Seismic Source Evaluation, Strong Motion Attenuation and Soil Response in Central America

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Abstract

A project of seismological cooperation has been established between seismological and geotechnical institutions in Norway and six Central American countries. The project, which is coordinated through CEPREDENAC and covers the time period 1991 to 1994, has included work concerned with seismic source evaluation, strong-motion data, seismic wave attenuation, soil response effects, regional seismic hazard, and site-specific hazard. This technical cooperation has been promoted through exchange of personnel both ways between Central America and Norway, and the work has been organized under separate research tasks. The present paper provides some of the organizational background, some technical results, and a brief discussion of future plans.

Introduction

Earthquakes are responsible globally for more than half of all casualties from different types of natural disasters, including floods, hurricanes, volcanoes, etc. In fact, the damages from earthquakes increase with time because of urbanization and development, with a three-fold increase only between the 1960's and the 1980's. The Central American countries have, over the years, taken a significant part of these costs.

In an effort to contribute to a mitigation of these problems a project of seismological cooperation, termed 'Reduction of Natural Disasters in Central America, Earthquake Preparedness and Hazard Mitigation', has been set up between Norway and the Central American countries of Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica and Panama. Part 1 of this project is operated by the University of Bergen and is concerned with the establishment and operation of regional and local data centres, while Part 2 is operated by NORSAR (an institution under the Research Council of Norway) in cooperation with the Norwegian Geotechnical Institute. It is this second part of the project, concerned with seismic zonation and earthquake hazard assessment, which is discussed in the present paper.

Counterparts in this cooperation on the Central American side are seismological and geotechnical institutions in six Central American countries. The project, which is supported by NORAD (Oslo) and coordinated through ASDI and KTH (Stockholm) and CEPREDENAC (Guatemala), covers work concerned with seismic source evaluation, strong-motion data, seismic wave attenuation, soil response effects, regional seismic hazard, and site-specific hazard. The cooperation within this project has been promoted in particular through frequent travels and visits both ways between Central America and Norway.

The project is coordinated with a similar but more broadly based project under the auspices of the Pan American Institute for Geography and History (PAIGH), as well as with the Global Seismic Hazard Assessment Program (GSHAP) under the auspices of the International Lithosphere Program (ILP). In the following we report on some of the technical work, results obtained, and future plans within this project.

Seismic source evaluation

A new and extensive catalogue of historical and recent earthquakes in Central America has now been established, including 17000 earthquakes above magnitude 3.5 (Rojas et al., 1993a, 1993b). The work has been based on an extensive collection of seismic bulletins and research papers and reports from all of the Central American countries, and the catalogue includes known damaging historic earthquakes, as well as the more important of the recent data, with both macroseismic and instrumental observations. The data base starts in the beginning of the 16th century and is limited to macroseismic data (reported phenomena and associated damage) until 1902, while for the period since 1962, it contains both macroseismic and instrumental observations. Recent local network solutions are normally included only for events above magnitude 3.5.

About 12000 of the earthquakes in the data base are shown in Figure 1 (left), plotted with symbol size proportional to magnitude. The coverage of the data base in magnitude-time space is shown in Figure 1 (right), where it is seen that the coverage often has been improved step-wise. Of these steps, the most dramatic one is the development in the beginning of the 1960s,when the improved global seismological networks came into operation. It is seen from the figure that there are no earthquakes in the new catalogue above magnitude 8, and that few earthquakes below magnitude 5 are reported before the present century. Figure 2 shows in this respect the earthquake distribution above magnitude 5, before and after 1930. A more detailed assessment of the catalogue (Rojas et al., 1993b) has shown that it is reasonably complete above M_S 7.0 back to around year 1820 and above M_S 5.5 back to around year 1900.

The catalogue information has been used by Rojas et al. (1993a, 1993b) in developing new relations between body wave magnitude m_b and surface wave magnitude M_S, between m_b and local magnitude M_L, and between M_S and M_L. New relations have also been developed between m_b, M_S and M_L and maximum intensity I_{max}, between M_L and felt radius, and between M_L and felt area for intensity levels between III and VIII. An example here is shown in Figure 3, covering intensity levels between IV and VII, based on data from Costa Rica since 1974. Such and similar correlations and relations are potentially important for a further development and improvement of the magnitude assessments for both newer and older earthquakes.

