*Paper No. 1647. (quote when citing this article)*
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

# SEISMIC ZONATION OF PUEBLA, MEXICO

C. RUIZ and J. JUAREZ

Facultad de Ingenieria Civil, Universidad Popular Autonoma del Estado de Puebla
21 Sur 1103, Puebla 72160, Puebla, Mexico.

## ABSTRACT

The results obtained from the first stage of the project for the seismic zonation of Puebla city are presented, based on the field estimation of the dynamic characteristics of the soil, the structural analysis of several buildings damaged by recent earthquakes and the study of the regional seismicity.

## KEYWORDS

Ambient vibration; code; isoperiod; Mexico; microzonation; modified Mercalli scale; Puebla; zonation

## INTRODUCTION

The city of Puebla, capital of the Puebla state, is considered between the cities of most seismic importance of the country. For this reason, the Universidad Popular Autonoma del Estado de Puebla (UPAEP) and the Universidad Autonoma Metropolitana (UAM) established an agreement in 1992, with the purpose of studying the seismic risk of the city and propose parameters for the seismic resistant design of the constructions, in accordance with a seismic zonation derived from the available information.

In spite of the fact that a construction regulation of for the city already existed in Puebla (Reglamento, 1988), it was based on information corresponding to Mexico City, so considered necessary to carry out a study that involved the particular characteristics of the city.

This work presents the results of the first stage of the project, that include the geodynamics characterization of the city, based on the field determination of the dynamic characteristics of the soil, and the proposal of seismic-resistant design parameters derived from the estimate of intensities produced by past earthquakes.

## TECTONICS AND SEISMICITY

One of the main tectonic mechanism that affects the city of Puebla is the subduction phenomenon of the Cocos plate under the North America plate, which gives origin to earthquakes of intermediate depth that, in spite of their moderate magnitude, produce high intensities due to their proximity to the urban centers of the interior of the country. Because of its location, Puebla is subject to the seismic activity of the

Volcanic Mexican Axis also. Table 1 presents some of the earthquakes that has more affected the city of Puebla according to Figueroa (1974), indicating magnitudes esteemed in the Richter scale and intensities in the Mercalli Modified scale.

Table 1.- Some of the earthquakes that has more affected the city of Puebla (Figueroa, 1974).

| Date | Magnitude | Intensity | Date | Magnitude | Intensity |
|---|---|---|---|---|---|
| 25-08-1611 | 7.5 | VI | 03-10-1864 | 7.0 | IX |
| 30-07-1667 | 7.0 | VII | 19-07-1882 | 7.5 | VII |
| 16-08-1711 | 7.5 | VIII | 24-05-1959 | 6.8 | VII |
| 22-11-1837 | 6.5 | VI | 28-08-1973 | 7.0 | VIII |
| 03-03-1845 | 6.0 | VII | | | |

## GEOLOGICAL AND GEOTECHNICS CONFIGURATION

Geological and geotechnical configuration of the city of Puebla is shortly described next (Fig. 1), based on the work of Auvinet (1976), and in the data provided by 93 deep drills and 14 superficial drills and for some representative cases are defined in Table 2.

