High-Resolution Monitoring of the Hayward Fault and Bay Area Bridges (Contract 59A0245)

Douglas Dreger[1], Robert Nadeau[1], Richard Clymer[1], Robert Uhrhammer[1], and Pat Hipley[2]

1. Berkeley Seismological Laboratory
2. Caltrans

Abstract

The Berkeley Seismological Laboratory (BSL) operates a number of geophysical monitoring networks that include regional broadband seismic and geodetic systems, and borehole networks at Parkfield and along the Hayward fault. The Hayward Fault Network (HFN) is comprised of borehole stations at free-field sites and also along the region's major bridges operated by Caltrans. These stations provide essential coverage of the active Hayward fault, and ongoing analyses of recorded microearthquake and non-volcanic tremor waveform data is beginning to illuminate fault behavior. The sites that are situated along the major bridges have been providing waveforms that may be used to investigate velocity structure in general and path and site effects specific to the instrumented bridges. In this fiscal year a new site has been established at the Napa River bridge. Colocated at this site are surface and borehole strong motion sensors operated by the CSMIP. The instrumentation at this shared site will provide a vertical sensor array that will help in the study of seismic wave propagation in basins and also site response. Another shared site is underway at the Petaluma River bridge. These two new sites will provide unprecedented high-resolution coverage of the region between the northern Hayward and Rodgers Creek faults, and lead to improved understanding of faulting mechanics, the seismic response of the San Pablo bay sedimentary basin, the non-volcanic tremor phenomena, and regional seismic hazard.

Introduction

Working with Caltrans over the past 6 years we have added borehole stations to the HFN at the Bay Bridge, the Richmond, the Carquenez, San Mateo and Dumbarton bridges, and also at a number of free-field sites including a deep borehole at Hercules. The stations shown in Figure 1 contribute to a broader multi-institutional borehole monitoring effort in the greater San Francisco bay area. Stations that were deployed and maintained with Caltrans support are shown in Figure 2. The bridge sites are important to have in general because of the improved coverage that they provide in areas otherwise not easily accessible. The sites presently operating at the bridges are collecting data that may be used for path and site characterization, and have also been utilized in BSL research investigating fault zone mechanics through the study of micro earthquakes (e.g. Bürgmann et al., 2000; Schmidt et al., 2005). This ongoing work has also recently revealed apparent non-volcanic tremor in the bay area similar to what has been recently reported elsewhere (e.g. Obara, 2002; Rogers and Dragert, 2003; Nadeau and Dolenc, 2005).

The borehole stations are essential in a region like the San Francisco bay area because the very high cultural noise levels at surface sites mask clear arrivals from microearthquakes, and low amplitude tremor signals. By placing instruments at depth, on the order of 100 to 200 m from the surface, it is possible to greatly enhance the signal to noise level of all recordings, but importantly it also makes it is possible record earthquakes and termors to magnitudes less than zero which in turn allows high resolution examination of faulting mechanics.

In this paper we report on our present activities with respect to deployment of new borehole sites, the quality of the data being recorded and some preliminary research results.

