Annual Report for 2013 SCEC Proposal

Title:"Millikan Shaking Experiments and High-Frequency Seismic Wave Propagation in Southern California"

Principal Investigator: Toshiro Tanimoto (UCSB)

Awarded amount: $25000 (UCSB)

Proposal category : B. Integration and Theory

Science Objectives: 6a, 6c, 6e

Period: February 1, 2013 – January 31, 2014

Intellectual merit:

The primary goal of this project is to obtain high-frequency seismic data and improve seismic velocity models in Southern California, so that we can understand the nature of high-frequency seismic wave propagation. In the past year, we have focussed on the analysis of narrow frequency-band shaking data (about 1.11 Hz and 1.64 Hz), generated by the resonant shaking experiments of the Millikan library on the campus of California Institute of Technology (Pasadena, California). This is a potentially useful data set for developing a seismic model in this region as high-frequency harmonic signals were recorded up to a distance beyond 300 km, covering a large fraction of Southern California, and the source location and time functions are well constrained from seismic stations in the building.

In 2013, we studied the nature of these signals from a combination of amplitude and phase analysis and numerical simulations. We learned two main things; the first is that the signal was dominated by surface waves. This may not be a surprise but we now know a way to compute depth sensitivity kernels which should be confined to shallow depths. The second is that we can measure group velocity for pairs of stations between MIK (at Millikan) and broadband stations in the regional network.

Our work so far was summarized and submitted for publication (Tanimoto and Okamoto, 2014, submitted to Geophysical Journal International, SCEC contribution No. 1908).

Broader impacts:

Understanding high-frequency (>1 Hz) seismic-wave propagation is important for mitigating seismic hazards as many buildings have resonant frequencies about 1-3 Hz. Improving our capability to predict high-frequency seismic motion is essential for building strong urban infrastructures in Southern California.

1. Progress in 2013

Study on the shaking experiments of the Millikan library has a long history from the late 1960s (Kuroiwa, 1967; Jennings, 1970). Recent summary can be found in Favela (2004) and Bradford et al. (2004). Its use for earth structure, however, has not been explored very much and that is the main motivation for this study.

In 2013, we made progress on two specific points: (1) understanding on the nature of signals and (2) a new approach of group-velocity measurements for this narrow frequency-band data.

(1.1) Dominant Surface Wave Signals

In order to understand what types of waves are in the observed harmonic signals, we used a theoretical approach using finite-difference simulations for the SCEC CVM-H 11.9.0. The

adjoint kernels were computed numerically and from the shape of kernels, we attempted to examine the question whether a signal was dominated by body waves or surface waves.

An example for the rigidity kernel is shown in Figure 1; SRC is the source location (Millikan) and RECV is a station (WBS), approximately 155 km to the north of Millikan. A depth slice of the kernel is shown in this figure. Amplitude patterns in the kernel indicate that there is an S (SH) wave that turns at a depth about 30 km but the near-surface amplitudes are much larger (which are surface waves). The same kernel is shown in a 3D plot in Figure 2 with the bottom panel showing the used seismic model, the SCEC CVM-H 11.9.0; the Moho can be identified from the contrast between light brown and dark brown. The main point is that surface-wave signals dominate the wavefields.

In the next step, assuming that the observed signals are surface waves, we fit the amplitude-distance data by the formula $u(x) = \frac{A}{\sqrt{x}} \exp(-\frac{\omega x}{2QU})$ where x is the epicentral distance, A is the amplitude, ω the angular frequency, Q is attenuation and U is group velocity (we use km/s). Regression with two parameters (Figure 3), A and QU, gave an estimate for QU of 95 ± 11 (< 50 km) and 1495 ± 224 (for distance larger than 50 km). The unit for U is km/s.

There exists a sharp change in trends at a distance about 50 km. The reason for this is most likely to be the 3D structure effects, because short-distance data (< 50km) traverse much of the LA Basin but long-distance data (>50km) do not contain paths in the LA Basin or in the San Fernando Basin (Tanimoto and Okamoto, 2014). From the cross-correlation analysis in the next section, we obtained U~0.5 km/s for short distance data, and therefore the estimate for Q is about 190.

(1.2) Group Velocity from Cross-Correlation

We analyzed phase information in the cross-correlation of data between station MIK (inside the Millikan Library) and stations in the broadband network (CISN). For many stations, we found quite stable phase in the cross correlation spectra in the oscillation frequency range (1.637-1.638 Hz). Figure 4 shows an example for the pair MIK-JVA. Phase difference between MIK and JVA is basically constant. Phase at MIK and at JVA are basically locked at this frequency. Phase velocity cannot be obtained, however, as the ambiguity in phase (the number of cycles along a path) cannot be resolved.