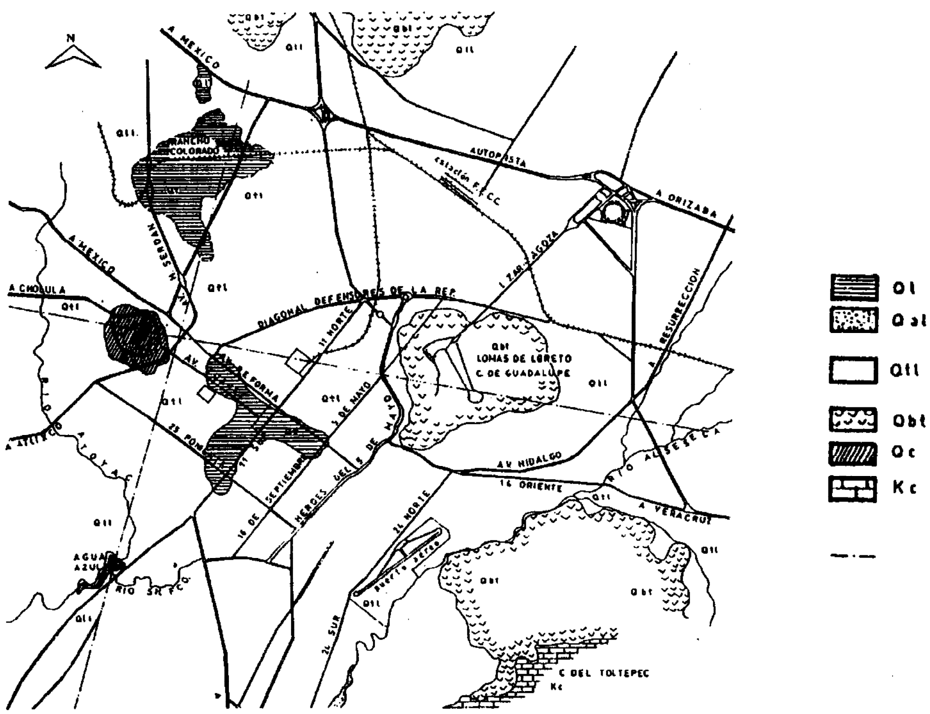


Fig. 1. Local geology of city of Puebla.

a) Limestone. This formation appears in the south limit of the city. The rock comes in strata of 20 to 30 cm thickness and is very fractured. To the north of the zone of blooming of limestones exist the hills of the Tepozochitl and Toltepec.

b) Basalts and muddy tuff. In the hills to the south and to the east of the city and in the hills of Loreto and Guadalupe appear basaltic lavas, covered by slime-sandy and sandy tuff of yellowish color, generally compact.

c) Basaltic Clinker. The Cerro de la Paz, located in the Northwest portion of the city, is a volcanic cone formed by basaltic clinker of reddish color.

d) Volcanic and Fluvial Deposits. In almost the entirety of the city are interstratified volcanic tuff with deposits of fluvio-lacustrine origin that goes from clays to even rolling stones.

e) Deposits of Travertine. Blooming of sulfurous temperate waters associated with deposits of travertine are located in the zone of Rancho Colorado, in the surroundings of the Cerro de la Paz, in the bathing resort of Agua Azul and in the Historical Center, to very different depths and in strata of variable thickness.
f) Alluvial Deposits. Along the Alseseca , San Francisco and Atoyac rivers, alluvial deposits mainly constitute for muddy sands exist.

## GEODYNAMICS CHARACTERISTICS

The natural period of the soft soil, T, was obtained from the information provided by boring points, from of the elastic model of propagation of shear waves (Zeevaert, 1988):

$$T=4\ \Sigma\, Hi/Vi \qquad (1)$$

where:
Hi= thickness of the ith stratum
Vi= speed of shear waves in the ith stratum $= (G_i/\rho_i)^{0.5}$
Gi= dynamic module of shear of the ith stratum
ρi= density of the material of the ith stratum

Table 2 shows the results obtained from 18 representative deep soil borings of the city. G values for the several strata were between 180 and 1500 kg/cm2. Firm stratum was considered as that one for which the number of blows in the test of standard penetration were more than 50.

Table 2. Localization of deep drills and calculated periods (Ruiz, 1992)

