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SEISMIC RISK ANALYSIS OF MORELIA

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ABSTRACT

The first part of the seismic risk analysis of the city of Morelia is presented; due to lack of instrumental records and geodynamical information for the area, alternative techniques were used in order to develop a rational approach that could be useful for many cities under similar conditions. Information on the geological and topographical conditions of the region were compiled, in addition to available information on soil mechanics. Measurements of the soil's fundamental period were recorded, using a short period field seismometer as a sensor for Enviromental vibration. An isoperiod contour map of Morelia was proposed based on: vibration measurements and analytical periods obtained from deep bore holes applying the unidimensional shear wave propagation theory. Based on historical data, seismic sources were identified and the maximum credible earthquake is reasonably expected for each source was selected. A preliminary design spectra derived from historical seismicity was estimated.

KEYWORDS

Seismic risk; soil's period; enviromental vibration; isoperiod map; seismic sources; seismic zonation.

INTRODUCTION

Morelia, capital of the state of Michoacán, is enclosed in the highest seismic area of México. In this century eight earthquakes with magnitudes $M_L > 7.0$, whose epicenters were located on the Michoacán coast have been reported. In the light of this activity, it is important to carry out focused studies to determine the dynamic characteristics of the soil and to estimate the seismic risk in the principal cities of the state. The current code for the city of Morelia, proposes design spectra for three different types of soil, that are classified according to the depth of the base rock and to the shear waves. In almost all the cases, there is not enough soil mechanics information to estimate these parameters; moreover, the acceleration coefficients of the design spectra are the result of a proposal based on a seismic macrozonation of the Mexican Republic, accomplished more than twenty years ago, that does not take into consideration the particular conditions of the city of Morelia.

REGIONAL GEOLOGY

The city of Morelia is located in the ancient valley of Guayangareo, limited by the Santiaguito hills to the north, the hills of Santa María to the south, the Punhuato hill to the east and is extending to the westward to town of Tzindurio. The Grande river and the Chiquito river are the two principal streams that cross the urban zone. The first belongs to the Lerma river basin, and runs southwest-northeast, while the Chiquito river descends from the knolls south of the city, and runs towards the northwest and joine the Grande river at the west. The course of both rivers was rectified some decades ago.

Stratigraphy

According to Mier *et al.* (1972), the geological history of the region began with an emission of volcanic rocks during the Pliocene. In the Pleistocene the volcanic activity continued forming basalts and tufas that were sedimented in a lacustrine environment. In the Holocene alluvial materials of clayish composition were deposited, and are located in the lowest areas of the city. The limited presence of these alluvial materials is indicative of the fact that the region is in a young stage. The tufas and lavas are the most ancient materials in the region and appear in the south of Morelia, in the Santa María hills, where a plateau that presents abrupt slope banks toward the left margin of the Chiquito river is formed. Lavas and tufas are located in the north and east areas of the city, forming small knolls that are covered by slime-sandy tufas of the Holocene. In the northwest region basaltic rocks are observed, product of the last volcanic events occurred in the area; these are covered by layers of clay in the proximities of the old airport. In addition to the basalts, slime-sandy tufas, highly compacted appeared in the hills downtown. Along the banks of the rivers clayish deposits less than 10 meters deep are located.

A fault is observed in the south of the city oriented east - west, in the geological contact between the Santa María hills and the left margin of the Chiquito river. Another fault is found in the west area of the city oriented northward, in the contact zone between the Santiaguito hills and downtown.

