Recent Enhancements to the NEES@UCSB Permanently Instrumented Field Sites

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SUMMARY:
The NEES@UCSB facility consists of experimental facilities and cyber infrastructure for active testing and passive earthquake monitoring at instrumented geotechnical field sites. Since the 14WCEE there have been a number of facility enhancements to both the experimental facilities and the cyber infrastructure for doing research at the NEES@UCSB equipment site or with the data it produces. Through both the maintenance and operations funding and the NEES Research program funding the scope of monitoring at the field sites continues to expand. Additional sensors have been installed in a dense Shape Accelerometer Array (SAA) at the Wildlife Liquefaction Array (WLA). A permanent cross-hole source and sensor array has been installed at the field sites to enable daily measurements of shear-wave velocity and automated post-earthquake observations. A new waveform explorer tool has been added to the NEES@UCSB data portal, to allow for users to select channels and browse through the earthquake observations made at the field sites before choosing to download the data.

Keywords: Instrumented Field Sites, InSitu Tests, Geotechnical, Liquefaction, Data Portal

1. INTRODUCTION

The University of California at Santa Barbara (UCSB) operates one of the 14 earthquake engineering experimental facilities that are part of the US National Science Foundation (NSF) George E. Brown, Jr., Network for Earthquake Engineering Simulation (NEES) Program. The NEES@UCSB facility includes two permanently instrumented field sites for the study of ground response, ground failure, soil-foundation-structure interaction, and liquefaction (*Steidl 2007; Youd et al., 2004, 2007; Steidl and Seale, 2010*). Since the facility became operational, continued enhancements have taken place in both the experimental capabilities, and the cyber infrastructure tools that facilitate research using the data from these sites. This paper summarizes the facility enhancements that have taken place since the last world conference.

1.1. The Garner Valley Downhole Array (GVDA)

The NEES 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 instrumented site is located in a narrow valley within the peninsular ranges batholith east of Hemet and southwest of Palm Springs, California. This seismically active location is 7km from the San Jacinto Fault and 40 km from the San Andreas Fault. The valley is 4-5 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 Figure 1.1. The details of the geotechnical site conditions and instrumentation at the GVDA facility can be found at the NEES@UCSB website (http://nees.ucsb.edu/), and in previous studies of the observations from this site (*Archuleta et al., 1992; Steidl et al., 1996; Bonilla et al., 2002; Tileylioglu et al., 2010*).

1.2. The Wildlife Liquefaction Array (WLA)

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. Earthquakes have frequently shaken this region, with six in the past 75 years generating liquefaction effects at or within 10 km of the WLA site (*Youd et al., 2004*). Based on this history, there is high expectation that additional liquefaction-producing earthquakes will shake the WLA site in the future, which led to the selection of this location for development of a permanently instrumented facility. Figure 1.2 is a view of the WLA site after construction was completed in Fall 2004. Details of the geotechnical site conditions and instrumentation at the WLA facility can be found at the NEES@UCSB website (http://nees.ucsb.edu/), and in previous studies of the observations from this site (*Youd and Holzer, 1994; Zeghal and Elgamal, 1994; Holzer and Youd; 2007; Steidl et. al., 2008, Steidl and Seale, 2010*)

Figure 1.1. The NEES@UCSB Garner Valley Facility in 2012.

Figure 1.2. The NEES@UCSB WLA Facility just after completion in 2004.

2. FACILITY ENHANCEMENTS

Each year as the NEES facility operations continue and experimental research activates take place under the NEESR program, the capacity and scope of the permanent field sites expands to meet the needs of the researchers. Two notable enhancements will be discussed here. First, the installation of a permanent cross-hole experiment added the capability for remote measurement of shear-wave velocity in the near surface materials. Second, cyber infrastructure development to the browser-based data dissemination portal added a waveform explorer providing the capability to plot, scroll though, and zoom in-and-out of ground motion and pore pressure time histories before selecting them for download.