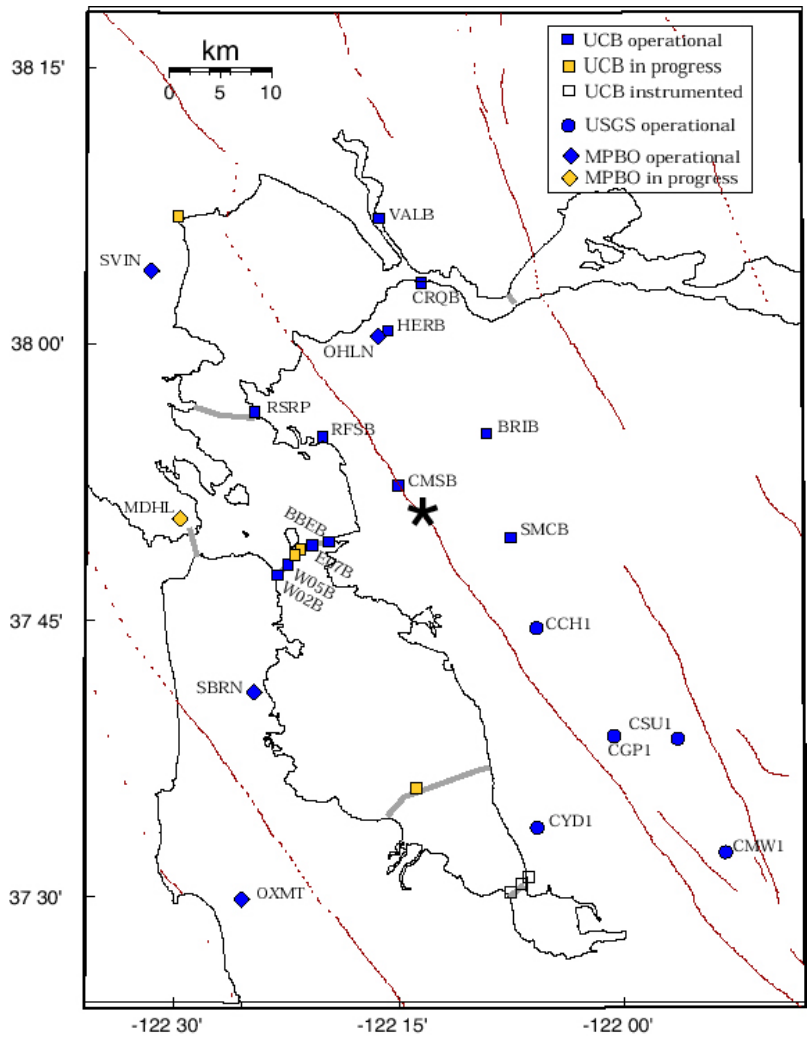

Figure 1. Site map of borehole stations. Blue symbols are operating, yellow symbols are in progress, and open symbols show sites that have deployed instrumentation but are not running presently. The circles show the USGS stations of the southern Hayward fault network. The diamonds show the BSL miniPBO sites with borehole strain meters, and the squares show the sites of the BSL Hayward Fault Network (HFN). The asterisk plots the location of a M3.4 earthquake on May 8, 2005 that we use to demonstrate data quality.

