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Prediction of response spectra at any site in Mexico City

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ABSTRACT: Using data from the Mexico City's accelerometric array, we present a formulation to obtain elastic and inelastic response spectra at any site in Mexico City given only the magnitude and the distance of a postulated subduction earthquake. A bayesian regression model allows to obtain expected amplitude Fourier spectra at a reference hill zone site. Spectral ratios were computed in order to obtain the amplification of motion due to the clay deposits; because of the relatively high density of accelerometer stations these ratios can be interpolated at almost any desired site. The amplitude spectra at hill zone and the interpolated ratio give us the amplitude spectra at the desired site. Finally, with the expected duration of motion at the site, we obtain response spectra applying random vibration theory and the linear equivalent method.

1 INTRODUCTION

A lot of research is in progress at present in order to improve the prediction of motion due to possible earthquakes. The acceleration data here has a relevant place because it can be used to infer the characteristics of the earthquake and the response of soil and structures. Through knowledge of accurate data we can make reliable predictions concerning future earthquakes.

In Mexico City we have at least three important sets of data: (1) data from a large variety of earthquakes that has been recorded in Ciudad Universitaria (CU) since 1965. These allows the characteristics of motion in the hill zone to be known. (2) Data from the devastating 1985 earthquakes enables the behavior of the soil which was subjected to extremely high forces and duration to be investigated. (3) The huge amount of data (almost 40,000 seconds of record) from the new accelerometric array of Mexico City. Since 1987 this array has registered more than nine small and moderate subduction earthquakes (5.0 < magnitude < 7.0). Subsequent analyses of these data has given us great insight into the valley behavior.

The present method to generate the elastic response spectra in Mexico City given a postulate earthquake was first proposed by Ordaz *et al.* (1989). The original work has been improved in most of its parts through the availability of recent earthquakes data; new main contributions are the interpolation of spectral ratios and the generation of inelastic response spectra.

2 FOURIER SPECTRA AT *CU*

Based on data of 18 subduction earthquakes registered at CU, south of Mexico City, a bayesian regression model was obtained to infer the Fourier amplitude spectra of accelerations produced by a subduction earthquake. This earthquake is defined only by its magnitude (M) and the minimum distance (R) from the rupture area to CU. This data set is in the range M from 5.0 to 8.1 and R from 260 to 470 km; figure 1 shows, for southern Mexico, M and the rupture area of some of these earthquakes.

From this knowledge we can obtain reliable spectra from 0.25 to 6 Hz; in this range we have established regression laws at 65 frequencies that defines the shape of the spectra.

This bayesian regression method is fully presented in CIS (1991) and is an improved alternative over the methods proposed before (Castro *et al.* (1988), Arciniega and Ordaz (1991)).

3 SPECTRAL RATIOS BETWEEN *CU* AND LAKE BED SITES

Singh *et al.* (1988), computed empirical transfer functions or spectral ratios of the Mexico City accelerometric array in order to obtain the empirical amplification of the lake zone sites with respect to CU.

With more data of earthquakes available, a recent study (Reinoso (1991)) has proved that the amplification obtained for any site due to subduction earthquakes, is quite similar for both horizontal compo-