2.1. Permanent cross-hole experiment at GVDA

Cross-hole tests are often used in site characterization studies to provide in situ estimates of shear-wave velocity at a particular depth by measuring the travel time from an active source deployed at depth in one well casing, to geophones located at the same depth in other well casings. Knowing the travel time and the distance between receiver casings, an estimate of the velocity can be made. The NEES@UCSB facilities were recently enhanced to include permanent cross-hole array experimental facilities in accordance with ASTM standards. The system is set to trigger the upward and downward hammer strike once per day automatically, thus providing observations that allow the measurement shear-wave velocity on a daily basis.

Additionally, the system is set to automatically activate the hammer source at shorter time intervals immediately following a large earthquake. This cross-hole experiment is unique in that these velocity measurements will be able to capture the decrease and recovery of shear wave velocity after a large event, and thus the degradation of shear modulus and its recovery with time at the same level in the soil. In combination with the permanent vertical array of accelerometers already deployed at Garner Valley, this new cross-hole experiment should provide a level of detail never before achieved in the observation of dynamic soil behavior during and following large earthquakes.

In the mean time, as we wait for the earth to provide larger motions, the once daily hammer strikes are recorded and analysed for potential temporal changes in velocity with seasons. The shear-wave velocity is determined by cross-correlation of the signals between the geophones of equal depth, separated by 4.82m. Initial analysis performing this cross correlation on the 5-meter sensors yields a shear wave velocity that fluctuates from 209-219m/s. We present the results of approximately one year's worth of daily hammer strikes alongside observed water pressure measurements to determine if there is seasonal variation of shear-wave velocity at the site related to variations in soil saturation and water table depth.

2.1.1. Overview of the cross-hole test

A dual direction hammer swings upward and then downward 30 seconds later with the motion recorded on a PCB accelerometer located adjacent to the strike plate, and four geophones at various distances and depths away from the hammer source. All the sensors are recorded at 200 sps continuously, and four of the sensors are also automatically sampled at 2000 sps when the tests are conducted. The triggering occurs once per day with two 8-second recordings capturing both hammer strikes. In addition, if a peak acceleration of more than 2% g is observed on all three channels of the quiet 150 meter depth borehole accelerometer (located in crystalline granite), the cross-hole systems automatically begins tests three minutes later, and continues to test automatically at regular but decreasing intervals until getting back to the normal once per day test.

2.1.2. Cross-hole instrumentation

A custom hammer was developed to generate the source excitation and is based on two solenoid-driven masses striking a center anvil plate. Large capacitors charge via 12V supply for 30 seconds before and between the upward and downward hammer strikes. A PCB piezoelectric capacitive accelerometer, series 3701, sits adjacent to the center anvil plate to provide accurate timing on the source through the GPS synced data acquisition system. The accelerometer sensitivity is 1 Volt/g with a full-scale range of +/-20g. The source is coupled to the borehole casing through a pneumatic bladder packer system. The receivers are GeoSpace GS-20DX 14hz uniaxial geophones, coupled to the casing via stiff leaf springs, but made to be adjustable so that the depth could be modified in the future. The four geophones are located at 2m and 5m depths on either side of the permanent structure at GVDA, and the hammer source is deployed in line ~2.4m away from the first geophone (Fig. 2.1).

Table 1. Cross-hole Instruments

Instrument #	Channel Name(s)	Type	Location	Depth	Sample Rate
11	SFSI_[EH]NZ_11	Accelerometer	Borehole 1	5m	200sps, 2000sps
21	SFSI_[EH]HZ_21	Geophone	Borehole 2	2m	200sps, 2000sps
22	SFSI_[EH]HZ_22	Geophone	Borehole 2	5m	200sps, 2000sps
41	SFSI_HHZ_41	Geophone	Borehole 3	2m	200sps
42	SFSI_[EH]HZ_42	Geophone	Borehole 3	5m	200sps, 2000sps