SOIL PROPERTIES

The stratigraphy of the subsoil of Morelia is related to the topography of the city. In the high zones a superficial clay over clayish and sandy limes deposits are found, and in some parts tufas are also found. In the low areas of Morelia, corresponding to the banks of the rivers, alluvial deposits are located, formed by clays and clayish limes of variable color, ranging from the black to dark brown (Mier, *et al.* 1972). The black clay deposits are expansive material and are located in the western area of the city and in the eastern side of the bed of the Chiquito river. Analytical computation of the soil's fundamental period was carried out with the information from sixteen deep bore holes, using the unidimensional model of vertical propagation of shear waves through a lineal system of horizontal layers. The period derivated from this model is:

$$T = 4 \ \Sigma \ Hi \ / \ Vi$$

where:
Hi = thickness of layer i
Vi = shear waves velocity in the layer i = $(Gi / \rho i)^{1/2}$
Gi = shear module of the layer i
ρi = mass density of the layer i

The periods calculated for the sixteen bore holes are shown in table 1.

ENVIROMENTAL VIBRATION

Eighty four sites distributed in the urban area, were selected in order to measure the natural periods of the soil under environmental vibration. Ten records, of thirty seconds, were registered in the north - south and east - west directions, resulting in twenty events for each site. A Butterworth filter was used, to eliminate frequencies greater than 15 Hertz. Fourier spectra was obtained, and the maximum amplitudes which consistently appear in the twenty records, were considered as the fundamental frequency of the soil. The comparison of the periods calculated by means of the unidimensional wave propoagation theory, based on the information from the deep bore holes was very useful. In figure 1 the Fourier spectra of the records obtained in some representative sites are shown. The highest period, of 0.58 sec (location 67), is quite close to the natural bed of the Chiquito river, in the east of the city. The lowest value (0.24 sec), is located in the zone of basalts, product of the volcanic emissions of the Quinceo, in the northwest region. At point

Table 1. Soil's fundamental periods computed analytically

Bore hole	Location	T (sec)	Bore hole	Location	T (sec)
S1	Infant Hospital	0.48	S9	ISSSTE 3	0.22
S2	Cathedral	0.53	S10	Ruelas bridge	0.38
S3	Campestre Club	0.27	S11	IMSS 1	0.24
S4	University campus	0.25	S12	IMSS 2	0.38
S5	Gral. Ramirez	0.20	S13	IMSS 3	0.21
S6	CFE	0.18	S14	Madero Av. 1	0.33
S7	ISSSTE 1	0.25	S15	Madero AV. 2	0.35
S8	ISSSTE 2	0.25	S16	Pemex	0.30

21, near the stadium, a period of 0.48 sec was obtained, however, it was eliminated due to the presence of deposits in the proximities of the stadium. Additional measurements in the zone (points 70, 75 and 76) in those with periods of 0.24, 0.28 and 0.30 sec respectively, confirm the rigidity of the soil in this area. It was not possible to obtain the periods for the locations 32, 44 and 61, because of transfer problems between the seismometers and the recording system. The periods measured are listed in table 2.

Kobayashi *et al*, 1986, and other authors, reported coincidence among the periods obtained during strong ground motions and those measured under environmental noise conditions. In spite of this, it is important to calibrate the periods recorded under enviromental conditions.

ISOPERIOD MAP

Based on the results of the environmental vibration measurements, the analytical periods obtained from the soil mechanics information, and considering the topographic and geological conditions, an isoperiod map is proposed. The higher periods are enclosed in the area limited by the curves of 0.5 sec, among the natural Chiquito riverbed and its rectified stream, as well as the western area of the city up to the zone limited by the volcanic basalts. The 0.4 sec curve is located in the lower areas of Morelia and follows the bed of the rivers. The curve that limits the period of 0.4 sec is located to the north of the current position of the Chiquito river. Additional measurements in that region (points 81, 82, 83 and 84), confirmed the position of the curve at the north of the riverbed. After consulting a plan of 1939, which shows the natural bed of the Chiquito river, it was observed that the isoperiod curve of 0.4 sec coincides quite well with the natural stream. In the south part of the city, between the left bank of the river and the Santa María hills the 0.3 sec line is located. There is a fault in this zone and abrupt changes in soil properties. The other 0.3 sec curve is located in the north and center of Morelia. Following the criterion of the Mexican codes the firm area is the one in which the period is lower than 0.4 sec, the intermediate area the periods are between 0.4 and 1.0 sec and the soft area the period is greater than 1.0 sec. According to the previous results, the city of Morelia has only with intermediate and firm zones.