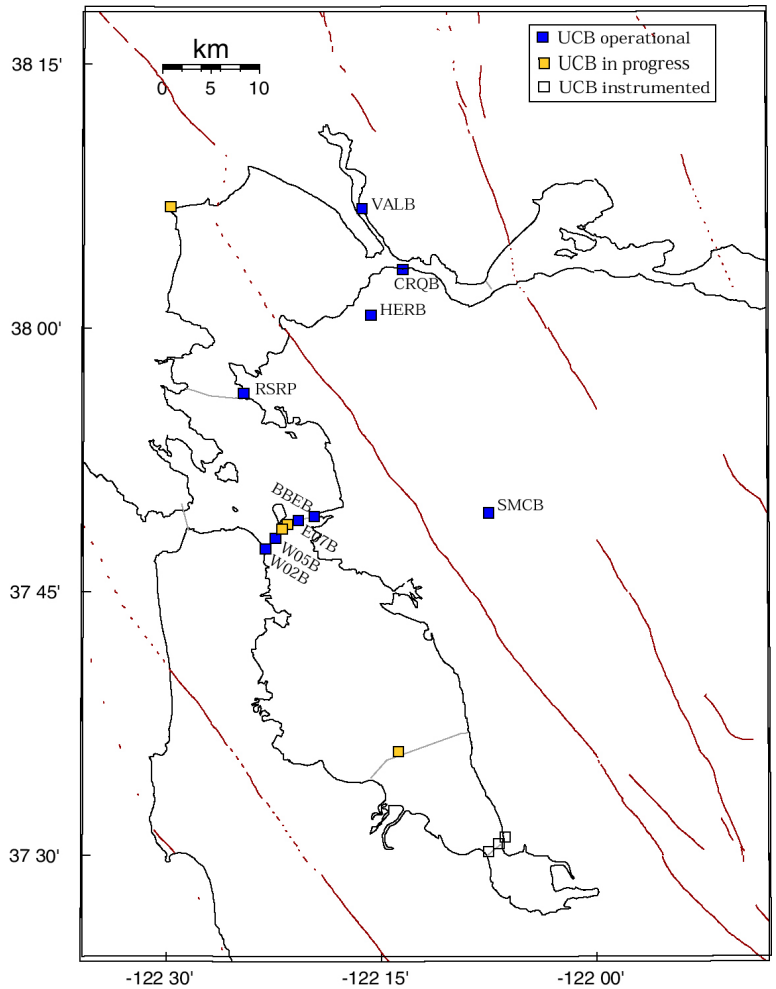

Figure 2. Map showing Caltrans supported stations located at the Richmond, Carquenez, Bay, San Mateo and Dumbarton bridges. Blue stations are operational and yellow stations are in progress. HERB and SMCB are free field sites that provide significant improved coverage of the Hayward fault.

New Sites

VALB at the Napa River bridge is our newest site. The sensor package is located at a depth of 155m. This is an important site in terms of its location near a critical structure, its proximity to the deep sedimentary basin, and the fact that it is co-sited with CGS strong motion instrumentation (Figure 3). At this site there is a CGS surface accelerometer as well as CGS downhole accelerometers at 58 and 145 feet depth, in addition to our very deep sensor package at 155m (492ft). Thus this cooperative site is expected to provide the engineering and seismological research community with valuable data for analyzing the physics of site amplification and the nature of basin influenced seismic wave propagation. In addition, its location with respect to the Haward fault provides essential coverage for monitoring micro seismicity that might be occurring beneath the San Pablo Bay and which is needed to help resolve structural and mechanical relationships between the Hayward and Rodgers Creek faults.

Another new site at the Petaluma river bridge is ready to be deployed when drilling at the site can be completed. This site is extremely important in terms of coverage of the transfer region between

the Hayward and Rodgers Creek faults. It will be located west of both faults near the assumed northern end of the Hayward fault. Earthquakes are known to occur in this area and it is expected that this site when operational will provide valuable data constraining the nature of micro-earthquake activity.

We are also working on obtaining access for a possible site at Point Pinole. This site, together with VALB and the Petaluma River bridge site will provide excellent coverage of the San Pablo Bay where little is presently known about the nature of micro-seismicity and the subsurface structure of the Hayward and Rodgers Creek faults. These three sites when fully operational will also provide an important new data set for characterization of the seismic response of the San Pablo bay sedimentary basin.

SMCB at Saint Mary's College is another site that we hope to improve by redeploying the existing sensors already there in a deeper borehole when drilling becomes available.

There are already deployed sensor packages at the San Mateo bridge which are presently offline since the bridge was retrofitted. In the coming year we will deploy electronic hardware at the site to begin collecting data and telemetering it to the BSL central recording site.

As part of the present research project we are fabricating additional downhole sensor packages to be deployed in other new sites which have been planned, and to have at the ready when drilling becomes available.

Figure 3a. VALB site. The box in the foreground shows the CGS borehole site. The UCB equipment boxes are in the background in front of the Napa River bridge.

Figure 3b. Photo of the VALB site showing the installed hardward boxes over the borehole pad and the telecommunications and power drop.

Data Quality

To illustrate the quality of data collected by the borehole network in Figure 4 we show three-component acceleration time histories for a M 3.4 earthquake, which occurred on May 8, 2005 4.6 km southeast of the UC Berkeley stadium (station CMSB) along the Hayward fault. The location of the event is shown on Figure 1. The event occurred at a depth of 5 km. This record displays excellent signal to noise levels, and waveforms that are rich in high frequency motions needed for high resolution study. In Figure 5 the acceleration spectra plot demonstrates the signal-to-noise ratio and signal bandwidth that can be achieved using modern low-noise borehole accelerometers. The signal bandwidth is 200 Hz and the SNR is above 50 dB in the 1-50 Hz band.