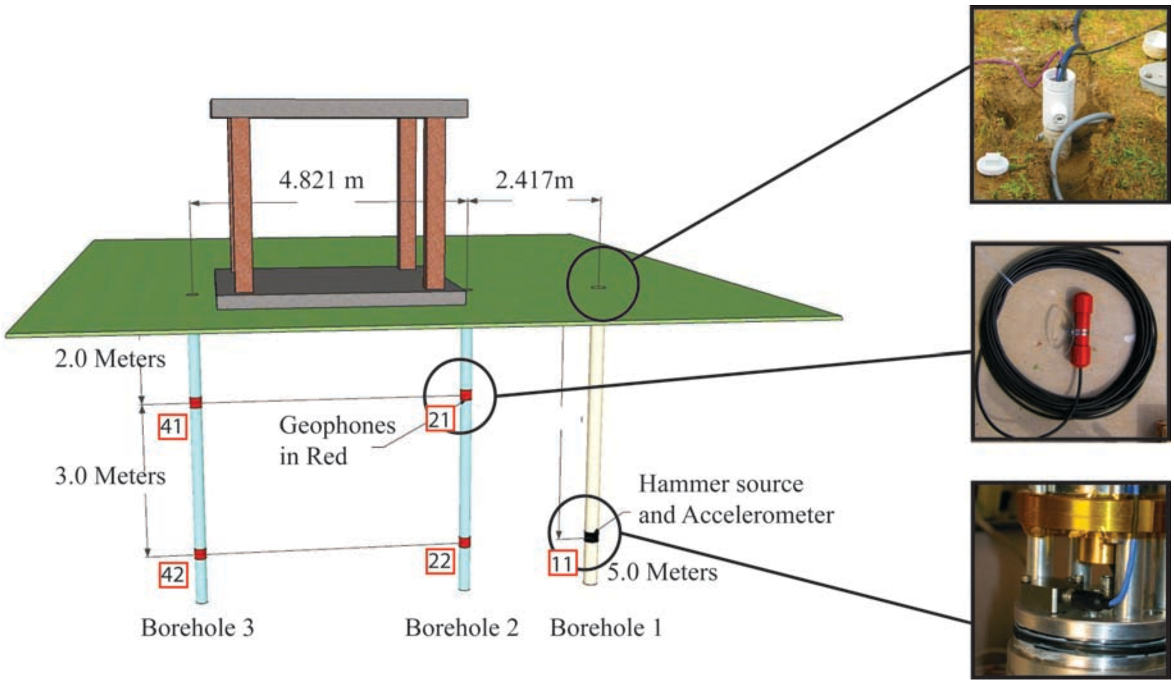

Figure 2. Layout of the cross-hole test at GVDA as viewed from instrumentation hut (looking west). Three boreholes form a line bisecting the SFSI structure at an azimuth of 325 degrees.

2.1.3. Temporal changes in shear-wave velocity

The once daily hammer strikes provide the capability to measure shear-wave velocity changes on a day-to-day basis. Using 2000sps data we calculate the travel time between the 5-meter geophones by cross-correlation of the similar waveforms, and then determine the shear wave velocity of the soil at that depth. Apparent seasonal variations of velocity are compared to observed water pressure measurements at the site.

Seismic velocity was calculated between December 2010 and August 2011. Values were determined by moving window cross-correlation of waveforms recorded at 5 meters depth on the geophones, which were separated by 4.82 meters (Fig. 2). Hammer upswing and downswing measurements show similar trends: a slight increase in shear-wave velocity from December 2010 to March 2011, and then a slight decrease in shear-wave velocity from April 2011 to August 2011 (Fig. 3).

