FINAL TECHNICAL REPORT

Grant Number 07HQGR0083

(Period covered: 03/01/2007-02/29/2008)

"WAVEFORM MODELING OF EARTHQUAKES WITH M_W>2"

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Non-Technical Summary

Aftershocks as triggered by the mainshock or by previous nearby aftershocks, provide unique information about the earthquake failure process in terms of damage zones and the style of stress release. Both issues are related to how to predict where and when the next earthquake will occur. We plan to extend modeling analysis to higher frequency (.5 to 8Hz) so that the source parameters for a significant population of a sequence of events ($2<M_s<6$) can be determined. With known source characterization, we can also estimate dynamic effects (fault-damage) and static adjustments and test simulations with real data. Moreover, knowing more about how to model small events can help us understand the initiation of large events and fault complexity (step-overs) such as occurred for the Landers earthquake. In addition, the mechanisms of small earthquakes along fault zones can provide estimates of the stress-field and how it changes in space and time, especially if the fault-plane can be established, as proposed in this study. Perhaps a better appreciation of the physics of small events can increase our understanding of larger earthquakes and aid in early warning and preventing earthquake losses for future events.

Investigations

We have conducted a broadband study of the TriNet data (10 Hz to 10 sec) utilizing components of modeling and empirically derived site and path responses. Over two hundred events have been modeled at long-periods (LP, periods > 5s) using the "Cut and Paste" methodology where phases are allowed to have timing shifts in the search for the best mechanism and depth. We now have over 6,000 paths with cross-correlations of synthetics and data with fits better than .85 for surface waves and extended P-waves (P_{nl}). We intend to use these solutions as master events to calibrate station sites and extend our solutions down to magnitude 2.

As demonstrated in our recent papers, we observed that at short-periods (SP, filtered from .5 to 2 Hz), the vertical components and radial P-waves motions in data become station-dependent relative to synthetics, but maintain the same amplitude ratios for events in clusters which can be used as local amplitude factors or calibrations, AF's. This behavior is easily explained by the shallow structure just below the station (top few kms). To calibrate, we fix the source (LP) and compare the observed P-waves (SP) with synthetics and determine the AFs for several events along with variances, keeping about 40 of the best stations at a distance less than 100 km. To validate, we use the AFs from a subset of large events to re-invert other events M>3.5 (with known mechanisms) and reproduce the same source parameters with amazing accuracy. These AFs can now be used to invert the P-waves (SP) for small events in the neighborhood of the larger "master" events. The method is applied to over a hundred aftershocks of the recent Big Bear Sequence with good resolution (down to $M_w = 2$) based on misfit estimates. Once the source parameters are determined for small events, we can correct for M_w and radiation pattern to produce high quality empirical Green's functions up to 10 Hz for the first second of P-waves. Preliminary applications indicate that we will be able to obtain directivity for events larger than about 3.

Results

1. A New Method for Determining Small Earthquake Source Parameters Using Short-Period *P* Waves.

Ying Tan and Donald V. Helmberger
(*Bulletin of the Seismological Society of America* , Vol. 97, No. 4, pp. 1176-1195, August 2007, doi:10.1785/0120060251)

ABSTRACT

We developed a new technique of inverting short-period (0.5-2 Hz) P waveforms for determining small earthquake (M < 3.5) focal mechanisms and moments, where magnitude ~4 events with known source mechanisms are used to calibrate the "unmodeled" structural effect. The calibration is based on a waveform cluster analysis, where we show that clustered events of different sizes, e.g., M ~ 4 vs. M ~ 2, display similar signals in the short-period (SP, 0.5-2 Hz) frequency band, implying propagational stability. Since both M ~ 4 and M ~ 2 events have corner frequencies higher than 2 Hz, they can be treated as point sources, and the "unmodeled" structural effect on the SP P waves can be derived from the magnitude 4 events with known source mechanisms. Similarly, well-determined magnitude 2's can provide calibration for studying even smaller events at higher frequencies, e.g., 2-8 Hz. In particular, we find that the "unmodeled" structural effect on SP P waves is mainly an amplitude discrepancy between data and 1D synthetics. The simple function of "Amplitude Amplification Factor" (AAF) defined as the amplitude ratio between data and synthetics provides useful calibration, in that the AAFs derived from different clustered events appear consistent, hence stable and mechanism-independent. We take a grid search approach to determine source mechanisms by minimizing the misfit error between corrected data and synthetics of SP P waves. The validation tests with