| Drill | Localization | T(sec) | Drill | Localization | T(sec) |
|---|---|---|---|---|---|
| S-5 | Tecnologico | 0.47 | S-53 | Av.Juarez y Chietla | 0.36 |
| S-7 | Heroes 5 de Mayo centro | 0.78 | S-55 | Panificadora | 0.36 |
| S-17 | Autopista Puebla-Orizaba | 0.35 | S-57 | Hospital UPAEP | 0.70 |
| S-22 | Resurreccion | 0.31 | S-67 | Rincon de Valle Dorado | 0.67 |
| S-27 | Paso superior FF.CC. | 0.30 | S-80 | Parque Juarez | 0.70 |
| S-31 | Av.25 Poniente y 13 Sur | 0.70 | S-82 | Club deportivo | 0.34 |
| S-40 | ISSSTE | 0.31 | S-92 | CERESO | 0.24 |
| S-48 | Infonavit "La Cienega" | 0.67 | S-98 | Atrio de Sto. Domingo | 0.70 |
| S-51 | Heroes 5 de Mayo y 7 Ote. | 0.71 | S-103 | Ex Balneario La Paz | 0.70 |

In order to extend the covering of the boring information available the determination of the natural periods of the soil from ambient vibration measurements was done. The equipment used for this purpose consist of a digital solid state recorder Kinemetrics SSR-1, with 16 bits resolution, three channels of access and a sample of 200 sps for channel, and two seismologic field sensors Kinemetrics WR-1, with 20Hz of nominal frequency and an efficient interval of 0.05 to 5.0 sec of period, all controlled by a portable computer and the corresponding software (Seismic, 1988).

Ninety-eigth points were selected in the valley of Puebla in order to make the measurements, as it is shown in Figure 2. Each place registered ten events of thirty seconds each in two directions, N-S and E-W, using a filter Butterworth type that eliminates the frequencies higher than 15 Hz. For the twenty events registered in each point the Fourier spectrum were obtained, their statistical analysis led to estimate the corresponding natural period. For this purpose it was very useful to have as reference the periods calculated from the information of deep drills. The results obtained in 60 representative points are shown in Table 3 together with their location; with all these values, the isoperiod curves were traced as it is shown in Fig. 2 for the values of 0.40, 0.50, 0.60 0.7 sec. The isoperiod curves, that define the dynamic properties of the soil, adjust well to the geologic map of Fig. 1. The 0.4 sec curve coincide with the topographical configuration of soft hills and with the limits of the tuff formations deposited in dry medium. The soils formed by eolics deposits of volcanic origin, which had been deposited in water; the altered tuff and the granular compact soils are between 0.4 and 0.7 sec curves. The trace that corresponds to values higher than 0.7 sec. defines zones with granular deposits of alluvial origin on tuffs formations, clay deposits with organic matter and deposits of travertine. In the predominantly firm soil to the north of the city, there is a small zone that appears more compressible. In a similar way, to the south, a hill defines a zone of firm soil inside an area of medium soft soil.

Table 3. Localization of mensurations of ambient vibration and calculated periods (Ruiz, 1993)