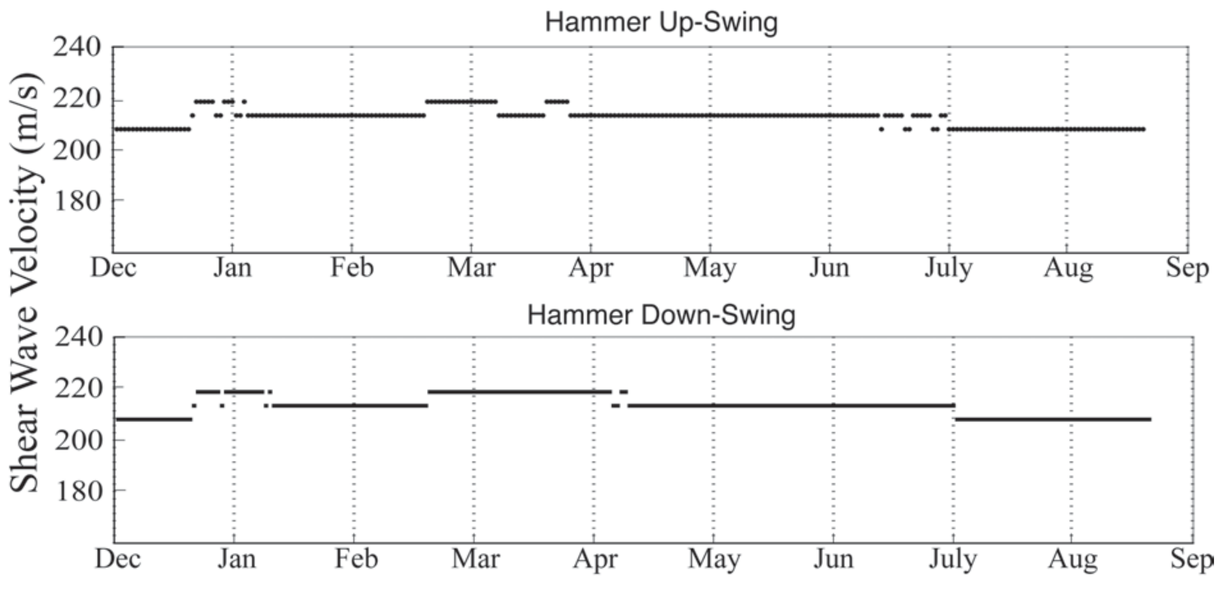

Figure 3. Shear-wave velocity over time from December 2010 to September 2011.

Using a borehole pore pressure sensor and barometric pressure measured at GVDA, the water table height below the surface could be calculated for the same time period. Figure 4 shows the pore pressure and barometric pressure for this time period

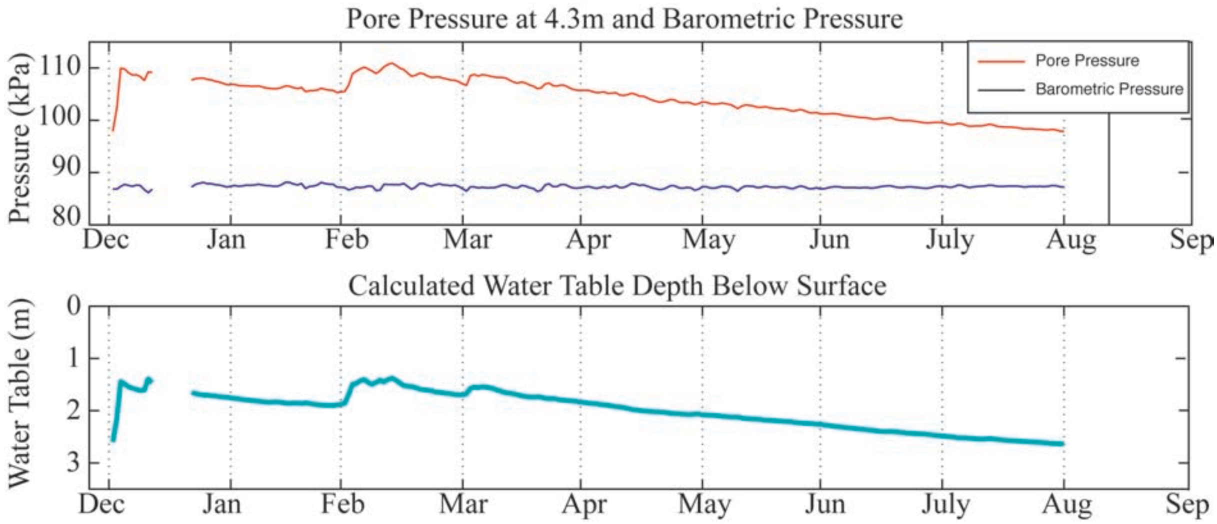

Figure 4. Seasonal Changes in the water table depth based on borehole pore pressure and barometric pressure observations at GVDA.

