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SEISMIC RISK ANALYSIS MODEL FOR MEXICO CITY USING SPECTRAL ACCELERATIONS

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ABSTRACT

This paper describes the development of a software system for modeling seismic risk in Mexico. The focus is on the special conditions in and around Mexico City that dramatically increase potential social and economic losses as evidenced by the 1985 Michoacan Earthquake. Observed losses varied widely within a few hundred meters' resolution and depended upon the location of the building within the city, depth and composition of underlying soils, as well as the height and type of building. The use of spectral accelerations in conjunction with an extensive calibration effort enable the system to model these losses at a high level of resolution and accuracy. Detailed models of the seismic hazard, building inventory, and vulnerability are combined in a risk management tool that enables insurance and reinsurance companies to better assess financial risk, as well as provide valuable emergency response and urban planning information to government agencies.

KEYWORDS

Risk management, seismic hazard, vulnerability, spectral accelerations, Mexico, insurance and reinsurance.

INTRODUCTION

The Mexico Michoacan Earthquake of September 19, 1985 (M_s=8.1), followed only a day later by its doublet earthquake of magnitude 7.5 (Hong & Rosenblueth, 1988), caused utter destruction to Mexico City. Though located a distant 360 km from the epicenter, the human death toll was 10,000, with 50,000 injured and 250,000 homeless. The economic loss mounted to $US 4 billion (1985 dollars) of which $US 275 million was insured. A total of 770 buildings collapsed, 1665 were severely damaged and 5,000 were slightly damaged (Munich Re, 1986).

Mexico City, which grew from 3 million people to perhaps the world's most populated city (~ 20 million) in less than three decades, is an example of increased risk due to urbanization. Risk, which is the convolution of exposure, hazard and vulnerability, sharply increased as the human and built exposure to seismic hazards out paced the improvements in structural performance.

Many factors contributed to the catastrophic losses in Mexico City: (1) an abnormally high energy content in the long period range, (2) the extremely soft soil conditions from the old lake bed underlying the city, (3) the exceptional long duration of ground shaking, (4) the path and directivity effects, (5) the overloading of buildings due to change of occupancy, (6) pounding between adjacent buildings, and (7) structural defects.

The Guerrero Gap along the coastal shallow subduction zone, which has been seismically quiescent since 1916 and is much closer to Mexico City (280 km), is expected to generate an even bigger earthquake of M_s=8.2±0.2. Governmental agencies and the insurance industry know very well that this is the worst case scenario they should be planning for when, not if, it happens.

Following is an outline of the development procedure used in the creation of the Mexico City component of IRAS, the Insurance/Investment Risk Assessment System developed by Risk Management Solutions, Inc. Although IRAS models seismic, wind, fire and flood perils in many other countries of the world, the earthquake model for Mexico and Mexico City in particular presents unique challenges. The focus of this paper is on the seismic risk and vulnerability of Mexico City caused by earthquakes along the shallow subduction faults on the south western coast of Mexico, which by far outweighs the risk of all other sources including the less common shallow crustal intraplate earthquakes that may occur further inland and closer to the city. It was imperative to do detailed model calibration at a very high resolution within Mexico City due to the extensive published data on the subject.

IRAS is composed of four modules that work within a geographical information system (GIS): (1) geocoding, (2) hazard, (3) vulnerability, and (4) financial modules. It enables users to model their exposure portfolio for deterministic and probabilistic analyses. These analyses help make important decisions with respect to risk management. Deterministic analyses include running what-if scenarios for historical and maximum credible earthquakes. The probabilistic analyses generate Exceeding Probability (EP) curves, Average Annual Loss (AAL) and Probable Loss Over Time (PLOT). Slicing the EP curve gives the insurance/reinsurance company their dollar losses with different return periods for their particular line of business, financial structure and exposure. AAL is used for insurance pricing as a pure premium. PLOT gives the insurance industry a financial perspective for a longer period of time.