In a separate effort (Redondo et al., 1993), published focal mechanism solutions that have been collected from a large number of sources, including 252 Harvard CMT (Centroid Moment Tensor) solutions between 1977 and 1993, and 154 solutions between 1934 and 1991 as taken from other published sources. These solutions are shown in Figure 4, including also rose diagrams for the inferred stress directions. The consistency in stress direction is striking, with a stability that makes it possible to see a small difference in stress direction between shallow (crustal) and deep (subduction zone) events.

The focal mechanism data base will be supplemented by new solutions as these become available from local seismological network data which now are being collected routinely at the regional centre in Guatemala. Further work here will also include simultaneous inversion of sets of focal mechanism solutions, assuming a common, uniform stress field. Such inversions can provide more stable estimates of the stress tensor and its level of confidence, and will provide a more stable basis for investigating regional differences between modes of faulting and stress regimes.

Building on existing geologic and tectonic information for Central America, the accumulated seismicity data are now being used in an effort to develop regional seismic zonation models (Rojas et al., 1993c).

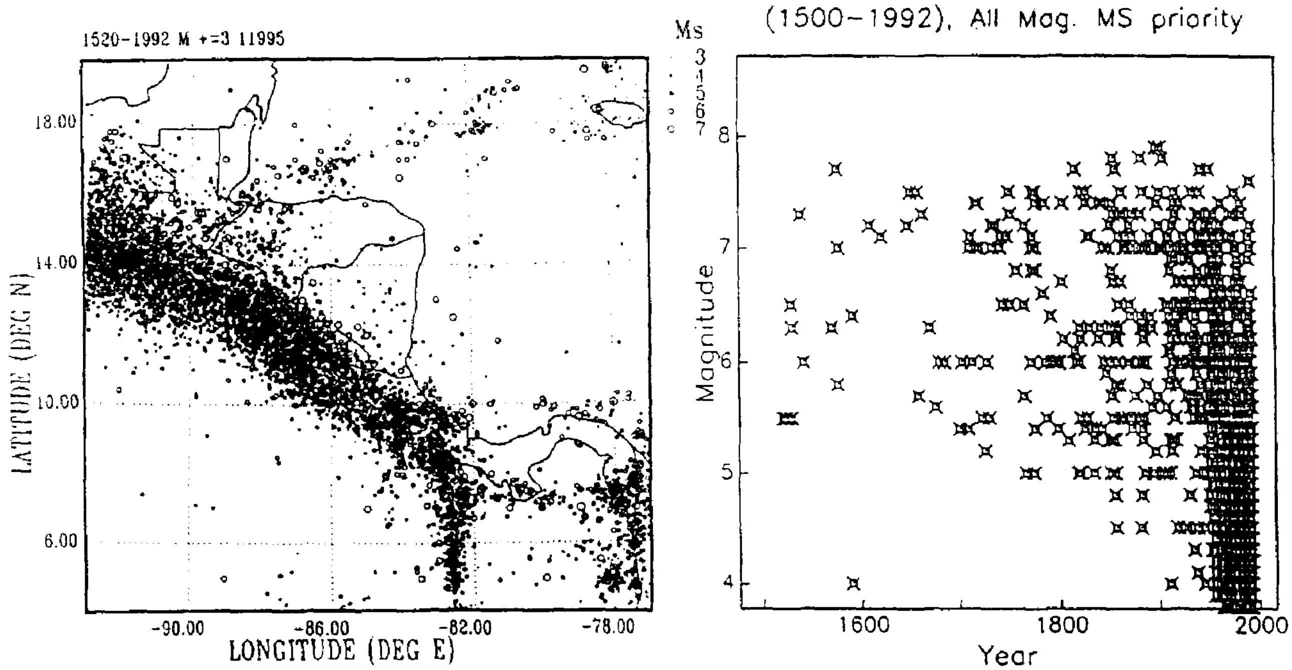

Figure 1: *Left*: Seismicity of Central America, 1520-1992, magnitudes above 3, as taken from the new earthquake catalog of Rojas et al. (1993). *Right*: Distribution of earthquake magnitudes in time for the same data base (from Rojas et al., 1993).

