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RESEARCH OPPORTUNITIES AT THE NEES PERMANENTLY INSTRUMENTED FIELD SITES

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SUMMARY

As part of the George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES), two permanently instrumented field sites for monitoring ground motion, pore water pressure generation, ground deformation, and soil-foundation-structure interaction (SFSI), were added to the NEES equipment portfolio. The sites are the Wildlife Liquefaction Array (WLA) and the Garner Valley Downhole Array (GVDA); both are located in highly seismic areas of the southern California; both have histories of monitored earthquake responses; both are underlain by liquefiable layers; and both have been well characterized. To engender ground deformation, the WLA site is adjacent to a 3-m high bank of the Alamo River. A reconfigurable, steel-framed structure has been constructed at the GVDA site and instrumented with sensors in the structure, foundation, and underlying soil to facilitate SFSI research. These field sites will monitor responses generated by earthquakes and by active experiments using shakers. These sites will provide test beds for new in-situ and non-invasive site characterization techniques and for development of new sensor technologies. Telepresence and teleparticipation capabilities will provide opportunities for collaborative research and educational interaction. The continuous streaming of data to the NEES data repository, ANSS, and local networks will provide ready access to the collected data.

INTRODUCTION

A goal of earthquake engineering research is to generate analytical and empirical models for accurate prediction of ground response, pore water pressure generation, ground deformation and soil-foundation-structure interaction (SFSI) and to understand how these predictions will affect the built environment. A required element for the development of these models is well-instrumented test sites where actual ground response and deformation, can be monitored during earthquake shaking to provide benchmark case histories for model development and verification. In addition, the use of active methods to shake the test sites can also provide benchmarks that can be compared with actual earthquake motions. One of the main issues when modeling nonlinear soil dynamics is the lack of knowledge of the soil properties. Indeed, one of the reasons why the equivalent linear method is so popular is due to the limited number of parameters needed. If a more sophisticated and complete method for simulation of dynamic soil

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behavior is used, that also translates into more parameters that must be specified. Unfortunately, the cost of laboratory and *in-situ* field tests is quite expensive, so a complete geotechnical description of a site is a rare and precious commodity. Site characterization information and ground motion records from experimental field sites provide essential information for development and validation of analytical and empirical models.

The purpose of this project is to provide such data by instrumenting two field sites, the Wildlife liquefaction array (WLA) and the Garner Valley downhole array (GVDA), as part of the National Science Foundation's (NSF) George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES) program. Both sites are located in highly seismic areas of southern California (Fig. 1). Each site is equipped with surface and downhole accelerometers, pore pressure transducers, and inclinometers to monitor ground response and ground deformation during earthquake shaking. The GVDA site will also be equipped with an instrumented reconfigurable steel framed structure to monitor SFSI response. In addition to monitoring earthquake shaking, the WLA and GVDA sites can also be artificially excited with shakers either on the ground or on the SFSI structure. There are significant opportunities for research using these permanent field sites and funding to support this research is being made available via a peer-reviewed program at NSF.

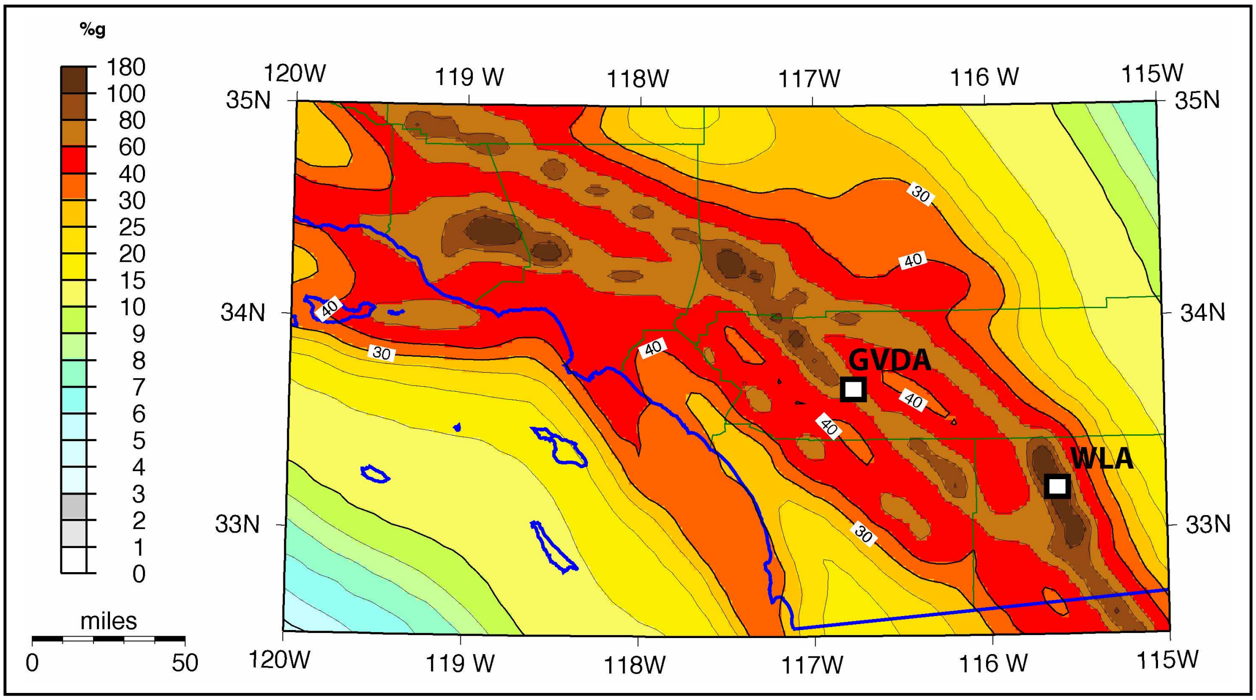


Figure 1. Location of the GVDA and WLA sites in Southern California shown with national seismic hazard map for 10% exceedance in 50 years of peak ground acceleration (PGA) at NEHRP BC boundary site conditions. State border outlined in bold blue line.

