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SEISMIC MICROZONING OF TOLUCA CITY

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ABSTRACT

The present work is the result of a joint project between Universidad Autonoma del Estado de Mexico and Universidad Autonoma Metropolitana. The objective of the project is to obtain the seismic microzoning of Toluca City, as well as to propose the design seismic coefficients. The above is based on in-situ determinations of the dynamic characteristics of the soil, the analysis of the structural behavior of affected buildings during past earthquakes and the study of regional seismicity as well. Results related with the regional geology, measurements of local dynamic characteristics of the soil (ambient vibration measurement) and the interpretation of existing data of soil mechanics studies are shown.

KEYWORDS

Zonation, ambient vibration, isoperiod, natural period, risk.

LOCAL SEISMICITY

Toluca City is located in the center of Mexico which is considerate as medium seismic activity region. The principal source of seismic risk is due to the subduction phenomena between the Cocos plate and the North America plate in the Pacific coast of Mexico, other important source of seismic risk is associated with local faults.

LOCAL GEOLOGY

Toluca City is located in the highest valley in the country. The portion of the valley in which Toluca City is located, is composed by alluvial deposits and it is surrounded by igneous rock formations and some volcanic tuff, also exist a small rock formation in the middle of this portion of the valley. With the soil mechanics information available from 18 bore holes (SPT), around the City, it was possible to define three different zones, according whit the soil type: The hill zone, with hard soil; the valley zone, with alluvial deposits soil; and the transition zone, between them.

DYNAMIC PROPERTIES OF THE SOIL

The period of the soil was determined by data from 18 bore holes (SPT). Fig. 1 Shows an example of bore hole data (Identified as S-1 in table 1).

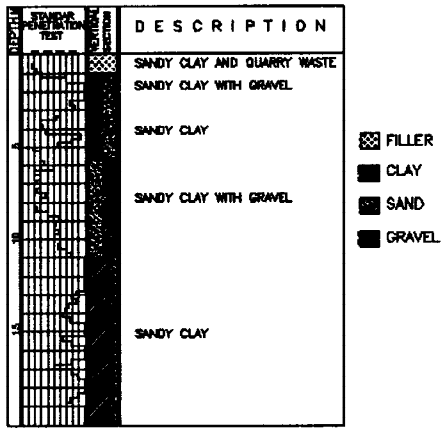

Fig. 1. Standard penetration test data, bore hole S-1

The period of the soil was estimated using the soil strata properties and utilizing the unidimentional wave propagation theory for shear waves in viscoelastic medium (Bowles, 1977). According with this method the natural period is:

$$T = 4 \Sigma H_i / \beta_i \quad (1)$$

Were:
H = i-stratum wide (m.)
β = Shear wave velocity = $(G_i/\tau_i)^{1/2}$
G = Shear Module.
τ = Material density.

Applying this formula to the bore holes data and considering only the soft soil stratums with less than 50 blows for each 300 mm of penetration, the values of period shown in table 1 were obtained.

Table 1. Location of bore holes and estimated period.

Bore-hole	Location	Period (sec)
S-1	Celanese	0.47
S-2	M. Hidalgo y G. Prieto	0.33
S-4	IMSS (J. Ortiz)	0.38
S-5	UAEM (Rectoria)	0.46
S-8SE1	Policlinica ISSEMYM	0.22
S-8SE2	Policlinica ISSEMYM	0.26
S-8SM1	Policlinica ISSEMYM	0.27
S-8SM2	Policlinica ISSEMYM	0.27
S-10SM1	P. Tollocan e I. Fabela	0.33
S-10SM2	P. Tollocan e I. Fabela	0.32
S-10SM3	P. Tollocan e I. Fabela	0.30
S-10SM4	P. Tollocan e I. Fabela	0.22
S-11SM1	P. Tollocan y Pino S.	0.50
S-11SM2	P. Tollocan y Pino S.	0.48
S-11SM3	P. Tollocan y Pino S.	0.45
S-11SM4	P. Tollocan y Pino S.	0.57
S-12	IMSS (Clinica 8)	0.34
S-13	Fabrica Nestle	0.32

Isoperiod Maps

The natural period of the soil was obtained with ambient vibration measurements taken in different points within the surroundings of the city. For this purpose, a seismometer register system was employed, consisting on:

a) Digital solid state recording, kinemetrics SSR-1 whit three access channels and 200 sps records by channel.

b) Two kinemetrics sensors WR-1 whit nominal frequency of 20 Hz and efficient response period range of 0.05 to 5.0 sec.

c) Laptop computer with 1 MB of random memory, for communication between the sensors and the recording.