Given that the peak signal level recorded at CMSB for the M 3.4 earthquake is 26.65k counts or 2.44 gals and characteristics of the CMSB seismograph system the upper clipping magnitude for events in the same location is about M 5.3. The system is capable of recording motions of larger earthquakes located at greater distance.

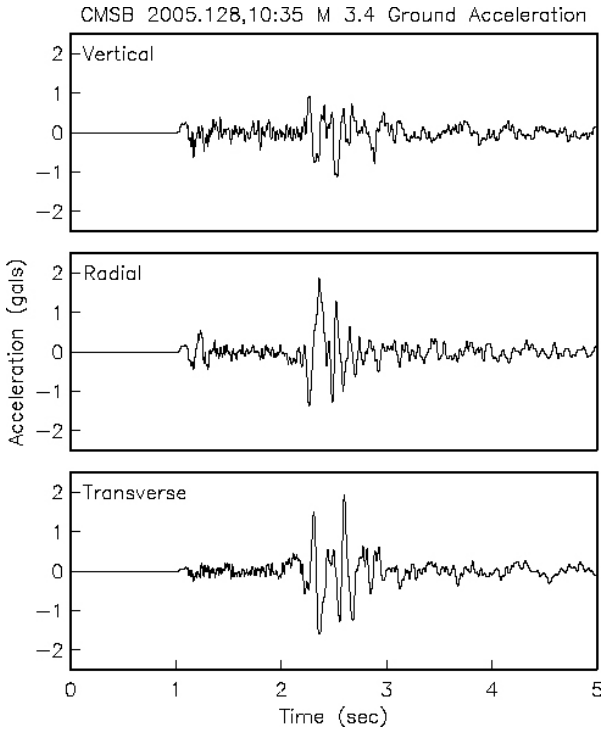

Figure 4. Example borehole accleration data at the CMSB site located at the Campus Stadium. The data have the instrument response removed and have been rotated into vertical, radial and transverse directions.

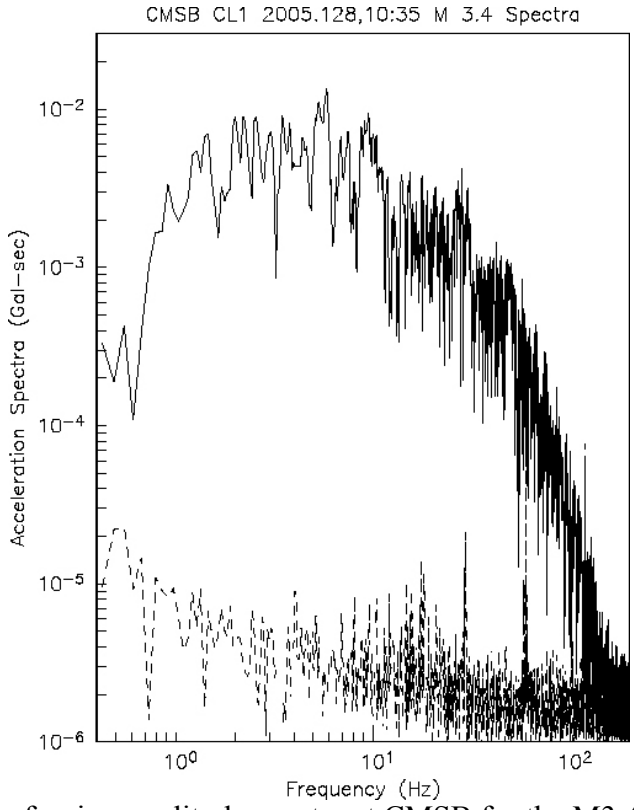

Figure 5. Accleration fourier amplitude spectra at CMSB for the M3.4 event (solid line) compared to a pre-event noise sample (dashed).