Demonstration projects at GVDA using shakers are being developed in cooperation with NEES projects at the University of Texas and the University of California at Los Angeles. These demonstration projects, scheduled for August 2004, will test the response of the instrumentation and demonstrate the capability of the electronic systems to stream data in real time to the NEES-grid network. In addition to active experiments on site, the continuous streaming of data in real-time back to the NEES data repository, ANSS, and local networks will provide an abundance of data from local and regional seismic activity.

Each of these events can be considered an experiment in itself, with the data freely available to the earthquake engineering community.

THE GARNER VALLEY DOWNHOLE ARRAY

The Garner Valley Downhole Array (GVDA) is located in southern California at a latitude of 33° 40.127' north, and a longitude of 116° 40.427' west. The instrument site is located in a narrow valley within the Peninsular Ranges Batholith east of Hemet and southwest of Palm Springs, California. The valley is 4 km wide at its widest and about 10 km long. The valley trends northwest-southeast parallel to the major faults of southern California. The valley floor is at an elevation of 1310 m and the surrounding mountains reach heights slightly greater than 3,000 m. A panoramic view of the GVDA field site is shown in Photo 1 below, taken during the NEES drilling and site characterization operations, Nov. 2003.

Photo 1. Panoramic view of Garner Valley and the GVDA test site.

GVDA is in a seismically active region and lies only 7 km from the main trace of the San Jacinto fault and 35 km from the San Andreas fault (Fig. 1). Historically, the San Jacinto is the most active strike-slip fault system in southern California. A fault slip rate of 10 mm/yr and an absence of large earthquakes since at least 1890 lead to a relatively high probability for magnitude 6.0 or larger earthquake on the San Jacinto fault near the site in the near future. The USGS/Caltech component of the California Integrated Seismic Network (CISN) and the UC San Diego Anza Array, also a component of CISN, located in the region surrounding GVDA provide excellent coverage of local and regional seismicity.

GVDA Site Conditions

The near-surface stratigraphy beneath the site consists of 18-25 m of lake-bed alluvium overlying weathered granite to a depth of 88 m. 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. The ground water levels beneath the site ranges from near surface in wet seasons to several meters depth during dry seasons. Information on the previous history of earthquake monitoring at the GVDA site and the local site conditions can be found in Steidl et al., 1998 [1].

Geotechnical properties of the site have been defined with samples from SPT borings and data from CPT soundings. Grain size and other index tests have bee conducted on the retrieved split-spoon samples. SPT have been conducted to a depth of 30 m and CPT to a depth of 18 m as part of the NEES and previous investigations. Figure 2 is cross section of sediment layers to a depth of 12 m compiled from CPT data.

To test liquefaction susceptibility of granular layers beneath GVDA, we applied the standard CPT procedure for evaluating liquefaction resistance as published by Youd et al., 2001 [2]. Results from this analysis using data from CPT 1, a magnitude 7.0 earthquake and PGA levels ranging from 0.2 g to 0.4 g are plotted on Figure 3. For a peak acceleration of 0.3 g to 0.4 g, a likely occurrence in the next 10 years, liquefaction would likely occur beneath the site.

Compression and shear wave velocities were measured to depths as great as 500 m using downhole and suspension logging techniques. Gamma radiation and electrical resistivity logs have also been compiled from geophysical tests in open boreholes. Logs of some of these measurements are plotted on Figure 4.

