SCEC Borehole Instrumentation Program

Report for SCEC Award #19139
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I. Project Overview

A. Abstract

In the box below, describe the project objectives, methodology, and results obtained and their significance. If this work is a continuation of a multi-year SCEC-funded project, please include major research findings for all previous years in the abstract. (Maximum 250 words.)

The ability for SCEC to respond rapidly to a major southern California earthquake with the deployment of seismographs in the near-source region was a catalyst for the creation of the PBIC. In between these major earthquake sequences, the PBIC equipment provides the ability to conduct individual PI driven research experiments. The PBIC has now phased out the original data acquisition equipment and is in the process of modernizing its instrument pool. The current PBIC instrumentation consists of 7 IP-based data acquisition systems capable of real-time data transmission to regional networks or UCSB, and low-noise strong motion sensors capable of recording events as small as magnitude 1.0 when close to the station, yet remain on-scale up to +/- 4g ground motions. This new equipment is network ready and when combined with a 4G cellular radios or IP radios, allows for integration directly with SCSN regional network operations. The PBIC has demonstrated the capability to deploy and integrate its stations into the regional network, providing high-quality observations that are being used for earthquake locations and shake map applications, and the data is archived immediately into the SCEDC along with the rest of the SCSN stations providing access to all community users. These stations have proven to be dependable, remaining deployed for multiple years without a site visit. More recently, the PBIC supported the deployment of USGS and PASSCAL nodal instruments following the Ridgecrest earthquake sequence, as well as supporting the more traditional 6-component broadband/strong-motion portable stations.

B. SCEC Annual Science Highlights

Each year, the Science Planning Committee reviews and summarizes SCEC research accomplishments, and presents the results to the SCEC community and funding agencies. Rank (in order of preference) the sections in which you would like your project results to appear. Choose up to 3 working groups from below and re-order them according to your preference ranking.

Seismology
Ground Motion Prediction (GMP)
Communication, Education, and Outreach

C. Exemplary Figure

Select one figure from your project report that best exemplifies the significance of the results. The figure may be used in the SCEC Annual Science Highlights and chosen for the cover of the Annual Meeting Proceedings Volume. In the box below, enter the figure number from the project report, figure caption and figure credits.

Figure 1. Satellite map (left) showing the Ridgecrest earthquake sequence surface rupture (red lines), cross fault nodal instrument deployments (cyan circles), and traditional portable stations from the USGS Pasadena (pink squares) and USGS ASL (blue diamonds). Photo image of a traditional 6-component station deployed along with two different nodal sensors for comparison with the strong motion and broadband data (right).

D. SCEC Science Priorities

In the box below, please list (in rank order) the SCEC priorities this project has achieved. See *https://www.scec.org/research/priorities* for list of SCEC research priorities. *For example: 6a, 6b, 6c*

3a, 4a, 1d

E. Intellectual Merit

How does the project contribute to the overall intellectual merit of SCEC? *For example: How does the research contribute to advancing knowledge and understanding in the field and, more specifically, SCEC research objectives? To what extent has the activity developed creative and original concepts?*

The portable instrument center contributes to the SCEC research priorities in many ways. It helps improve the accuracy of locations by densification of the regional network, providing data that will lead to improvements in the community velocity model and community fault models. It improves our understanding of strong ground motions, including the variability and causes of damage during the aftershock sequences of large earthquakes, by providing a pool of RAMP instruments that can be deployed within 24 hours of a significant earthquake in southern California. It has also provided individual researchers with equipment to search for and improve the imaging capability of tremor activity, and the ability to examine fault damage and healing through trapped wave experimental deployments.

F. Broader Impacts

How does the project contribute to the broader impacts of SCEC as a whole? *For example: How well has the activity promoted or supported teaching, training, and learning at your institution or across SCEC? If your project included a SCEC intern, what was his/her contribution? How has your project broadened the participation of underrepresented groups? To what extent has the project enhanced the infrastructure for research and education (e.g., facilities, instrumentation, networks, and partnerships)? What are some possible benefits of the activity to society?*

The educational impact of the PBIC is demonstrated by the number of undergraduate and graduate student participants in field deployments, and in the routine maintenance and operations of the PBIC. UCSB continues to use undergraduate and graduate students in the deployment and maintenance of the stations, many at UCSB, but also at other institutions within California. Giving the students hands-on experience in how the data is collected is an important part of the education of future geophysicists, especially in a time when data is so readily available via the Internet without any knowledge of what is involved in the data collection process. In addition, the number of women and minority students previously and currently involved in the PBIC program is significant. Outreach to K-12 students has always been an important part of the PBIC program, with the “make your own earthquake” (MYOE) demonstration developed initially through SCEC, now being used at institutions across the country.