The geocoding module locates the longitude/latitude coordinates of a site using different levels of address or location information (i.e. postal code within Mexico City and municipio in other regions). The hazard module attenuates Peak Ground Accelerations on bedrock (PGA_{rock}) from the earthquake source to the site. It also retrieves any location specific data on soil type, landslide and liquefaction potential. The seismic hazard for the entire country of Mexico is discussed in detail in another paper published in these proceedings (Wang et al, 1996). The paper delineates 220 line and area sources in Mexico that model (1) the subduction zone along the boundaries of the Cocos and Rivera plates dipping under the North American plate, (2) the spreading ridge system that bisects the Gulf of California, and (3) the southern continuation of the San Andreas fault system from southern California into the north western part of Mexico.

The PGA_{rock} is converted to spectral acceleration (S_a) by means of the Dynamic Amplification Spectra (DAS) associated with that particular site. The S_a is used as the primary hazard index and is passed directly to the vulnerability module. The vulnerability module relates the hazard index to a mean damage ratio (MDR) uniquely for each combination of building type and height range. The financial module applies the insurance policy and/or reinsurance treaty structure (i.e. deductible, limit, pro rata share, etc.) to the insured value in order to assess the financial exposure from any perspective.

Fig. 1 shows the boundaries of the Federal District and the State of Mexico. Most of Mexico City lies in the Federal District with only a small portion in the State of Mexico. The shades of gray (from dark to light gray) mark different soil types: bedrock, transition zone and lake bed. The boundaries between the latter two are fuzzy since the transition zone is essentially shallow lake bed. The two white zones within lake bed are where most of the damage from the 1985 earthquake occurred. CRESTA zones known to the insurance industry are also marked on the map.

DEVELOPMENT PROCEDURE

In order for the model to work within the framework of IRAS and to take advantage of the sophisticated features discussed above, a different approach was pursued compared to CENAPRED's model (Ordaz et al, 1994 and Reinoso et al, 1992). Instead of attenuating the fourier spectra to a reference station (CU station), calculating site specific fourier spectra using transfer functions, and then converting the derived fourier spectra to response spectra; the Dynamic Amplification Spectral (DAS) method was used. For any given location in and around Mexico City, a DAS was developed to represent the soil characteristics, topography and geographic location of that site. The DAS was assumed to be independent of earthquake magnitude, an assumption sufficiently accurate for large magnitude earthquakes, which represent the main threat to Mexico City.

Fig. 2(a) shows typical response spectra recorded on bedrock, shallow and deep lake deposits. *Sapeak* is the peak value of the response spectra, and *Tpeak* is the period at that peak. *Tpeak* is highly correlated and almost synonymous to the predominant soil periods, Ts, shown in Fig. 3b. A clear pattern is evident in Fig. 2(b) when all available response spectra, recorded on transition or lake bed soils, are normalized with respect to *Sapeak* and *Tpeak* along both axes. By fitting a smooth envelope to the data, the problem is reduced to 2 degrees of freedom; namely, *Tpeak* and *Sapeak* , i.e., knowing those two parameters for sites located on lake bed and transition zone, the whole response spectrum is defined. For bedrock locations, a smoothed curve of the response spectrum recorded at the CU station is assumed to represent all sites on bedrock.

Fig. 3(a) shows contour plots of *Sapeak* generated by surface interpolation of peak spectral accelerations at the recording stations for the Michoacan Earthquake. Even though some of these stations where not in place during the 1985 earthquake, estimated response spectra where used from Ordaz et al (1988). Fig. 3(b) shows the contours of predominant soil periods, Ts, (Ordaz et al, 1994). For any given location, by knowing *Sapeak* and *Tpeak* , the smoothed response spectra is reconstructed for the Michoacan Earthquake. To make the spectral accelerations earthquake independent, S_a is further normalized by the attenuated PGA_{rock} (Crouse, 1991) at the given location to yield the Dynamic Amplification Spectra discussed before. DAS were calculated and stored as a lookup table in IRAS for all the postal codes in Mexico City (1612 postal codes), all 16 municipios of the Federal District and 26 municipios in the State of Mexico where there are soft soils.