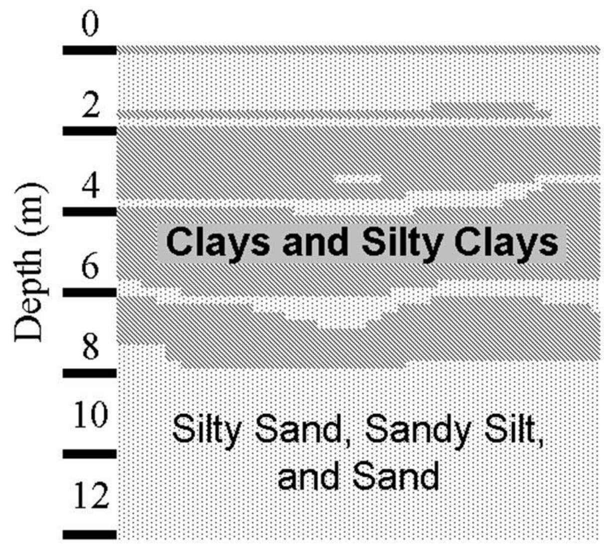


Figure 2. Cross section of sediments beneath GVDA interpreted from 2003 CPT data

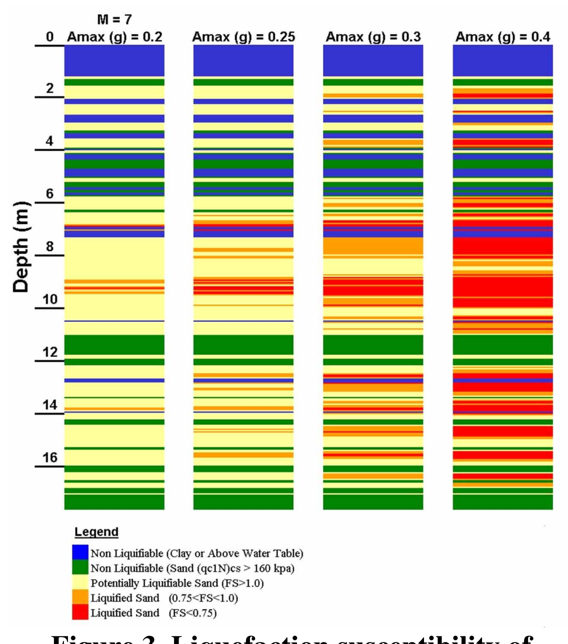


Figure 3. Liquefaction susceptibility of sediments beneath GVDA calculated from CPT data.

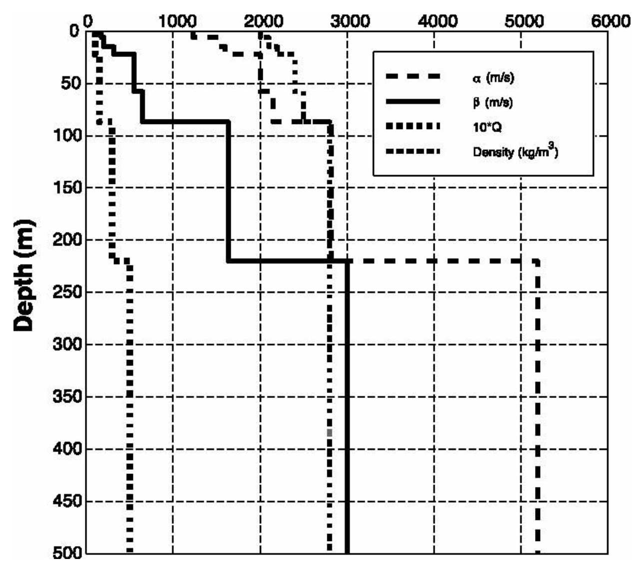
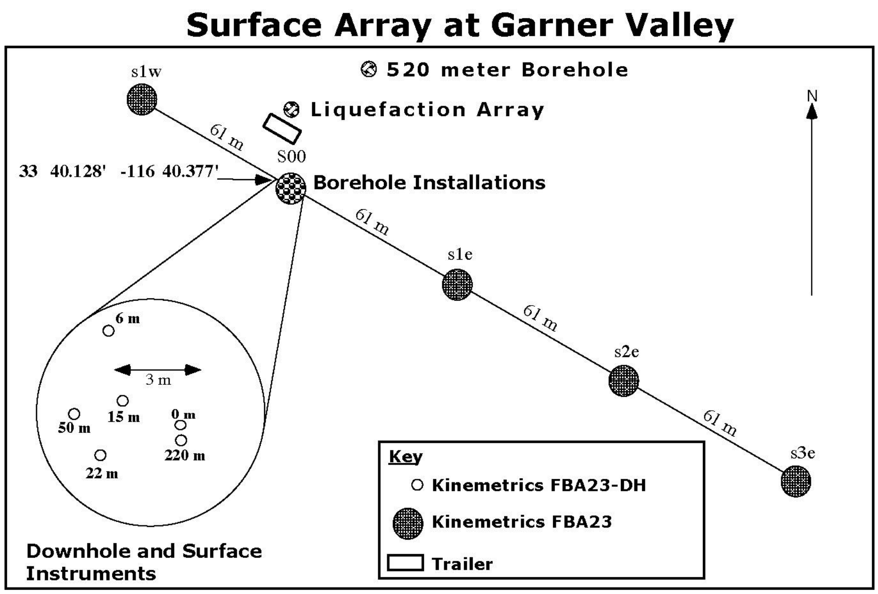


Figure 4. Compression-wave (α) and shear-wave (β) velocities and other geophysical measures beneath GVDA site

GVDA Instrumentation

Earthquake ground motions are monitored at GVDA by an array of five surface and six downhole Force-Balanced Accelerometers (FBA's). The map position of the various FBA's is noted on Figure 5. Figure 6 is a cross section of the site with plotted depths of the downhole FBA's. All of the FBA's noted on Figures 5 & 6 were placed prior to the NEES project, except for the FBA at 150 m, with support from previous projects and supporting agencies. In addition to the FBA arrays noted above, there is a remote rock station at the edge of the valley set on a bedrock outcrop 3 km east of the main site. This station contains an FBA set into the rock surface and a second downhole FBA set at a depth of 30 m. Data from this remote site is telemetered back to the main station via a radio link.

Figure 5. Horizontal distribution of FBA's and relative location of liquefaction array at GVDA.



