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# Source parameters of two moderate Mexican earthquakes estimated from a single-station, near-source recording, and from MT inversion of regional data: A comparison of the results

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**RESUMEN**

Dos sismos recientes de magnitud moderada (marzo 27, 1996, $M_w$ = 5.4; enero 21, 1997, $M_w$ = 5.4), ocurridos cerca de la localidad de Pinotepa Nacional, Oaxaca, México, fueron registrados en la estación de banda ancha (VBB) PNIG a distancias de campo cercano y en otras estaciones de la red de VBB de México, localizadas a distancias regionales. Ambos eventos saturaron el sensor de velocidad (STS-2) en PNIG. En este estudio primero utilizamos los registros de velocidad y desplazamiento, obtenidos directamente de la integración de los acelerogramas en PNIG, para obtener la localización, profundidad, tiempo de origen, mecanismo focal, momento sísmico escalar, y la función temporal de la fuente para ambos eventos. Luego realizamos una inversión del tensor de momento sísmico (MT) de los registros de desplazamiento regionales, filtrados con un paso de banda de 20 a 50 sec, para estimar los parámetros de la fuente de los dos sismos. Para estos eventos, la solución de MT obtenidos concuerdan razonablemente con los obtenidos con los datos cercanos a la fuente de la estación PNIG. Nuestros resultados muestran que: (a) detalles de los parámetros de la fuente pueden obtenerse de una sola estación, cercana a la fuente, con tres componentes, y con alta calidad de registros, y (b) una estimación aproximada del mecanismo focal, y momento sísmico de sismos mexicanos puede obtenerse de una inversión de MT con datos regionales utilizando la estructura de corteza hasta ahora conocida; sin embargo, una determinación más precisa requiere de un mejor conocimiento de la estructura cortical, principalmente para estimar la profundidad de centroide.

PALABRAS CLAVE: Parámetros de fuente sísmica, sismogramas cercanos a la fuente, inversión de tensor de momento sísmico regional.

**ABSTRACT**

Two recent, moderate earthquakes (March 27, 1996, $M_w$=5.4; January 21, 1997, $M_w$=5.4), which occurred close to the town of Pinotepa Nacional, Oaxaca, Mexico, were recorded at the near-source VBB station of PNIG and by several other stations of the Mexican VBB seismological network located at regional distance. Both events saturated the velocity sensor (STS-2) at PNIG. We first use velocity and displacement records, obtained by direct integration of the accelerograms at PNIG, to obtain location, depth, origin time, focal mechanism, seismic moment, and source time function of the two earthquakes. We then perform a moment tensor (MT) inversion of regional band-pass filtered (20 to 50 sec) displacement seismograms to estimate the source parameters of the two earthquakes. For these events, the MT solutions are reasonably close to those obtained from the near-source data of the single station of PNIG. Our results show that: (a) detailed source parameters can be retrieved from a single, near-source, high-quality three-component recording, and (b) a rough estimation of focal mechanism and seismic moment of Mexican earthquakes may be possible from MT inversion of regional data using presently known crustal structure. But more precise determinations would require a better knowledge of this structure, mainly to estimate the centroid depth.

KEY WORDS: Source parameters, near-source seismograms, moment tensor inversion for regional data.

## INTRODUCTION

A quick and reliable estimation of gross source parameters of moderate and large earthquakes ($M_w \geq 5.5$) has now become routine. For example, Harvard University and the Earthquake Research Institute (University of Tokyo) report centroid moment tensor (CMT) inversion solution and the University of Michigan reports the source time function of almost all $M_w \geq 5.5$ earthquakes worldwide within a few hours of their occurrence. For detailed source studies of such events, and for routine estimation of source parameters of smaller earthquakes, an analysis of local and regional data is required. Thus, local and regional broad-band data is being used in routine determination of moment tensor solutions of small and moderate events in California (Thio and Kanamori, 1995; Gee *et al*., 1996). In recent years, a network of 15 very broad-band (VBB) seismographs have been installed in Mexico. This network routinely records high-quality seismograms at regional distances and, on rare occasions, also at near-source distances. These data should permit us to obtain quick and reliable moment tensor (MT) solution of Mexican earthquakes.

