Observations and Analysis of Ground Motion and Pore Pressure at the NEES Instrumented Geotechnical Field Sites

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ICS UCSB INSTITUTE FOR CRUSTAL STUDIES · NSF · UCSB · NEES

Abstract:

The Garner Valley and Wildlife sites are producing a large data set that includes very interesting observations from earthquakes in the magnitude 4 to 7 range, with peak accelerations of ~10%g, at the threshold where nonlinear effects start to become important. In addition, hundreds of smaller earthquakes are recorded each month that provide the control data representing the linear behavior of the site. With the larger motions, we begin to see pore pressure build up on the liquefaction array at both the NEES Garner Valley Array site and at the NEES Wildlife Liquefaction Array site. We present the results of simulated pore pressure generation using the observed ground motions and a nonlinear anelastic hysteretic finite difference model of the soil response for the 1999 M7.1 Hector Mines event. We are able to reproduce this onset of pore pressure generation that occurs under the moderate strain levels associated with these ground motions. Pore pressure data and the ground motions recorded from the accelerometers within the vertical WLA array are shown for the recent M7.2 Sierra el Mayor earthquake. Continuing studies on these unique data sets are improving our understanding of the physical process that drives liquefaction.

Stations and Locations:

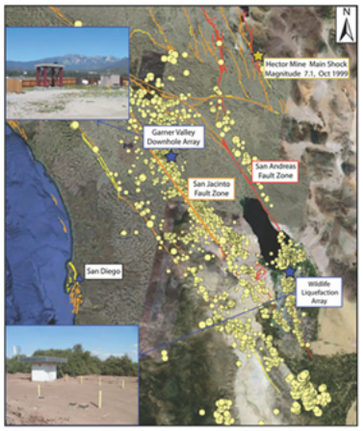


Figure 1- Location of the Garner Valley Downhole Array and the Wildlife Liquefaction Array (blue stars) shown with over 7500 recorded earthquakes representing 3-years of seismicity (yellow circles) from August 2005 through August 2008.

Garner Valley Downhole Array (GVDA):

The Garner Valley station is located 7km from the San Jacinto Fault and 40 km from the San Andreas Fault (Figure 1). A geotechnical cross-section of the GVDA site is shown in Figure 2. Cone Penetrometer Testing (CPT) at the site in a line that spans a 10-meter section of the site in close proximity to the downhole pore pressure and accelerometer arrays, and a reconfigurable instrumented structure built to study soil-foundation-structure interaction (SFSI). The GVDA site conditions are soft soils with ~20 meter thickness over a 70-meter layer of weathered granite with crystalline granite (Vs=3.0 km/s) at ~90 meters depth.

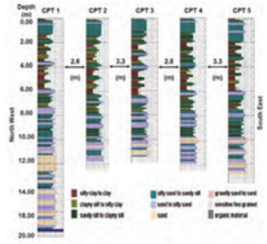


Figure 2- Geotechnical cross-section for GVDA developed from CPT data.

The vertical array of accelerometers consists of 3-component sensors placed at the surface and at depths of 6, 15, 22, 50, 150 and 501 meters below ground level. In addition, five pore pressure transducers are located within the soft saturated alluvium at depths of 3.5, 6.2, 8.8, 9.9, and 12.4 meters below ground level (Figure 3). Data is collected continuously from all sensor channels at a 200 Hz sampling rate (~1Gb per day total) and is stored both locally on site, and brought back to UCSB in real-time via high performance wireless telemetry. At UCSB the continuous data is archived on RAID storage servers for processing, where earthquake data is segmented out of the continuous data stream, and eventually made available via a web-based data dissemination portal. The continuous data is migrated to tape archive for long-term storage, once the event processing has been completed.

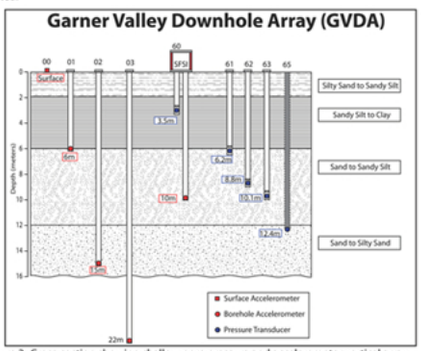


Figure 3- Cross-section showing shallow pore pressure and accelerometer vertical array instrumentation at GVDA.

Wildlife Liquefaction Array (WLA):

The facility is located within the Brawley Seismic Zone, a region of very active seismicity along the Pacifc - North American plate boundary between the Imperial and San Andreas Fault zones (Figure 1). The location was selected because of the six events in the past 75 years generating liquefaction effects within 10 km of the WLA site (Youd et al., 2004b). The near-surface geology of the WLA site consists of a layer of saturated silty sand, from approximately 2 – 7 m, with silty clay above and below the layer. A geotechnical cross section of the site based on the extensive CPT work done at the site is shown in Figure 4. The NEES@UCSB WLA facility is a combination of the newly instrumented 2004 location (figure 5) and the older 1982 USGS facility that was re-instrumented in 2005 (figure 6). These two sets of instrumentation are located approximately 80 meters apart along the bank of the Alamo River.