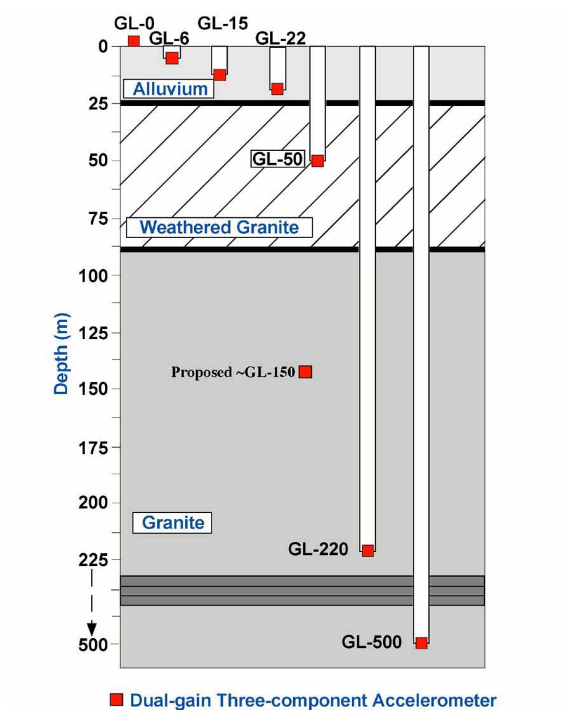


Figure 6. Cross section of GVDA site with depths of installed FBA's

As mentioned in the previous section, there is a significant potential for liquefaction at the GVDA test site. Pore pressure transducers have been deployed previously at the site in years 1996 and 2000. A single pressure transducer at 12 m depth was functioning during the 1999 M7.1 Hector Mine earthquake and elevated pore pressures were observed along with a slow decay back to the pre-event level. The event was more than 100 km from the site and the ground shaking was only 10% g, however the elevation of pore pressure from such a distant event supports the analysis of liquefaction potential presented in Figure 3. The deployment of pore pressure transducers at the GVDA site are shown in cross section in Figure 7. Continued monitoring of pore pressure in the near surface soil at GVDA is part of the NEES program for this site.

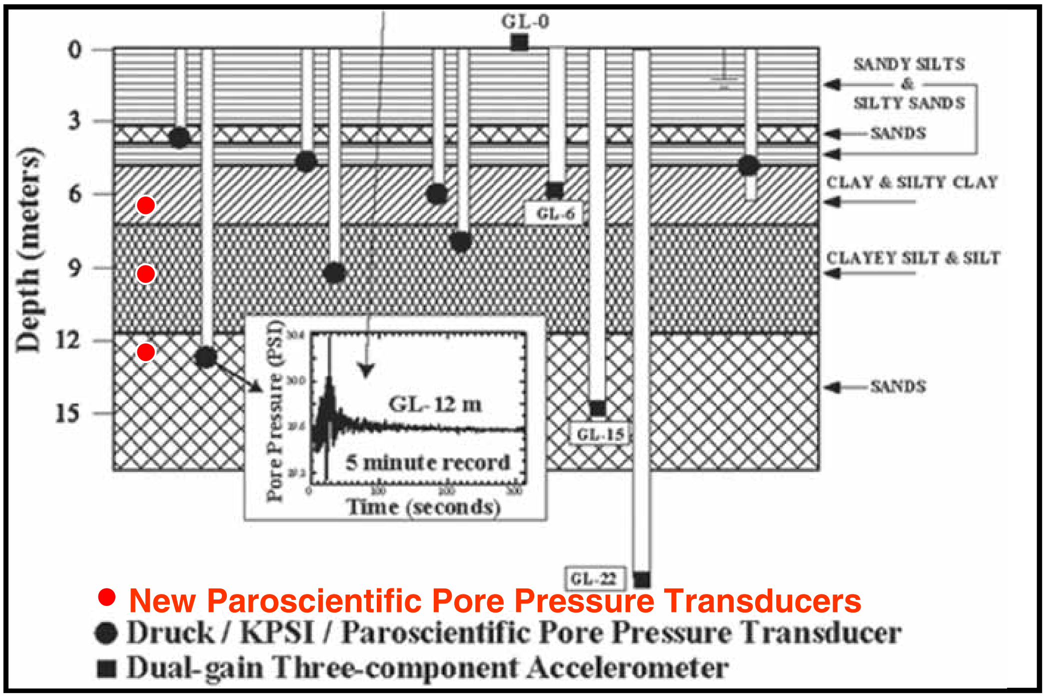


Figure 7. Cross section of the shallow allucium at the GVDA site showing depths of electrically transduced piezometers and accelerometers. Soil types interpreted from 1996 CPT data. Pore pressure record from the 1999 M7.1 Hector Mine earthquake recorded at 12 m depth inset.

GVDA SFSI Test Structure

A major addition to the GVDA site for the NEES project was the construction of a test structure for monitoring of soil-foundation-structure-interaction (SFSI) during active testing and earthquake shaking. This structure can be excited by shakers mounted on the structure or nearby on the ground surface. The general purpose for the SFSI test structure is to provide a medium-scale reconfigurable steel-frame structure founded on a rigid, massive concrete slab on grade. The superstructure is of a size appropriate for testing on a large NEES shake table (4m x 4m x 4m). Provisions are made for mounting shakers on the roof for active experiments to complement the primary purpose of passive response to earthquake monitoring (see Figure 8).

