Ground Motions: Rapid Response

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Overview

A new near-realtime software system that automatically determines the finite-source parameters of regionally recorded earthquakes, and uses this information to estimate the level of near-fault strong shaking has been developed and implemented as part of the Rapid Earthquake Data Integration (REDI) system at the Berkeley Seismological Laboratory (BSL). The method has been functionally integrated with the TriNet ShakeMap system (e.g. Wald et al., 1999). This approach utilizes three-component regional distance broadband data to resolve the fault plane orientation, fault dimensions, and rupture kinematics of earthquakes in near-realtime, and is used to estimate the level of near-fault ground motions. The ground motion estimation involves several steps, which includes the use of directivity-corrected attenuation relationships and the direct integration of the fault slip distribution using near-source Green's functions. The estimated near-fault ground motion parameters are provided as input to the ShakeMap software, which integrates the ground motion estimates with available observations to produce a ShakeMap.

Applicability

Strong ground motion parameters such as peak ground acceleration (PGA), peak ground velocity (PGV) and spectral acceleration (Sa) at discrete periods provided in near-realtime is considered to be valuable information needed by emergency responders to obtain an overview of the earthquake emergency, make decisions on deploying resources, and to facilitate the recovery. For this information to be the most useful to public and private organizations it is needed within the 30-minute post-earthquake time frame. The TriNet ShakeMap method (Wald et al., 1999) calculates maps of PGA, PGV, Sa (at periods of 0.3 1.0 and 3.0 seconds), as well as instrumental intensity. The reported ground motions are based on observed time histories combined with estimates from suitable attenuation relationships. The results are

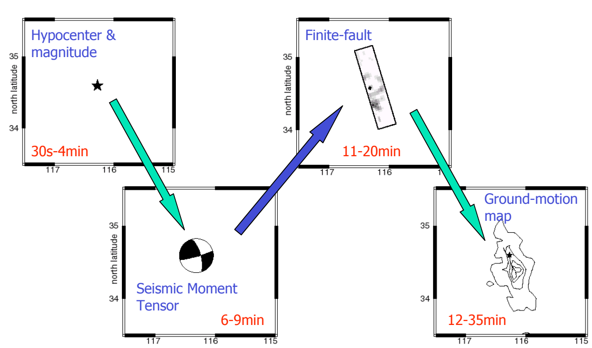

Figure 1 – Schematic showing automated processing stream

most robust in areas with dense coverage by strong motion stations such as is the case in the urban areas under the California Integrated Seismic Network (CISN). In many areas of California and the United States the density of realtime reporting strong motion networks is insufficient to provide optimal results. For these areas, and to serve as a redundant approach in the well-instrumented regions, we have developed a source-physics-based approach. The method described below has been integrated as part of the REDI system in operation at the BSL, and is currently operating in realtime on the test system. As configured it is capable of determining finite-source information and near-fault strong shaking parameters for earthquakes in central and northern California.

Method

The BSL together with the USGS at Menlo Park operates the Joint Notification System (JNS) in which waveform and parametric data and derived source information is exchanged and reported in realtime. The JNS provides earthquake location and magnitude information within 30 seconds to 4 minutes (depending on the level of the analysis) of an earthquake in central and northern California. For M>3.4 events broadband waveform data from the Berkeley Digital Seismic Network are requested and automated procedures for determining the seismic moment tensor are initiated (e.g. Pasyanos et al., 1996). Currently the seismic moment tensor is determined within 6-9 minutes after the origin time of an event in the automated processing region. In addition, strong motion data is requested to determine the PGA, PGV and Sa parameters for the earthquake, which is then provided to the ShakeMap systems operating in parallel at the USGS Menlo Park and BSL. At the BSL, for M_W>5.4 events, broadband and strong motion waveform data is requested, sent to a dedicated processing computer, and the automated finite-source/ShakeMap procedure is initiated. Figure 1 is a schematic of the near-realtime processing stream that has been developed. With this system it is possible to obtain finite-source and near-fault strong shaking information within the 30-minute post-earthquake time frame.

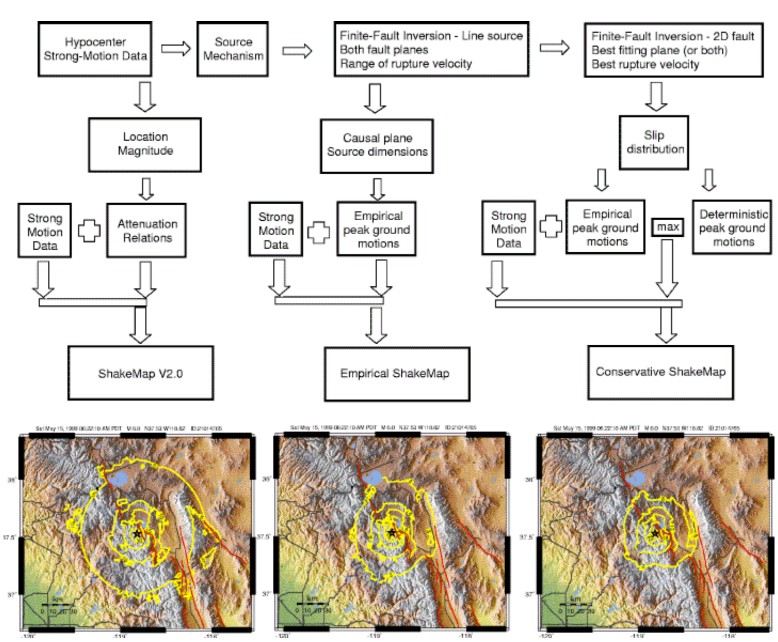

Figure 2 – Example of updated ShakeMaps for a M6 event in Mammoth Lakes, CA

The first stage of processing involves solving for the best line-source solution. This is done by using the scaling relationships of Wells and Coppersmith (1994) and Somerville et al. (1999) to determine the dimension of the model fault plane. The dimensions derived from these relationships are doubled and then increased by an additional 10% safety factor to ensure that the model fault plane is large enough to account for unilateral rupture in either direction. The broadband displacement data are inverted using line-source models for both of the nodal plane orientations from the moment tensor results. The line-source inversions are performed over a range of rupture velocity to find the optimal value. The dislocation rise time is held fixed and is determined *a priori* from the scalar seismic moment (e.g. Dreger and Kaverina, 2000; Somerville et al., 1999). The line-source inversions are very fast, and result in a determination of the causative fault plane, the fault length, and the rupture velocity.

