Source Characteristics and Strong Ground Motion during the 2001 El Salvador Earthquake

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The January 13/2001 El Salvador earthquake (Mw7.6) occurred 50 km south of the El Salvador coast at the subduction region of the Cocos plate, producing a large amount of casualties and damage and an extensive landslide at the Nueva San Salvador (Santa Tecla) city. In the present work we make a broadband frequency strong ground motion simulation of the earthquake in order to determine an approximate rupture model of the source. The model is based on a characterized asperity model, and is aimed to produce ground motion in the frequency range from 0.1 to 10 Hz. We found that a preferred rupture model corresponds to a fault plane dipping to the North-west with a large asperity located west of the hypocenter, therefore the rupture propagates mainly from east to west and down dip. The ground motions across the country tend to be larger in the western part, where the velocity waveforms at several stations shown a forward directivity pulse.

Key Words : *the 2001 El Salvador Earthquake, Broadband frequency ground motion, Source rupture process, Strong motion characteristics.*

1. INTRODUCTION

The January 13 /2001 earthquake (Mw 7.6) was produced by the subduction of the Cocos plate beneath the Central American plate. The epicenter was located at approximately 50 km south of the coast of El Salvador at a depth of 32 km (Centro de Investigaciones Geotécnicas CIG). The solution of the focal mechanism determined by several agencies shows a normal fault, related with an extensional stress regime. The source parameters are summarized in Table 1. The aftershocks distribution of the mainshock determined by the CIG National Seismic Network are distributed across an area of approximately 70 km along the strike and focal depths between 20 and 80 km. A cross section of the aftershock do not clearly show a particular fault plane (figure 1).

From an analysis of the three different solutions of focal mechanisms in Table 1, we can observe that the actual fault plane that ruptured during the January 13 mainshock has two main possibilities: one is a fault plane dipping to the south-west at a strike angle between 119° to 152° and a dip angle between 33° to 45°. The second possibility is a fault plane dipping to the north-east at a strike angle between 306° to 318° and a steeper dip angle between 48° to 58°.

Table 1. Source Parameters of the January 13, 2001 El Salvador earthquake

Agency	Strike,Dip,Rake Fault Plane No1	Strike,Dip,Rake Fault Plane No2	Mw	Depth (Km)
USGS	149, 45,-73	306,48,-107	7.6	39.0
Harvard-CMT	119,34,-98	309,56,-85	7.7	57.4
ERI	152,33,-78	318,58,-98	7.6	50.0

ERI: Earthquake Research Institute (Tokyo University)
Harvard-CMT: Harvard University, Centroid Moment Tensor Solution.

2. GROUND MOTION CHARACTERISTICS

The available strong ground motion recordings during the 2001 El Salvador earthquake (UCA 2001) show in general larger amplitudes in the western part of the country compared with the eastern part. This behavior can be observed in the recorded velocity waveforms shown in figure 2. The largest PGV was obtained at the Santa Tecla Station (Te) with a value of approximately 57 cm/s (figure 2). The acceleration waveforms show a similar behavior as can be appreciated from figure 3. The largest PGA (1109 cm/s^2) was recorded at La Libertad station (Li), (figure 3). The complexity of the velocity waveforms reveals a very complex velocity structure model. We can however appreciate from one of the closest stations to the fault plane (Li station) a 10 sec low frequency pulse probably associated with a forward rupture directivity of a large asperity.

3. SIMULATION METHODOLOGY

The basic idea of the simulation methodology is to evaluate the strong ground motion radiated from a finite source model composed of **asperities** or regions in the fault plane with a large slip, embedded in a layered velocity structure.

The ground motion estimation methodology aims to produce ground motions in a broadband frequency range (0.1Hz to 10 Hz) in order to be able to compare the simulated ground motions with the observed damage distribution. The procedure to be applied is a hybrid ground motion simulation technique, which consists in the generation of ground motions in a low frequency (<1Hz) and high frequency (>1Hz) bands (Kamae and Irikura 1998).