MODEL CALIBRATION

Loss data, whether actual losses for the Michoacan or estimated for the hypothetical Guerrero Earthquakes, were obtained from Ordaz (1995-96) for the purposes of calibration. Mean damage ratios were given at each of the 751 grid cells (city blocks) for several combinations of building type and height range. Spectral accelerations at the period corresponding to the building height of interest were calculated at each grid cell and associated with the MDR. These are the points shown in Figs. 4 (a) and (b) for two building types. Damage curves were fitted to the loss data using least square regression to match the aggregate loss per building and height range.

After assembling the IRAS modules, extensive calibration was carried out using results published in Ordaz et al (1993 a and b), Esteva et al (1988), Ordaz et al (1992) and Smolka (1989). The results in the first three reports were presented for different building types and the fourth was per line of business. Deterministic results were calibrated for the Michoacan and hypothetical Guerrero Earthquakes. Probabilistic results in the form of Probable Loss Over Time (PLOT) and Average Annual Loss (AAL) were also compared. Sample results of the IRAS deterministic analyses performed for the Guerrero event are presented for two common building types in Table 1. The results match pretty well.

EXPECTED GUERRERO LOSS RATIOS %		CRESTA Zones					
Building Type		**I (E)**	**II (F)**	**IIIa (G)**	**IIIb (H1)**	**IIIc (H2)**	**All**
Confined Masonry (1 story)[#]	IRAS	0.59	2.26	3.56	2.00	2.61	1.79
	Ordaz, 1993*	0.61	1.55	2.87	2.63	1.94	1.73
RC MRF with Infill Walls (7 story)	IRAS	4.46	8.96	24.45	17.75	12.81	12.59
	Ordaz, 1993*	3.12	3.68	29.35	21.45	12.73	12.75

* Loss ratios derived from an electronic database developed by Ordaz et al (1993 a and b). Data aggregated by CRESTA Zone from the 751 blocks in the Federal District for each building type.

[#] Refer to Meli (1994) for a discussion on performance of confined masonry structures.

RESULTS

In order to estimate losses by line of business (as opposed to a specific building type), an inventory of building stock obtained from personal communications with Esteva (1995-96) and Ordaz (1995-96) was utilized. The inventory is used as a weighting function to compute composite damage functions from the damage curves per building type and height range. The same inventory is used to geographically distribute an estimated building exposure in the Federal District at the 751 grid cell level. While IRAS has the ability to analyze locations at these high levels of resolution, results are presented here on an aggregate municipio basis. Sample results of several analyses are presented in Figures 5 and 6.

Fig. 5 shows the deterministic losses for a mid-rise commercial line of business due to the hypothetical Guerrero Earthquake. Part (a) of the figure shows the MDR and (b) shows the relative concentration of losses. The data for both figures are calculated at the grid cell level and aggregated at the municipio level. Fig. 5(b) gives a better sense of relative risk concentration by convoluting hazard, vulnerability and total exposure all together, whereas Fig. 5(a) gives relative damage ratios. Given a million dollar loss in the Federal District, Fig. 5(b) tells us what percentage is on average expected to be in each municipio for that particular line of business and height range.

Figs. 6 (a) and (b) show the AAL for low-rise single family residential and mid-rise commercial portfolios for each municipio in the Federal District. AAL is used by the insurance and reinsurance companies in setting the pure premium by line of business. It is a convolution of losses from all possible faults that can cause any damage and the probabilities associated with these losses averaged over a one year period.

CONCLUDING REMARKS

The paper outlines the development of a seismic risk analysis model for Mexico City using spectral accelerations within the framework of the IRAS software package for risk management. Deterministic as well as probabilistic results were discussed to help insurance and reinsurance companies to better assess financial risk, as well as provide valuable emergency response and urban planning information to government agencies.