The SFSI structure will itself be instrumented with uni-axial and tri-axialaccelerometers, displacement gauges, foundation pressure cells, and a rotational sensor. An additional accelerometer and pore pressure sensor will be installed directly below the SFSI structure. Open cased holes have been installed at the center of each side of the SFSI structure to enable monitoring of the soil properties beneath the structure over time using cross-hole techniques. Additional channels of data acquisition have been set aside for researchers to be able to install sensors in these open cased holes on a temporary basis during experiments. A conceptual drawing that shows the possible input forces to the SFSI test facility at GVDA is shown in Figure 9. The instrumentation plan is shown in Figure 10.

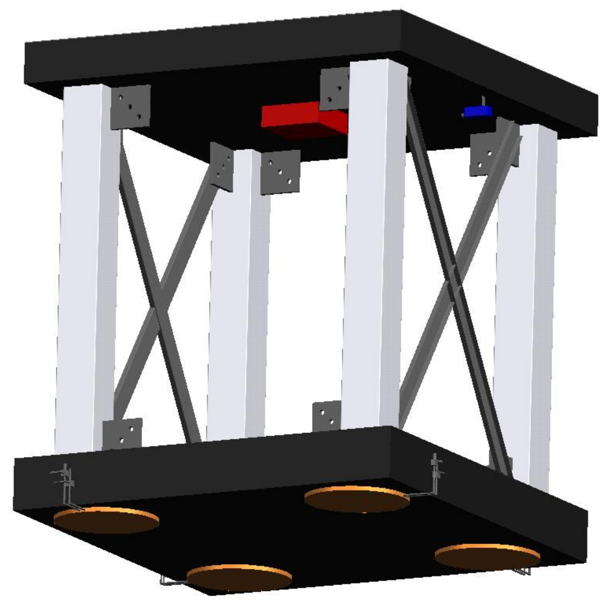


Figure 8. Conceptual model of the SFSI structure at the GVDA test facility.

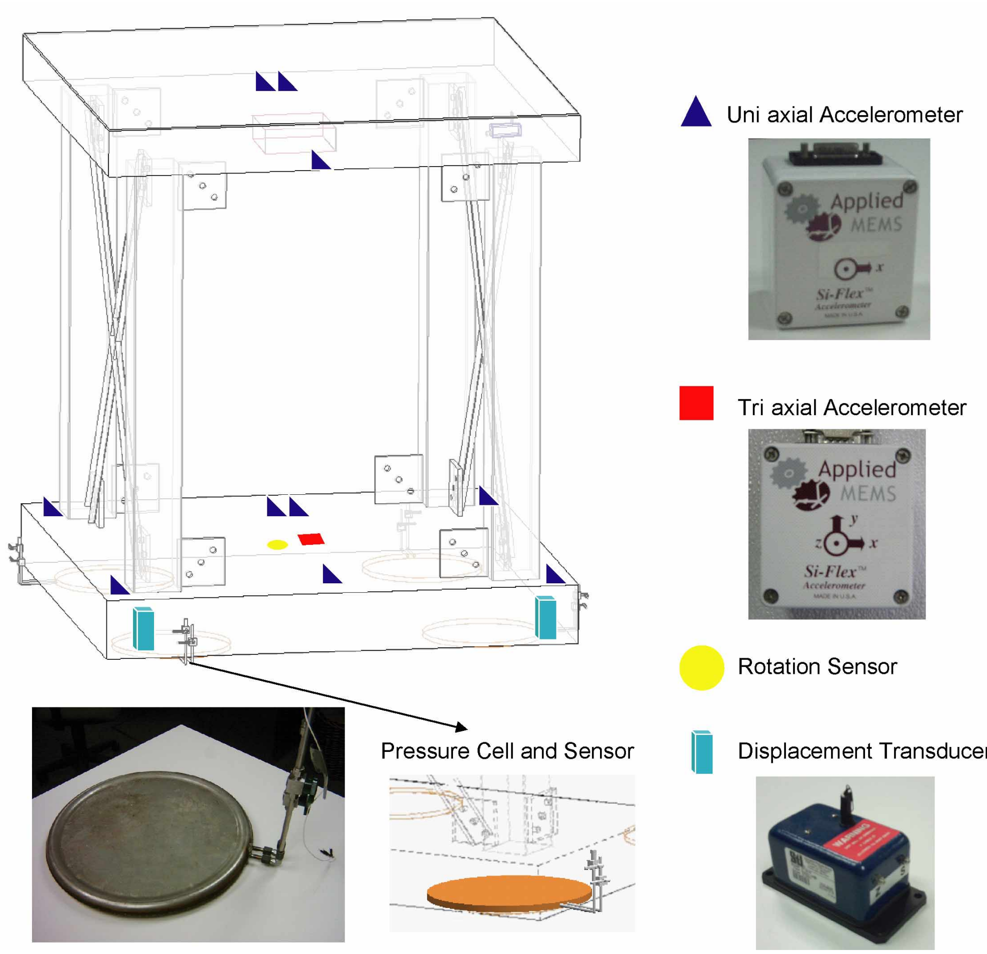


Figure 9. Planned instrumentation fot the SFSI test facility at GVDA.