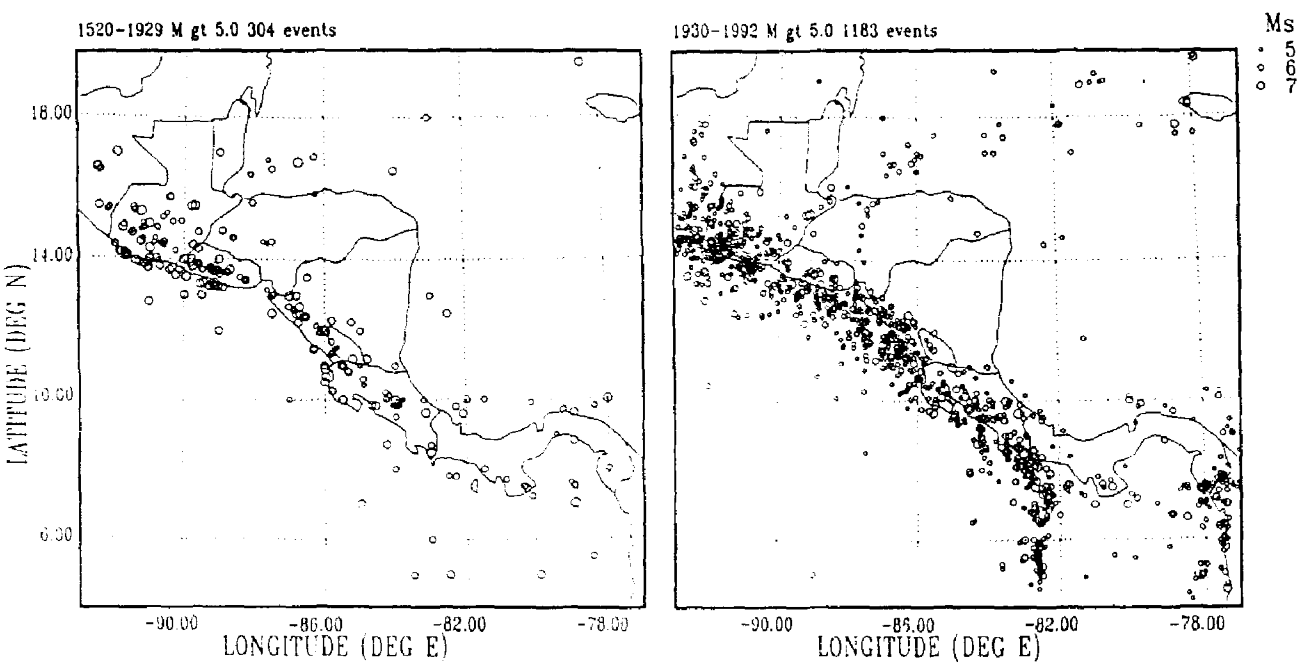

Figure 2: Earthquakes above magnitude 5 in Central America as taken from the same catalog as used in Fig. 1, for the time before (*left*) and after (*right*) 1930. (from Rojas et al., 1993).

