SOURCE PROCESS AND RUPTURE HISTORY OF THE 3 MARCH 1985 CENTRAL CHILE EARTHQUAKE

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RÉSUMÉ: Nous avons obtenu par inversion simultanée des données d'accélérométrie, des ondes de volume télésismiques et des ondes de Rayleigh de très longue période, l'histoire du processus à la source du séisme du 3 mars 1985, du Chili central. Cette histoire est aussi confirmée par l'inversion des ondes de volume télésismiques. La modélisation du mécanisme de rupture est donc simple, et ne nécessite pas une composante lente du déplacement pour expliquer l'amplitude observée des ondes de longue période.

KEY WORDS: rupture history, inversion, rise time, seismic moment, source duration.

INTRODUCTION

The use of finite-fault inversion schemes has become relatively common in the study of large earthquake ruptures. They have been applied to near-source strong ground motions and teleseismic body-wave observations to identify the spatial and temporal rupture pattern as a function of position on the fault. To date, seismic data recorded at period longer than 100 sec have not been readily considered in finite-fault studies though they provide information on the overall size and duration of the earthquake.

In this study, we were interested in the large 7.8 Ms Central Chile seismic event of 3 March 1985 . We apply a linear, point -by- point inversion scheme to the long-period Rayleigh waves, in addition to near-source strong motions and teleseismic body-waves, to infer the source properties of the earthquake rupture. For this event, the seismic moment calculated using surface waves and geodetic data are consistently greater than determined using teleseismic body waves. This discrepancy in estimated seismic moment has led some to suggest that the 1985 Chile earthquake involved a slow component of fault slip that radiated little or no body-wave energy. Moreover, the rupture length as the depth extent of faulting are also not well constrained.

Our results indicate however that a single rupture model with a variable dislocation rise time can explain the entire suite of observations well, and it is not necessary to introduce a significant component of slower fault motion to reconcile the long-period Rayleigh-wave amplitudes.

FINITE-FAULT INVERSION

1) Seismic waveform data

Our set of data consist of local strong ground motion records, teleseismic body-wave from the GD-

SN and surface-wave from GEOSCOPE and IDA networks. All the data were corrected for the response of the instrument and bandpass-filtered with a Butterworth filter. The strong motion records were integrated to velocity and filtered from 2.0 to 7.5 sec. Body- and surface-wave records include teleseismic P and SH waveforms filtered at intermediate-periods and very long-period R1, R2 and R3 vertical fondamental Rayleigh wave trains bandpass-filtered from 100 to 350 sec.

2) Method

The procedure requires placing a fault plane in the earthquake source region and subdividing it into a finite number of subfaults. Synthetic Green's functions are then generated for each subfault assuming a dislocation rise time of finite duration and a constant propagation of rupture away from the hypocenter (Hartzell, 1989). Nevertheless, we relax the restriction of a fixed triangular rise time by using a time-window approach that allows multiple consecutive slip intervals that discretize the subfault rise time and rupture time. In this approach, the slip function at any point on the fault is approximated by a discrete number of boxcars of fixed duration and variable amplitude. The inversion then solves for the contribution of slip within each time window thus allowing for a variable subfault rise time and relaxing the constraints of fixed rupture velocity.

Strong-motion and teleseismic body-wave synthetics were calculated using local crustal velocities. Surface-wave synthetics were calculated from the PREM model. Synthetic waveforms were bandpass-filtered in the same way as the data.

Following Choy and Dewey (1988), we identify a realistic fault geometry for the 1985 event: the fault has a srtike of 5° and consists of two separate segments with different dips and rakes. The upper segment has a dip of 15° and a rake of 90° and the lower portion a dip of 30° and a rake of 110°. The two fault segments meet at a depth of 26 km.

3) Teleseismic body-wave analysis

The 1985 Chile earthquake is characterized by a series of multiple events that are well separated in time in the recorded P waveform. Choy and Dewey (1988) identify three distinct P arrivals, including two precursory phases (ms1 and ms2) prior to the main shock (MS).