The low frequency part of the ground motion is calculated from the radiation of an asperity model, propagating in a flat-layered velocity structure, applying the Discrete Wave Number method for the elastic wave propagation in a layered media (Bouchon 1981). An extended source discretized into several subfaults is used to calculate the ground motion from each asperity. The contribution from each subfault inside the asperities is time delayed according to an assumed rupture velocity.

The high frequency motion generation uses the idea of the empiricals Green's function technique (Irikura 1983), which consists in using recordings from small events (aftershocks) in order to reproduce the ground motion from a large event (mainshock). For that purpose the scaling relation of the source spectra and the source parameters together with an appropriate selection of the small event is considered. For regions, where no appropriate recording of aftershocks is available, the seismograms of the small event are generated stochastically in such a way that they follow an omega square model and a regional attenuation relationship (Boore 1983). Then the empirical Green's function method is applied using the synthetic aftershock waveform obtained previously.

4. BROADBAND SIMULATION OF THE JANUARY 13 MAINSHOCK

We performed a broadband frequency strong ground motion simulation of the January 13, 2001 El Salvador earthquake at the Santa Tecla (Te) and la Libertad (Li) stations. The first step of the simulation was determining which fault plane preferably ruptured during the El Salvador earthquake by selecting the solution that optimized the fitting of the velocity and acceleration waveforms as well as velocity and acceleration response spectra. For that purpose we analyzed the six possible fault plane solutions given in table 1. For Each solution we assumed a fault plane consisting of only one asperity whose seismic moment was assumed to be a 40% of the total seismic moment of the earthquake. The asperity area was determined according to the empirical scaling between seismic moment and asperity area (Somerville et al. 1999).

We made forward modeling of the low frequency waveforms (0.1 to 1 Hz) at the Li and Te stations, for each of the six possible fault plane mechanism. In each case we also tried different locations of the asperity. We finally obtained that the solution giving the best fit to the waveforms was the one corresponding to the USGS fault plane solution No.2, namely a fault plane dipping to the North-East. We found that a preferred location of the asperity is close to the CIG hypocenter (figure 1).

The second step of the simulation was the inclusion of the high frequency part into the waveforms (1 to 10 Hz). For performing this step we used the asperity model obtained from the low frequency part. For the inclusion of the high frequency ground motion three main factors should taken into account: the source spectra, the regional attenuation spectra and the site effect. For the source spectra we assumed an omega-square and frequency dependent attenuation.

Concerning the site effects, from the observed acceleration response spectra at the Li station for the NS component (figure 4) we can observe a very large spectral acceleration peak at approximately 0.2 seconds. We think this peak is related with the site conditions at the Li station. In fact we found that the only way of getting a good acceleration spectral fitting for periods between 0.1 and 1.0 sec, is by means of applying a spectral site effect factor. For the Li station we found that a very large spectral factor of 7 is needed to get closer to the observed acceleration spectra in the short period range. We observed that the velocity waveforms are less sensitive to the site effect than the acceleration waveforms, and are mostly dominated by the low frequency component (figure 4). A similar observation holds for the Te station but in this case a spectral site effect factor of 5 should be applied (figure 5).

5. CONCLUSIVE REMARKS

Several fault plane solutions where analized in order to understand what was the fault plane that preferably ruptured during the January 13, 2001 El Salvador earthquake. A fault plane dipping to the Northeast with an asperity rupturing from east to west, starting close to the epicentre was found to give an optimum spectral and waveform fitting at the Li and Te stations. However this rupture model is only given as a rough approximation of the rupture process of the earthquake, since the number of stations used and available are very limited.

From the observed strong motion recordings we can observe that the waveforms tends to be larger towards the west (in particular the velocity waveforms). This could be related with the rupture directivity producing a forward directivity pulse clearly seen at the Li station. We found that the site effect has a large influence in the short period range of the Li and Te stations. We optimised the spectral fitting between observations and simulations at this period range by including a large factor of spectral amplification into the simulations. Concerning the waveforms amplitudes we found that the acceleration waveforms are more sensitive to the site effect compared with the velocity waveforms.