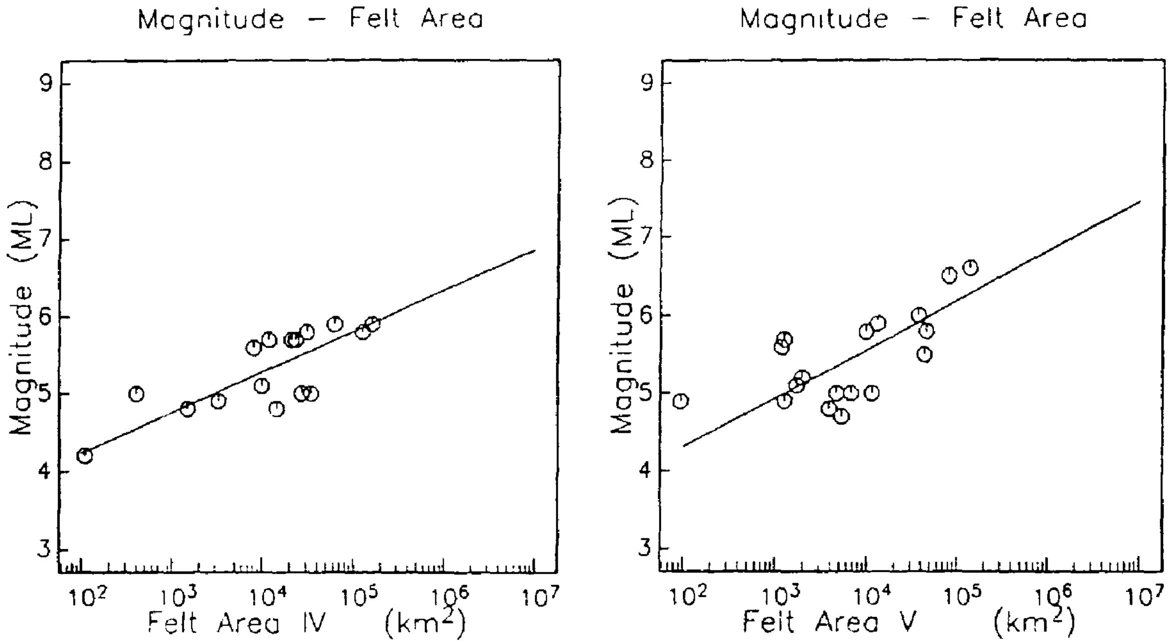

Figure 3: Local magnitudes M_L for Costa Rica earthquakes for the time period since 1974, vs. log felt area for intensity levels IV and V (from Rojas et al., 1993b).

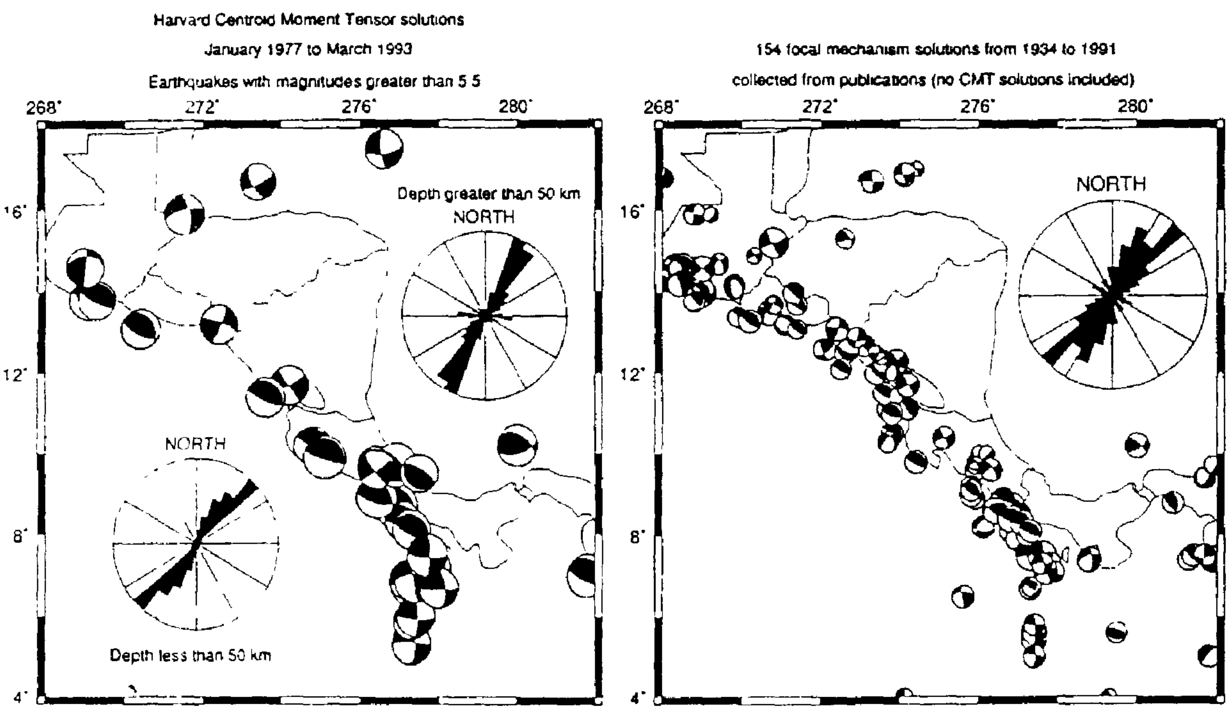

Figure 4: *Left*: 35 Harvard CMT solutions, 1977-1993, for M >5.5, together with P-axis rose diagrams for 110 deep (upper right) and 140 shallow (lower left) CMT solutions; *Right*: 154 focal mechanism solutions, 1934-1991, from other published sources, where the rose diagram now covers all events (Redondo et al , 1993).

Strong motion attenuation

Before 1992, very few digitized accelerograms were available for Central America. This situation is now significantly improved in that more new recording equipment has been installed, in addition to advanced digitizing equipment which is now in operation in several countries (including at NORSAR, to support visitors from Central America). Digital and continually recording accelerometres are now in operation as integral parts of the local seismological networks in the region.