In this study, we concentrate our analysis on the MS portion of the recorded waveforms to constrain the location and depth of the principal moment release. The nucleation point of this MS event is at a depth of 40 km in the lower segment of the hinged fault (Choy and Dewey, 1988). Slip distribution obtained by inverting the MS teleseismic body waveform show four regions of peak slip on the fault (Fig.1). The corresponding seismic moment is 1.2×10^{28} dyne-cm. This value is computed by summing the individual subfault moments over the entire fault. The most intense moment release occurred in the vicinity of the hypocenter and lesser, but significant, moment release occurred on the southern portion of the fault. Rise times observed for the zones of maximum slip vary between 10-15 sec. The nucleation point of the mainshock MS at a depth of 40 km reaches a depth of about 55 km.

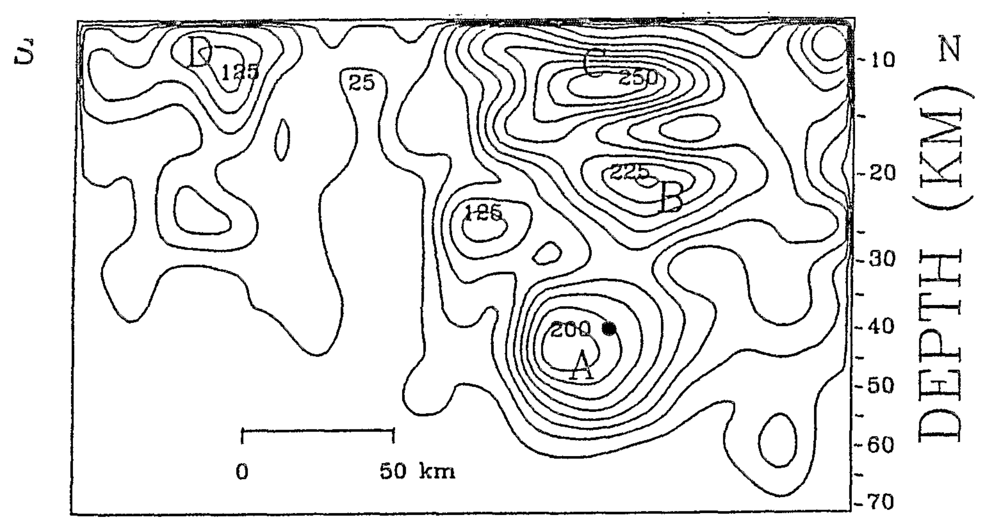

Figure 1. Slip distribution obtained from time-window inversion of the teleseismic body waves using a 1-sec time-window interval. Cumulative slip is contoured at 25-cm intervals and contains all fault displacements occuring within 10 sec after the passage of a rupture front propagating at 3 km/sec away from the hypocenter (filled circle). A, B, C and D mark the areas of maximum slip.

Source durations published for the 1985 Chile earthquake using long-period surface-wave are between 60 and 80 sec. We re-examine the source duration and seismic moment of that event by inverting the full Rayleigh waveforms, using a point-source time-window approach. We find that the majority of the long-period moment release occurs in an interval from 20 to 80 sec following main rupture initiation, consistent with previous surface-wave results. The surface-wave moment in the first 80 sec. is 1.2×10^{28} dyne-cm, consistent with previous estimates and similar to our body-wave moment.

4) Body-wave, surface-wave, and strong-motion analysis

We have performed a simultaneous inversion of the teleseismic body waves, very long-period surface waves, and local strong-motion to further constrain the distribution of mainshock slip on the hinged fault used in the body-wave analysis. Each of the three data sets is weighted appropriately to prevent any one data type to dominate the result. The solution is very similar to that obtained using only body waves (Fig.1) and shows mainly fault motion along the shallow portion of the plate boundary (Fig.2). The mainshock source duration is 68 sec with the principal moment release occurring within a 40-sec time interval beginning about 5 sec after the rupture nucleation. The total seismic moment is 1.5×10^{28} dyne-cm.