Kanamori *et al*. (1990) have shown that a single-station, near-source, three-component, high-quality recording can significantly improve the estimated source parameters of an earthquake. Singh *et al*. (1997) used the near-source recording of the March 27, 1996 ($M_w$=5.4) Pinotepa Nacional, Mexico earthquake at the VBB station PNIG to estimate such source parameters as location, depth, origin time, focal mechanism, seismic moment, and source-time function. The recent earthquake of January 21, 1997 ($M_w$=5.4), which also occurred close to the town of Pinotepa Nacional, was again recorded by the near-source station of PNIG, as well as by many other stations of the Mexican VBB network. In this paper we first determine the source parameters of this earthquake from the PNIG recording alone. We then obtain MT solution of both January 21, 1997 and March 27, 1996 earthquakes by inverting band-pass filtered (20 to 50 sec) regional seismograms. Our goal is to compare the source parameters obtained from the near-source data with those obtained from the MT inversion. These comparisons are important since a routine estimation of moment tensor solutions of small and moderate events in Mexico has to be based on regional data (near-source recordings are likely to be rare because of the sparse nature of the network). A favorable comparison would suggest that our knowledge of crustal structure is adequate, and may give a green light to routine estimations of MT. Large differences in the parameters, on the other hand, would point toward the need for a better crustal structure, or an algorithm based on a wave type which is less sensitive to it.

## DATA

In this analysis we have used data from VBB stations located at epicentral distance, $\Delta \leq 500$ km. Within this distance range, nine and seven VBB stations recorded the earthquakes of January 21, 1997 and March 27, 1996, respectively. The station locations are shown on Figure 1. Both of these earthquakes were recorded by the near-source station PNIG.

All VBB stations of the Mexican network consist of an STS-2 seismometer and a Kinematrics FBA-23 accelerometer connected to a 24-bit Quanterra digitizer. Continuous velocity data, sampled at 1 Hz and 20 Hz, are saved in a buffer memory. For triggered events both velocity and acceleration channels, sampled at 80 Hz, are saved. We have used the triggered channels in this study. Because of intense ground motion, the STS-2 sensor at PNIG saturated during both events.

## ANALYSIS OF NEAR-SOURCE RECORDINGS AT PNIG

### (1) The Earthquake of January 21, 1997

Figure 2 shows PNIG accelerograms (top), velocity traces obtained by direct integration of the accelerograms (middle), and velocity seismograms from the STS-2 sensor which saturated during the S-wave (bottom). The earthquake had an (S-P) time of 2.8 s at PNIG. The peak accelerations were 63 gals, 171 gals, and 93 gals in Z, EW and NS directions, respectively. In all further analysis of the event, we

Fig. 1. VBB seismographic stations of the Mexican network whose data are analyzed to estimate source parameters of the two Pinotepa Nacional earthquakes. Station name is followed by numbers 1 and/or 2, indicating the event(s) recorded by the station. 1: January 21, 1997; 2: March 27, 1996. Stars show the locations of the events.