In Figure 6 we show the 1Hz lowpass filtered records for the same event obtained from the CRQB site at the Carquinez bridge. At higher frequencies the record is contaminated by cultural noise, however at frequencies less than 1 Hz useable records are obtained. CRQB is located 24.4 km NE of the epicenter and strong short-period (1 second) S-waves are seen on both the radial and transverse components. This waveform complexity could be due to signal generated scattering near the site.

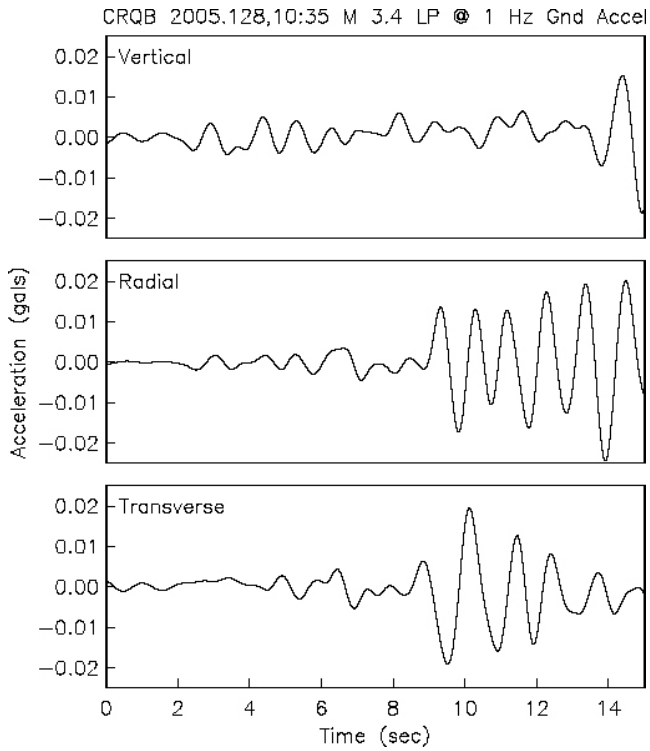

Figure 6. Three component acceleration waveforms (vertical, radial, and transverse) for the shallow borehole site at the Carquenez bridge.

Research

One important purpose of the HFN is to monitor the attributes and pathologies of very low amplitude seismic signals that may provide clues to the dynamic processes associated with the evolution of the fault zone during the seismic cycle and the nucleation of large damaging earthquakes. In particular, the deep (~50 to 200 m) borehole emplaced sensors of the HFN record seismic data with dramatically reduced cultural noise with a low enough noise floor to cleanly record the low amplitude seismic signals needed to study nonvolcanic tremor and very small microearthquakes (< M0.0) and in so doing significantly increase the resolvability of time-varying deep deformation related phenomena. Continuous 20 sps data archiving of HFN collected signals (needed for nonvolcanic tremor studies) is also done by the Berkeley Seismological Laboratory's the NCEDC (Northern California Earthquake Data Center).

Nonvolcanic tremor acitivy is a recently discovered phenomena that is closely associated with fault zone deformation occurring below the seismogenic zone and it appears to correlate with the occurrence of earthquakes (Obara, 2002; Rogers and Dragert, 2003; Nadeau and Dolenc, 2005). Therefore, changes in the rate of tremor acivity appear to signal stress changes in the deep fault zone that correspond to stress changes that stimulate earthquakes. Tremor activity generates very

low-amplitude long-duration signals that require very low-noise and high-sensitivity data collection and we are now embarking on a program using the HFN data to monitor for changes in tremor activity in the Bay Area for possible indications of increased stressing rates that may precede the occurrence of earthquakes. During a 247 day testing period (ending on 31 December 2004) our search for non-volcanic tremor activity found only one very small episode of possible tremor activity (Fig. 7), suggesting that deep earthquake related stress changes in the Bay Area were small during that period. We are now in the process of automating the tremor monitoring scheme to enable us to monitor for tremor activity continuously.