The work within strong-motion seismology has so far mostly been concerned with the collection, collation, digitization and processing of available data (Santos, 1992; Taylor, 1992; Taylor et al., 1992; Matus, 1993a; Climent et al., 1993). The digitization work, which is based on the use of scanner technology, requires high levels of precision, and the cooperation and exchange of experience between different groups has turned out to be particularly fruitful here. It has been found, for example, that a scanner with a resolution of 300 dots per inch (dpi) is sufficient for accelerations only down to about 5% of g, while 600 dpi is needed for weaker signals. Such signals may be important to include in a regression analysis in order to obtain a more stable estimate of the magnitude scaling parameters.

This work has now resulted in the existence of about 700 digitized acceleration records from Central America, mostly from Costa Rica, Nicaragua, and El Salvador. About 400 additional records from Mexico are also available.

Figure 5 shows an example of recorded and digitized strong-motion data, with a record from the M_S 7.6, 22 April 1991 Limon earthquake to the left, and with the response spectrum to the right. Some preliminary wave attenuation models for PGA have also been established, and Figure 6 shows here some of the available wave paths together with observed PGA values. We emphasize that the example shown in Figure 6 includes only some of the data now available, and that further regression and inversion efforts using a larger data base is now in progress (Climent et al., 1993).

The main focus from now on within this field will be on spectral attenuation, which is essential in the context of probabilistic seismic hazard estimation. As the work proceeds, wave attenuation models will be derived for the whole of Central America as well as for smaller areas (individual countries) depending on what the data allow.

Soil response

Experience from past earthquakes shows that the presence of soil or sedimentary rock layers at a given site may drastically change the characteristics of the ground motion during an earthquake relative to the motion in hard rock. The largest damage during earthquakes happens often on soft or loose deposits of clay or sand where the shaking tends to be much stronger than on rock and harder soil. The local soil response is thus an essential element of any site-specific seismic hazard evaluation. The problem has received significant attention in earthquake engineering in the last 20 years. Both empirical relationships based on experience from past earthquakes and analytical models have been developed to provide estimates of the impact of the local soil conditions on the seismic hazard.

The work on soil response has been concerned with providing the Central American organizations with state-of-the-art software for analytical simulations, and verification of the software on the basis of the recorded motions in Central America. The computer programs SHAKE(N) (Selnes, 1987) and AMPLE (Nadim, 1991) have been provided to organizations in Guatemala, El Salvador, Costa Rica and Panama. Both programs model the one-dimensional propagation of shear waves through a horizontally layered soil profile. However, their mathematical formulations differ significantly.

Special soil response studies for sites in Guatemala City (Matus, 1993b), San Salvador (Figueroa, 1993; Atakan and Figueroa, 1993), and Alajuela and Cartago, Costa Rica (Laporte, 1993) were also performed. The aim of the site response studies in El Salvador and Costa Rica was to calibrate and verify the SHAKE(N) and AMPLE models.

