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Importance of source effects on strong-motion seismograms

Stephen Hartzell
United States Geological Survey, Denver, Colo., USA
Masahiro Iida
Earthquake Research Institute, University of Tokyo, Japan

ABSTRACT: Source effects on strong motion records are demonstrated in one of the best instrumented earthquakes to date, using an inversion method. A large number of near-source, strong-motion records from the 1987 Whittier Narrows, California, earthquake are inverted to obtain the history of slip. The pattern of 17 stations that form good 360° azimuthal coverage of the source is expected to give good resolution. The inversion results show a complex rupture process within a small source volume, with at least four separate concentrations of slip. The waveforms of data records and synthetics are fit well in both shape and amplitude. The ground motions can be explained by considering only source effects coupled with the same averaged propagation path effects to each strong motion station.

1 INTRODUCTION

In almost all earthquakes, the largest damage occurs in the earthquake source area. Near-source strong-motion records are mainly affected by source effects and local site effects because propagation path effects are minor. Although site effects on strong-motion records have been undoubtedly verified by numerous studies, no study has been done to investigate source effects that are closely related to damage and intensity patterns in the high-frequency range. The most likely reason is luck of well-instrumented earthquakes.

In our present study, source effects on strong motion seismograms are demonstrared in one of the best instrumented earthquakes to date. A large number of near-source, strong-motion records from the 1987 Whittier Narrows, California, earthquake with a local magnitude of 5.9 are inverted to obtain the history of slip (Hartzell and Iida 1990). The pattern of the 17 stations that form good 360° azimuthal coverage of the source is expected to give good resolution (Iida et al. 1988; Iida 1990) (Fig. 1).

The strong motion data used in this study come from three main sources: the California Division of Mines and Geology network (California Strong Motion Instrumentation Program) (Shakal 1987), the U.S. Geological Survey (Etheredge and Porcella 1987; Brady et al. 1988), and the University of Southern California (Trifunac 1988). To minimize propagation path effects, which are often difficult to distinguish from source effects, only stations within 15 km of the epicenter are used. With this cutoff, the station ranges are comparable to or less than the source depths, which emphasize the direct body waves.

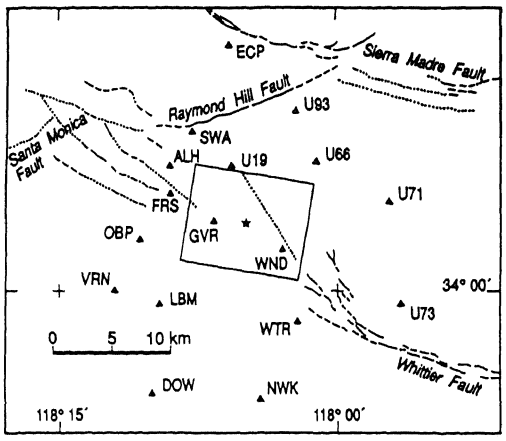


Figure 1. Area map showing the locations of strong motion stations used in this study and the surface projection or map view of the model fault plane indicated by the rectangular box. The epicenter is indicated by the star.

Each of the 17 stations recorded three components of ground accelerations. However, only the horizontal components are used, which are dominated by S wave energy. Because of the difficulty in modeling very high frequencies, band-pass filtered