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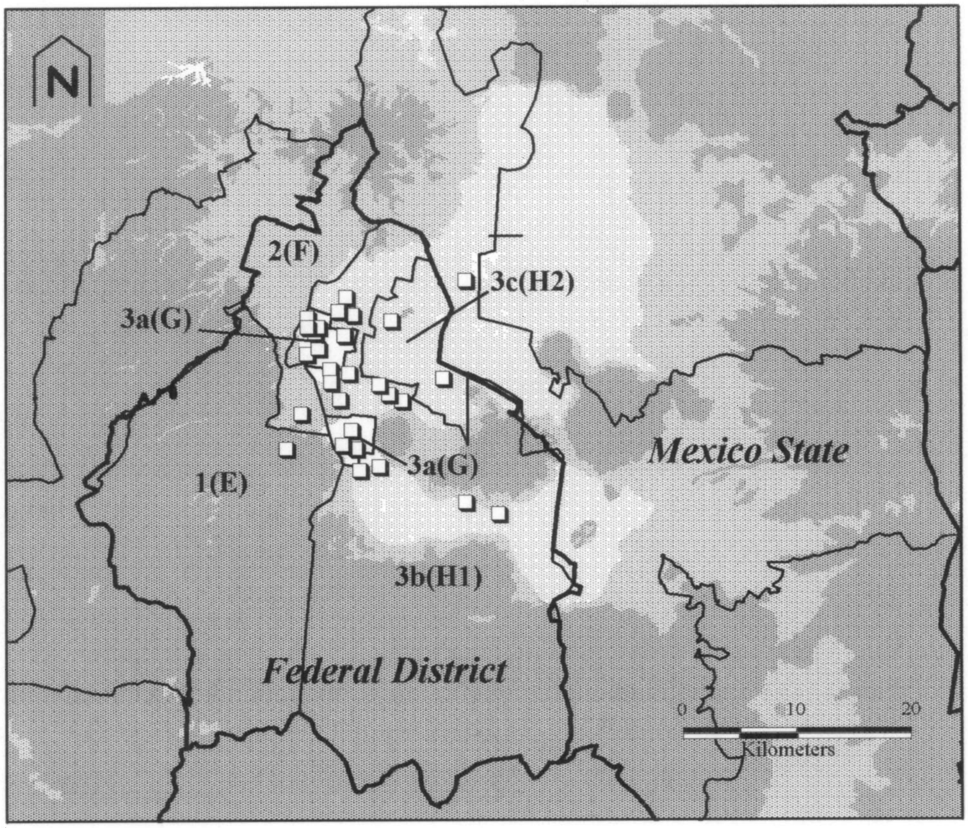


Fig. 1. Map of Federal District, part of Mexico State, CRESTA zones, soil boundaries (darkest = bedrock, lighter = lake deposits) and recording stations.

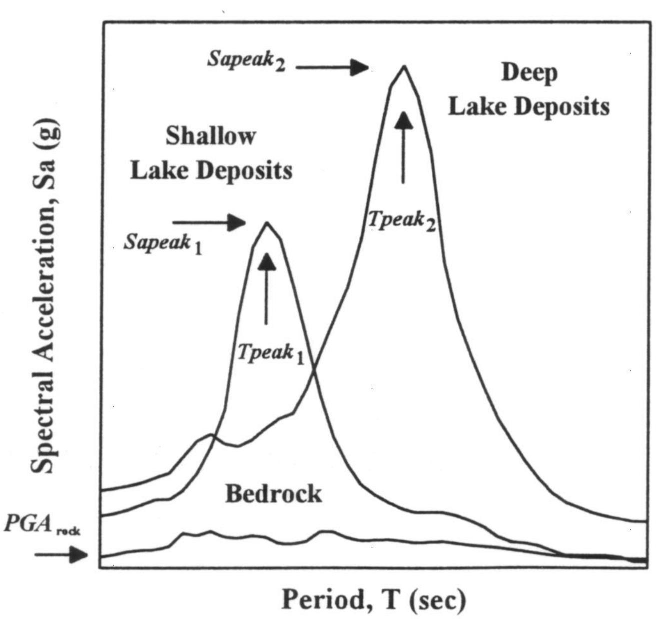


Fig. 2a. Typical Response Spectra for different soil types.