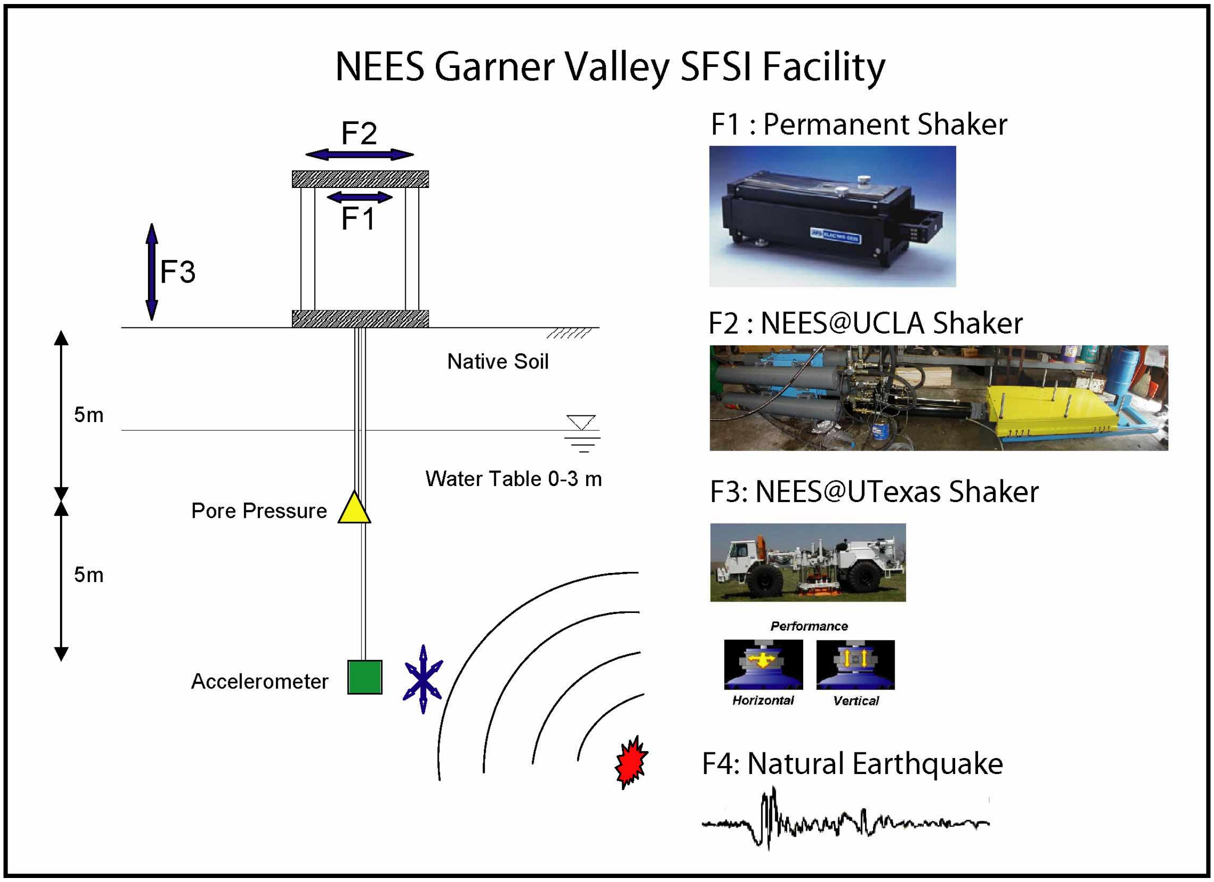


Figure 10. Possible input sources for the GVDA test facility.

A web-based simulation tool is being developed to assist the design of SFSI experiments at GVDA. The primary purpose of the simulation tool is to provide users with a simple JAVA-based interface to perform finite element analyses of the SFSI structure. The simulation tool will be a web-based application with the finite element analyses performed on the server side by implementing the JAVA SERVLET technology. The results will be displayed for the remote user via a TCP/IP protocol through a web browser. This simulation tool will eventually will be used to verify the structural configurations and the shaker parameters for experiments to be conducted at the GVDA test facility.

THE WILDLIFE LIQUEFACTION ARRAY

Background

The Wildlife Liquefaction Array (WLA) is located on the west bank of the Alamo River 13 km due north of Brawley, California and 160 km due east of San Diego. The site is located in the Imperial Wildlife Area, a California State game refuge. This area has been frequently shaken by earthquakes with six earthquakes in the past 75 years generating liquefaction effects at or within 10 km of the WLA site (Figure 11). Photo 2 is a picture of one of those effects, a sand boil that erupted during an earthquake in 1950 at a locality about 1.5 km northwest of WLA. Based on this history, there is high expectation that additional liquefaction-producing earthquakes will shake the WLA site during the 10-year operational phase (2004-2014) of the NEES program.