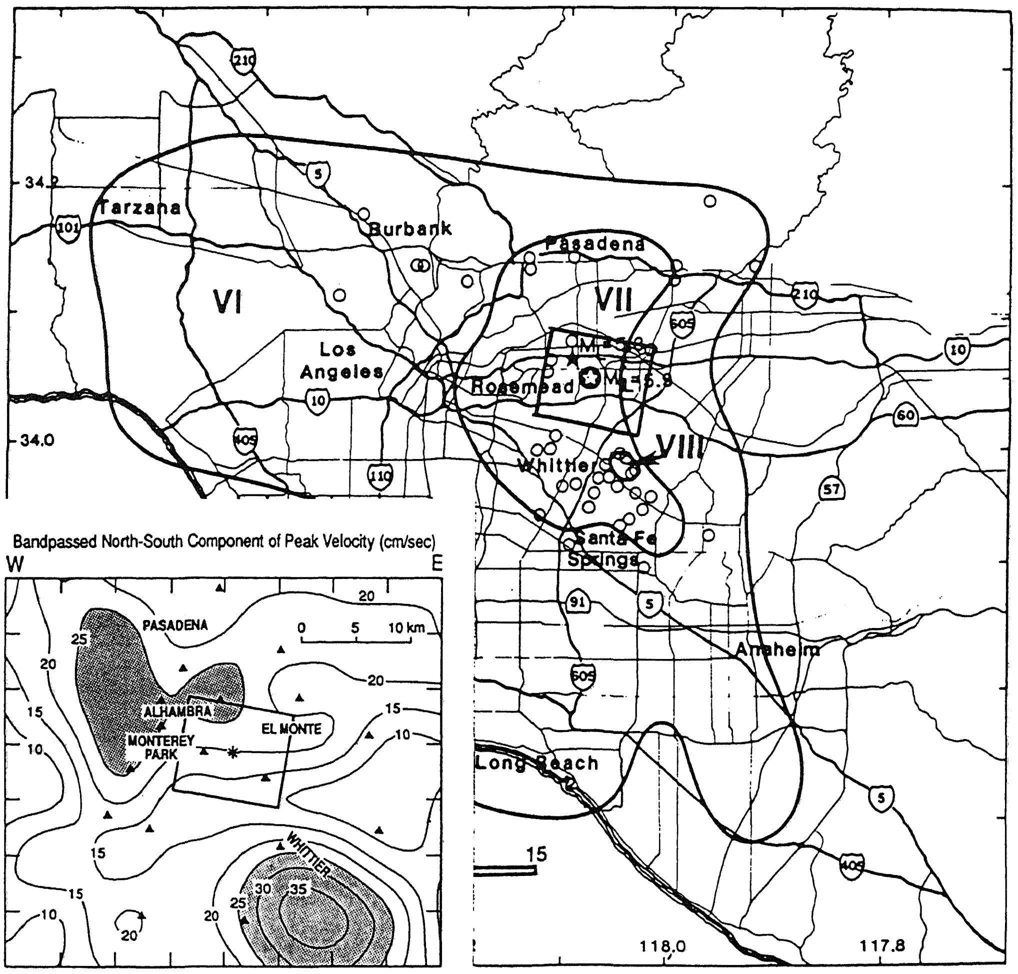


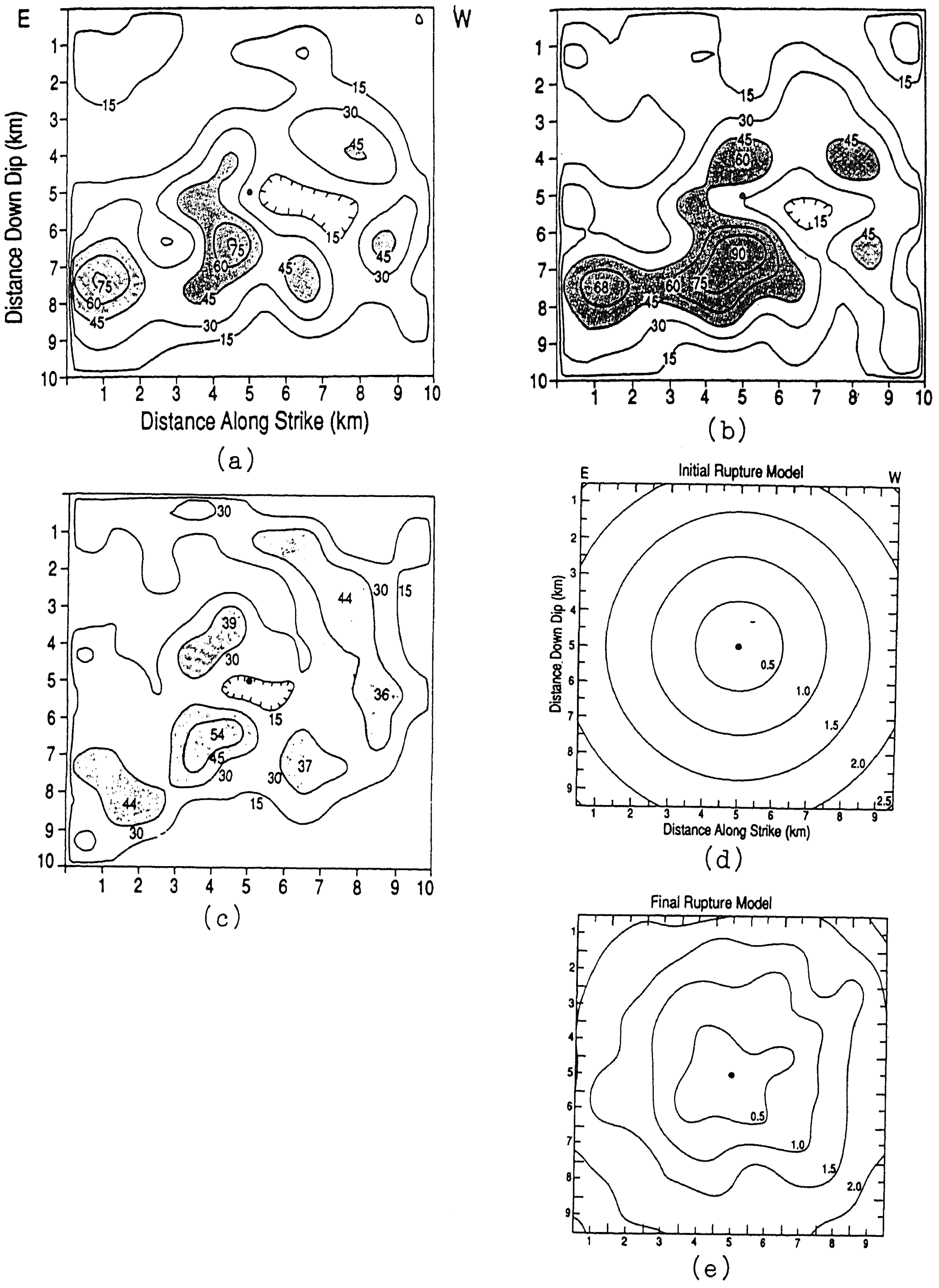
Figure 2. Regional Modified Mercalli intensity isoseismals of the Los Angeles area in the earthquake of October 1, 1987. Open circles represent the center of the census tracts surveyed. The circled star is the main shock epicenter (After Leyendecker et al.). Predicted peak velocities (cm/s) for model (b) of Fig. 3 in the bandpass 0.2 to 3.0 Hz are shown on the same scale at the lower-left corner. Values contoured are peak whole record velocities in the north-south component of motion. The stations used are indicated by solid triangles.

velocity records (rather than accelerations) from 0.2 to 3.0 Hz are used. This frequency range is responsible for much of an earthquake's damage and intensity.

We note the unusual damage and intensity pattern of this earthquake, which cannot be explained by only local site effects (Leyendecker et al. 1988) (Fig. 2); In other words, Whittier, which is not located in the source area, experienced the greatest damage. Also, the northwestern side of the fault had more damage than the surrounding areas.