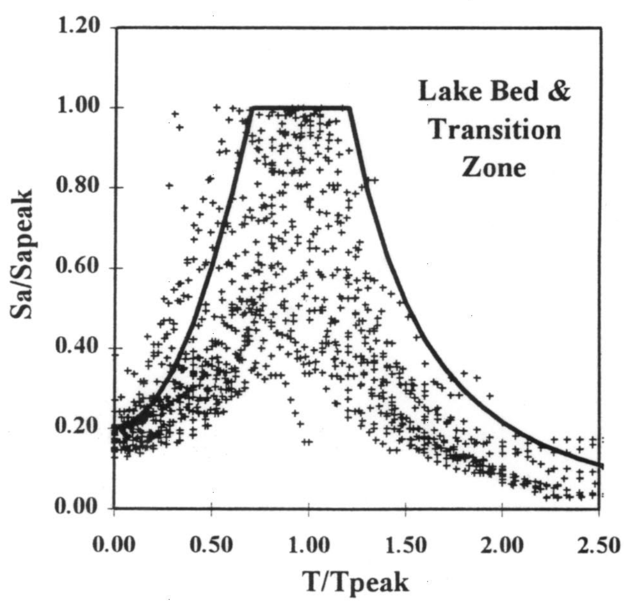


Fig. 2b. Normalized Response Spectra for Lake Bed and Transition Zone.

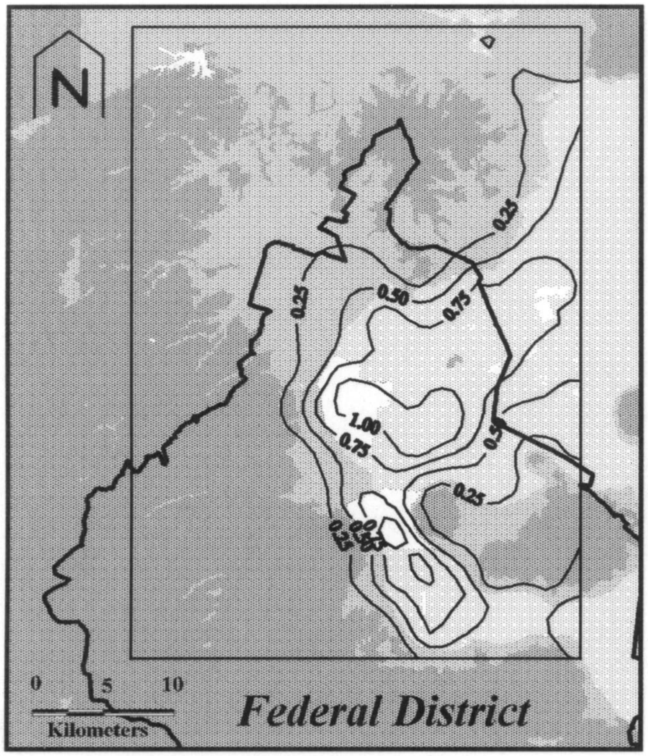


Fig. 3a. Contours of Sapeak (g).