On the other hand, we noted that some pairs show relatively clean gradient in phase (i.e. frequency dependence), even though the frequency range is narrow. We took advantage of this feature and developed an approach which derives group velocity of surface waves. The key in this approach turned out to be in the estimate of $\partial\phi/\partial f$, i.e., the frequency derivative of phase.

In order to estimate this derivative reliably, we used stacking by computing spectra for 90 different time windows (overlapping). The blue lines in Figure 4 show the phase for stacked spectra. From the gradient (fit by a linear red line between 1.637 and 1.638 Hz), we can estimate group velocity. Since we are using great-circle distance, the estimates are approximate but should be quite good.

Measured group velocities are shown in Figure 5 which generally show slow paths in the basins. However, the path coverage is too sparse to make further progress for our understanding of structure by these data alone. This remains a challenge but additional shaking experiments are always possible and may provide us more data. At the least, we have obtained an approach to get group velocity estimates for the Millikan shaking estimates.

Figures:

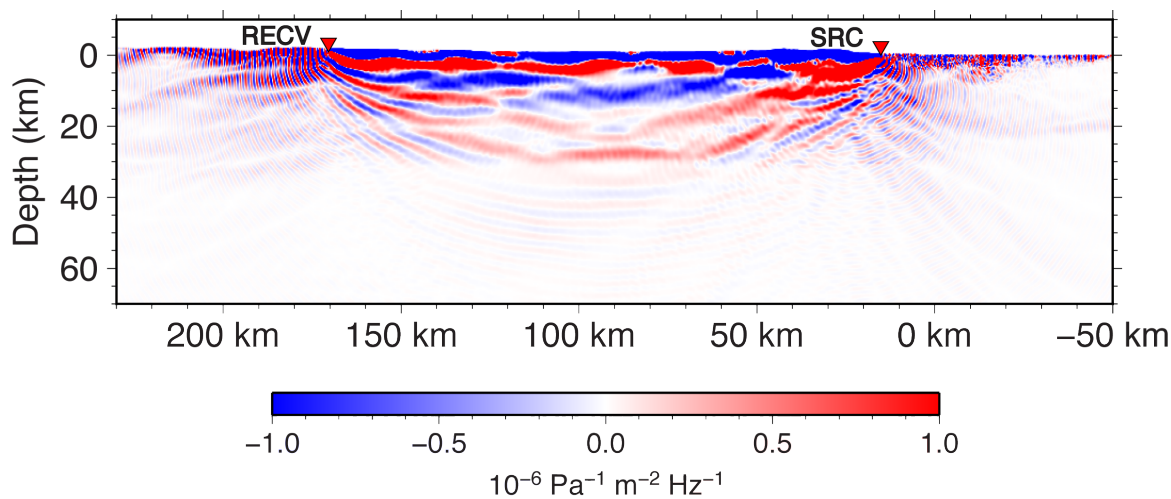

Figure 1: The depth slice of the rigidity kernel. Surface waves make near-surface high amplitudes (blue and red regions) that connect the Millikan library (SRC) and a station at 155 km to the north. There is a turning S waves near the Moho but their amplitudes are much smaller than the near-surface part.

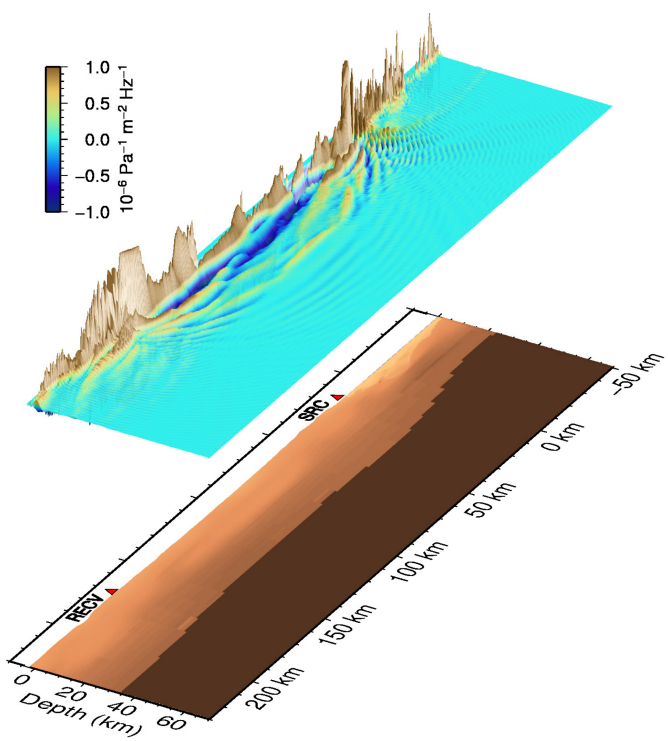

Figure 2: (top) Same kernel with Figure 1 in a 3D plot. (bottom) P-wave velocity in SCEC CVM-H 11.9.0. This figure is shown to indicate where the Moho is.