2 INVERSION METHOD

Following Hartzell and Heaton (1983), our inversion is performed. The inversion method was discussed in detail by Hartzell and Iida (1990), and is roughly reviewed here. The model fault is a square planar region 10 km on an edge which generously encompasses the zone of aftershocks. We fix the strike of our model fault at 280° . Two different values of dip, 30° and 40° were tried, and a dip of 30° gave a marginally better fit to the data. The hypocenter is located at the center of the fault plane at a depth of 14.6 km. The fault plane is divided up into small rectangular regions of equal area. Each subfault is 1km^2. The Green's functions that include all theoretical arrivals are calculated for each subfault and station pair, using the discrete wave number/finite element method of Olson et al. (1984)



(a) (b) (c) (d) (e)

Figure 3. Contours of slip in centimeters. (a) Each subfault ruptures once at a constant rupture velocity of 2.5 km/s. (b) Each subfault is allowed to rupture twice with a small time interval to allow for a more complex source-time function. Two ruptures progress at a fixed speed of 2.5 km/s. The rupture times of (d) are assumed in two cases of (a) and (b). (c) Each subfault ruptures once, but the rupture times for each subfault are free to vary. Starting with the initial rupture times of (d), the final rupture times of (e) are obtained.

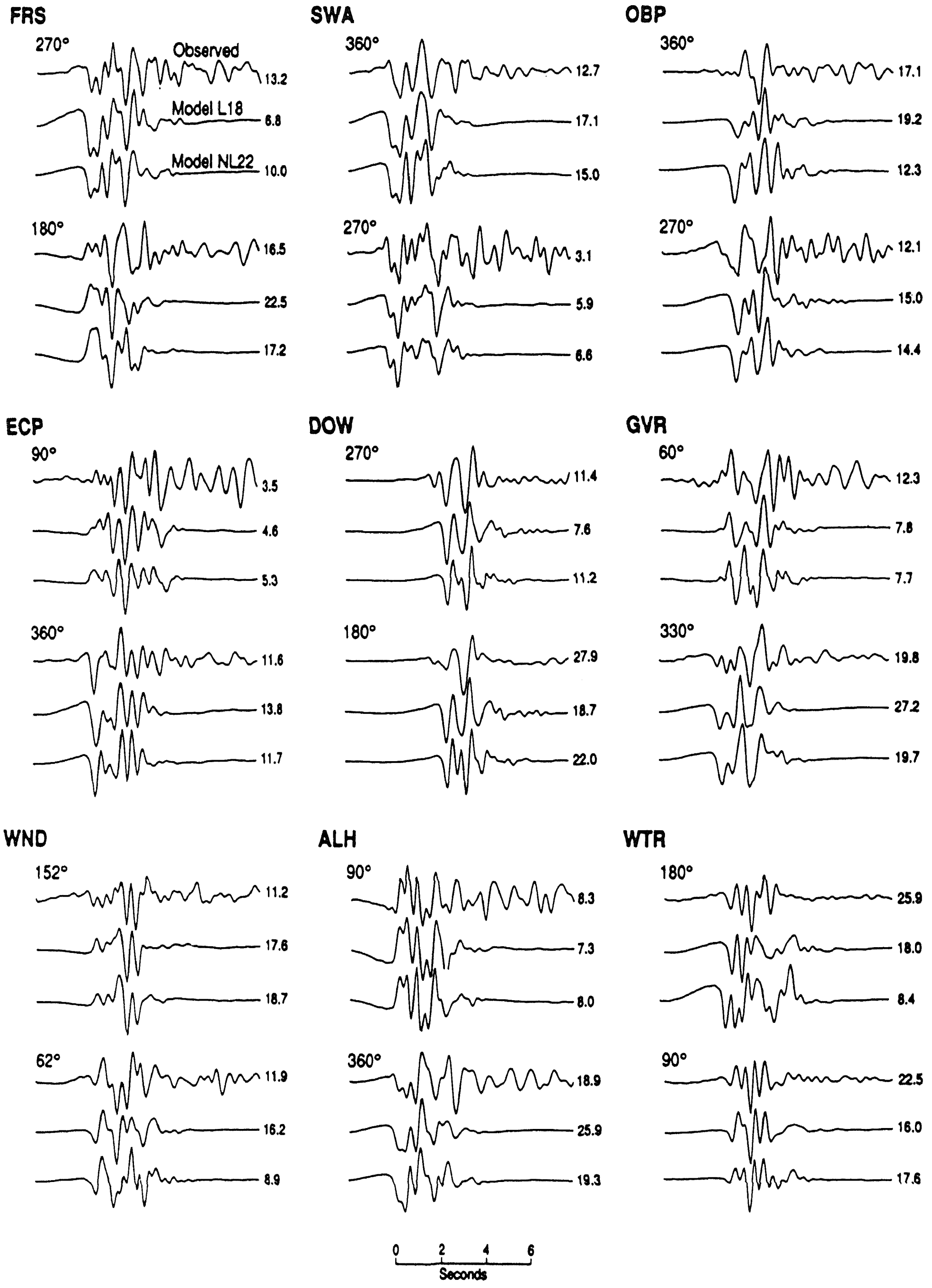


Figure 4. Comparison of the observed strong motion velocity records (first trace) with the synthetic ground motion records for model (b) of Fig. 3 (second trace) and model (c) of Fig. 3 (third trace).

applicable to a 1-dimensional velocity gradient model. The velocity model includes slow surface velocities and steep gradients in velocity in the upper 5 km, typical of the Los Angeles basin. Actually, a cross section of the Los Angeles area does not show uniform underground structure in the horizontal direction (Davis et al. 1989). Although no local effects are taken into account, abnormal site effects are not recognized as far as we visually inspect the seismograms.

If we wish to solve for the slip amplitudes for a prescribed rupture velocity, the problem is linear. The observed records and the subfault synthetic records then form an overdetermined system of linear equations. Because instability of the solution arises, the problem is stabilized by appending linear smoothing constraints. The solution vector is solved for using a Householder reduction method that invokes a positivity constraint on the solution (Lawson and Hanson 1974).

If we wish to solve simultaneously for the magnitude of the slip and the rupture initiation time for each subfault, the problem is nonlinear and is solved in an iterative manner. We then have an overdetermined problem which is solved using a least squares criterion for a model parameter perturbation vector.