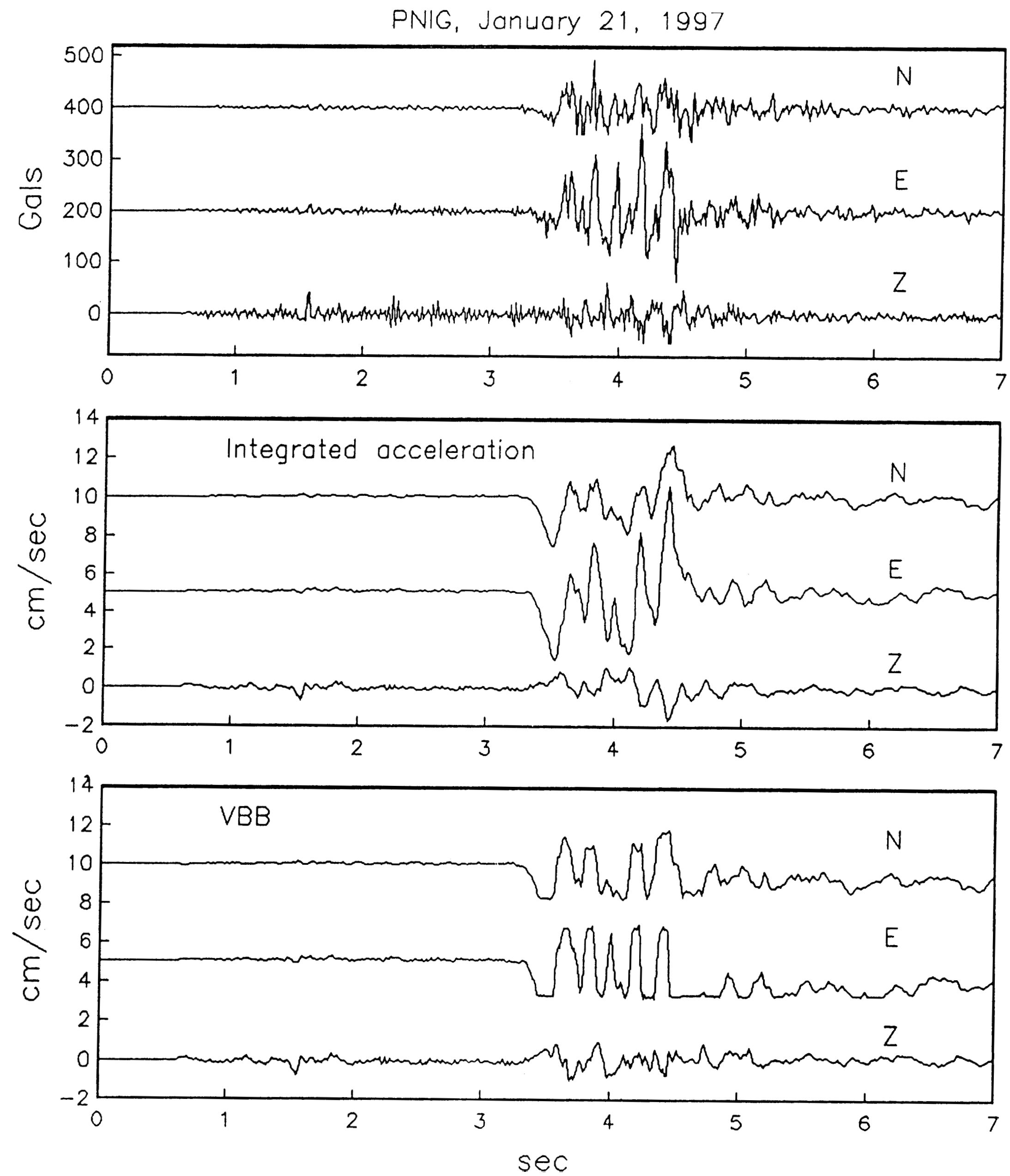


Fig. 2. Near-source recording of the earthquake of January 21, 1997 at PNIG. Top: accelerograms, middle: velocity traces computed by direct integration of the accelerograms, bottom: velocity seismograms from the STS-2 sensor. Note that the seismograms are clipped in the bottom frame.

have used velocity and displacement records computed by direct integration of the accelerograms.

In the estimation of the source parameters, we followed the method discussed in Singh *et al.* (1997), which we briefly summarize here. First the azimuth of the station with respect to the source, $\phi_s$, is computed from the amplitude and polarity of P wave from the three components of velocity seismogram ($\phi_s$=112˚). The horizontal traces are then rotated into radial and transverse components and the angle of incidence at the surface ($i_0$) is computed from the radial and the vertical components of P wave ($i_0$=21˚). We take a layer ($\alpha$=5.0 km/sec) of thickness 1.5 km overlying a half space ($\alpha$=6.2 km/sec) as an appropriate model for the upper crust below PNIG (see Singh *et al.*, 1997 for details). For this crustal model, the epicentral distance ($\Delta$), the depth (H), and the takeoff angle ($i_h$), required to match the (S-P) time of 2.8 sec and the angle incidence at PNIG, are 10.2 km, 20.9 km, and 153.6˚, respectively. Since the coordinate of PNIG is 16.392˚ N and 98.127˚ W, we obtain the location of the earthquake as 16.427˚ N and 98.218˚ W. With respect to this location, the P-wave travel time to PNIG is 3.81 sec. Subtracting this time from the P-wave arrival time at PNIG gives the origin time of the earthquake as 21:19:58.68.

To obtain the focal mechanism of the earthquake, first ranges of strike, dip, and rake values are determined as those which (a) either satisfy those available from first-motion data or, (b) are in accordance with previously reported mechanisms in the region. The amplitudes and the polarities of P and SV wave on Z, and SH wave on transverse component are measured on the near-source displacement seismograms. A grid search is then performed over the range of possible focal mechanisms to select those solutions which are in agreement with measured relative amplitudes and the polarities (for more details see UNAM and CENAPRED Seismology Group, 1995). In this search we allow for realistic errors in the observed values. [Note that theoretical amplitudes are calculated for a dislocation in an infinite space. For this reason, this approach gives reasonable result only when the depth is greater that the epicentral distance]. Finally, the accepted solutions are used to generate synthetic seismograms in the appropriate crustal model and compared with the observed waveforms, thus obtaining the focal mechanism, the seismic moment, and the source time function.

In the case of the January 21, 1997 earthquake, we searched for a solution similar to the focal mechanism of the nearby earthquake of March 27, 1996 given in Singh *et al.* (1997). The final focal mechanism, the observed and synthetic seismograms, and the source-time function are shown on Figure 3. The observed seismograms clearly show contribution of the near-field term, which is seen as the ramp between P and S waves. The fit between the observed and the synthetic seismograms is reasonable. Note in Figure 3 that our mechanism is consistent with the first-motion polarities although we did not use them to obtain the focal mechanism. We summarize the source parameters of the earthquake in Tables 1 and 2.