Communication and data acquisition was performed using Quick Talk and Quick Look software, The data information processing was done by CNVSSR, the Fourier spectra was obtained with the FFT (Kinemetrics, 1989).

The ambient vibration measurements were taken in 92 points which were 81 inside the city. The location of these points are shown in Table 2.

Table 2. Location of ambient vibration measurements and its corresponding period.

Point	Location	Period (sec)	Point	Location	Period (sec)	Point	Location	Period (sec)
1	Morelos (Celanese)	0.38	29	A los Mtos.-Santos D	0.33	66	Constituyentes-Motl	0.30
2	Hidalgo - G. Prieto	0.39	30	I. Fabela.-Rivera.	0.43	67	Constituyentes-Gzlz.	0.32
3	A.los Mtos-Santos D.	0.43	31	V.A del Mazo-Galilei	0.38	68	V.Dominguez.-Hgo.	0.38
4	J. Ortiz (IMSS)	0.38	32	1 de Mayo (Neztle)	0.42	69	P. Amistad-2 de Abr	0.35
5	B. Juárez (Rectoria)	0.38	33	Iglesia de Sta Ana.	0.38	70	Lirios-Casa Blanca	0.34
6	Juárez-Pasaje Florida	0.43	34	L Cardenas -Minerva	0.40	71	Ex Hda del Carmen	0.35
7	Indep - N. Bravo	0.33	42	L.del Volcan -Pl de V	0.38	72	R. Bosh-Tollocan	0.40
8	Ordoñez-21 de Mayo	0.48	43	L Sayula-L Valencia.	0.48	73	1 de Mayo-Chrysler	0.34
9	Hgo Fray A de Castro	0.33	44	L Atabasca-L Mitla	----	74	A.Ind.Autom.(Darex)	0.34
10	Tollocan - 5 de Mayo	0.37	45	L Huapgo-L Palomas	0.37	75	Pemex	0.54
11	Tollocan-Pino Suarez	----	46	Ant.Est .Sismologica	0.28	76	P.Gonzalez.-Col. Ind.	0.34
12	Tollocan - Neza.	0.38	47	Col la Joya	0.47	77	San Lorenzo (Indetel)	0.34
13	Fac. Ciencias Quím.	0.37	48	Mercado Hidalgo.	0.29	78	S. Miltepec (Iglesia)	0.41
14	Sanatorio Toluca	0.42	50	Av.Automotriz .	0.22	79	L. Vicario.-Lerdo	0.30
15	Fac. de Ingeniería	0.33	51	Fracc.Pilares	0.44	80	Nigromante-21Marzo	0.32
16	Ant. Est. Simologíca	----	54	Panteon S. Mateo O.	0.47	81	Morelos (IMSS)	0.38
17	Mercado Hidalgo	----	55	L Mist-L Huapango	0.39	82	San PedroTotoltepec	0.20
18	Prim. Gustavo D.O.	0.42	56	L Atabasca-L Caim.	0.37	83	Ejido Sta Ana Tlapal.	0.37
19	Prepa. López Mateos	0.38	57	VCarranza-Alpinismo	0.42	84	Hgo-Villada S Lrnzo.	0.42
20	Cerro del Calvario	----	58	LCardenas-VCarranz.	0.38	85	A del Mazo-V Lopez	0.39
21	Tollocan (Crysler)	0.52	59	Prol S Buena-Tana	0.35	86	Col. Corralitos	0.37
23	Tollocan - 5 de Mayo	0.39	60	LTamiaguaXochimilc	0.39	87	Col Nuevo Progreso	0.38
24	Tollocan-Pino Suarez	0.38	61	Schz. Colin.-Tollocan	0.38	88	L Cardenas-C.C.M.	0.37
25	Mon. al Maestro	0.38	62	APinzón-J Rodriguez.	0.37	89	L Cardenas-J Aldama	0.39
26	Matamoros-J Alvarez	0.43	63	J Rodriguez-Peñaloza	0.32	90	L Cardenas-5de May	0.39
27	Cerro del Calvario	0.31	64	Prol S Buena-Tixtla	0.30	91	Col. Providencia	0.38
28	Rayón (Cosmovitral)	0.31	65	J.M. la Fragua-Gro.	0.40	92	Izcalli Cuauhtemoc I.	0.28