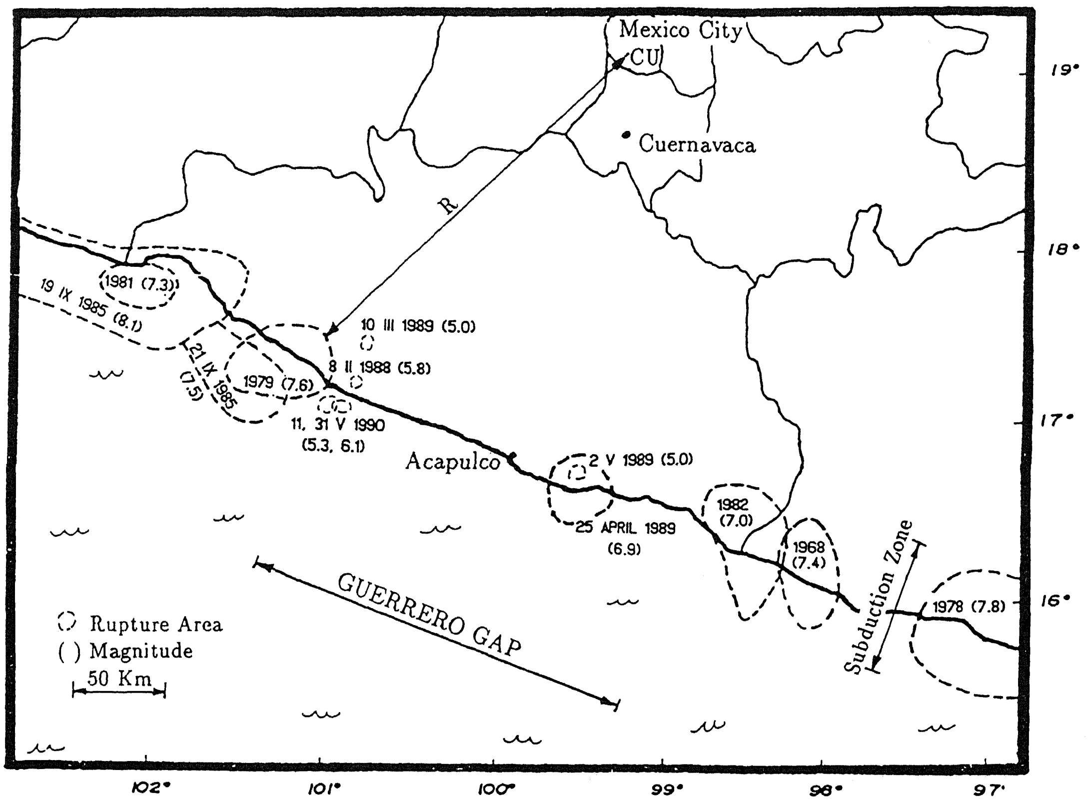

Figure 1 Date, magnitude and rupture area of some earthquakes along the mexican subduction zone

nents and for all earthquakes, including those of 1985 in which one could expect important nonlinear behavior. Therefore, for subduction earthquakes and for any site, the amplification of the clay deposits is apparently always the same, no matter what the earthquake size, distance or azimuth. For most sites these amplifications can be reproduced by the one dimensional theory, however, there are some localized zones where the topographic effects seem to be important (Reinoso (1991)).

For the purpose of the present work, after selecting reliable data, we compute the spectral ratios of all earthquakes and all sites with respect to CU. The ratios obtained, for each component and each site, were the average of all earthquakes. In figure 2 we plot for some representative stations, the spectral ratios of both horizontal components.

4 DOMINANT PERIOD

In sites where spectral ratios are available, we consider the dominant period as the value in which the largest amplification of the ratio occurs. In this way we have obtained more than 90 dominant periods.

In addition, we have considered the results of the microtremor technique (Lermo *et al.* (1988)); here, the dominant period is defined as the period in which the largest amplitude of the velocity spectra of the ambient noise is presented.

Both results were successfully combined (Reinoso and Lermo, (1991)) and are presented in figure 3; this shows a three dimensional plot of the dominant period in the valley considering both results for more than 400 stations. Note that the dominant periods in Mexico City are up to 5.2 seconds.

The need to compute this dominant period from each site is essential for the interpolation of spectral ratios and obtaining the duration of motion.

5 INTERPOLATION OF SPECTRAL RATIOS

In order to obtain a reliable interpolation of spectral ratios, we first normalize the ratios by their own dominant periods and then apply an interpolation algorithm (Pérez-Rocha *et al.*, (1991)). This gives us the shape of the ratio. Next, we multiply this shape by the interpolated dominant period of the corresponding site.

As we can see in the distribution of the stations, there are zones where the lack of spectral ratios does