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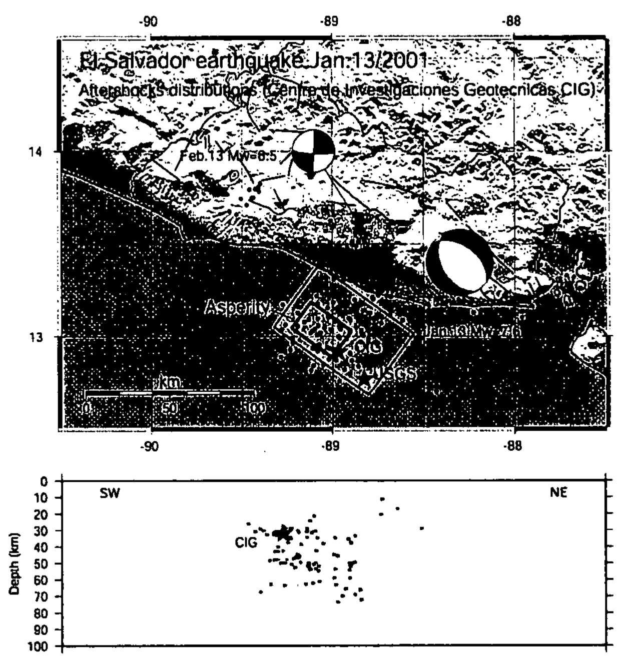

Figure 1. USGS focal mechanism solutions and CIG afterschocks distribution of the El Salvador January 13, 2001 earthquake (dark gray) The approximate rupture area corresponding to the USGS fault plane solution No2 is shown by a rectangle. The CIG and USGS epicenter are shown by a star. The asperity rupture model determined by this study is shown by a thick rectangle. Aftershocks projection perpendicular to the USGS fault plane solution No2 is shown (Lower panel).

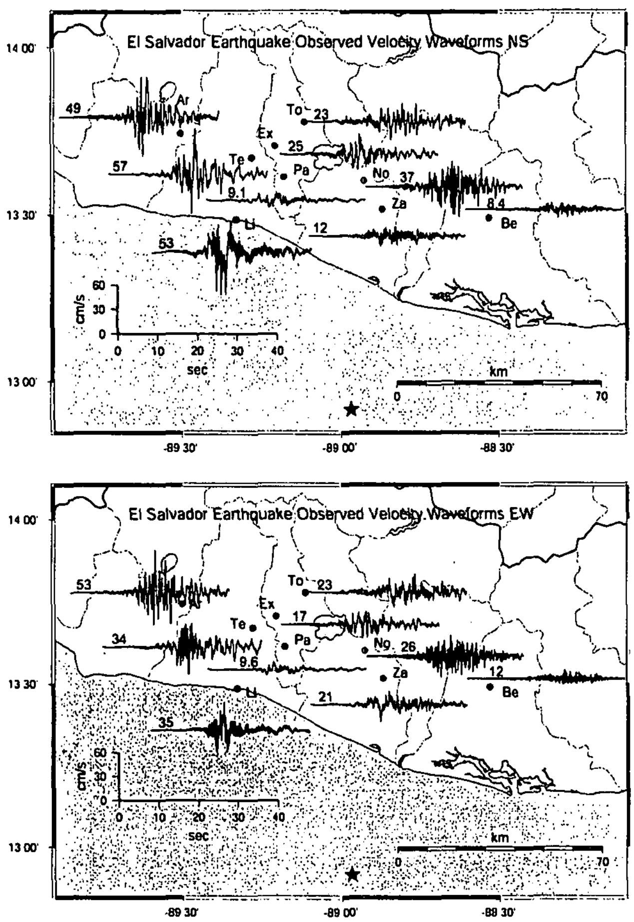

Figure 2. Spatial Distribution of the recorded velocities waveforms EW and NS components, during the January 13/2001 El Salvador earthquake. The PGV values at each station are shown. The CIG epicenter is shown by a star.