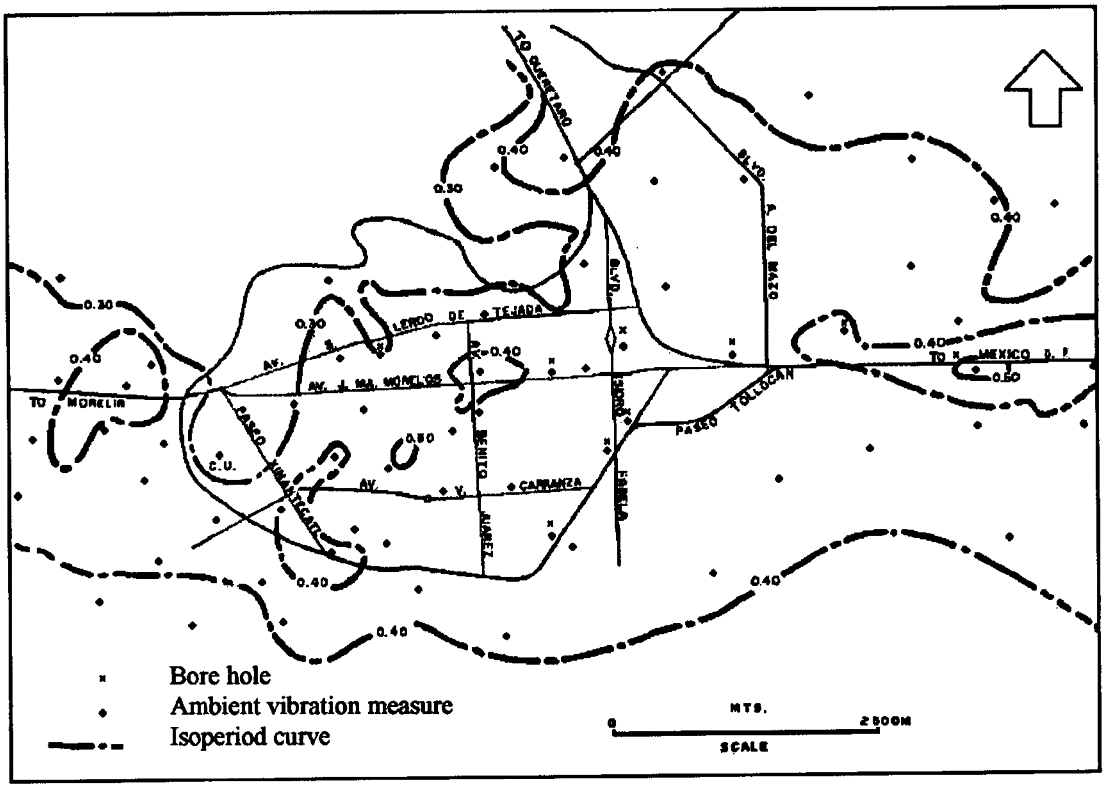

Fig. 2. Isoperiod contour map for Toluca City

In each place 10 events were recorded for both horizontal components (N-S, E-W), the duration of each record was of 30 sec. The natural period of each place was obtained from Fourier spectra of the signals recorded, identifying the frequencies associated with the maximum incidence amplitude, and taken the natural period obtained from soil mechanics data like a reference. The dominant frequency generally is located in the zone where the amplitude increases significatively and not necessarily where the spectral amplitude is maximum. The maximum spectral amplitude may be associated with local perturbation sources like human traffic or industrial activity, for example in the number 75 point the maximum spectral amplitude fitted to a frequency of 3.54 Hz, but the dominant frequency of place is estimated as 1.87 Hz. The periods obtained in this manner are shown in table 2. Using this information an isoperiod contour map was obtained (fig. 2).