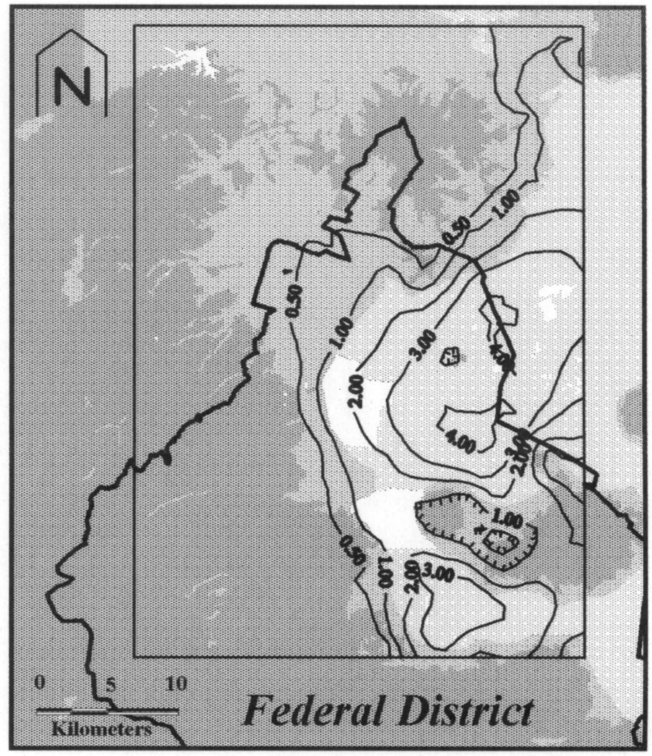
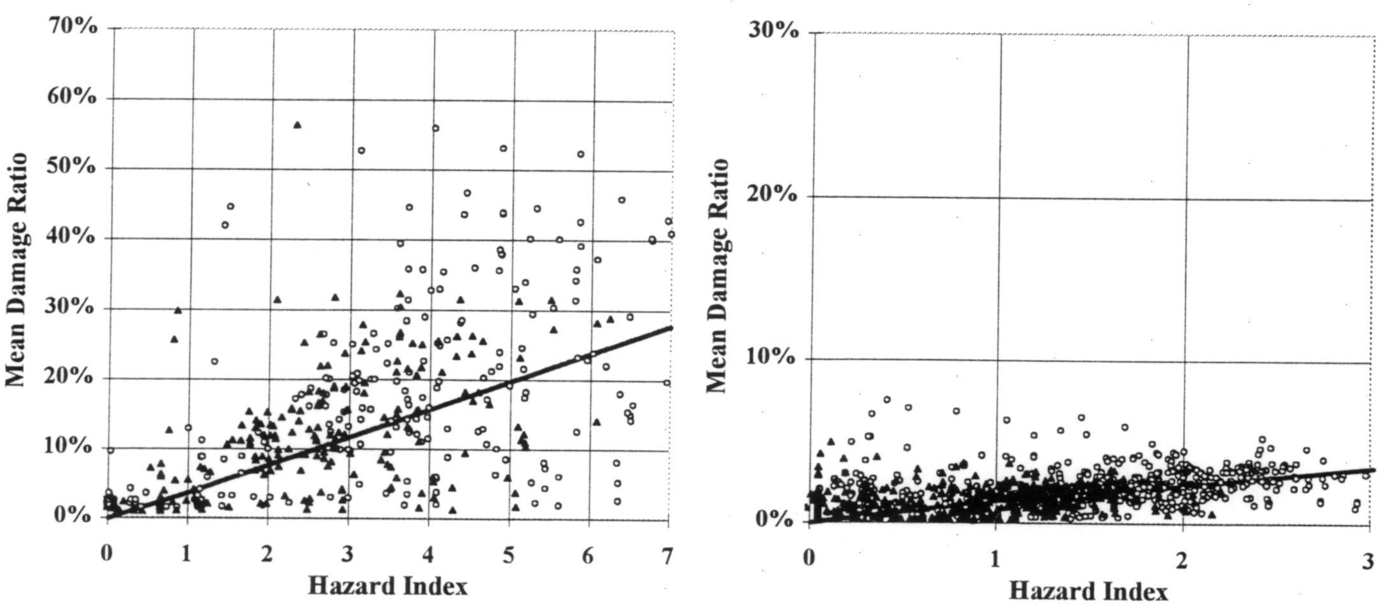