SEISMIC ZONING

The isoperiod curve that limits periods of 0.3 sec is located in the transition between the lower parts of the city with the Santa María hills to the south and with the Santiaguito hills to the north. The isoperiod curve that limits periods of 0.4 sec is near the banks of the rivers. The following criteria in defining the zoning was adopted: firm soil for T < 0.3 sec and intermediate soil for T > 0.3 sec.

No soft soil zone was proposed soft soil for the city because the highest period obtained by analytical computation and by environmental vibration measurements was of 0.58 sec. The seismic zoning map was adapted to location of existing streets to facilitate the identification of the zones (Fig. 2).

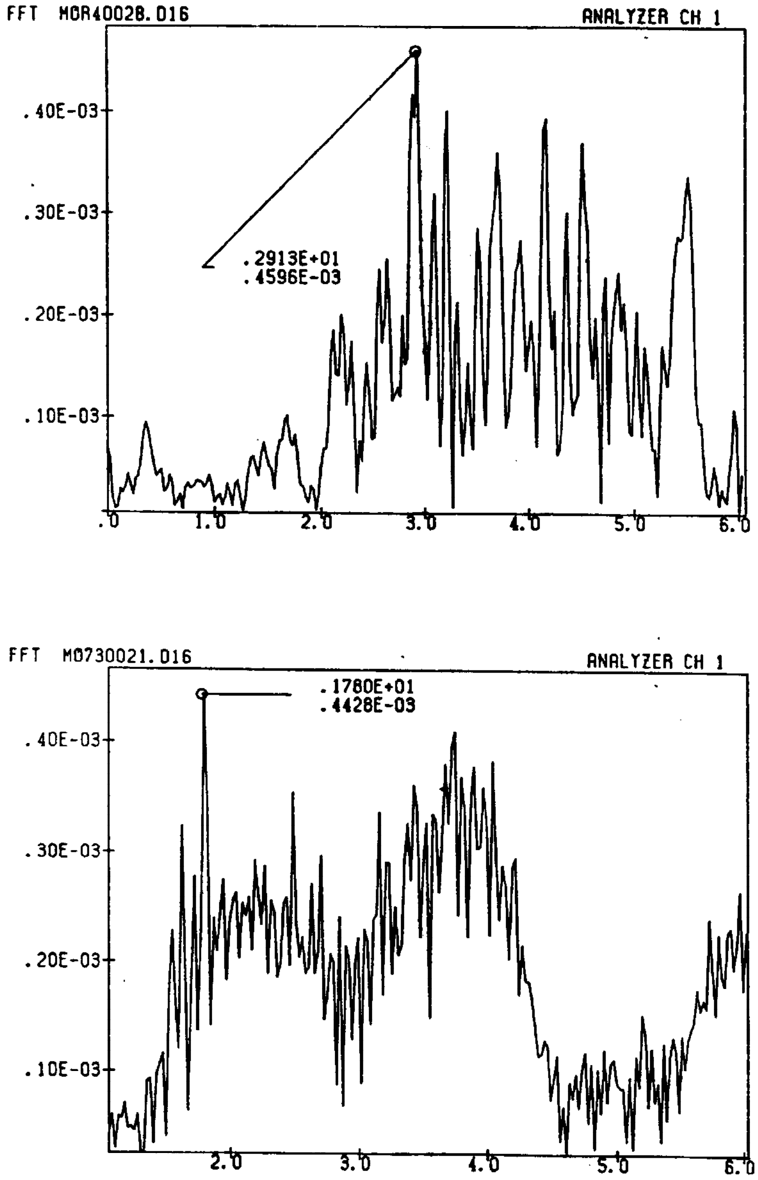

Fig. 1. Fourier spectra for firm and intermediate soil

RISK ANALYSIS

Two approaches will be considered to obtain seismic design spectra, a deterministic analysis and a probabilistic one. To date, two activities of the deterministic criteria have been developed: the identification of seismic sources and the evaluation of the expected maximum magnitudes for each source.