3 RESULTS

Three different types of waveform inversion are performed. The first and simplest approach assumes a constant rupture velocity with each subfault rupturing once. The second formulation also uses a fixed rupture velocity, but each subfault is allowed to rupture twice with a small time interval, to allow for a more complex source-time function. The third type of inversion allows each subfault to rupture once, but the rupture velocity, in other words, the rupture time of each subfault may vary.

Fig. 3 shows the contours of slip in centimeters of the solutions for the three inversion problems. We should note the similarity of slip distribution in the source region obtained by different rupture modes. The results show a complex rupture process within a small source volume, with at least four separate concentrations of slip. The complexity of the slip for the Whittier earthquake is the most obvious result of this study.

The data records are compared with the synthetics for the second and third models in Fig. 4. In general, the waveforms are fit well in both shape and amplitude, especially the earlier parts of the records. We should note that the large-amplitude sections are not influenced so much by local site effects. Because the duration of strong motion is often related to earthquake damage, the later parts of the records are also important. The later parts most likely contain propagation path effects not included in our simple two-dimensional model.

4 DISCUSSION

The inferred distribution of slip can be used in a forward calculation to predict the ground motion in the epicentral region. This calculation is done using model (b) of Fig. 3. The results are shown in Fig. 2, where peak velocities are contoured. We notice the consistency of this result with intensity and damage distribution. The area of highest expected velocities is near the town of Whittier. The second largest amplitudes are to the west and northwest of the epicenter. Whittier experienced the greatest damage during the earthquake (Leyendecker et al. 1988; Hauksson et al. 1988), with some houses coming off of their foundations. Alhambra and Monterey Park had less damage, but more than the surrounding areas, with numerous broken chimneys. These damage records are well predicted by model (b) of Fig. 3. Kawase and Aki (1990) have explained the heavy damage in Whittier by critically incident SV waves in conjunction with a topographic effect. The results of this study indicate that although these processes may be partly responsible for the damage in the Whittier area, the ground motion can also be explained by considering source effects coupled with the same averaged propagation path effects to each strong motion station.

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