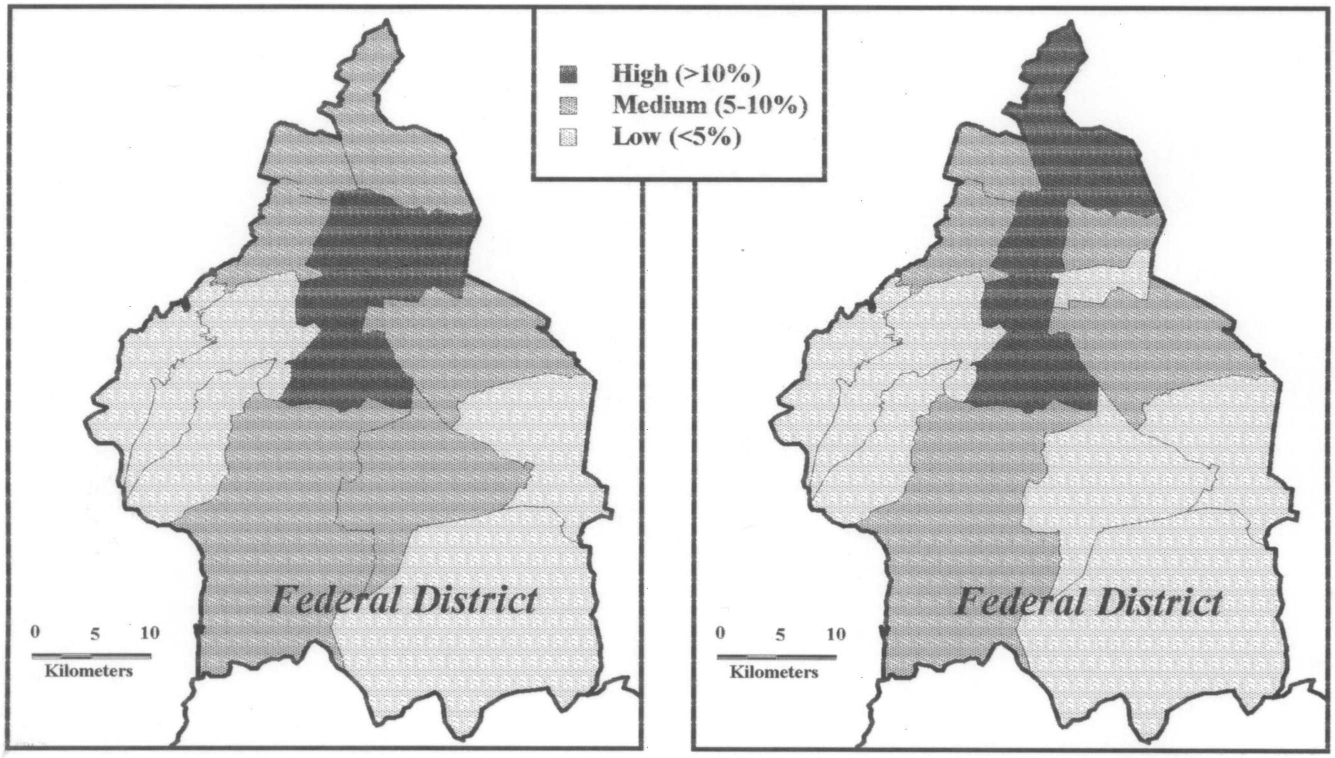
Fig. 3b Contours of Ts (sec) ≅ Tpeak (sec)



(a) Mid-Rise (7-story)
RC MRF with Infill walls.