The analysis presented in Fig. 3 and Fig. 4 suggest that the shear-wave velocity in the shallow soil at 5 meters depth may have a slight variation with season, with the velocity increasing when the water table rises, increases the vertical stress on the soil column. The two predominant peaks in the water table appear to correlate with peaks in shear wave velocity with delays of ~2 weeks. Note that the water table never drops below the ~5m geophones so this change in velocity cannot be attributed to soil fluctuating between fully saturated and unsaturated. The changes are small, and just about at the resolution of the current data acquisition system, a Kinemetrics Granite system, which has a maximum sample rate of 2000 sps. Future analysis of the data from these sensors using a DAQ with a much higher sampling rate will provide better resolution, and help determine if these changes are real. The addition of multiple years of data from this cross-hole experiment will provide data over multiple rainy seasons.

2.2. Enhancements to the NEES@UCSB data dissemination portal

Since the beginning of the NEES@UCSB operations, the goal has been to make the data from the permanently instrumented field sites readily available to the seismological and earthquake engineering community. Software development of a web-based data dissemination portal began early in the operational phase of the NEES program, and has continued throughout. This development includes web-based data dissemination and waveform viewing tools available through the NEES@UCSB website [http://nees.ucsb.edu/data] and a tutorial on using these tools can be downloaded from the NEES@UCSB homepage.

At the data portal main page, the user is presented with a Google-map interface and drop down menu to select from the various vertical array field sites operated by UC Santa Barbara, or from partners making their data available through the portal. Once a particular site of interest has been chosen, the user can then create a search query using magnitude, date, and distance ranges to select earthquakes recorded by the vertical array. A list of events is returned to the user along with an interactive Google-map showing the location of the events relative to the station. The ability to download relevant geotechnical site characterization data from the sites of interest is also provided to the user.

Once a particular earthquake has been selected, the user is then presented with a list of the waveform data available from the site for that earthquake, and now, the ability to open an interactive waveform viewer within the web-browser window making it platform independent tool. This allows the user to view the data before deciding to download, and even perform some operations on the data, such as filtering or removing the mean. The waveform explorer tool is customizable, allowing the user to select the color theme, and default filter configurations that is saved so it remains the same whenever they return (Fig. 5). A help tab is also presented to the user for quick instruction on keyboard shortcuts for moving around the time histories.