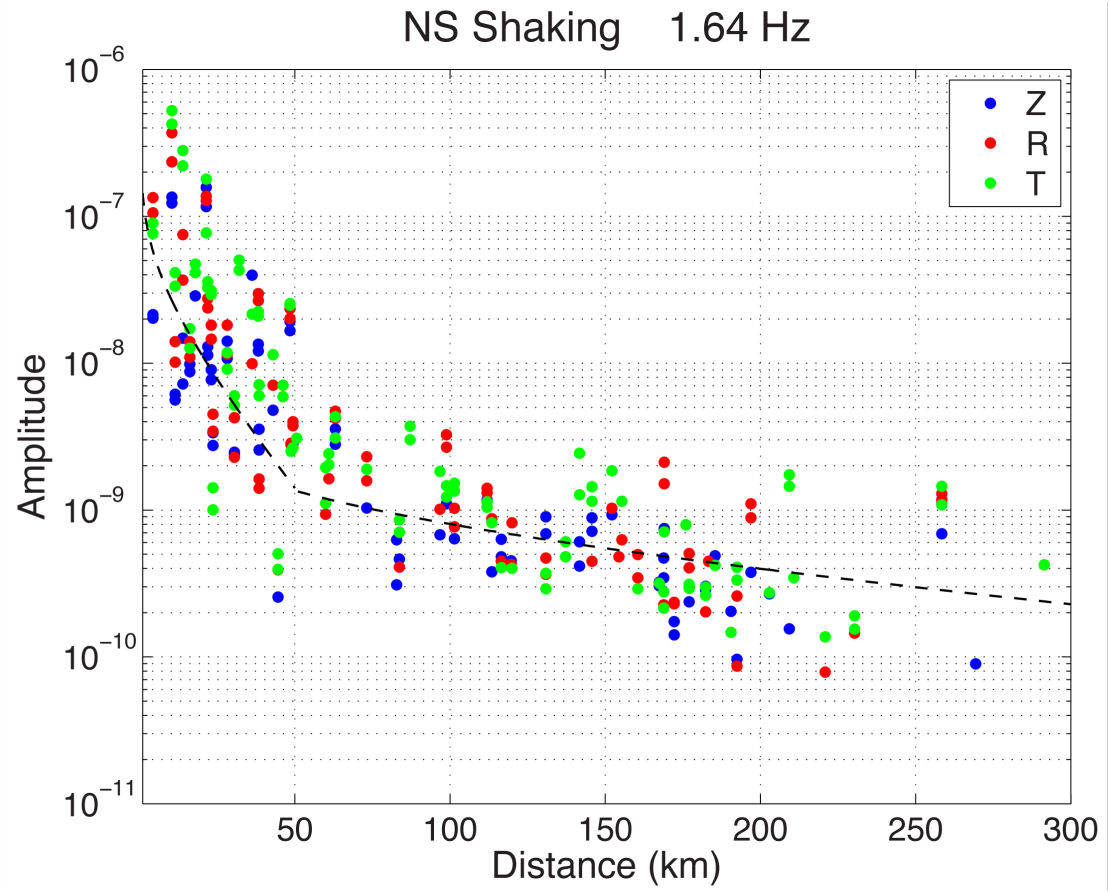

Figure 3: Amplitude-distance plot from the results of two experiments at 1.64 Hz. Using the assumption that the signals are surface waves, we regressed data to determine the values for QU where Q is attenuation and U is group velocity (km/s). There is a marked contrast across 50 km. Long-disatnce paths (>50km) do not contain paths in LA Basin or San Fernando basin whereas short-distance paths are dominated by such paths in the basins.