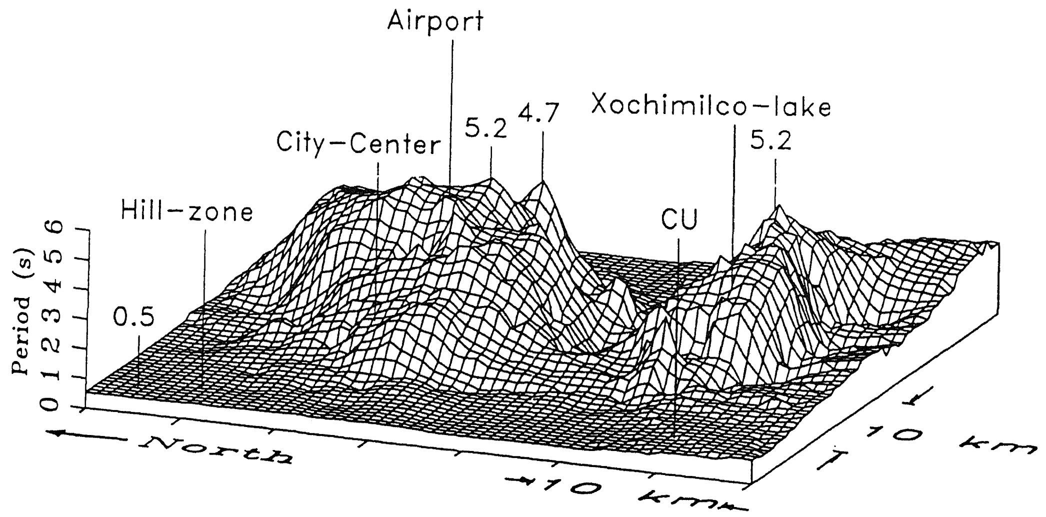

Figure 2 Dominant periods in Mexico City Valley

not allow reliable interpolation of the results. Fortunately, this is not the case in the city center and 1985 damaged zones, where density of stations is high.

6 ELASTIC AND INELASTIC RESPONSE SPECTRA

Multiplying the Fourier amplitude spectra in CU by the interpolated spectral ratio, we obtain the Fourier amplitude spectra at this site. Then, with an estimation of the duration of motion, we apply the random vibration theory (Carthwrith and Longett-Higgins (1956), Boore (1983)) and obtain elastic response spectra for any damping.

Pérez-Rocha and Ordaz (1991) have extended this approach to obtain inelastic response spectra based on the linear equivalent method.

6.1 *Estimation of strong motion duration*

For Mexico City Valley, random vibration theory gives suitable results (Ordaz and Reinoso (1987), Reinoso *et al.* (1990)), provided that we consider the duration of strong motion as the time between 5 and 95% of the Arias' intensity (Arias (1969)).

In this way, we have evaluated all durations of all accelerograms. For instance, in the earthquake of 25th April 1989, these durations for both horizontal components and for all sites are shown (figure 4) plotted against the period of each site. Note that computed strong motion durations vary from 30 seconds, in hill zone sites, to 140 seconds in lake zones (for some accelerograms in lake zones, duration of records are up to five minutes). The dependence of the duration with respect to the period of the site is quite clear. Results for other earthquakes are similar to this.

On the other hand, for a group of sites with the same period, we present in figure 5 the duration computed for several earthquakes. The dependence of duration of magnitude is again clear. Results are similar for all sites.

Therefore, we have formulated a regression with the given magnitude and the distance of the earthquake and the period of the site, that enables us to obtain the expected duration of motion.

7 COMPUTER CODE *CERCMEX* & RESULTS

We have developed a computer code (CERCMEX, Cálculo de espectros de respuesta en la Ciudad de México, CIS (1991)) that can be used in any PC. The input are: magnitude and distance of the earthquake, latitude and longitude of the desired site, fraction of critical damping and ductility .

Because all data base is packed in object files, the whole procedure takes only a few seconds. The sequence of solution is as follows: obtaining the Fourier amplitude spectra in CU, interpolation of dominant period, interpolation of the spectral ratio, estimation of strong motion duration and computation of response spectra.

We present in figure 6 interpolated acceleration response spectra computed with 5% of critical damping and for three values of ductility Q: 1, 2 and 4. The results could also be presented in contour maps of expected acceleration for any period, curves of maximum response, etc.