Seismic sources

The city of Morelia is affeccted by the subduction movement on the Pacific coast. The earthquakes associated with the subduction process can be classified in two groups: those which originate on the coast with depths lower than 35 km, and the normal earthquakes that have their epicenters toward the interior of the continent and of greater depth.

The superficial earthquakes are those have their epicenters on the coast and are the most frequent and those which dissipate greater quantity of energy. As was mentioned before, eight events with magnitudes M_L > 7.0 have occurred in this century, and all of them belong to this group of earthquakes.

Table 2. Soil's fundamental periods recorded under ambient vibration

Num.	T (sec)	Num.	T (sec)	Num.	T (sec)	Num.	T (sec)
1	0.33	22	0.44	43	0.30	64	0.38
2	0.29	23	0.48	44	----	65	0.39
3	0.33	24	0.54	45	0.28	66	0.53
4	0.40	25	0.48	46	0.42	67	0.34
5	0.33	26	0.27	47	0.32	68	0.38
6	0.30	27	0.28	48	0.42	69	0.32
7	0.43	28	0.31	49	0.31	70	0.24
8	0.33	29	0.33	50	0.35	71	0.48
9	0.29	30	0.28	51	0.37	72	0.48
10	0.43	31	0.29	52	0.35	73	0.56
11	0.38	32	----	53	0.43	74	0.42
12	0.44	33	0.27	54	0.38	75	0.28
13	0.43	34	0.34	55	0.39	76	0.30
14	0.38	35	0.33	56	0.35	77	0.36
15	0.29	36	0.44	57	0.39	78	0.32
16	0.54	37	0.36	58	0.38	79	0.35
17	0.49	38	0.51	59	0.46	80	0.38
18	0.28	39	0.50	60	0.35	81	0.30
19	0.45	40	0.39	61	----	82	0.58
20	0.27	41	0.37	62	0.29	83	0.41
21	0.48	42	0.38	63	0.37	84	0.31

Intermediate depth earthquakes are produced as a result of the normal stresses induced the gravity and the drag caused by the magmatic streams in the Cocos plate beneath the North American plate. In spite of the smaller expected magnitudes for normal earthquakes, their nearness to Morelia is the cause of the serious damage produced in the city in the past century. For the Santa Juliana earthquake (19 of June of 1858), a IX intensity level was estimated.

In the interior of the continental plate, stresses produced by the convection currents and friction originated in the borders of the plates, causes the slip of seismic faults. In particular, the fault system running from Acambay in the State of México to Maravatio and Pátzcuaro in the State of Michoacán, are the most dangerous for Morelia. In 1912 the Acambay graben gave caused to an event of magnitude M = 7.0.

Maximum erthquake

In the deterministic approach it is necessary to define the maximum magnitude for each source, in order to select the earthquake(s) whose ground motion will dominate the effects of all the events.