**Table 1**

Hypocentral parameters

| Event | Time | Lat(° ) | Long(° ) | Depth (km) |
|---|---|---|---|---|
| 960327 | 12:34:48.35 | 16.365 | -98.303 | 18.0 |
| 970121 | 21:19:58.68 | 16.427 | -98.216 | 20.9 |

**(2) The Earthquake of March 27, 1996**

As mentioned earlier, this earthquake was analyzed by Singh *et al.* (1997). In Figure 4 we show the focal mechanism, the observed and synthetic seismograms, and the source time function. In Tables 1 and 2 we list the source parameters of the event to facilitate their comparison with the MT solution obtained in the next section.

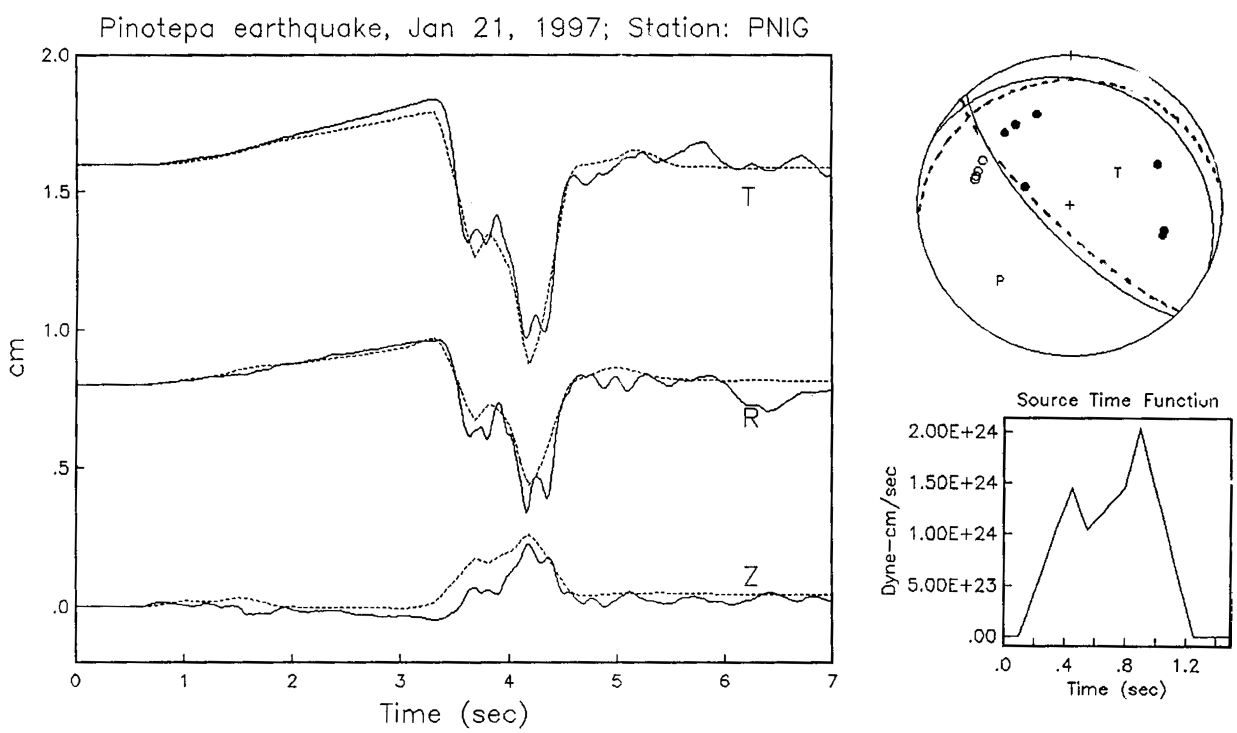


Fig. 3. Observed (continuous) and synthetic (dashed) displacement seismograms of January 21, 1997 earthquake. The contribution of near-field term is clearly visible. The focal mechanism and the source time function are given on the right side of the figure. Nodal planes with continuous line: from PNIG seismograms; dotted nodal planes: from MT inversion of regional seismograms.