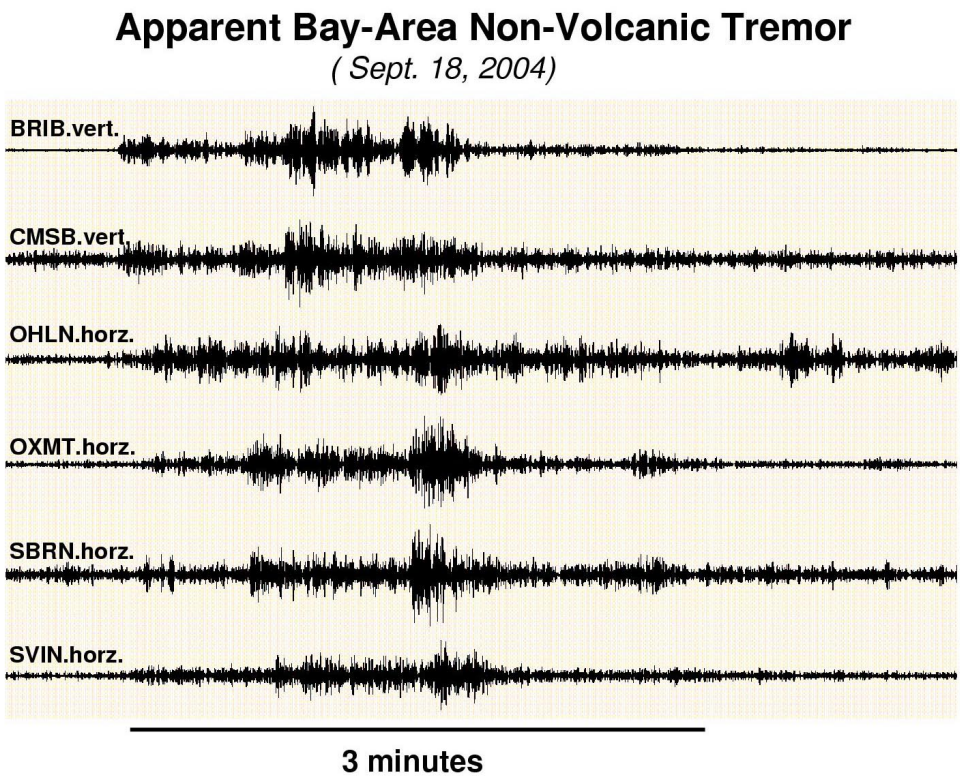

Figure 7. Apparent non-volcanic tremor event found during the 247 day test period. Shown are 3-8 Hz band-pass filtered seismograms recorded by the integrated borehole northern Hayward Fault and mini-PBO seismic networks. Tremors are long-duration low-amplitude signals that are indicative of deep (~ 30 km) fault zone deformational events that are believed to stress the shallower fault zone and stimulate earthquake activity. The total energy released by individual tremor events is small (magnitude equivalent < 2), but often correlate with deep aseismic slip of much larger moment release. In the Bay-Area where cultural noise is high, borehole recordings such as that from the HFN are required to detect these events. The event shown produced seismic shaking lasting ~ 3 minutes and a seismic energy release approximately equivalent to a magnitude 0 microearthquake.

We use the HFN for routine microearthquake event detection and location. High resolution locations of events on the Hayward fault have revealed that they are highly clustered as is observed at Parkfield. Sequences of repeating microearthquakes have also been detected on the Hayward fault, and these observations allow for investigation of recurrence behavior and mapping of deep fault strain rate (e.g. Burgmann et al., 2000; Schmidt et al., 2005).

Additional details of our ongoing research will be presented at the conference.

Summary

The BSL is continuing to work with Caltrans to deploy new sites, and activate existing seismic instrumentation at bay area bridges to collect high resolution seismic waveform data for a variety of seismological research applications. These data are being archived at the Northern California Earthquake Data Center (www.ncedc.org) and are easily accessed online.

Detailed information regarding the operation of the HFN and ongoing research conducted at the BSL using these data can be obtained from the online BSL annual reports at www.seismo.berkeley.edu.

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