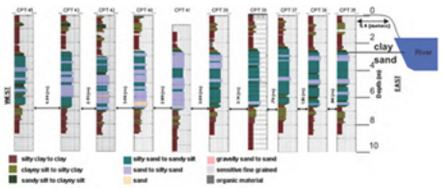
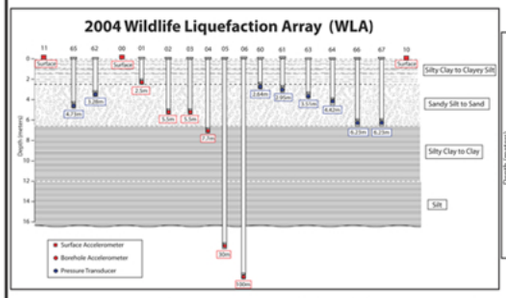
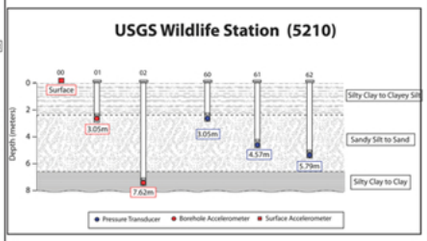
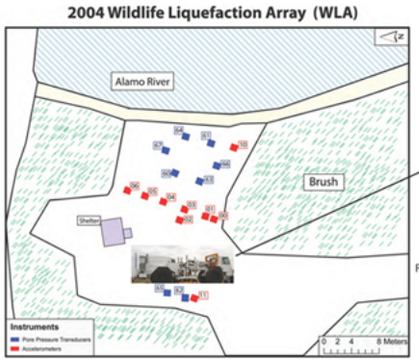


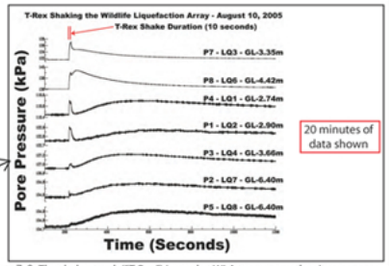
Figure 4- Geotechnical cross-section for WLA developed from CPT data.





Figures 5, 6- Cross sections displaying shallow pore pressure and accelerometer vertical array at WLA and 5210 USGS Wildlife Station.





Figures 7, 8- The shaker truck ("T-Rex") is used at WLA to measure the site response to active source shaking, providing unique data that will be used for years to come by researchers to develop and improve ground motion simulation techniques that include the effects of pore pressure. From the record, it can be observed that the pore pressure requires a significant amount of time to reach equilibrium after the initial disruption.

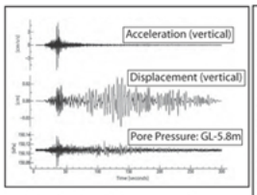


Figure 9- Acceleration, displacement, and pore pressure recorded at WLA from a M3.6 event. The pore pressure response appears to be correlated to the displacements from surface waves in the imperial valley.

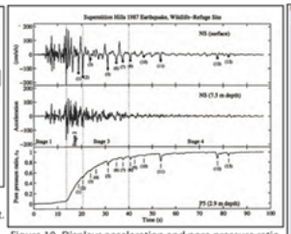


Figure 10- Displays acceleration and pore pressure ratio records from the Superstition Hills 1987 earthquake, which triggered liquefaction at WLA. Liquefaction occurs when the pore pressure ratio reaches 1 (Zeghal et al, 1996).

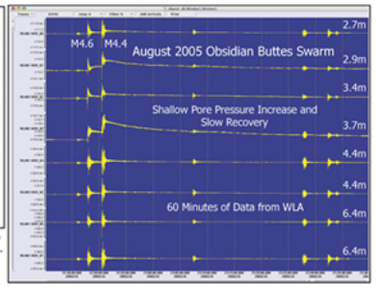


Figure 11- Displays pore pressure records from the WLA vertical array from August of 2005 Obsidian Buttes swarm when a magnitude 4.4 event occured only a few minutes after a magnitude 4.6 event.

The 1999 M7.1 Hector Mine Earthquake:

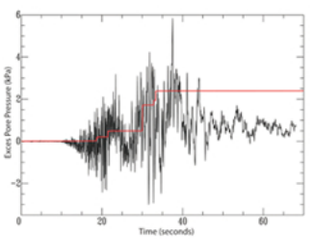


Figure 12- Observed excess pore pressure recorded at GVDA during the Hector Mine earthquake. The red line is the linear approximation of the pore pressure input to the NOAH model.