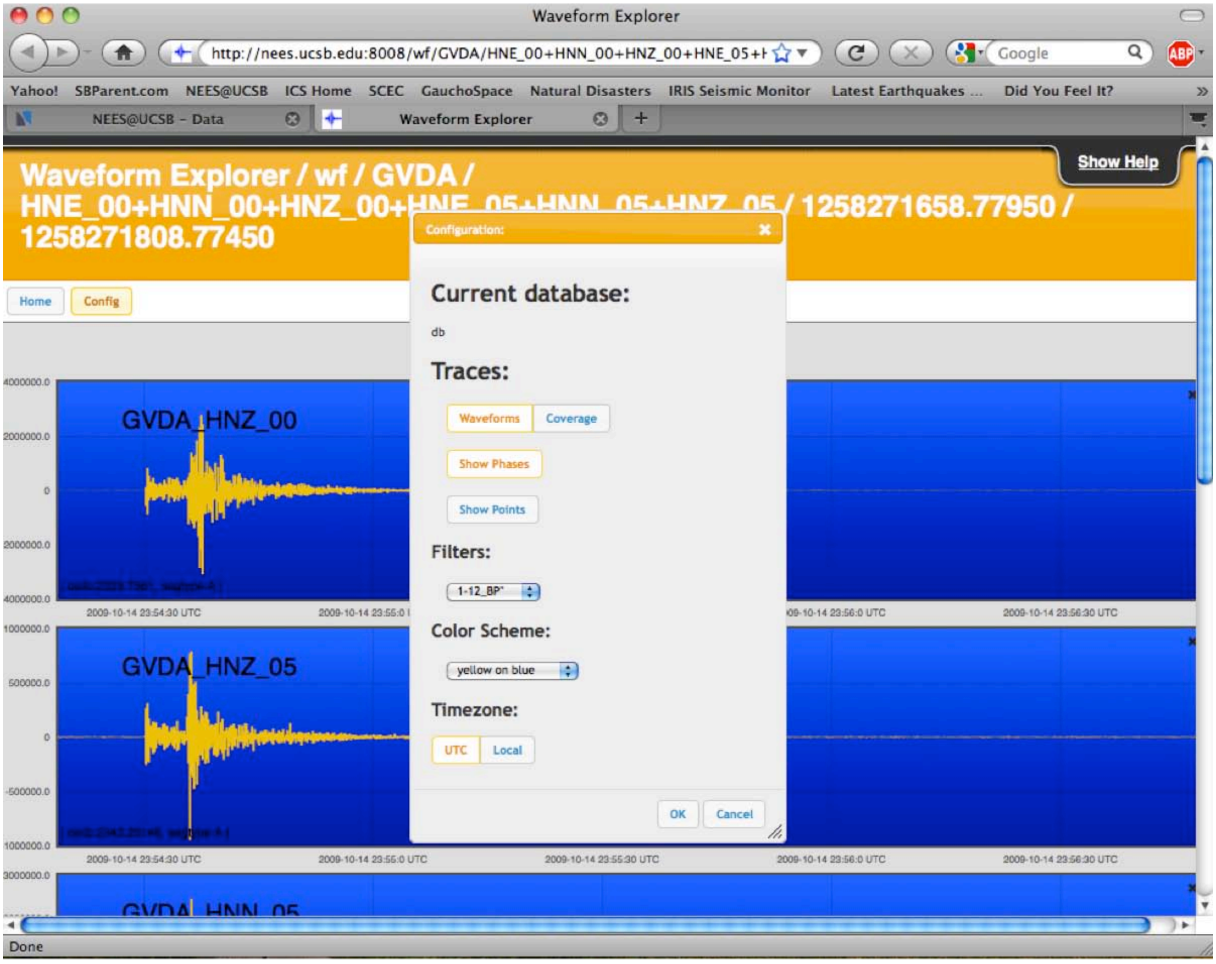

Figure 5. A screenshot of the NEES@UCSB Waveform Explorer with user-configurable interface.

Often it is desirable to quickly inspect data before downloading the actual ground motion time histories to your computer. The waveform explorer provides zoom in/out capabilities, and scrolling left or right through the waveforms to enable a more detailed viewing of the records before selecting for download (Fig. 6). After closer inspection, the data can be downloaded as an event zip-file in a variety of formats, including miniseed, SAC, and two text-based formats. Individual channels can also be downloaded in miniseed format. In the future, we plan to provide a matlab reader for the miniseed file format. In addition to the waveform data, the station metadata, including sensor calibration information, sensor layouts in map-view and cross-section, and site characterization information can all be downloaded from the portal. These metadata are critical to any future analysis of the ground motion or pore pressure records.

Each year we include more instrumented geotechnical array sites into the data portal, providing access to borehole array data from not only the NEES facilities, but also from other data providers. Our goal is to continue to expand the data collections, making it easier for researchers to find data from different geographical regions and from different geotechnical site conditions.