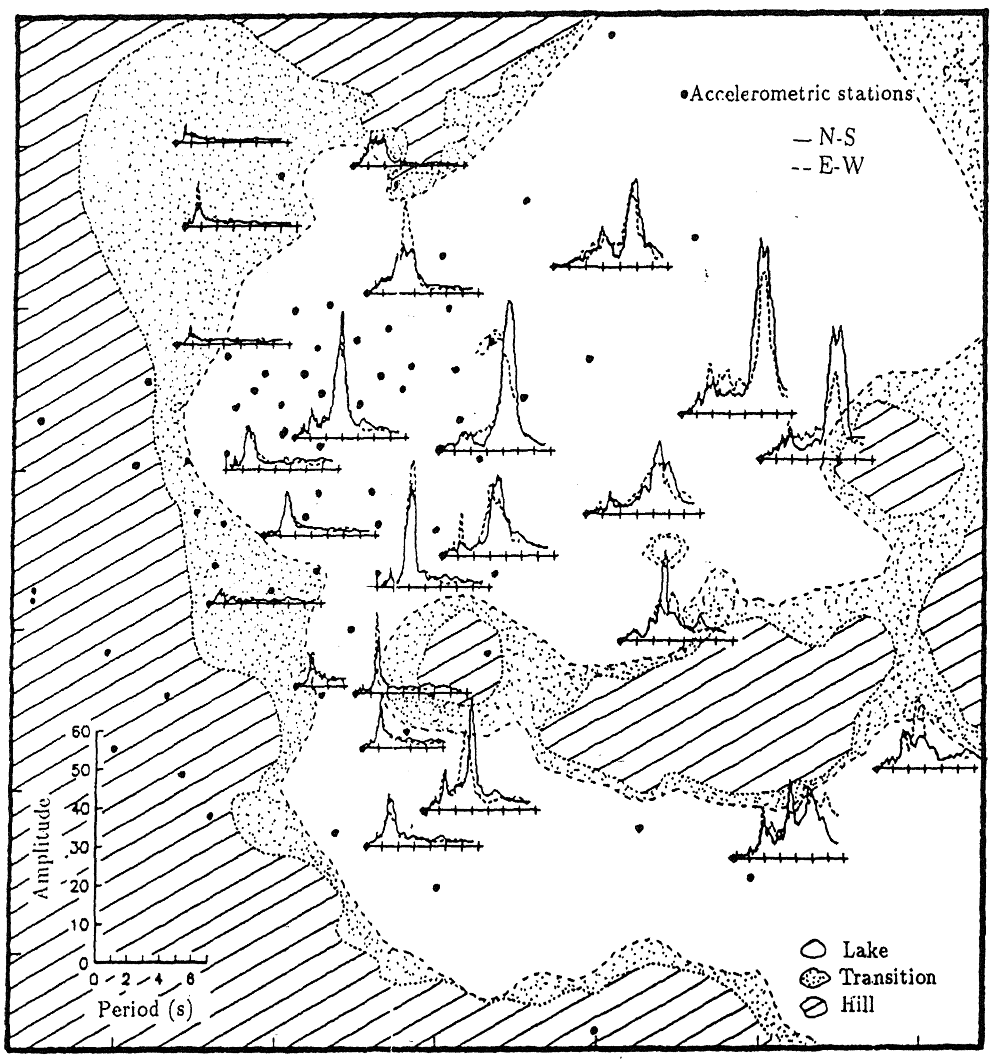

Figure 3 Accelerometric stations and representative spectral ratios in Mexico City Valley

The formulation does not include uncertainties. They are present in: obtaining the amplitude spectra in CU, interpolation of spectral ratios, application of random vibration theory and linear equivalent method. Despite these uncertainties the estimation of the spectral ordinates is reasonable at least for microzonation and vulnerability analyses.

CONCLUSIONS

We had combined different works that have their own weight and a wide range of applications. The whole procedure here presented is to obtain response spectra in Mexico City at almost any desired site. This is applicable to any place for which enough data is available.

The CERCMEX code will be used by the City Ministry as a tool to decide demolitions, retrofit and areas of risk. Researchers of CENAPRED (National Center for Disaster Prevention) are studying the distribution of damage along Mexico City with the CERCMEX output. The program is suitable for calibrations and its use can be extended also to designer engineers and insurance companies.

A research work is in progress at present to quantify uncertainties and to elucidate the limitations of the results. As soon as more data is available, we can extend this approach to other kind of earthquakes, for instance, normal fault, continental and local earthquakes.