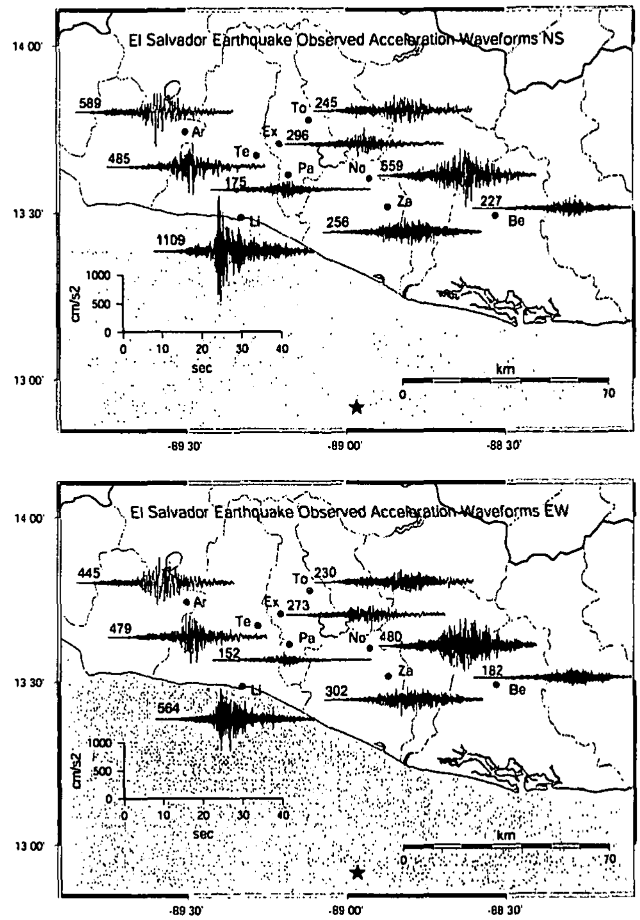

Figure 3. Spatial Distribution of the recorded acceleration waveforms EW and NS components, during the January 13/2001 El Salvador earthquake. The PGA values at each station are shown. The CIG epicenter is shown by a star.

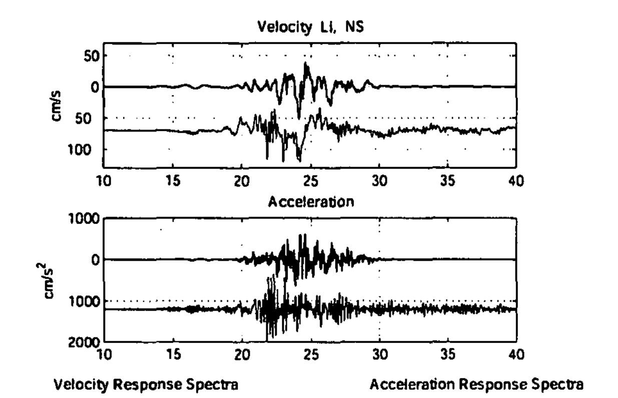

Figure 4. Comparison between the simulated (thick line) and observed NS component (velocity and acceleration waveforms and reponse spectra) at the Li station (Unidad de Salud, La Libertad) during the January 13, 2001 El Salvador earthquake. The waveforms are bandpassed filtered between 0.1 and 10 Hz.

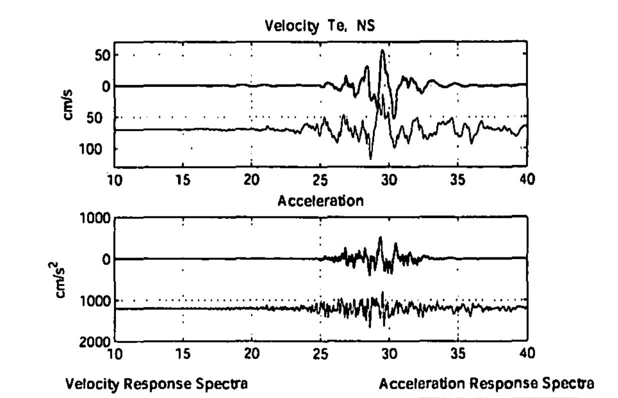

Figure 5. Comparison between the simulated (thick line) and observed NS component (velocity and acceleration waveforms and response spectra) at the Te station (Hospital San Rafael, Santa Tecla) during the January 13, 2001 El Salvador earthquake. The waveforms are bandpassed filtered between 0.1 and 10 Hz.