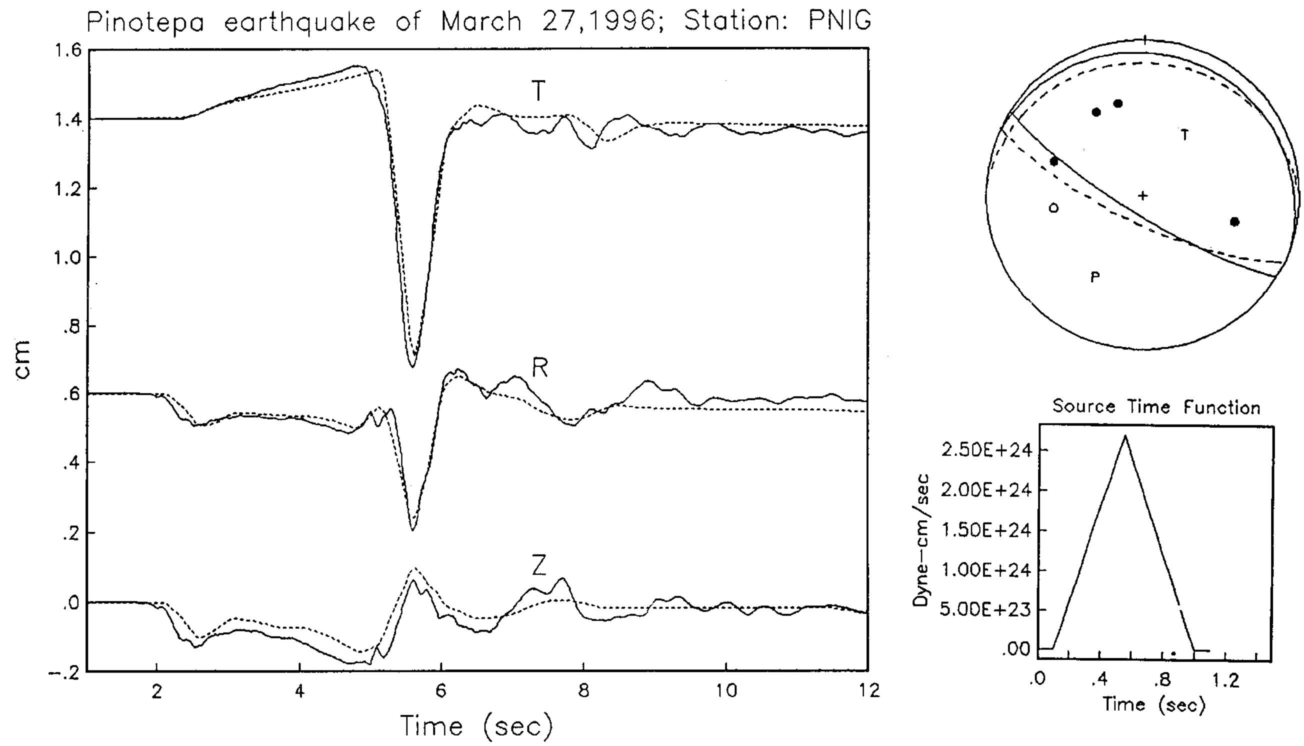


Fig. 4. Observed (continuous) and synthetic (dashed) displacement seismograms of March 27, 1996 earthquake. The focal mechanism and the source time function are given on the right side of the figure. Nodal planes with continuous line: from PNIG seismograms, dotted nodal planes: from MT inversion of regional seismograms.

**Table 2**

Source parameters

| Event | Moment (N-m) | Strike (°) | Dip (°) | Rake (°) | Source-time function |
|---|---|---|---|---|---|
| 960327 | $1.2\text{x}10^{17}$ | 291 | 10 | 80 | Isosceles triangle base of 0.9 sec. A small event Mw 4.1 preceded the mainshock by 0.18 sec. |
| 970121 | $1.2\text{x}10^{17}$ | 296 | 18 | 70 | Two isosceles triangles, each with base of 0.35 sec., separated by 0.48 sec and seismic moments of $4.8\text{x}10^{16}$ and $7.2\text{x}10^{16}$ N-m. |

## MT SOLUTIONS FROM INVERSION OF REGIONAL SEISMOGRAMS

In this section we determine MT solutions of the two earthquakes by inverting regional seismograms. We follow the procedure of Randall *et al*. (1995) which uses a time-domain moment-tensor inversion scheme described by Langston (1981). The inversion is performed over a time window, which begins with the P wave and includes surface waves. In the inversion we use displacement seismograms which have been band-pass filtered between 20 and 50 seconds. For these earthquakes, longer periods are not recoverable from the background noise and at shorter periods the signal is affected by fine details of crustal structure, which are not known. As surface waves are the predominant feature of the seismograms, we compute synthetic seismograms for a crustal model given by Campillo *et al*. (1996) which was obtained from the inversion of surface waves. We used the PREM model (Dziewonski and Anderson, 1981) for the upper mantle (Table 3).