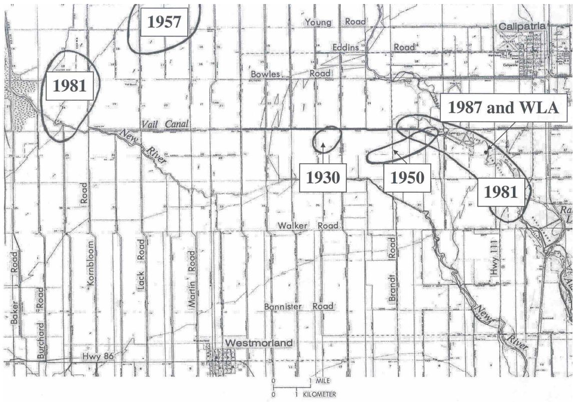


Figure 11. Area surrounding WLA site showing localities where liquefaction effects have occurred during earthquakes in the past 75 years

Photo 2. 1950 Sand boil deposit near house about 1.5 km northwest of WLA site

Because sand boils erupted pervasively in the floodplain of the Alamo River during the 1981 Westmorland earthquake, an instrumented site was established at that locality in 1882 by the US Geological Survey (USGS), with T.L. Youd as project leader. That site, noted as "the 1982 Site" on Photo N+1, was equipped with a surface and downhole force-balance accelerometer (FBA) and six electrically transduced piezometers. The 1982 instrumentation is described in detail in Bennett et al, 1984 [2]. In November of 1987 WLA was struck by two earthquakes, the Elmore Ranch event (M = 6.2) at 5:54 pm PST November 23 and the Superstition Hills event (M = 6.6) 11 hours later at 5:15 am PST November 24. Ground motions and pore water pressures were recorded during the Elmore Ranch event, but the pore pressures did not rise significantly. During the Superstition Hills event, however, pore pressures rose to a pore pressure ratio of 100 % and numerous sand boils erupted within and near the instrumented site as described by Holzer et al., 1989 [3]; and Youd and Holzer, 1994 [4]. Lateral spread displacements as great as 300 mm were also measured during the Superstition hills event, Dobry et al., 1992 [5]. Many researchers have used the data collected from the 1987 earthquakes to analyze the response of the site and to develop or verify models for predicting ground response and ground deformation.

WLA Site Conditions

Since 1987, the piezometers installed in 1982 have failed and the site has been disturbed by additional investigations. Because of the deterioration of the 1982 site, we proposed and developed a new NEES equipment site to reestablish WLA, but at a locality 65 m down river (northward) from the 1982 USGS site. The localities of both the old and new sites are marked on Photo 3, and a scaled map of the sites is reproduced in Figure 12. Also noted on the map are localities of 24 CPT soundings we installed in April 2003 to define the sediment stratigraphy beneath the new site. Figure 13 is a stratigraphic cross section beneath line A-A' developed from the CPT data. Figure 13 also indicates the position of the free face at the river bank. Photo 4 is a view of the steep river bank and the USGS CPT rig working at the site.

Photo 3. Aerial view of WLS showing localities of old and new sites

To test the liquefaction susceptibility of sediments in the granular layer beneath WLA, we applied the CPT procedure for evaluating liquefaction resistance published by Youd et al., 2001 [6] to the data collected from CPT 35 for a magnitude 6.5 earthquake and peak ground acceleration (Amax) levels ranging from 0.2 g to 0.4 g. The results of that analysis, shown in Figure 14, indicate that for a peak acceleration of 0.3 g to 0.4 g, a likely occurrence, much of the granular layer would liquefy. With the nearness of the incised river, liquefaction to this extent would likely lead to ground deformation and lateral spread toward the river.

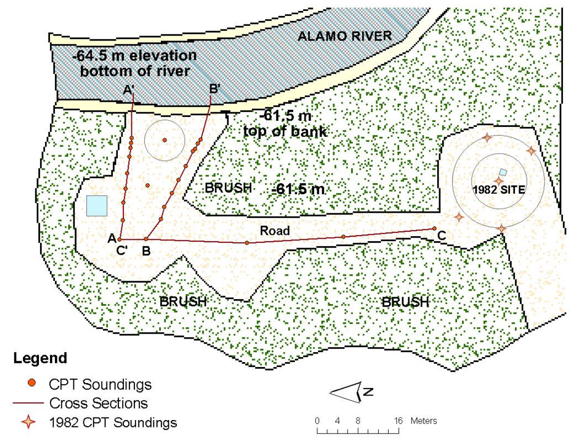


Figure 12. Map of 1982 and new WLA site with localities of CPT soundings

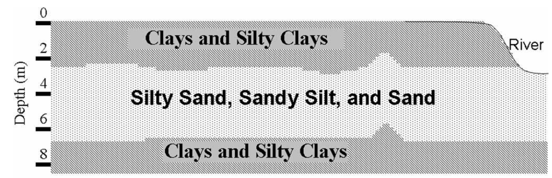


Figure 13. Cross section A-A' at WLA showing continuity of granular layer between 2.4 m and 7.0 m depth and intersection of those layer with the 3-m deep Alamo river channel

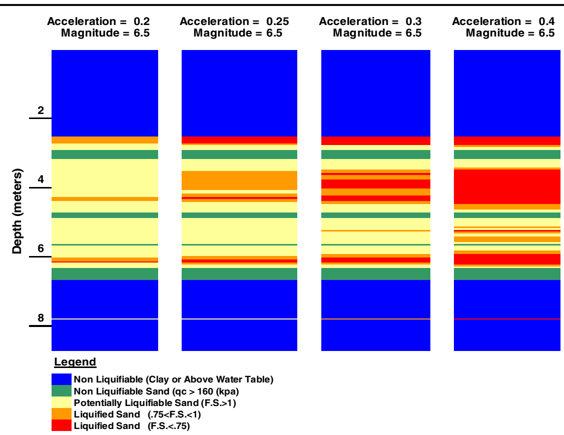


Figure 14. Liquefaction resistance of sediments penetrated by CPT 35 at WLA for a magnitude 6.5 earthquake and various level of PGA

Photo 4. Free face of Alamo River with USGS CPT rig conducting a sounding at WLA site

WLA Instrumentation

As part of the new NEES facility at WLA, a dense array of surface and subsurface instrumentation is being deployed to monitor ground motions, ground deformation, and pore pressure changes. A new permanent instrumentation shelter will be constructed at the site to house the data acquisition and communications equipment. The site will be linked back to the NEES grid system at UCSB via the UC

San Diego High Performance Wireless Research and Education Network (HPWREN) and data will be telemetered continuously in real time. Figure 15 shows the layout of new dense array of instrumentation.