G. Project Publications

All publications and presentations of the work funded must be entered in the SCEC Publications database. Log in at *http://www.scec.org/user/login* and select the Publications button to enter the SCEC Pubications System. Please either (a) update a publication record you previously submitted or (b) add new publication record(s) as needed. If you have any problems, please email *web@scec.org* for assistance.

II. Technical Report

The PBIC was established more than 2 decades ago through funding from SCEC to provide a pool of digital seismic recording equipment for use in post-earthquake response, and in individual PI driven research experiments within southern California. While the uses of the PBIC equipment remain unchanged over the years, the PBIC is now in the process of modernizing its broadband instrument pool with posthole form factor sensors to adopt this more recent style of station deployment. The PBIC is also adopting the use of 3-component nodal stations into the post-earthquake response plans, initially through partnership with the USGS and IRIS PASSCAL instrument center.

The ability for SCEC to respond rapidly to a major southern California earthquake with the deployment of both weak- and strong-motion instruments in the near-source region was a catalyst for the creation of the PBIC and remains an important asset of SCEC seismology infrastructure and earthquake research community. This has been highlighted by successful deployments of PBIC equipment following previous earthquakes. The southern California region has been relatively quiet in recent years, with the last RAMP deployment during the 2010 El Mayor–Cucapah earthquake. This event was the first post-earthquake response using the modern real-time capable PBIC equipment, with stations deployed and data delivered directly back to UCSB and then relayed to the regional seismic network (SCSN). Two of the PBIC stations remained deployed through June of 2014, providing data to the network for more than four years after the mainshock, without requiring a site visit.

Other successful RAMP deployments include the 2008 shakeout exercise along the southern San Andreas, the 2004 Parkfield and 2003 San Simeon earthquakes, as well as the four major earthquake sequences in the previous decade (1992 M6.1 Joshua Tree and M7.3 Landers, 1994 M6.7 Northridge, and 1999 M7.1 Hector Mine). The ability to conduct individual PI driven research experiments in between these major earthquake sequences using PBIC equipment is another very important component of the PBIC program. The PBIC continues to modernize and provide the SCEC community with seismic monitoring stations to facilitate PI research.

A. Highlights of SCEC5 2019 PBIC Activity

PBIC Response to the 2019 Ridgecrest Earthquake Sequence

The 2019 Ridgecrest Earthquake sequence was the first experience for the PBIC in the deployment of nodal arrays following a major event. The number of traditional 3- and 6-component portable stations being deployed by the USGS (Pasadena and ASL), and UC Riverside, and the lack of access to deploy directly on the Naval Air Weapons Station (NAWS) at China Lake meant that the traditional SCEC PBIC were not needed, and remained deployed in central CA. SCEC PBIC did provide solar equipment for some of the USGS Pasadena stations, and assisted with permitting some sites for the USGS ASL stations.

However, even though the tradition PBIC stations were not used, partnering with the USGS and IRIS PASSCAL, the PBIC was able to gain access to the fault rupture (most of which was on the NAWS) and deploy a number of fault crossing arrays using nodal instruments the PBIC borrowed from the IRIS PASSCAL instrument center combined with USGS nodal instruments. Figure 1 below shows a satellite map view of the fault rupture and station deployment (left), and an image of one of the traditional portable station deployments (GS.CA01). At GS-CA01 (and also at two other traditional portable stations) we deployed a USGS SmartSolo 3-component node alongside the PASSCAL Fairfield 3-component node. Sensors deployed at these traditional portable sites included the Nanometrics compact Trillium 3-component broadband and the Kinemetrics Episensor 3-component strong-motion instrument. This combination of sensors will allow for side-by-side comparison of the two 3-component nodal systems with each other, as well as with the broadband and strong-motion sensors deployed with the traditional portable stations.

Figure 1. Satellite map (left) showing the Ridgecrest earthquake sequence surface rupture (red lines), cross fault nodal instrument deployments (cyan circles), and traditional portable stations from the USGS Pasadena (pink squares) and USGS ASL (blue diamonds). Photo image of a traditional 6-component station deployed along with two different nodal sensors for comparison with the strong motion and broadband data (right).

Approximately ~450 nodal stations were deployed for 1-month, with 162 PBIC borrowed IRIS Fairfield nodes, 56 borrowed Sandia Fairfield nodes (Univ. of Utah), and the new SmartSolo USGS nodes, with the majority of these on fault crossing lines as shown in Figure 1 above. A 60x70 km regional grid (10-km spacing) of SmartSolo nodes was also deployed. This data is all be now available publicly at the IRIS DMC and is being used extensively by researchers within the SCEC community and beyond.