**Table 3**

Crustal structure used in the MT inversion of regional seismograms

| Top of layer (km) | $\alpha$ (km/sec) | $\beta$ (km/sec) |
|---|---|---|
| 0.0 | 5.30 | 3.06 |
| 5.0 | 5.48 | 3.37 |
| 17.0 | 6.70 | 3.87 |
| 45.0 | 8.02 | 4.41 |
| 85.0 | 7.88 | 4.43 |
| 225.0 | 8.73 | 4.71 |

In order to minimize the dependence of the inversion on origin time, event location, and the chosen velocity structure, we align the theoretical P wave arrivals with the observed ones. We obtain moment tensor solutions for various depths. The best centroid depth is obtained through a grid search and the best estimate is taken as that which gives the lowest rms residual between observed and synthetic seismograms, and lowest percentage of compensated linear vector dipole (CLVD) component from the total double-couple component.

### (1) The Earthquake of January 21, 1997

Figure 5 shows a graphic of rms as a function of depth (focal mechanisms). Both, rms and percentage of CLVD to double-couple component (triangles) have a minimum value at 10 km depth. However, there is no significant variance reduction in neither of these two parameters from 0 to 30 km depth. Thus, the depth is not very well defined from the study of regional waves. From 5 to 20 km depth the focal solutions do not differ considerably, and they are in close agreement with the solution obtained from PNIG alone. Observed and synthetic seismograms corresponding to 10 km depth are shown in Figure 6. The fits are reasonable except for coastal stations of HUIG and ZIIG where the synthetics are delayed and at TUIG where they are advanced with respect to the observed seismograms. The seismic moment is $1.74 \times 10^{17}$ N-m and the focal mechanism has a strike=265˚, dip=18˚, and rake=42˚. As shown in Figure 3, the focal mechanism compares well with the one obtained from PNIG only. As it will be expected, the seismic moment obtained from regional surface waves is larger than that obtained from near-field seismograms, as we are using longer period waves. We conclude that for this earthquake the MT inversion, using relatively long-period regional waves, yields focal mechanism

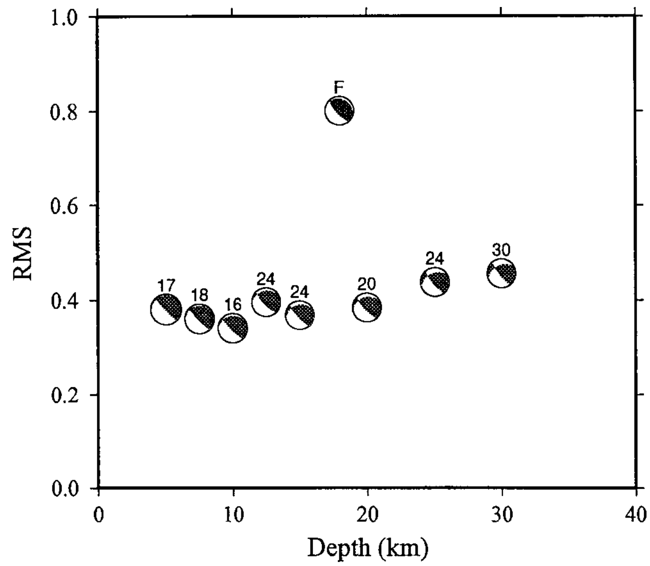


Fig. 5. Rms as a function of depth for the earthquake of January 21, 1997. The data points depict the corresponding focal mechanism and triangles the percentage of CLVD to double-couple component. The focal mechanism marked F was obtained from the modelling the near-source PNIG seismograms (Fig. 3).