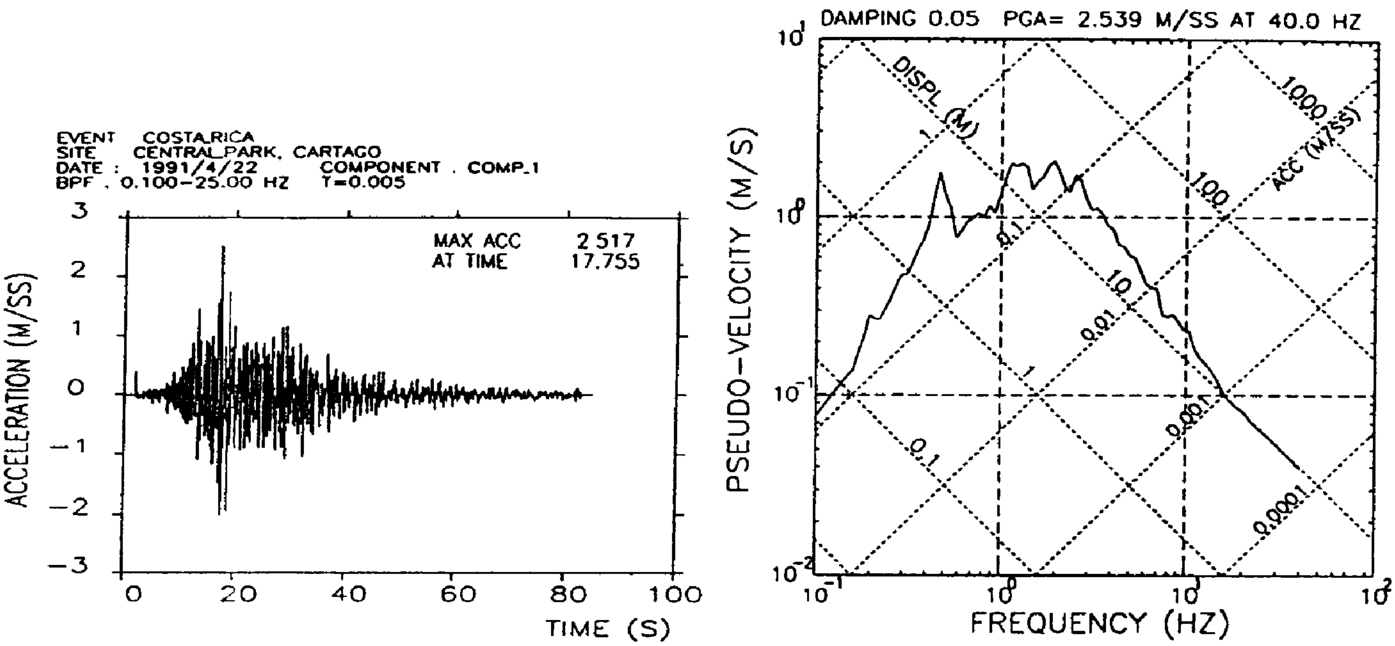

Figure 5: *Left*: Accelerogram from the M_S 7.6, 22 April 1991 Limon earthquake, recorded with a peak ground acceleration of 25% g on soft soils 87 km away in Cartago, Costa Rica. *Right*: Pseudo-velocity response spectrum at 5% damping ratio for the record shown to the left, normalized to 1 g.

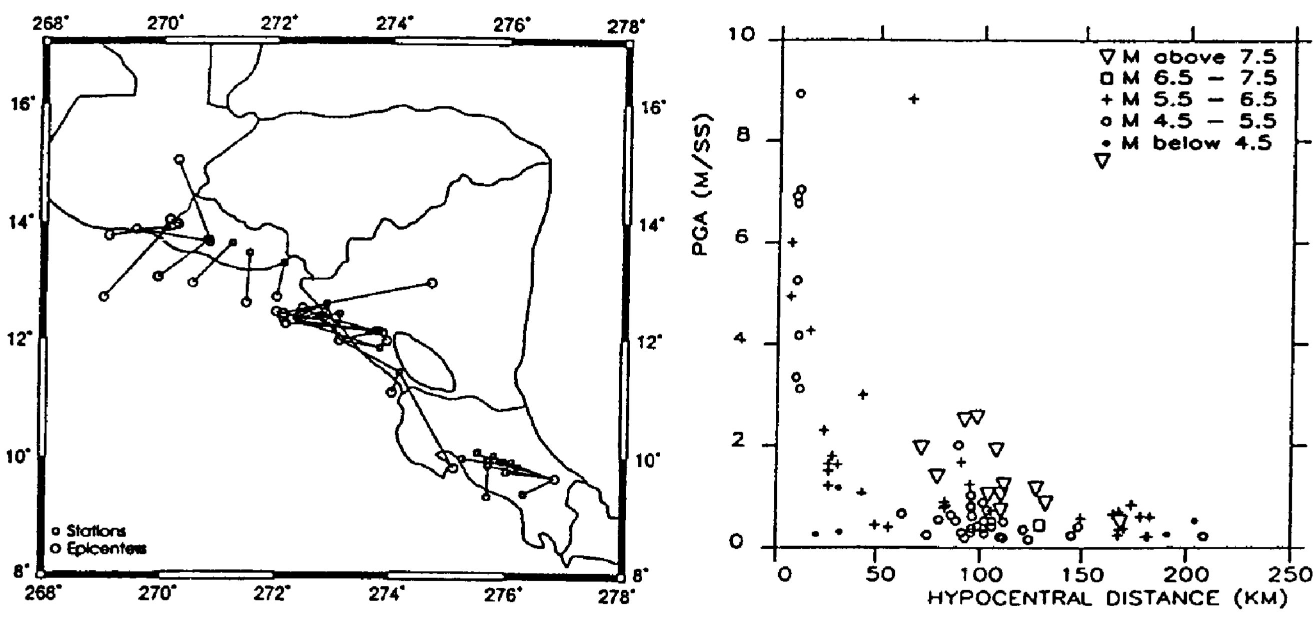

Figure 6: *Left*: Travel paths of earthquakes waves for which PGA readings have been collected under this project (most of these records are digitized). *Right*: PGA values from the data base shown to the left, plotted versus hypocentral distance.