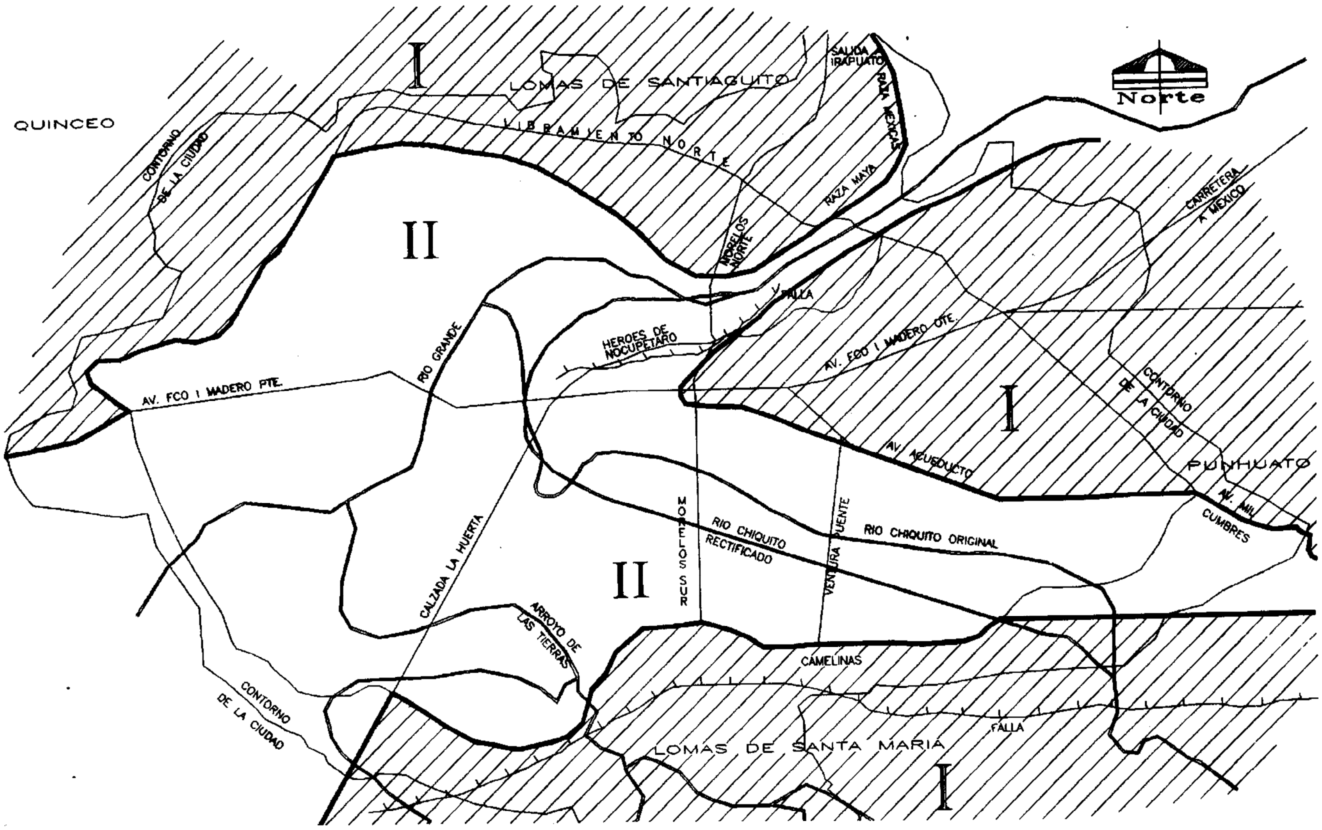

Fig. 2. Seismic zonation of Morelia

Historically the maximum magnitude recorded in the subduction zone is M=8.3, on the coast of Jalisco, however, the registered magnitudes in the State of Michoacán are lower (M=8.1). In 1858, a normal earthquake with epicenter near Morelia, caused severe damage in the city (MMI=IX). The only available data for local earthquakes is a M=7.0 shock originated in the Acambay graben.

Design coefficients are estimated on the basis of the relationship (table 3) between the Mercalli Modified Intensity scale (MMI) and the design shear base coefficient reduced by ductility (k), obtained from damaged buildings in Mexico City during the earthquakes of 1985 (Jara, et al, 1989). For the 1858 earthquake, (MMI=IX); according to table 3, k = 0.125 could be considered. For a ductility factor of 4.0, the shear base coefficient is c = 0.125 x 4 = 0.50 g. If the maximum intensity is considered to be concentrated in the intermediate type of soil, the previous coefficient would be applicable only to this zone. To define the coefficient for the firm soil a conversion factor of 1.5 is used, derived from the intensity distribution observed in the Mexico city in 1985. Therefore, the coefficient for firm soil is 0.50/1.5 = 0.33 g.