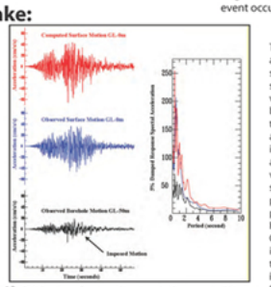


Figure 13- Synthetic surface accelerations(red) computed by NOAH compared to observed.(blue) for the Hector Mines earthquake at GVDA and their spectra. The motion input to the model at 220 m is shown in black.

The 1999 Magnitude 7.1 Hector Mine earthquake occurred at a distance of approximately 110km from GVDA. The unique in situ observations of both ground motion and pore pressure in saturated alluvium during the Hector Mine earthquake provided the ideal data set for examination of the dynamic soil behavior properties during ground shaking. These observations included ground motions on the order of 10%g, generally considered to be at the range where nonlinear soil behavior and excess pore pressure generation might be considered a factor in site response estimation. The pore pressure observations from this event include a steady increase in pore pressure with time, and then a slow steady decrease back to the pre-event pore pressure level. Riding on top of this longer period trend are higher frequency dynamic oscillations. The Hector Mine event was the first recorded earthquake at Garner Valley that generated an observed pore pressure increase in the near-surface alluvium. This data set was used to perform full nonlinear modeling of ground response, including the effects of the pore pressure (Steidl et al., 2001). Synthetic accelerations were computed at the surface by the finite difference code NOAH (Bonilla et al., 1998). The results are plotted along with the recorded surface accelerations in Figure 13.

Two interesting results from M7.2 Sierra el Mayor, 4/4/2010:

Figure 14- This event originated from Baja California on 04/04/2010 at 22:40 UTC time and was observed at the Wildlife Liquefaction Array on multiple sensors. The station has an epicentral distance of ~110Km from the main shock.

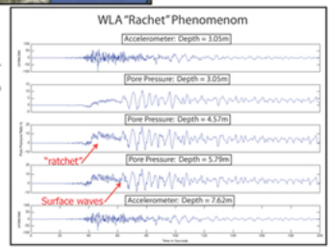


Figure 15- Displays two acceleration and three pore pressure records from the 5210 Wildlife site displaying the "rachet" phenomenom. The known response of pore pressure to strong ground motion is a sharp jump at the S-wave arrival, which is a response to the sudden increase in shear strain. It is followed by a long, exponential decay back to the level before the event. If there is another large S-pulse before the pore pressure has had a chance to return to it's starting level, the same sharp jump in pore pressure occurs on top of the old one; this is described as the "rachet."

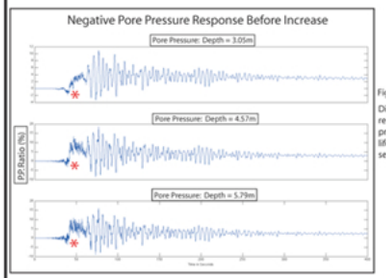


Figure 16- Displays the negative pore pressure response (marked by) at pore pressure transducers at the 5210 Wildlife site in response to the El Mayor seismic event.

Web-Based Data Dissemenation :

The Google Map API provides JavaScript mapping and GIS interface. Our page works with Firefox 3.1 and Safari 4.0 (and later). We currently experience problems with Internet Explorer. The following three bullet items below outlines the steps to download data from the Superstition Mountain site and correspond to the screen shots shown at the bottom of the poster. Data is available from 1/1/2006 to 12/31/2009 and will eventually be available from 2003 on. To begin, go to the URL http://nees.ucsb.edu/facilties/data where you should see the a map with markers to our stations from Alaska to the Salton Sea.

1 First select a station from the drop down list on the right. When you do, a list of all available sensors for that station will appear.

2 Next you must select a single event. You can search by distance, magnitude and time, but only earthquakes that meet a general magnitude/distance formula are available here. (Note that we also have continuous data on LTO2 tape and other media.)

3 Finally, you "package" it by selecting the file formats and any options that apply to those formats. It is possible to only download specific channels by clicking on the channel name. The RDV and Excel compatible formats can have the calibration applied. The button "Add Package" stores the options. When you have all the data you're interested in added into the packages window, you can then enter your email address and click the "download packages" button.

Conclusions and Ongoing Study:

Research using earthquake data has traditionally focused on liquefaction in hindsight: identifying the point in time at which the pore pressure ratio exceeds one, the soil liquefies, and then studying the subsequent ground response. Future work includes the development of an empirical model to enable the prediction of pore pressure generation before a large earthquake occurs based on expected ground motions within a saturated soil column. The new prediction model will be based in large part on the observed data from the GVDA and WLA field sites as well as site response data from active source shaking. Our ongoing study focuses on understanding the mechanism for the generation of pore pressure increase and sustaining pressure during surface waves, the influence of elevated pore pressure on material properties, and a close examination of shear stresses and strains in the liquefiable layer.

Acknowledgements:

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