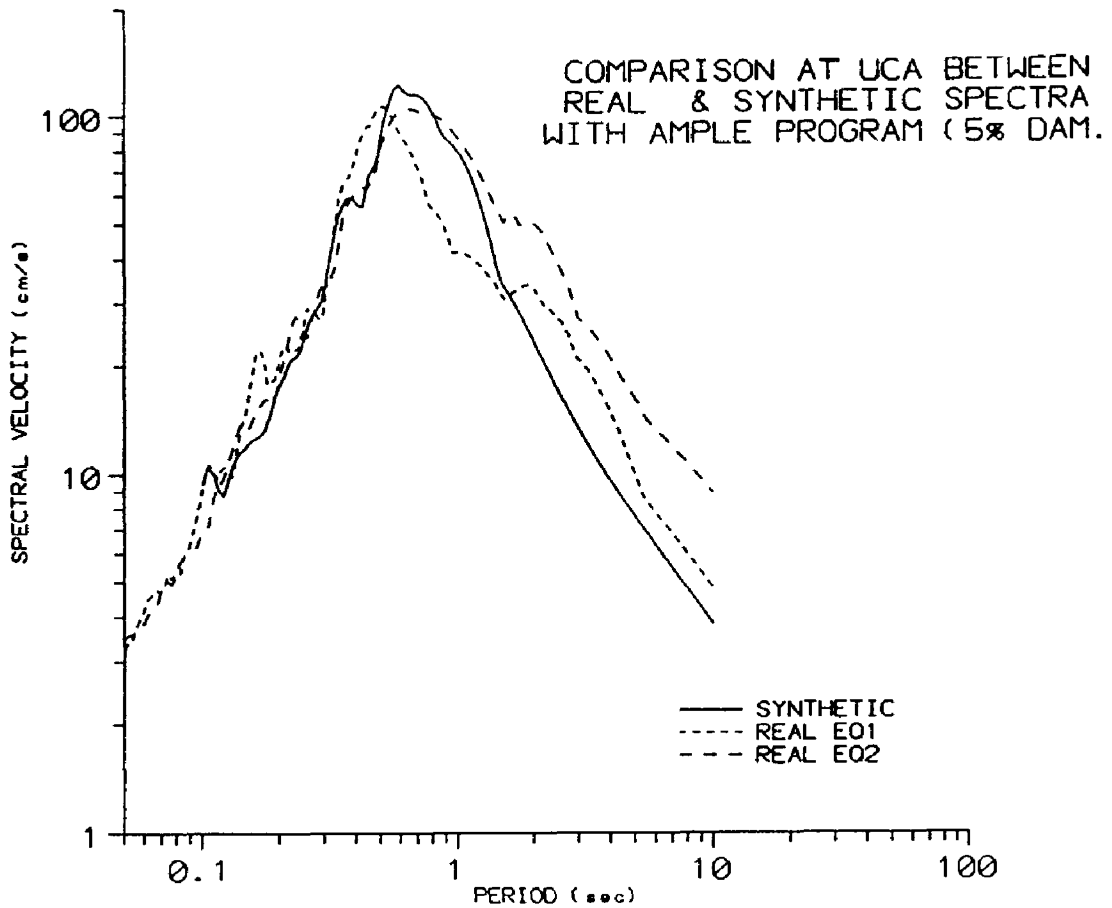

Figure 7: Pseudo-velocity response spectra at 5% damping ratio of the recorded horizontal motion (2 components, dashed lines) at Universidad Centro Americana during the 10 October 1986 San Salvador earthquake, and the simulated motion with AMPLE (solid line) for the same site and event.

The studies showed that, with a reasonable choice of dynamic soil parameters, the simple wave propagation models can explain the peculiarities of the motion at a given site. For example, Figure 7 compares the pseudo-velocity response spectra of the simulated motion with AMPLE and the actual recorded motion at Universidad Centro Americana (UCA), San Salvador, during the 10 October 1986 earthquake (Figueroa, 1993).

The key problem in all the studies was to obtain the correct dynamic soil properties needed for the analysis. Very little work has been done in establishing databases of engineering properties for typical soils encountered in Central America. This aspect will be emphasized more in the next phase of the project.