| Point | Localization | T(sec) | Point | Localization | T(sec) | Point | Localization | T(sec) |
|---|---|---|---|---|---|---|---|---|
| 1 | Upaep | 0.72 | 30 | Arroyo Xonaca | 0.36 | 61 | Panteon la Piedad | 0.69 |
| 2 | Zocalo | 0.72 | 31 | Parque Ecologico | 0.45 | 62 | Agua Azul | 0.70 |
| 4 | Paseo Bravo | 0.72 | 32 | San Jose | 0.37 | 64 | El Mirador | 0.70 |
| 6 | Rio Atoyac | 0.73 | 33 | Fuerte de Loreto | 0.34 | 67 | Loma del sur | 0.38 |
| 8 | Valle Dorado | 0.73 | 35 | Villa Verde | 0.37 | 69 | Guadalupe Hgo. | 0.50 |
| 13 | Guadalupe Hidalgo | 0.64 | 36 | Joaquin Colombres | 0.34 | 70 | Tres Cruces | 0.52 |
| 14 | 5 sur y 43 Pte. | 0.73 | 37 | Resurreccion | 0.30 | 72 | Alamos | 0.39 |
| 15 | Heroes 5 de Mayo | 0.74 | 38 | Revolucion Mex. | 0.39 | 77 | El Batan | 0.38 |
| 16 | Parque Juarez | 0.73 | 39 | Villa Frontera | 0.36 | 80 | Bosques La Calera | 0.23 |
| 18 | Colonia B. Juarez | 0.73 | 40 | San Pablo | 0.37 | 82 | La Margarita | 0.54 |
| 19 | Hospital del Niño | 0.73 | 42 | Moratilla | 0.36 | 86 | San Baltazar | 0.36 |
| 20 | Federal a Cholula | 0.57 | 44 | Alvaro Obregon | 0.74 | 88 | El Cerrito | 0.37 |
| 21 | Central de Abastos | 0.38 | 46 | Las Pedreras | 0.37 | 90 | Universidad | 0.38 |
| 22 | San Jeronimo | 0.45 | 48 | San Felipe | 0.43 | 91 | Vista Alegre | 0.43 |
| 24 | Rio Alseseca | 0.40 | 49 | Aquiles Serdan | 0.38 | 92 | San Manuel | 0.34 |
| 25 | Feria de Puebla | 0.37 | 50 | La Libertad | 0.40 | 95 | Puebla 2000 | 0.28 |
| 26 | El Chamizal | 0.41 | 51 | Romero Vargas | 0.39 | 99 | Hotel del Alba | 0.73 |
| 27 | Hermanos Serdan | 0.52 | 56 | Zavaleta | 0.74 | 101 | Recta a Cholula | 0.43 |
| 28 | Santa Cruz | 0.48 | 58 | Belisario D. | 0.69 | 106 | Club de Golf | 0.71 |
| 29 | Barrio El Refugio | 0.42 | 59 | Cerro de la Paz | 0.26 | 107 | Panteón Jardin | 0.47 |

Considering Mexico City as a point of reference, the firm soil is characterized by values of the natural period T< 0.40 sec, the transition soil for 0.40 sec< T< 1.00 sec and the soft soil by T> 1.00sec, for this reason it was considered that in Puebla city there are firm and transition soil only.

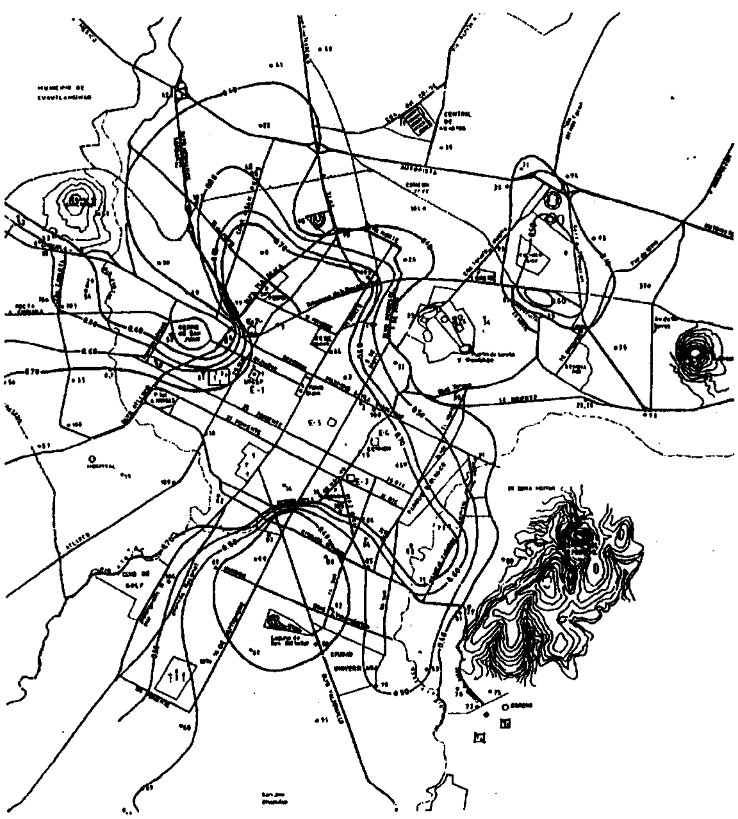

Fig. 2. Isoperiod curves map for Puebla city

LOCAL INTENSITIES STUDY

With the purpose of estimate the maximum intensity of the 1985 earthquake in the city of Puebla, the earthquake resistant capacity of five concrete buildings that were damaged during that event and have the necessary information available, was determined. The location of the buildings under study is shown in Fig. 2. In all cases, the determination of the resistance coefficient, K, that is the seismic coefficient, c, reduced by ductility, Q, corresponding to the damage, was carried out by the simplified method of evaluation proposed by Iglesias (1989).