SEISMIC LOCAL INTENSITY

According with the isoperiod contour map, it was possible to define two zones delimited by the 0.4 sec isoperiod curve: zone I (hard soil) with natural periods less than 0.4 sec and zone II (medium soil) with natural periods equal or grater than 0.4 sec. Due to the absence of seismographic information recorded in Toluca City, the seismic coefficient was estimated taken into account the followings aspects: a) association of seismic capacity of damaged building during the 1985 Mexico earthquake whit the seismic intensity at the construction site. b) historical information. c) seismic risk analysis and proposals of different authors.

Damaged buildings.

The seismic capacity of two reinforce concrete buildings and one corridor deck with steel structure was estimated. These structures were damaged during 1985 Mexico earthquake. The seismic capacity coefficient (K) of those structures was determinate by the simplified method (Iglesias, 1989) as the shear coefficient at the bottom of the building at failure reduced by ductility (K=C/Q). In one of the R/C buildings and in the corridor deck, the dynamic analysis was possible because more information was available. The K coefficient values and the corresponding seismic coefficient(C), take in to account a ductility factor Q=2 for the reinforced concrete structures and Q=1 for the steel structure, these values are shown in table 3.

Table 3. Seismic coefficient for studied buildings.

Structure	Damage	Levels	K=C/Q		C	
			Static A.	Dynamic A.	Static A.	Dynamic A.
E-1	Severe	5	0.061	0.100	0.122	0.200
E-2	Strong	8	0.042	------	0.084	------
E-3	Collapse	1	------	0.170	------	0.170

The shear coefficient at the bottom of the building at failure, for the E-2 reinforced concrete structure was affected by a damaged conversion factor equal to 0.75, to take into account the difference between strong and severe damage (Iglesias, 1987)

Historical information.

The maximum seismic intensity reported in Toluca City is VI in Modified Mercally scale. According with table 4 (Jara 1989) for this intensity, the seismic capacity coefficient of K=< 0.06 is suitable.

Table 4. Modify Mercally scale Vs seismic capacity coefficient.

Modified Mercally Scale	Seismic capacity coefficient (K)
VI	K<=0.06
VII	0.06<K<=0.08
VIII	0.08<K<=0.11
IX	0.11<K<=0.14
X	K>0.14

Seismic risk analysis.

For the seismic risk estimation, the results of previous studies are taken into account. The 1985 Mexico earthquake can be considered as a representative event of the subduction activity in the Pacific coast of Mexico. For this earthquake, the seismic capacity coefficient was estimated as K=0.17, as is shown in table 3. According with Romero a seismic coefficient of C = 0.19 for hard soil and C= 0.30 for medium soil are suitable, in both cases 5% of critical damping was used (Romero, 1991). Esteva and Ordaz, 1988, in their study of seismic risk for Mexico, recommend for Toluca area, C=0.16 and C=0.36 for hard and medium soil respectively. This study is based on general attenuation laws for seismic intensity and their experience in Mexico City for local amplifications. Table 5 shows the seismic coefficient from different sources, including those mentioned above.

Table 5. Seismic coefficients proposed for Toluca City (5% of critical damping).

Source	C (Hard soil)	C (Medium soil)
C: F. E.	0.16	0.20
R. D. F. 87	0.16	0.32
R. E. M.	0.16	0.32
Trigos	0.26	0.26x1.5=0.39
Esteva and Ordaz	0.16	0.36
Romero	0.19	0.30
Maximum Intensity 1985	0.2	0.2x1.5=0.30
VI Intensity M. Mercalli	0.33/1.5=0.22	0.06x4/0.75=0.32

C: F. E. Federal Electricity Company.
R. D. F. 87 Mexico City Code 1987
R. E. M. Proposal for Mexico State Code

The results from dynamic analysis was corrected dividing by 0.72 to consider the differences between static and dynamic analysis results (Gomez, 1989). The factor of 1.5 was used to obtain the corresponding values from hard to medium soil.