Seismic hazard

This parallel work discussed above within source zonation, wave attenuation and soil response is now leading up to an eventual regional seismic hazard map for all of Central America. The source model behind this will naturally have to be both simple and quite coarse, and so will be the case for the wave attenuation models.

At a later stage, the regional models should be able to serve as a basis for more detailed site-specific hazard studies. Such studies will require a higher level of details and precision than the regional zonation, including in particular the modelling of potentially active faults and the inclusion of modification factors in the cases when the soil conditions are different from the average conditions behind the attenuation model.

Discussion and conclusions

The answer to the increasing societal costs from earthquakes, even though this increase to a large extent is connected to and resulting from development, is not less development, but more. In the foreseeable future, the answer to the threat from earthquakes will not come from earthquake prediction, but rather from earthquake hazard work, even though these two areas of research strongly complement each other.

When sufficiently reliable regional zonations and local hazard estimates are made available, these will in turn serve as a basis for the development of building codes, land use planning, seismic design criteria, etc. The main limitations here in the long run are not really on the scientific side of the problem, but rather tied to the economic and social development of the region.

The present project is aimed at contributing on the technical side to what is needed for a further mitigation of earthquake hazards in Central America. A very essential condition for success in this respect is the active participation of personnel from the region, for many very obvious reasons. Another important factor is cooperation, where the main point in the present project is not the cooperation between Central America and Norway but rather between the individual countries and between institutions in each country.

Another project phase for the years 1995-2000 is now being discussed.

Acknowledgements

The author thanks K. Atakan, A. Climent, A. Dahle, J.C. Figueroa, M. Laporte, C. Lindholm, M. Matus, F. Nadim, C. Redondo, W. Rojas, P. Santos, J.B. Shepherd, S.K. Singh, J. Tanner and W. Taylor for important contributions to this paper (where the author only acts as rapporteur). The successful execution of this project, which is financed by the Norwegian Agency for Development Cooperation (NORAD), would not have been possible without the active and enthusiastic support and cooperation from a large number of people in Central America, these people are too many to be named here.

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Study of the México City Seismic Data Set: Semiempirical Approach and Deterministic Spectral Analysis

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Abstract

The recently installed accelerometer network of Mexico City has allowed us to record extensively seismic ground motion from coastal events. The large spatial variability of amplitudes, the long duration of recorded seismograms and their peculiar polarization cannot be explained in terms of a one-dimensional shear model alone. Two- and three-dimensional shear model effects must be invoked in order to account for the observations. The study of horizontal motion strongly suggests that the enhanced response at certain locations is produced by locally generated surface waves as a three-dimensional effect. In this work, we analyze instrumental observations of ground motion recorded in Mexico City since the September 19, 1985, Michoacan Earthquake, in order to yield a semiempirical method to compute response spectra at any site in the city. This method uses empirical spectral ratios to account for site effects and a two-dimensional interpolation technique to infer them at any location. A Bayesian regression model is applied to estimate the input Fourier spectrum in terms of the magnitude and the epicentral distance of a postulated earthquake. On the other hand, the study of vertical motion in Mexico City for the April 25, 1989, Guerrero earthquake leads to identification of a prominent long period Rayleigh wave at almost all the stations. This fact and the availability of absolute time for some stations allowed us to establish a common reference time and to perform a space-time analysis. We present a method to separate the Love (SH) and Rayleigh (P-SV) wave components in a sedimentary setting based on the frequency-wavenumber spectra, which works as a filter that accouns for kinematic properties of the wave field. This technique is applied to the April 25, 1989, Guerrero earthquake data and permits the depiction of dispersion in the data set and local generation of surface waves.

Estimation of Response Spectra from Response Spectral Ratios

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Abstract

At many sites on soft ground, spectral ratios for distant earthquakes are just slightly sensitive to focal mechanism, location and magnitude. This makes such spectral ratios useful for estimating smoothed Fourier amplitude spectra at a number of stations if that at one station, usually on firm ground, is known or has been estimated from semiempirical attenuation formulae. From the Fourier amplitude spectra and the estimated duration of the motion at each site, use of random vibration theory leads to expected response spectral ordinates as functions of damping ratio and natural period, although this step can be obviated by working directly with empirical response ratios. Such ratios are as stable as those of Fourier amplitude spectral ratios. The aim of this study is to estimate response spectra through the use of empirical response ratios at different sites of the Valley of México and compare them with the observed response spectra.