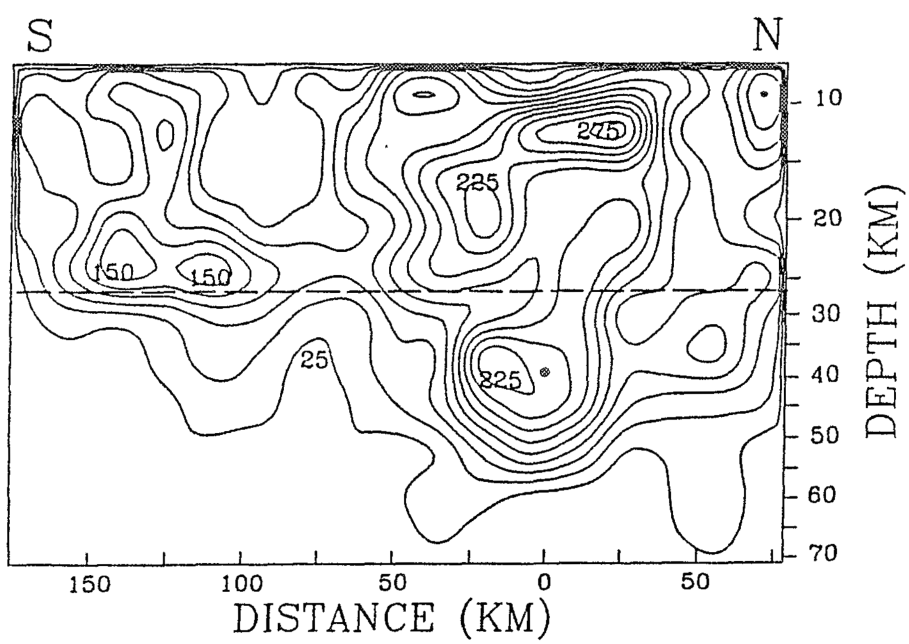

Figure 2. Results of the hinged-fault, time-window inversion of the entire teleseismic, surface-wave, and strong-motion data set. The slip distribution shows cumulative fault slip contoured at 25-cm intervals 10 seconds after the passage of the rupture front propagating at 3 km/sec away from the hypocenter (filled circle). The dashed line marks where the fault dip changes from 15° to 30°.

As we can see in Fig. 2, the majority of the moment released can be attributed to a broad source region in the northen half of the fault which contains two distinct zones of slip spanned between 5 and 55 km depths: one zone of 2.3-m peak, near the rupture nucleation point and another of 2.8-m peak, updip in the more gently-dipping portion of the plate interface (Fig.2). The southern portion of the rupture area includes a narrower region of lesser slip of 1.5-m peak which does not extend deeper than 30 km.

These results indicate that the observed seismic data considered here, which cover a very wide range of frequencies (from 2 to 350 sec), can be explained by a single rupture model. This inferred dislocation model predicts the observed Rayleigh-wave amplitudes quite well and does not require a seperate longer-duration component of fault motion, suggesting that a depth extent of 5-55 km is appropriate for the 1985 Chile earthquake. This depth range is in excellent agreement with the depth extent inferred by Barrientos (1988) from a finite-fault inversion of the post-seismic geodetic measurements. The inferred depth range is also consistent with the long-period surface-wave centroid depths.

CONCLUSIONS

We have examined local strong ground motions and teleseismic body and surface waves recorded for the earthquake using a variable rise-time finite-fault inversion scheme to recover a detailed rupture history of the principal moment release. This data set contains a wide range of frequencies that include periods from about 2 to 350 sec. We assume a hinged fault with two different dips (15° for the shallower portion and 30° for the deeper one) to simulate the landward increase in plate-boundary dip suggested by Choy and Dewey (1988). The inversion yields a rupture model that explains all three data types equally well. The mainshock source duration is 68 sec with the majority of the moment release occurring in the first 45 sec. The total seismic moment is 1.5×10^{28} dyne-cm. The entire rupture area covers a lateral distance of about 200 km.

A variable rise-time inversion using only the teleseismic body-wave data yields a very similar distribution of mainshock slip with a slightly lower seismic moment (1.2×10^{28} dyne-cm); This result indicates that the body-wave data provide a fairly accurate measure of the earthquake rupture history. Thus, a significant downdip component of relatively slow fault motion is not required to fully explain Rayleigh wave data set. The small difference in seismic moment may reflect the band limitation of the body-wave data. The observed rise times are consistent with the dynamic rupture of local asperityies and may indicate a mechanism of earthquake generation characterized by the failure of individual asperities across the fault.

The rate of relative plate convergence in this region (9 cm/yr) would suggest an accumulation of 7.1 meters of tectonic slip in the 78.5 years between the 1906 and 1985 earthquakes. Our inferred maximum slip of 2.8 meters for the 1985 Chile earthquake would indicate that either a significant amount (about 60 percent) of aseismic motion occurs across the entire plate boundary or a future large-slip event has yet to occur in the area.

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