Finally in this work it was decided to recommend 0.20 and 0.32 seismic coefficients for hard and medium soil respectively, this values approximately cover the VI Modify Mercally intensity presented in the City as well as most of the criteria analyzed.

SEISMIC ZONATION.

The isoperiod contour map of fig. 2 allows to distinguish a hard soil zone, with period less than 0.4 sec, from the rest of the City where the highest value of the natural period is 0.52 sec (table 2). It was decided to propose the zonation seismic map shown in fig. 3, which distinguish a hard zone soil (zone A) and a medium soil (zone B). For aseismic design, expressions 2 and 3 and table 6 are proposed for construct the design spectra, the seismic coefficient was proposed in the above section. For estimation of Tb the maximum period of soil measured in each zone was 0.4 and 0.54 sec, for zone A and zone B respectively, but due to the possible mistakes in the natural period estimation of structures, those values were increased by 1.5 times. In addition due to the possible amplification in the response for high periods in medium soils like it have been reported in Chilpancingo City (Carballo 1993), was decided to keep Tb = 1.5 sec (fig 4), according with R.E.M. proposal. These assumptions could be changed when enouhg acelerographic records are obtained in Toluca City to permit carry out a local seismicity study. This study adopt the r values included in the Mexico City Code. The spectral amplitude, a, as percentage of acceleration gravity is given by the following expressions:

$$a = C \qquad \text{if } T <= Tb \qquad (2)$$

$$a = C(Tb/T)^r \qquad \text{if } T > Tb \qquad (3)$$

Where T is the structural period and Tb is the period in point of discontinuity in the design spectra.