calibration events demonstrate the importance and usefulness of the AAF corrections in recovering reliable results. We introduce the method with the 2003 Big Bear sequence. However, it applies equally well to other source regions in southern California, since we have shown that the mechanism-independence and stability of the AAFs for source regions of 10 km by 10 km are typical. By definition, the AAFs contain the effects from the station site, the path and crustal scattering. Although isolating their contributions proves difficult, the mechanism-independence and stability of the AAFs suggest that they are mainly controlled by the near-receiver structure. Moreover, the ratios between the AAFs for the vertical and radial components from various events at different locations appear consistent, suggesting that these AAF (v)/AAF (r) ratios might be simple functions of site conditions. In this study, we obtained the focal mechanisms and moments for 92 Big Bear events with M_L down to 2.0. The focal planes correlate well with the seismicity patterns, while containing abundant finer-scale fault complexity. We find a linear relationship between $\log(M_0)$ and M_L, i.e., $\log(M_0) = 1.12M_L + 17.29$, which explains all the data points spanning three orders of magnitude ($2.0 < M_L < 5.5$).

2. Rupture Directivities of the 2003 Big Bear Sequence

Ying Tan and Donald V. Helmberger
(Submitted to *BSSA, January 2008)*

ABSTRACT

We have developed a forward modeling technique to retrieve rupture characteristics of small earthquakes, including rupture propagation direction, fault dimension, and rupture speed. The technique is based on an empirical Green's function (EGF) approach, where we use data from co-located smaller events with fault parameters as Green's functions to study the bigger events. Compared to deconvolution, this forward modeling approach allows full use of both the shape and amplitude information produced by rupture propagation. Assuming simple 1D Haskell source model (*Haskell*, 1964), we parameterize the source time function of a target event as the convolution of two boxcars, featuring the rise time τ_r and the rupture time τ_c, and we solve for τ_r and τ_c in a grid search manner by minimizing the waveform misfit between the three-component data and the "synthetics" from the EGFs. By fitting the observed azimuthal pattern of τ_c with the predictions from the model for both P and S-waves, we obtain estimates of fault length and rupture velocity. We have applied the approach to the 11 strike-slip events with magnitude greater than 3 from the 2003 Big Bear sequence in Southern California. We generally chose smaller events with similar focal mechanisms for EGFs, however, we show that the smaller events with different focal mechanisms can work equally well when corrected for radiation pattern effects. The studied events show rupture propagation in all azimuths with a wide-range of rupture speeds (1.5-3.5 km/sec), implying the complexities introduced by a multi-fault-plane fracture zone. Events propagating along the mainshock strike (Mode II) tend to have lower stress drops and faster rupture velocities than those involved in cross-faultings.

3. Sparse Network Source Inversions from a well-calibrated region: Southern California

Ying Tan, Don Helmberger, and Alex Song
(Submitted to *BSSA, February 2008)*

ABSTRACT

We conduct a detailed test of a recently developed technique, CAPloc, in recovering source parameters from a few stations against results from a large broadband network. The method uses a library of 1D Green's functions which are broken into segments and matched to waveform observations with adjustable timing shifts. These shifts can be established by calibration against a distribution of well-located earthquakes and assembled in tomographic images for predicting various phase-delays. Synthetics generated from 2D cross-sections through these models indicates that 1D synthetic waveforms are sufficient in modeling but simply shifted in time for hard-rock sites. This simplification allows the source inversion for both mechanism and location to easily obtain by grid search. We test one-station mechanisms for 160 events against the array for both PAS and GSC which have data since 1960. While individual solutions work well (about 90%), joint solutions produce more reliable and defensible results. Inverting for both mechanism and location also works well except for certain difficult paths across deep basins and along mountain ridges.