In addition for the two cases in which structural detailed information was available, the evaluation was carried out with the help of the SUPER-ETABS program (Maison *et.al.*, 1985). the values of K obtained, as well as the corresponding seismic coefficient, c, if a factor of reduction Q=4 is considered, are shown in Table 4.

Table 4. Resistance Coefficients of the evaluated buildings (Q = 4).

| Building | Number of floors. | Type of damage | K = c / Q | | c | |
|---|---|---|---|---|---|---|
| | | | MES | S-ETABS | MES | S-ETABS |
| B-1 | 4 | Not Structural | 0.113 | 0.145 | 0.452 | 0.580 |
| B-2 | 10 | Not Structural | 0.052 | 0.097 | 0.208 | 0.388 |
| B-3 | 8 | B. Slight | 0.059 | ---- | 0.236 | ---- |
| B-4 | 3 | B. Strong | 0.054 | ---- | 0.216 | ---- |
| B-5 | 11 | B. Slight | 0.090 | ---- | 0.360 | ---- |

In order to associate the maximum intensity with the resistance coefficient, the observed damages should be severe, according to the classification of Iglesias (1985), however, anyone of the analyzed buildings presented this level of damage and only one had structural strong damage. In this last case a factor of conversion of the strong damage to severe equal to 0.75 was used, based on the analysis of a great amount of buildings damaged in 1985 (Iglesias, *et.al.*, 1987). In this way a resistance coefficient K = 0.41 and a seismic coefficient c= 0.162 was obtained for the building B-4.

As for the historical information, it is possible to observe in Table 1 that intensity VII of Mercalli Modified is frequent , and is considered that the earthquake of 16-08-1711 reached a maximum intensity of VIII, which according to Table 5, derived from the experience of 1985 in Mexico City, correspond to a resistance coefficient in the range of $0.08 < K < 0.11$.

Table 5. Modified Mercalli scale vs. of resistance coefficients (Jara, 1989).

| MM | K |
|---|---|
| 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 | $0.14 < K$ |

SEISMIC RISK ANALYSIS

A first approach to the estimate of the seismic hazard consists of the evaluation of possible scenarios. From this point of view, the earthquakes of 1985, whose maximum intensity was K= 0,041 (c= 0.162), according to the previous incised, could be considered as representative of an important and superficial subduction event.The VIII intensity event reported in 1973, that corresponds to a maximum intensity of K= 0.11 (c= 0.44) (Table 5), is an extreme case of a subduction earthquake of intermediate depth that are most destructive for the city.

The study of seismic hazard carried out by Trigos (1988), using general attenuation laws for values of maximum acceleration and speed, proposes a seismic coefficient for firm soil in the city of Puebla of c= 0.26, for 5% of damping. The work of Esteva and Ordaz,(1988), which present a study of seismic risk for the Mexican Republic using general laws of attenuation of the seismic intensity, proposes the division of the country in four zones, for which it provides values of seismic coefficients recommended for design, so much in hard soil as in intermediates and soft soils, based on the experience of Mexico City for the estimate of the local amplifications.

Table 6 is a summary of the values of the seismic coefficients derived from the scenarios considered and the studies previously described. Like the concept of resistance coefficient is associated with the static analysis method which led to shear forces 72% less than the dynamic analysis, for typical concrete buildings of medium height (Gomez *et.al*, 1989), the values corresponding to the resistance coefficients obtained are divided between 0.72 for their correct comparison. It is also considered that the maximum intensities observed correspond to the intermediate soil zone and that the studies of seismic hazard provides results for firm soil only. In order to obtain the values in each case corresponding to the other soil type, an amplification factor from the firm soil to the intermediate of 1.50 has been used, derived from the distribution of intensities observed in Mexico City in 1985 (Iglesias *et.al.*, 1987).