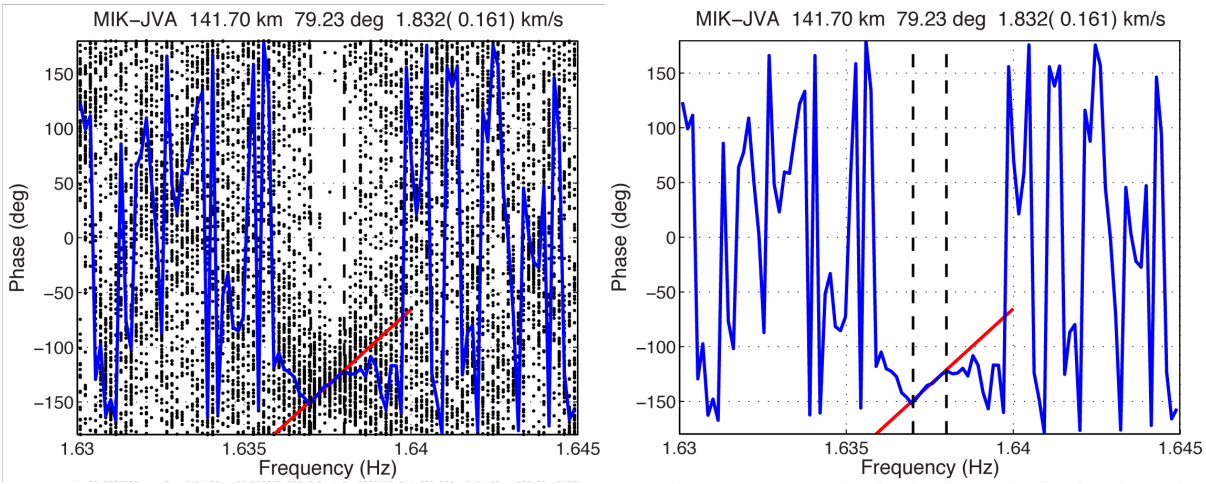

Figure 4: An example of cross-correlation phase between MIK and JVA (distance 141.7 km). Original phase data are shown on left (dots) which are from 90 overlapping windows with 2-minute shifts. The blue line in both panels are the stacked phase. The frequency band of the main signal, 1.637-1.638 Hz, shows a stable phase range (-150 to -100 deg) while phase is widely scattered outside this narrow frequency band because there is no signal (left panel). Within the range between 1.637 and 1.638 Hz, a linear trend is evident in the stacked phase and yields an group velocity estimate 1.832 km/s for this pair.

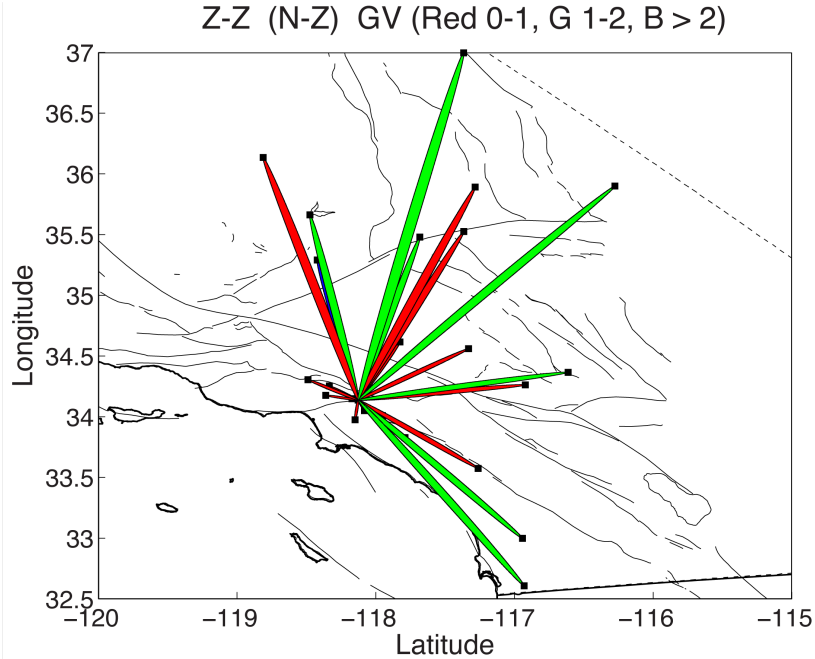

Figure 5: Measured group velocities. Red paths are 0-1 km/s, green are 1-2 km/s and blue are higher than 2 km/s. They are from the cross-correlation spectra between MIK and broadband stations. In general, they are too sparse to address large-scale systematic patterns.

Publication related to this project

Tanimoto, T. and T. Okamoto (2014). The Millikan shaking experiments and high-frequency seismic wave propagation in Southern California, submitted to Geophysical Journal International. SCEC contribution #1908.