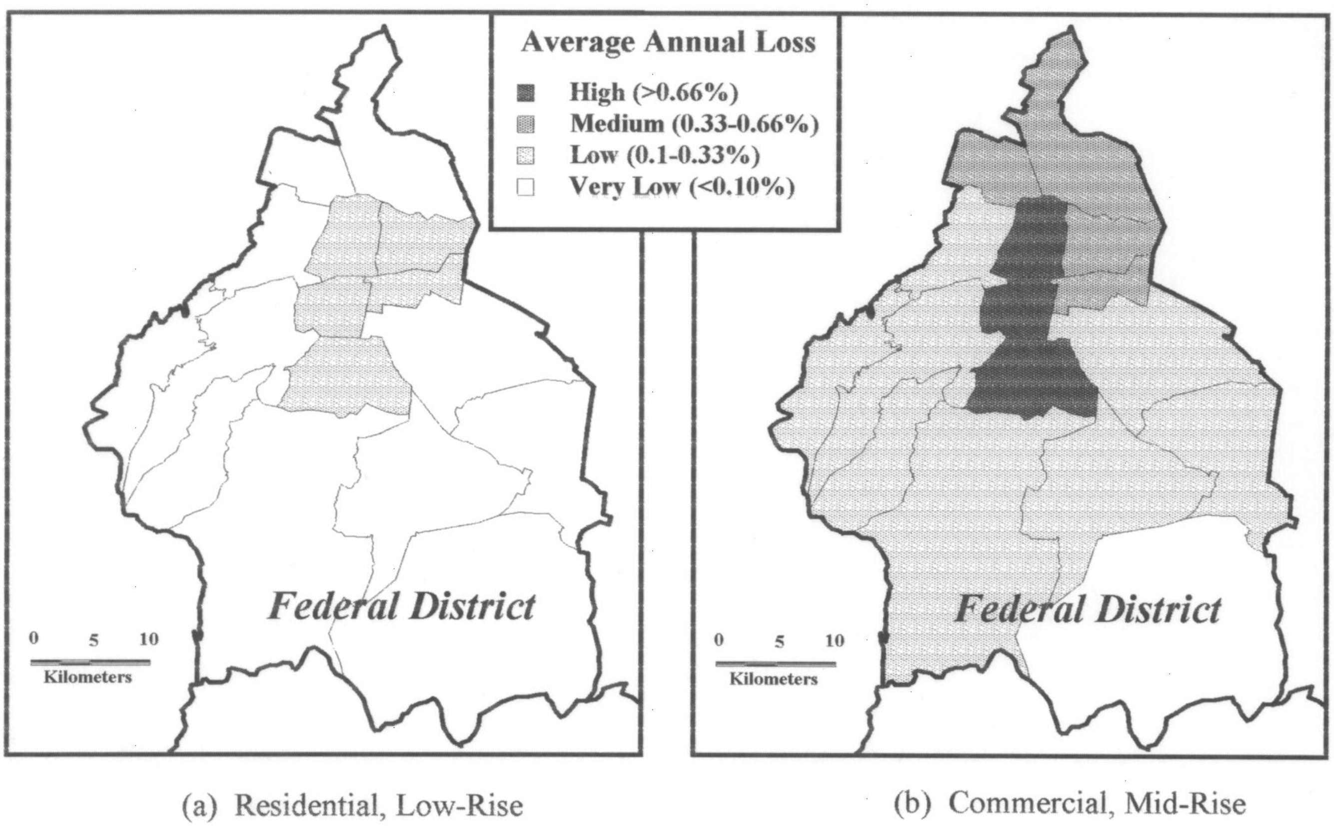
(b) Low-Rise (1 story)
Confined Masonry.

Fig. 4. Damage curves and loss data for Michoacan (triangles) and Guerrero Gap (circles) events.



(a) Mean Damage Ratio (b) Loss Concentraion

Fig. 5. Losses from the hypothetical Guerrero earthquake
to a Mid-Rise Commercial line of business



(a) Residential, Low-Rise (b) Commercial, Mid-Rise

Fig. 6. Average Annual Loss by line of business.