The second stage of processing involves the estimation of PGA, PGV and Sa using attenuation relationships corrected for directivity following the method of Somerville et al. (1997). The ground motion estimates are then provided to the ShakeMap software, which combines the estimated and observed ground motions to produce an updated ShakeMap.

In the third stage, a planar-fault inversion is performed to determine the slip distribution of the event. The dislocation rise time as determined above and the best rupture velocity from the line-source inversions are assumed, and held constant. Only a single fault plane is used and the slip direction (rake) is also held fixed. This is a relatively simple parameterization, which is necessary to keep processing times short for emergency response applications. Offline analysis of the results can incorporate multiple fault segments, variable slip direction, and multiple time windows to account for dislocation rise time and rupture velocity variability.

The final stage of processing deterministically integrates the fault slip model using appropriate near-fault Green's functions to synthesize time histories. PGA, PGV and Sa are determined from the time histories, and combined with the values from the second stage by taking the larger of the two estimates. The estimated ground motion parameters are then provided to the ShakeMap software, which incorporates the observations and generates the ShakeMap. This final ShakeMap includes the effects of source finiteness, source directivity and the earthquake specific slip distribution in the estimates used to interpolate the data. For the earthquakes tested (1992 Landers, 1994 Northridge, and 1999 Hector

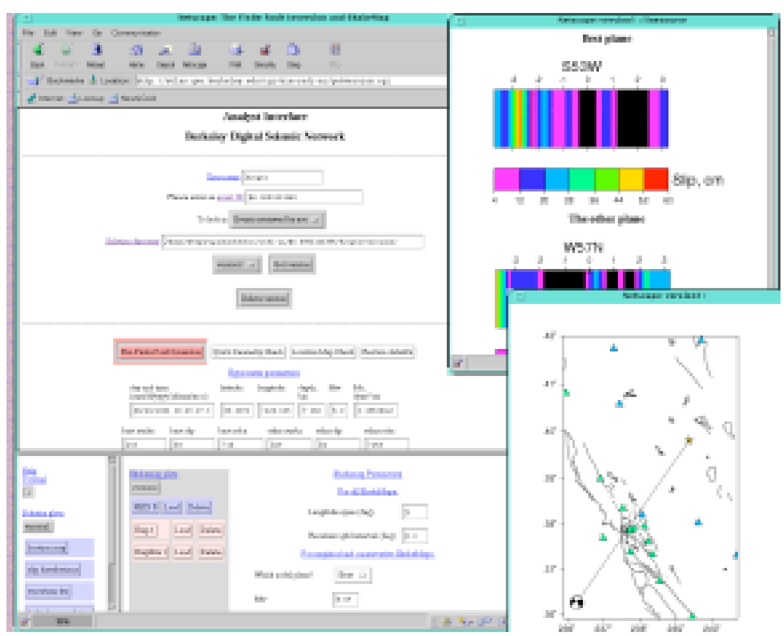

Figure 3 – Screenshot of analyst interface

Mine), in areas with very few strong motion recording instruments the method produces a superior estimation of likely near-fault strong motion levels.

An example of the program output, and description of the processing stream for a recent M6 earthquake in Mammoth Lakes, CA is provided in Figure 2. The top row of the flow chart shows the improvements in earthquake source information with increasing time from left to right. The first ShakeMap (TriNet ShakeMap; Wald et al., 1999) utilizes event location, magnitude, observed ground motions, and point-source attenuation. The second ShakeMap combines finite-fault/directivity corrected (e.g. Somerville et al., 1999) estimated ground motions with the observations. The third ShakeMap incorporates the slip distribution by taking the larger of the empirical and deterministic ground motion estimates combining them with the observations. The three maps are generated in the 4-6, ~15, and ~30 minute post-earthquake time frame, respectively.

To facilitate the review and update of the finite-source/ShakeMap results we developed an analyst interface based on html forms that allows the analyst complete control of offline processing. During the review of the results, the analyst may adjust the orientation and dimension of the fault, the rupture velocity and the dislocation rise time, and the data and Green's functions employed, and certain inversion parameters. Figure 3 shows a screenshot of the analyst interface. When the analyst is satisfied with the updated finite-source results and ShakeMap revision may be generated.

In conclusion, we have implemented an automated finite-source inverse procedure that allows for the simulation of near-fault ground motions making use of fault finiteness, rupture directivity, and detailed fault slip information. The estimated ground motions are provided to the TriNet ShakeMap software to combine with the available observations. This software system is operational on the REDI test system. We continue to work with the Pasadena and Menlo Park USGS ShakeMap groups toward the integration of these procedures into the authoritative ShakeMap system for California.

For further information

This work has been published into research articles (Dreger and Kaverina, 2000; Kaverina et al., 2002). Inquiries can be directed to Douglas Dreger (dreger@seismo.berkeley.edu).

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Keywords

Earthquake source, finite source, seismic inversion, strong motion, PGA, PGV, ShakeMap.