This method can also be applied for earthquakes that have already occured and from which we know

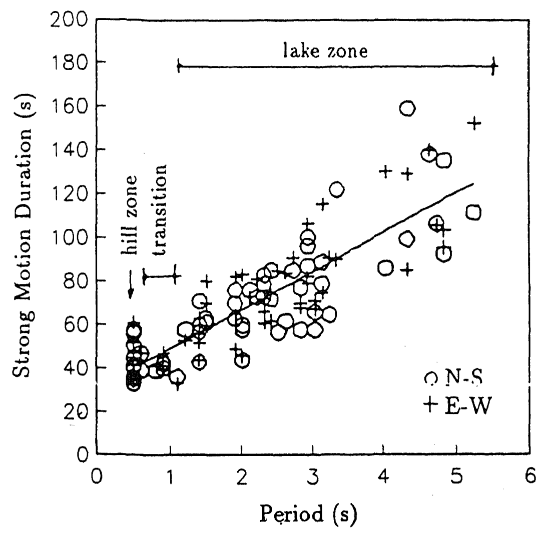

Figure 4 Strong motion duration *vs.* dominant period (earthquake of 25th April 1989)

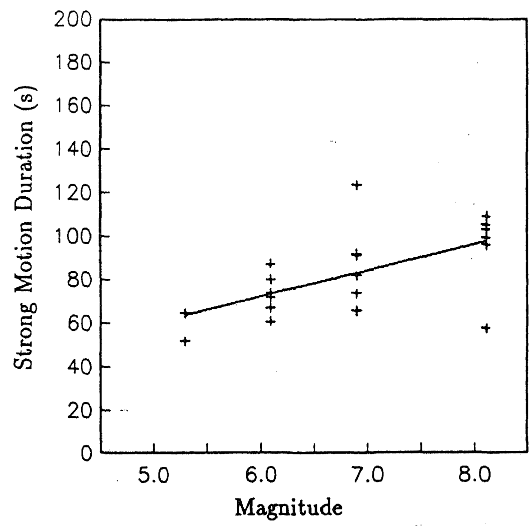

Figure 5 Strong motion duration *vs.* magnitude (for three sites with the same period)

the Fourier amplitude spectra. For instance, Ordaz *et al.* (1988), computed the response spectra that could be presented during the 1985 earthquake in the actual accelerometric stations, using not a postulate earthquake but the amplitude Fourier spectra in CU of the registered accelerogram. Now, this work can be extended to any place and to obtain inelastic spectra.

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REFERENCES

Arciniega, A. & M. Ordaz 1991. Método semiempírico para estimar espectros de amplitud en Ciudad Universitaria. *Soc. Mex. Ing. Sís.* 41:27-46.

Arias, A. 1969. A measure of earthquake intensity. *Seismic Design for Nuclear Plants*, MIT Press.

Boore, D. M. 1983. Stochastic simulation of high-frequency ground motions based on seismological models of the radiated spectra. *Bull. Seism. Soc. Am.* 73: 1865-1894.

Cartwright, D.E. & M. S. Longuett-Higgins 1956. The statistical distribution of the maxima of a random function. *Proc. Royal Soc. London* A237: 212-232.

Castro, R., S. K. Singh & E. Mena 1988. An empirical model to predict Fourier amplitude spectra of horizontal ground motion. *Earthquake Spectra* 4: 675-685.

CIS 1991. Respuesta del Valle de México, aplicaciones y Teoría. *Final research report*, Centro de Investigación Sísmica, Mexico D.F.

Lermo, J., M. Rodríguez & S. K. Singh 1988. Natural period of sites in the Valley of Mexico from microtremor measurements. *Earthquake Spectra* 4: 805-814.

Ordaz, M., E. Reinoso, S. K. Singh, E. Vera & J. M. Jara 1989. Espectros de respuesta en sitios del valle de México ante temblores postulados en la brecha de Guerrero. *Proc. 8th Nat. Conf. of Earthquake Engineering* 1: A187-A198.

Ordaz, M. & E. Reinoso 1987. Uso de la teoría de vibraciones aleatorias para la determinación de espectros de diseño del Reglamento para las Construcciones del D.F. *Proc. 7th Nat. Conf. of Earthquake Engineering* 1: A155-A167.

Ordaz, M., S. K. Singh, E. Reinoso, J. Lermo, J. M. Espinosa & T. Domínguez 1988. Estimation of response spectra in the lake bed zone of the valley of Mexico. *Earthquake Spectra* 4: 815-834.

Pérez-Rocha, L. E., F. J. Sánchez-Sesma & E. Reinoso 1991. Three- dimensional site effects in Mexico City: evidences from accelerometric network observations and theoretical results. *Proc. 4th Int. Conf. of Microzonation* 2: 327-334.