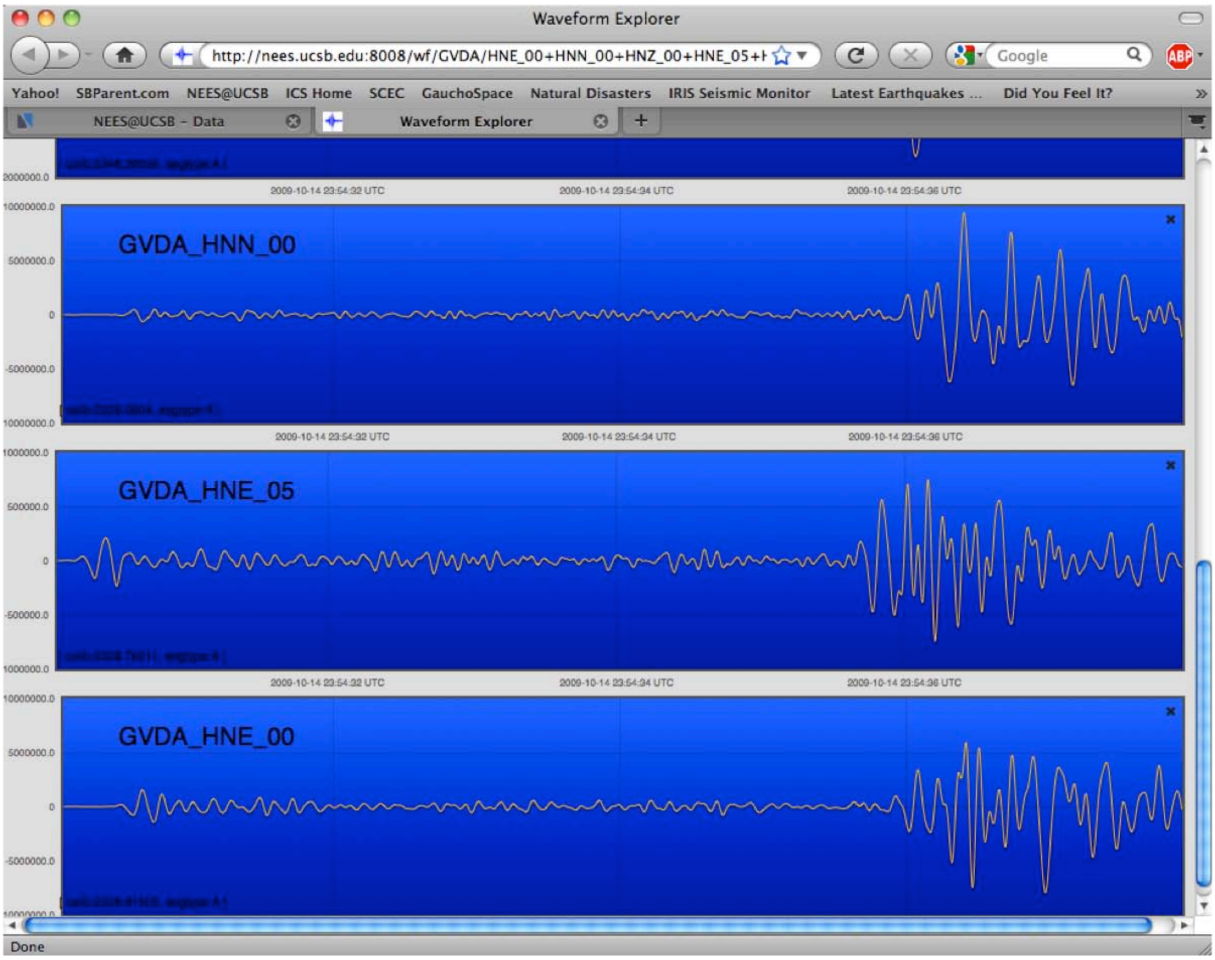

Figure 6. Zoom and scroll capabilities built into the NEES@UCSB web-based waveform explorer.

2. FUTURE OPPORTUNITIES

The research projects conducted over the last few years at the NEES@UCSB facility are also contributing to future potential facility enhancements. These include the testing of a small reconfigurable structure at both the WLA and GVDA sites, with both low-level and high-level testing using the NEES@UCLA shakers. The data sets will become available from these tests for future re-use, and the structure, which is basically a smaller version of the permanent structure at GVDA, has been left at the GVDA site and could be used for future experiments or site instrumentation enhancements.

The WLA site has also had a deployment of seven Shape Accelerometer Arrays (SAA's) which each contain 24 3-component MEMS accelerometers at approximately 0.3 meter spacing that span the upper 8 meters of the site, from above to below the liquefiable layer. These provide an unprecedented level of detail in observing the wave field form large earthquakes as they propagate up through the near-surface soil layers. When this NEES research project is completed, these SAA's could become a permanent component of the WLA facility. To date there have been two active source tests using mobile shakers to excite these shape arrays at WLA, and this data will also be available via the NEES project warehouse for re-use.

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