Table 6. Seismic coefficients proposed for 5% of damping

| Source | | c/T. Firm | c/T. Intermediate |
|---|---|---|---|
| Current regulation | | 0.16 | 0.20 |
| Maximum intensity 1985 | | 0.162/0.72/1.5= 0.15 | 0.162/0.72= 0.23 |
| Maximum intensity 1973 | | 0.440/0.72/1.5= 0.41 | 0.440/0.72= 0.61 |
| Intensity VII MM | K=0.06 | 0.240/0.72/1.5=0.22 | 0.240/.72=0.33 |
| | K=0.08 | 0.320/0.72/1.5=0.30 | 0.320/0.72=0.44 |
| Trigos, 1988 | | 0.26 | 0.26x1.50= 0.39 |
| Esteva y Ordaz, 1988, Zone B | | 0.16 | 0.36 |

Finally, in this work it was decided to adopt the seismic coefficients of 0.24 and 0.36 for firm and medium soft soil respectively, values that approximately cover the VII Mercalli intensity, that historically is quite frequent, and even the results of the studies of seismic risk available.

## SEISMIC ZONATION

Similar to Mexico City, the zonation map (Fig. 2) allows to distinguish a zone of firm soil, with periods less than 0.40 sec, different from the rest of the city, where the biggest period is of 0.74 sec (Table 3). From the above mentioned, it was decided to propose the map of seismic zonation of the Fig. 3 , which distinguishs a zone of firm soil (Zone A) of another of medium soft soil ( Zone B).

For seismic-resistant design, it was proposed the use of the design spectra defined by the expressions 2 and 3 and the Table 7, based on the seismic coefficients derived from the previous incised. The values recommended of the maximum dominant periods of the soil, Tb, was obtained upon multiplying the bigger periods corresponding to each zone in 1.50, this is: 0.40sec and 0.70 sec, in order to considering possible errors in the estimate of the natural period of the structures. The values of the exponent, r, correspond to those of the present code. In this way, the spectral ordinate, a, like percentage of the gravity acceleration, is calculated with the following expressions:

$a = c$, if $T < Tb$ (2)

$a = c\,(Tb/T)\,r$, if $T > Tb$ (3)

where T is the structural period of interest.