Table 3. Mercalli modified intensity (MMI) and design base shear reduced by ductility (K).

MMI	K = C/Q
VI	$K \leq 0.06$
VII	$0.06 < K \leq 0.08$
VIII	$0.08 < K \leq 0.11$
IX	$0.11 < K \leq 0.14$
X	$0.14 < K$

In this century, the maximum intensity reported is MMI = VI. For this intensity K= 0.06. The base shear coefficient is c = 0.06 x 4.0 = 0.24 g for intermediate soil and c= 0.16 for firm soil.

Trigos, 1988, presents design spectra in firm soil for 116 localities of the country, obtained from a seismic risk study using atenuation laws for acceleration and maximum velocities. The coefficient for the intermediate area is 0.2 x 1.5 = 0.3 g. The study of Esteva and Ordaz on the seismic risk of Mexico, that has been incorporated in the CFE-1993 code, reports the following coefficients: for firm soil, 0.14 g; and for intermediate soil, 0.30 g . To transform the values from firm to intermediate soil, an amplification factor of 2.14 was used.

On the basis of these data the design coefficients would be: 0.2 g for firm soil and 0.32 g for intermediate soil. The design spectra shown in Fig. 3 considers the expressions traditionally used in Mexican codes. This preliminar spectra will be compared to the results of the deterministic and probabilistic approaches that will be developed in the second part of the project.

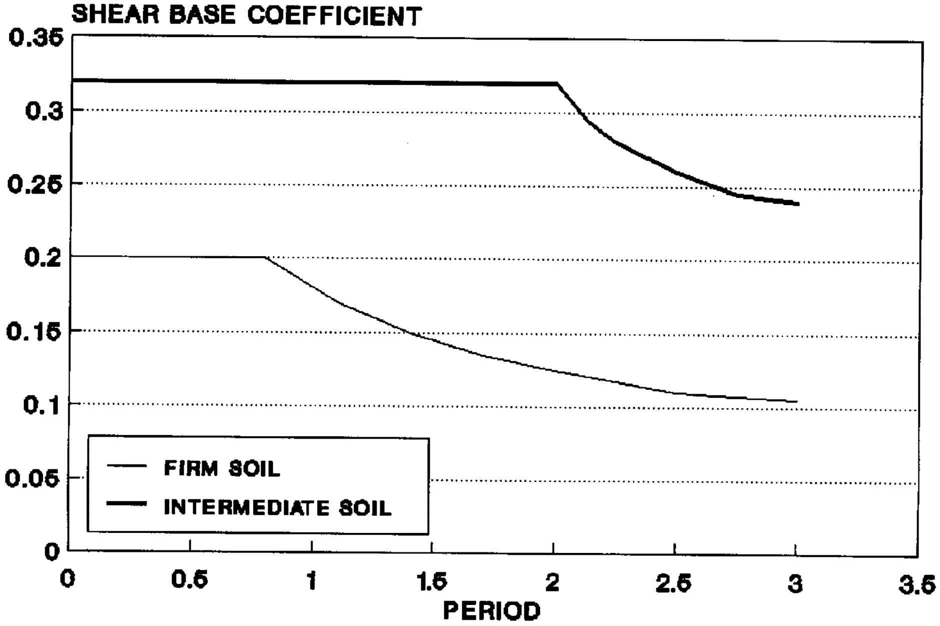

Fig. 3. Design spectra derived from historical seismicity

CONCLUSIONS

The seismic zonation of Morelia is proposed based on: information on the geological, topographical and soil mechanics data; measurements of the fundamental soil period under enviromental vibration; and computed analytical periods using data from deep bore holes. Seismic sources were identified and the maximum credible earthquake which is reasonably expected is selected for each source. A preliminary design spectra derived from the historical seismicity is estimated.

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