceleromenter borehole (A5).

The test specimens taken from split-spoon samples were collected from Boreholes X1, X2, SI1, P1, P4 and P5. The test results from these samples are recorded on the borehole logs and on the grain-size distribution sheets that are keyed to the borehole logs. These results can be retrieved as directed for the Sieve and Hydrometer tests. However, for convenience of retrieval of Atterberg limit data, copies of the data sheets have been compiled in a document entitled “Atterberg Limits.xls.” This document is filed in the Appendix as noted below.

- …\Appendix\SPT Data\WLA\Atterberg\Atterberg Limits.xls

This document also includes the results of Atterberg limit tests on the two samples of drill cuttings from taken the Borehole A5. The cutting for these tests originated at depths of 85 to 90 ft (25 to 27 m) and near 320 ft (96 m). The reliability of these tests is uncertain because the cuttings were carried to the surface in the drill mud, and the samples may have been contaminated with the bentonite.

Atterberg limit tests were conducted on specimens taken from three Shelby tube samples retrieved from Borehole D2. These results are filed in the appendix with the following addresses:

- WLA; D2; D2_Atterberg.pdf.
- …\Appendix\SPT Data\WLA\Atterberg

12.2.1.6 Consolidation tests

Three consolidation tests were preformed on specimens cut from the Shelby tube samples extracted from Borehole D2. These tests were conducted by laboratory technicians at IGES, Inc., Salt Lake City, in accordance with ASTM D 2435. The consolidation test results are filed at the following locations in the appendix:

- WLA; D2; D2_Consol_2.5.pdf
- WLA; D2; D2_Consol_5.pdf
- WLA; D2; D2_Consol_22.pdf
- …\Appendix\SPT Data\WLA\Consolidation

The IGES technicians also measured specific gravities of the sediments for use in their consolidation test calculations. The specific gravity test results are noted on the consolidation reports, which are filed at the localities noted above. Also, another report summarizing just the specific gravity tests is filed at the locality noted below:

- …\Appendix\SPT Data\WLA\Specific Gravity

Photographs of X-ray images of samples while still in the Shelby tubes were prepared by Terratek, Inc., Salt Lake City. These photographs are included in the appendix at the following locality:

- WLA; D2; D2_Scans.pdf
- …\Appendix\SPT Data\WLA\Sample Pictures\X-ray Scans

The approximate locations from which the UU and consolidation test specimens were cut are marked on the X-ray photographs stored in PDF documents filed in the appendix at the locality identified by the path noted above.

12.2.1.7 UU tests

Unconsolidated undrained triaxial shear tests (UU) were preformed by technicians at IGES, Inc., Salt Lake City, using procedures specified in ASTM D 2850. Three UU tests were run on material from WLA. The results from these tests are filed at:

- WLA; D2; UU_D2_2.5-4.pdf
- WLA; D2; UU_D2_5-7.5.pdf
- WLA; D2; UU_D2_22-24.5.pdf
- …\Appendix\SPT Data\WLA\UU data

12.2.2 Permeability Tests

Permeability tests were conducted in seven piezometer casings at WLA. Six of these piezometers are those installed in a ring near the river bank on the east side of the site (P1, P2, P3, P4, P5, and P6). The seventh test was in casing P8, located away from the river on the west side of the site. (A test was not conducted in P7.) The data files from these tests are filed at the following locality:

- …\Appendix\Permeability Tests\WLA Permeability

The depths, diameters, and other geometric dimensions of the casings are recorded in the Excel files at the following location:

- WLA; P1; Perm_WLA P1.xls
- WLA; P2; Perm_WLA P2.xls
- WLA; P3; Perm_WLA P3.xls
- Etc…
- …\Appendix\Permeability Tests

12.2.3 P- and S- wave Velocity Profiles

P- and S-wave velocities were measured with a seismic CPT in two soundings at WLA. Proctor (2004) prepared profiles of these velocities from the USGS data files. These profiles and accompanying data files are filed in the Appendix at the following location:

- …\Appendix\USGS Data\Imperial\Seismic

The formatting and location of CPT data files are explained in a document titled "Read me" prepared by Proctor (2004). This text file explains the contents of the "USGS Data" folder and it is in the following location:

- …\Appendix\USGS Data

In addition to the velocity profiles collected during CPT testing, Mr. Rob Steller used an Oyo suspension logger to collect P- and S- wave data from Borehole A5, which extended to a depth of 100 m. The results from that test are included in the Appendix at the following localities:

- WLA; A5; WLA100m prelim.xls
- …\Appendix\P and S Data

13. Summary

Both of the NEES field sites, WLA and GVDA, were preexisting research sites which have been upgraded and re-instrumented for the NEES Colaboratroy. The Garner Valley site is primarily a ground motion research site. However, the installation of four electrically transduced piezometers in liquefiable deposits and the addition of a one story SFSI structure have made this a multipurpose site. WLA is primarily a ground motion and liquefaction research site.

The purpose of this report is to describe field and laboratory geotechnical investigations at these two sites, document the results of the investigations, and provide guidance for retrieving the test data and results. This summary briefly describes the results of the laboratory and geotechnical investigations and gives a final overview of the Appendix structure.

13.1 GVDA

The GVDA site is primarily a ground motion research site, however, with subsurface liquefiable materials and the construction of a SFSI structure during the NEES project, the site is now a multi-purpose facility. This enhanced site now includes six downhole accelerometers, five surface accelerometers, four electrical piezometers, one standpipe piezometer, and six slope inclinometer casings.

Several in-situ tests characterize the subsurface sediments at this site, including five CPT soundings and two SPT borings. Laboratory tests were conducted on split-spoon and Shelby-tube samples taken from the boreholes, and hydraulic conductivity tests conducted in the piezometer casings. The laboratory tests include grain size analysis, Atterberg limits, unconsolidated undrained shear strength, and consolidation tests. All of the test results, both field and laboratory, are compiled in an appendix included on a CD attached to the back cover of this report. The data is retrievable either through links to GIS maps or directly from files in the appendix.

The SPT data is summarized on logs for each SPT borehole. The CPT data is listed in files with a plotted profile for each sounding. Cross sections show the sediment layering across the site. P- and S- wave velocities were measured with a seismic CPT. These data and accompanying velocity profiles are also contained in files in the Appendix. The seismic CPT shear-wave velocity data indicate that the average s-wave velocity in the upper 18 m of sediment varies with depth from 170 to 300 m/s (560 to 1000 ft/s). Data and calculated hydraulic conductivities of the material around the piezometers are also listed in the appendix. These hydraulic conductivities range between 10^{-4} and 10^{-5} cm/s, typical of very fine sands and inorganic silts and mixtures of these materials. Most of the retrieved samples classified as silty sand (SM) with some well graded silty sands (SW-SM). In the lower part of the sediment (below 12.5 m) the material transitions to poorly graded silty sand (SP-SM). All of the samples tested were non-plastic. The average UU shear strength of the upper and lower clay samples ranged between 500 and 1400 kPa (1040 and 3000 psf).

13.2 WLA

The WLA site is a ground motion and liquefaction research site. This site includes five downhole accelerometers at depths of 2.4 m, 4.8 m, 7.2 m, 30 m and 97 m, three surface accelerometers in a linear array across the site perpendicular to the Alamo river, eight electrical piezometers, two standpipe piezometers, five slope inclinometer casings, and three flexible casings.

Several in-situ tests were conducted to characterize this site, including SPT with hammer energy measurement, CPT, shear wave velocity, and hydraulic conductivity tests. Split spoon samples were taken from all of the piezometer holes and tested in the laboratory to determine grain size gradations and Atterberg limits. Unconsolidated undrained shear strength and consolidation tests were conducted on specimens cut from Shelby-tube samples taken from the upper and lower clay layers penetrated by Borehole (D2).