Pérez-Rocha, L. E. & M. Ordaz 1991. Cálculo rápido de espectros de respuesta inelásticos. *Proc. 9th*

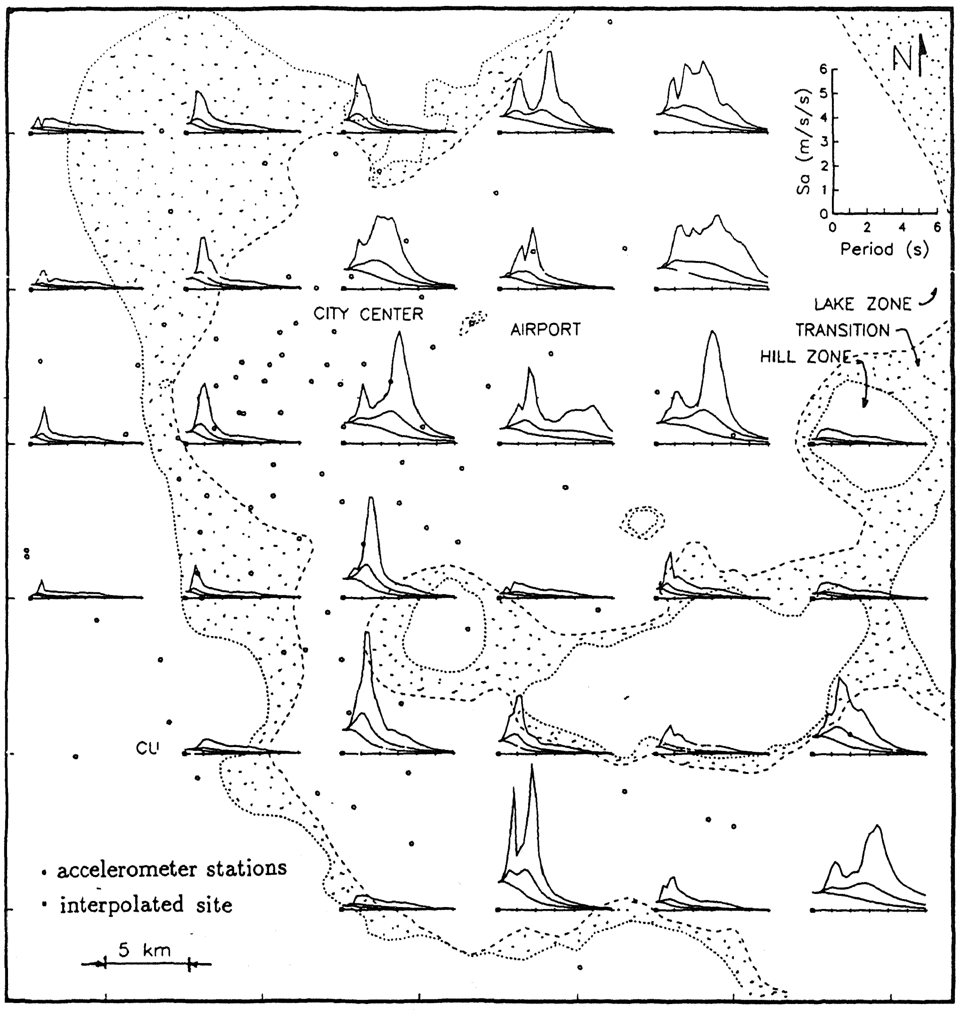

Figure 6 Response spectra in some arbitrary sites given a postulated earthquake (for the N-S component)

Nat. Conf. of Earthquake Engineering 1:87-97.

Reinoso, E., M. Ordaz & F. J. Sánchez-Sesma 1990. A note on the fast computation of response spectra estimates. *Earthquake Engineering and Structural Dynamics* 19-7: 971-976.

Reinoso, E. 1991. Efectos sísmicos locales en el valle de México: amplificación medida en la zona lacustre. *Proc. 9th Nat. Conf. of Earthquake Engineering* 1:63-76.

Reinoso, E. & J. Lermo 1991. Periodos del suelo medidos en el valle de México durante sismos y con vibración ambiental. *Proc. 9th Nat. Conf. of Earthquake Engineering* 1:136-141.

Singh, S. K., J. Lermo, T. Domínguez, M. Ordaz, J. M. Espinosa, E. Mena & R. Quaas 1988. A study of amplification of seismic waves in the Valley of Mexico with respect to a hill zone site. *Earthquake Spectra* 4: 653-673.