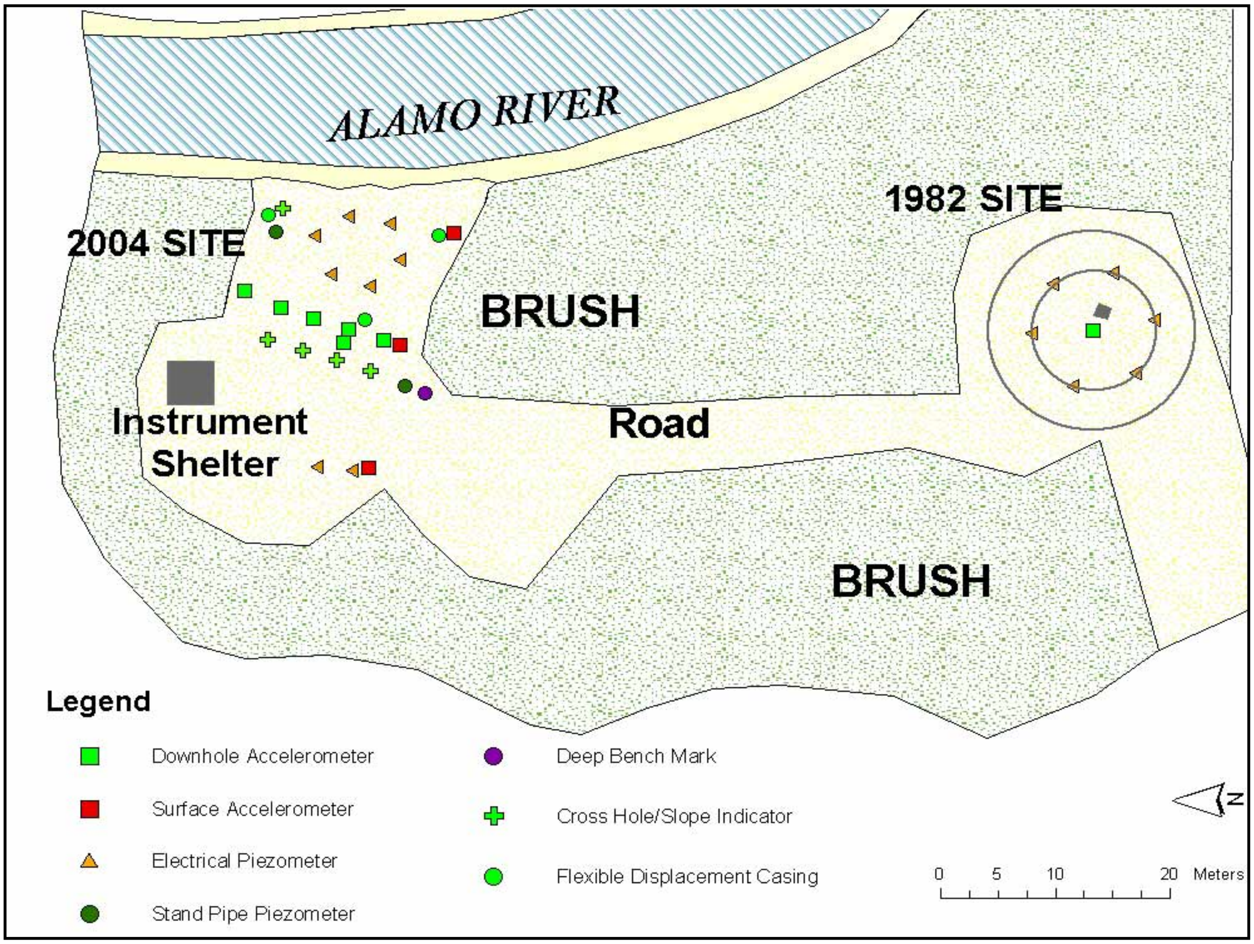


Figure 15. Map view of 1982 and new WLA site with localities of downhole and surface accelerometers, pore pressure transducers, bench marks, and other well casings.

FUTURE RESEARCH AT THE NEES PERMANENTLY INSTRUMENTED FIELD SITES

The NEES facilities described in this document are shared use facilites. They have been constructed for the earthquake engineering research community and are a national shared resource for experimentation. They have been constructed in a modular way, so that additional experiments can be conducted that expand on the current capabilities of the sites.

Funding for research at the NEES field sites is being provided through an annual NEES Research solicitation by the National Science Foundation, NSF 03-589 [7]. The authors encourage investigators to submit proposals to this program and to make use of these facilites.

ACKNOWLEDGEMENTS

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