The standard penetration data are summarized on logs for each borehole in which SPT tests were conducted. The CPT data are tabulated in files in the Appendix along with tip-resistance and friction-resistance profiles for each sounding and cross sections showing sediment stratigraphy across several soundings. P- and S- wave velocities were measured with both a seismic CPT and an OYO suspension logger. These data and accompanying velocity profiles are also contained in files in the Appendix. The seismic CPT shear-wave velocity data indicate that the average s-wave velocity in the upper 15 m of sediment varies with depth from 100 to 250 m/s (330 to 820 ft/s). The OYO suspension logger data indicates shear-wave velocity varies with depth from 150 to 500 m/s (500 to 1000 ft/s) with a few peaks to 750 m/s (2500 ft/s) and p-wave velocities averaged near 1650 m/s (5400 ft/s). Hydraulic conductivities of the material around the piezometers set in the granular silty sand layer range from 10^{-3} to 10^{-5} cm/s. These hydraulic conductivities are typical of silts and fine sands and mixtures of these materials. Most of the granular sample classify as silty sand (SM) with some transition of silt to lean clay to fat clay near the upper and lower boundaries of the granular layer. The silty sand layers were non-plastic. The range of liquid limits and plastic indices in the upper clay layer range from 30 to 37 and 9 to 19, respectively, with an outlier with LL and PI of 68 and 48 respectively. In the lower clay layer these indices range from 35 to 45 and 13 to 31, respectively. From X-ray diffraction tests, clay-size minerals in the granular layer were identified as Illite, Kaolinite, and quartz. Only one of the tested specimens contained a detectable amount of smectite. The average UU shear strength of the upper and lower clay samples ranged between 360 and 250 kPa (760 and 520 psf).

13.3 Appendix overview

All of the data from WLA and GVDA is contained in the Appendix. The Appendix is divided into nine folders: GIS Maps; Liquefaction Analysis; P- and S-wave data (P and S Data); Permeability Tests; Project presentations (Projectpres); Reports "Report"; SPT Data; Survey Data; USGS Data. "GIS Maps" contains the ArcView 9.0 maps of GVDA and WLA and their linked documents. The results of the CPT based liquefaction analyses preformed by Proctor are filed in the "Liquefaction Analysis" folder. The Oyo suspension logger results are filed in the "P and S Data" folder along with directions on how to locate the CPT seismic wave measurements (in the "USGS Data" folder). Results and original data files of the permeability tests are located in "Permeability Tests." The "Projectpres" folder contains the BYU graduate seminar presentations of Jacob and Bartholomew (2004), and "Report" contains their respective project reports. The "SPT Data" folder is further subdivided into "WLA" and "GVDA" folders. The "…\Appendix\SPT Data\WLA" folder contains eight folders; Atterberg, Borehole Logs, Clay Mineral Data, Consolidation, Hammer Energy, Sample Pictures, Specific Gravity, and UU data, each containing the results from the tests after which they are named. The "…\Appendix\SPT Data\GVDA" contains the same folder found in WLA folder except for "Clay Mineral Data." The May 2004 and April 2003 site surveying files for GVDA and WLA are found in "Survey Data" folder. The final folder in the Appendix, "USGS Data," is the same folder as contained in Proctor's Appendix (2004). It divides it contents into two folders, "Imperial" and "Riverside," which are the counties in which WLA and GVDA are located, respectively. This folder contains a document titled "Read me" which further explains the format and location of the original CPT data files and CPT analysis results.

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15. Files Compiled in the Appendix

GIS Maps	Garner Valley	GIS Info ....tin
		Links
	Wildlife	GIS Info
		LINKS
Liquefaction Analysis	Garner Valley	
	Wildlife	New Site
		Old Site
P and S Data		
Permeability Tests	GVDA Permeability	
	WLA Permeability	
Projectpres	Hannah Bartholomew	
	Jacob Proctor	
Report	Hannah Bartholomew	
	Jacob Proctor	
SPT Data	GVDA	Atterberg
		Borehole Logs
		Consolidation
		Hammer Energy
		Sample Pictures
		Specific Gravity
		UU data
	WLA	Atterberg
		Borehole Logs
		Clay Mineral Data
		Consolidation
		Hammer Energy
		Sample Pictures
		Specific Gravity
		UU data
Survey Data		
USGS Data	Imperial	CPD
		Dissipation
		PDF
		Seismic
	Riverside	CPD
		PDF2
		Seismic