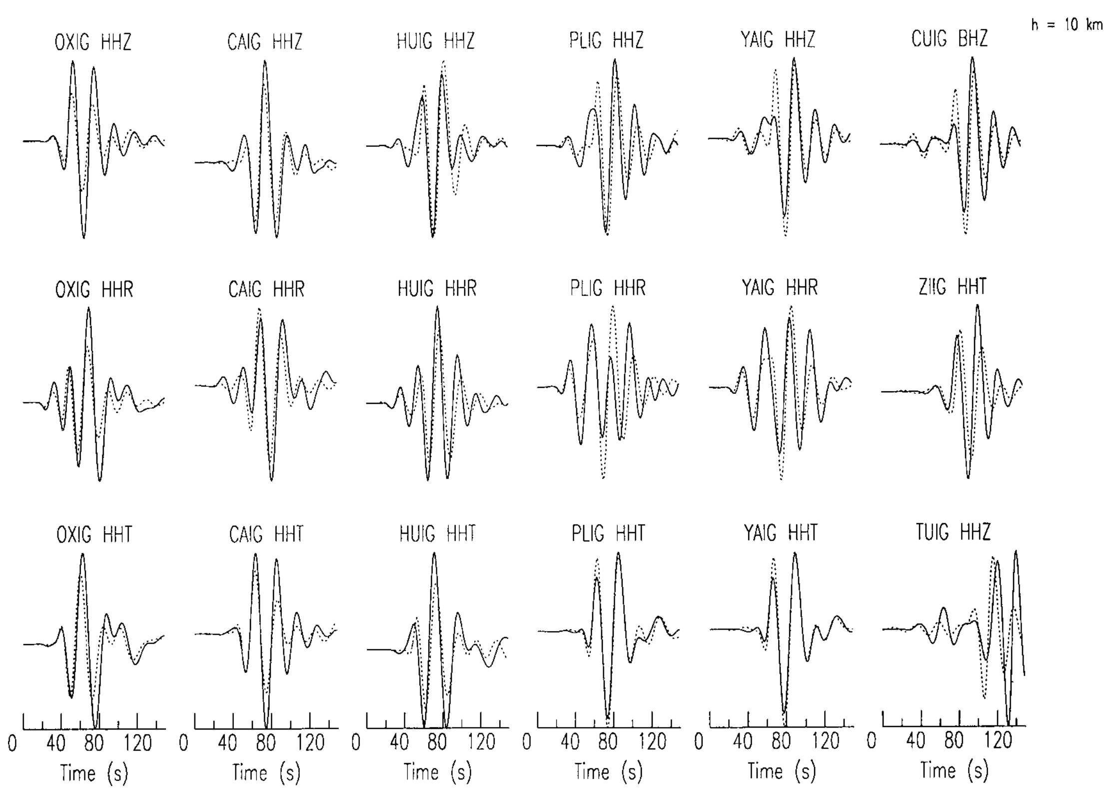


Fig. 6. Observed (continuous) and synthetic (dotted) regional displacement seismograms of January 21, 1997 earthquake. Synthetic seismograms correspond to the 10 km centroidal depth.

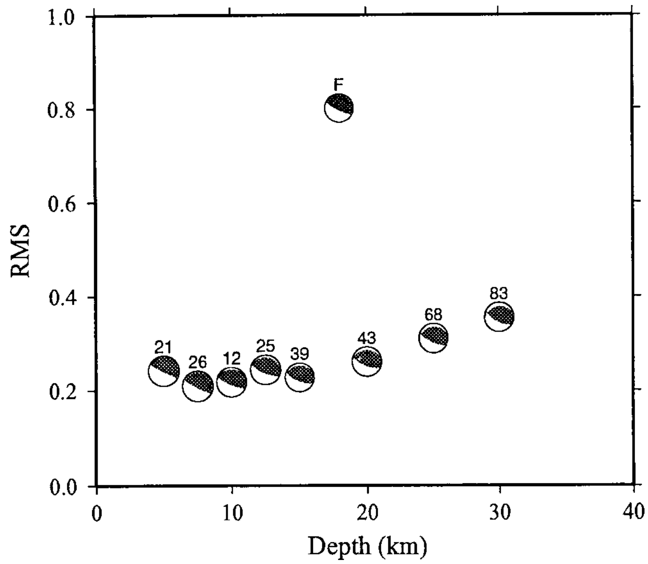


Fig. 7. Rms as a function of depth for the earthquake of March 27, 1996. The data points depict the corresponding focal mechanism and triangles the percentage of CLVD to double-couple component. The focal mechanism marked F was obtained from the modeling the near-source PNIG seismograms (Figure 4).

and seismic moment which are in good agreement with those obtained from PNIG; however, the centroid depth obtained from the inversion cannot be constraint.

**(2) The Earthquake of March 27, 1996**

Similarly to the results obtained from the previous event, Figure 7 shows a lack of resolution for the centroidal depth, there is no significant variance reduction for the rms as a function of depth. In this case, the percentage of CLVD smaller values (less than 50%) for shallow depths. The focal solutions for the tested depths are very similar, with the dip angle varying the most. For a depth of 10 km, the scalar seismic moment, $M_0$, is 2.11x$10^{17}$ N-m, and the focal mechanism parameters are strike=270˚, dip=16˚, and rake=66˚ (Figure 8). Again, the seismic moment obtained from regional surface waves is larger than that obtained from the near-field seismograms. This mechanism is compared with the one obtained from PNIG in Figure 4. The comparison of the solution obtained from the MT inversion and the analysis of PNIG data alone for this earthquake leads to the same conclusion as the previous event: MT inversion provides a reasonable estimate of the seismic moment, the focal mechanism, but no good constraint on the centroid depth.