Maintaining the CPSLO (San Luis Obispo station in Central CA)

In the summer of 2017, the first of the new PBIC compact-posthole broadband sensors was deployed at a station adjacent to Cal Poly University, and has been operating continuously since deployment. The station provides real-time data to both SCSN and NCSN, as it lies at the boundary between the two regional networks. The posthole broadband sensor is picking up both local and regional earthquakes as well as teleseisms from global events. The site also includes a strong motion sensor for near-field strong motion monitoring and ShakeMap production.

Deployment of PBIC stations for Fragile Geological Features (FGF) study

Previously identified FGR's at the Double Rock formation located on the uplifted marine terrace approximately 5km from the Diablo Canyon Power Plant are considered to be undisturbed for the past 17-62 kyr, somewhat inconsistent with shaking that should have dislodged them based on existing hazard curves. We are now in the second year of temporary seismic observations on the two rock formations, as well as the surrounding marine terrace. These observations are being collected to investigate the potential role of site response in the survival of the FGF's. Accelerometers have been mounted directly on the rock formations in close proximity to the FGR's. The compact-broadband posthole sensors and accelerometers are deployed at three additional stations nearby on the marine terrace.

Research funding has been provided to UCSB by PG&E, and these funds have been used to cover the deployment, maintenance, and data analysis costs. Three PBIC seismic stations including posthole broadband sensors and strong motion sensors are used for this deployment. UCSB also used PG&E funds to purchase of two Etna2 accelerographs for mounting directly on the rock. These Etna2's will become part of the PBIC instrument pool after this project is completed. The total SCEC budget request for the PBIC operations has been reduced again in 2020, due to the support from PG&E for conducting this experiment.

B. PBIC Data Integration with Regional Seismic Networks (RSN's).

The modern PBIC stations are capable to streaming data in real-time and when possible, we work with the RSN's to integrate these stations within the larger California monitoring effort. In the case of the CPSLO station, the data flow to both the NCSN and SCSN. The CPSLO data is archived at the SCEDC and NCEDC, where both event data and continuous waveforms are available. These data are used for both locating earthquakes as well as ShakeMap production. In figure 2 below a recent M3.3 earthquake west of Templeton, CA was felt and the events ShakeMap used the SCEC PBIC station (above left). The waveforms for this event located 30km from the site show very clean records on both strong motion and broadband sensors (above right).

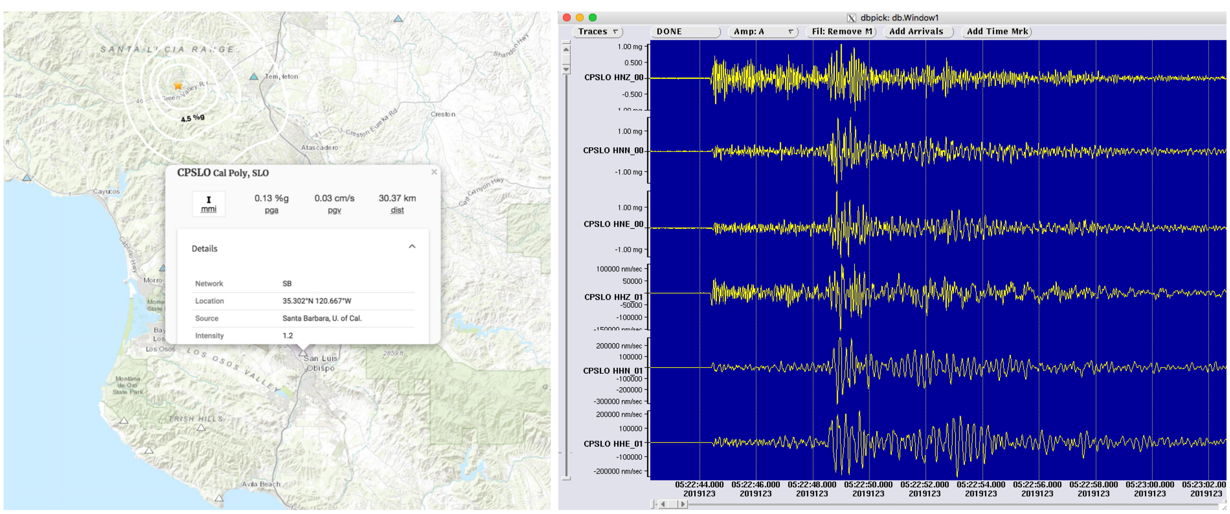

Figure 3. USGS interactive recent earthquakes ShakeMap page (left) showing the PBIC CPSLO station details for the 3 May 2019, M3.3 earthquake at ~30km from the station. Surface accelerometer (top three traces on right) and posthole broadband sensor (bottom three traces on right) waveforms are shown.