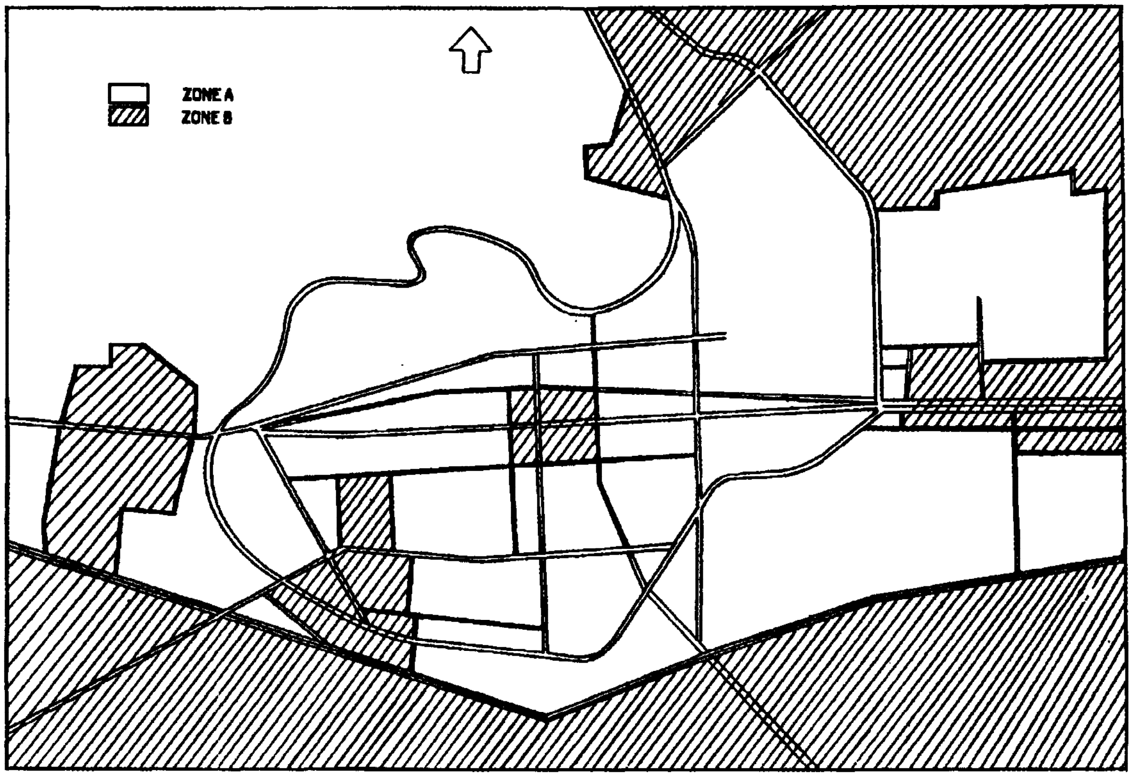

Fig. 3. Seismic microzoning map for Toluca City

Table 6. Design spectrum recommended for Toluca City

Zone	C	Tb (sec)	r
Hard Soil (Zone A)	0.20	0.60	1/2
Medium soil (Zone B)	0.32	1.50	2/3

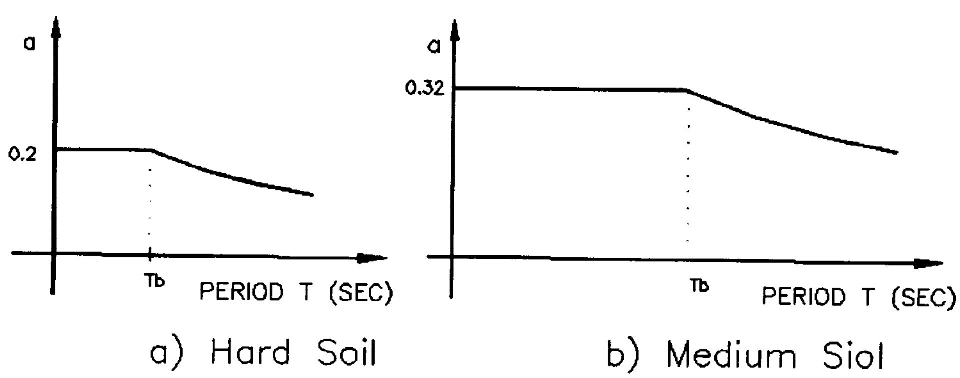

Fig. 4. Design spectra recommended for Toluca City

CONCLUSIONS

From the bore holes data, the soil period around the City shows values from 0.22 to 0.57 sec. With ambient vibration measurements, the soil periods was estimated in the range of 0.2 to 0.54 sec. A good correlation between the period obtained with ambient vibration and bore holes data was observed. With the experience in this work, it is confirmed that ambient vibration measurements gives a suitable method for seismic microzoning works in places with few soil information. The soil periods in the urban area oscillates from 0.2 to 0.5 sec. thus only two types of soil were selected (hard soil and medium soil), this is reflected in the proposed seismic microzoning map.

The maximum historical intensity in the City is VI in Modified Mercalli scale, a seismic coefficient reduced by ductility of 0.06 was assumed, on the other hand in the analytical study of the damaged structures during the earthquake the maximum value was estimated as 0.17. Finally seismic design coefficient of 0.2 and 0.32 for hard soil and medium soil are recommended respectively.

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REFERENCES

Bowles J.E. (1990). Foundation Analysis and Design. Third Edition, Mc.Graw Hill, New York.

Carballo J. E. (1993). Estudio de riesgo sismico para la ciudad de Chilpancingo, Gro. X Congreso Nacional de Ingenieria Sismica.

Castro G., Castro S., Soriano G., ( ) Regionalizacion Sismica del Estado de Mexico, U.A.E.M.

Gama A.(1992). Propuesta de Microzonificacion Sismica para la ciudad de Chilpancingo Gro. ESIA., I.P.N.

Iglesias J. Aguilar J., Mota O., Gomez A., Teran A., Ortega R., Gonzalez E., Guerrero J., Juarez H., Paniagua J.P., and Sordo E. (1987). Estudio de las Intensidades del Sismo del 19 de Septiembre de 1985.

Kinemetrck Systems (1989). Seismic Workstation Software, Pasadena Cal.

Martinez E. (1976). Estudio de Suelos para la Ciudad de Toluca. VIII Congreso de Mecanica de Suelos.

Romero D. (1991). Analisis de Riesgo Sismico para el Estado de Mexico. Fac. de Ingenieria U.A.E.M.