## DISCUSSION AND CONCLUSIONS

One of the important objectives of the newly installed VBB seismographic network of Mexico is a quick and reliable estimation of source parameters of earthquakes. For two moderate earthquakes recorded at a near-source VBB sta-

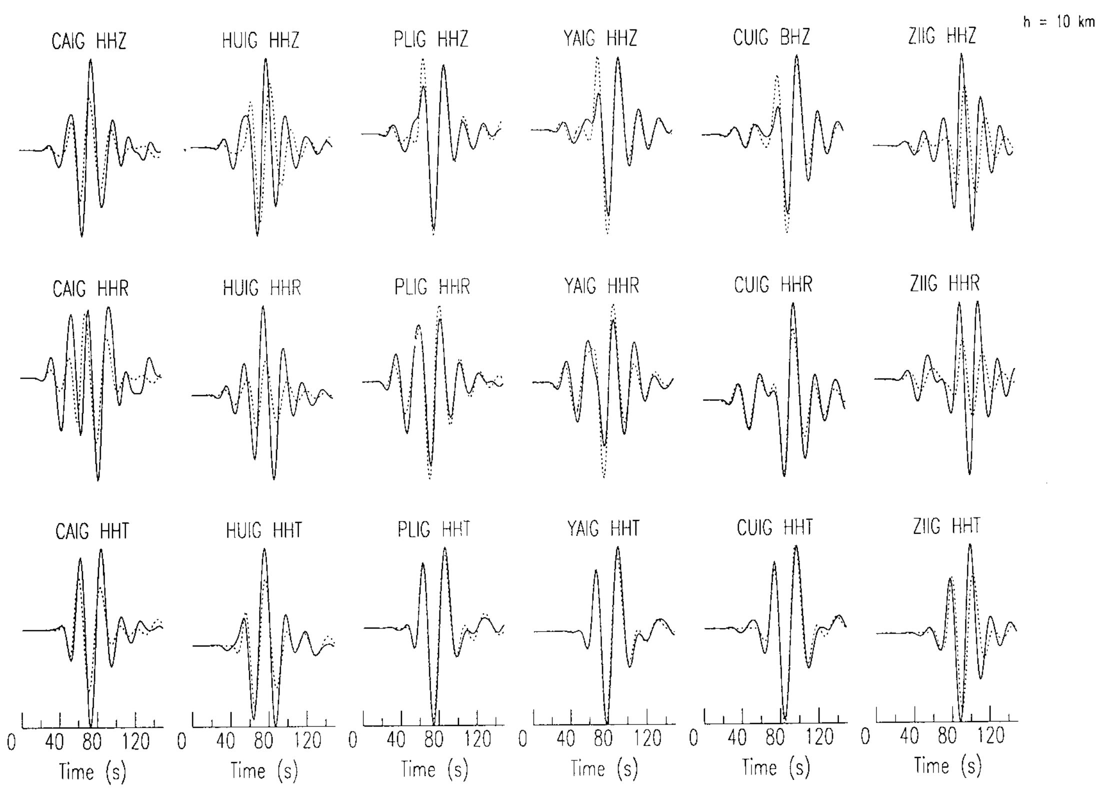


Fig. 8. Observed (continuous) and synthetic (dotted) regional displacement seismograms of March 27, 1996 earthquake. Synthetic seismograms correspond to the 10 km centroidal depth.

tion, we find, in common with some other studies, that it is possible to obtain detailed source parameters from the analysis of the seismograms from this single station. Most earthquakes in Mexico, however, are being recorded at regional distances. At such distances, seismograms are strongly affected by the crustal structure. To retrieve the source parameters of these earthquakes, we must either know this structure in detail or make use of long-period waves so that the fine structure of the crust becomes of little consequence. For moderate earthquakes recorded at regional distances, the signal is indistinguishable from noise at periods greater than 50 sec. It is for these reasons that we have begun experimenting with a MT inversion method, which uses 20 to 50 sec period regional waves. Since at these periods the signal is dominated by surface waves, we are using a crustal model, which was obtained from the inversion of group velocity of surface waves themselves. This model, however, is strictly valid for trajectories from the Guerrero coast to Mexico City.

For the two moderate events whose source parameters are known from near-source records, the MT inversions provide reasonably similar solutions. This is an encouraging result. The misfit between observed and synthetic seismograms at some stations, however, is large, suggesting a need to develop different crustal structures along different paths. Also, the depth resolution is poor, probably because we have used relatively long-period waves. This problem could be resolved by constraining the focal depth to that obtained from the hypocentral location of the event. Furthermore, the inversion needs to be tested with a greater number of moderate and large earthquakes with different geographical locations and depths before it can be routinely used. Finally, we foresee problems with MT inversion of smaller ($M_w$<5) Mexican earthquakes. For these earthquakes long-period waves will be lost in the noise which will force us to use smaller-period waves. This would require a more detailed knowledge of the crustal structure, which we presently lack.

## ACKNOWLEDGEMENTS

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