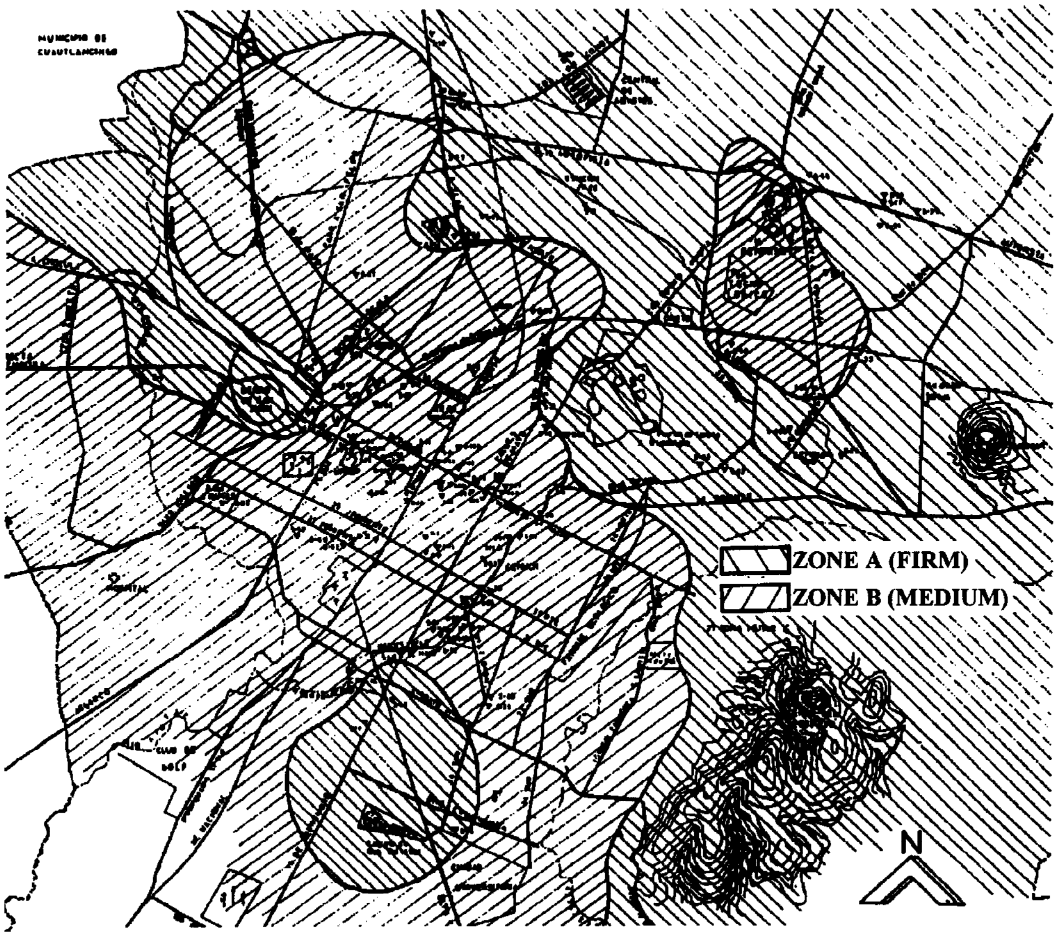


Fig. 3. Seismic zonation map.

Table 7. Design spectra recommended for the city of Puebla

| Zone | c | Tb(sec) | r |
|---|---|---|---|
| A | 0.24 | 0.60 | 1 / 2 |
| B | 0.36 | 1.00 | 2 / 3 |

## CONCLUSIONS AND RECOMMENDATIONS

In this work, a seismic zonation for the city of Puebla is proposed, obtained from available geological information and the use of ambient vibration measurements. The study of the historical seismicity, as well as the evaluation of five significant buildings damaged during the 1985 earthquakes, allowed to consider the studies of seismic risk available to the light of a vision of the seismic vulnerability of the city, with the purpose of propose the design spectra corresponding to the seismic zonation map.

This proposal should be considered as a first effort to incorporate the local available information to the seismic-resistant design of structures in Puebla. In order to improve it, it will be necessary to obtain more information and carry out more detailed studies. It is necessary to obtain accelerometric records of the local earthquake ground motion through the installation of accelerometers and it is also recommended to carry out deep drills outside downtown, that allow to confirm the results obtained with the ambient vibration measurements. In the future this information will allow to do seismic hazard studies that consider of local attenuation laws, as well as the amplification characteristics between the firm and soft soil. Finally, it is important to continue with the evaluation of the seismic capacity of the constructions of the city, in order to define their vulnerability and carry out studies of seismic risk that allow to take more rational decisions.

ACKNOWLEDGEMENTS

In order to carry out the evaluation of the sismo-resistant capacity of the studied buildings , we had the collaboration of the students of civil engineering of the Universidad Popular Autonoma del Estado de Puebla: J. Díaz, A. Cabañas, F.A. Lino and M. Patiño.

REFERENCES

Auvinet G. (1976). Estudio de Mecánica de Suelos para la ciudad de Puebla. *Memorias del VIII Congreso Nacional de Mecánica de Suelos*. Tomo II, No.13, Guanajuato, Guanajuato.

Esteva L. y Ordaz M. (1988). Riesgo sísmico y espectros de diseño en la República Mexicana. *Memorias del III Simposio Nacional sobre Ingeniería Sísmica*. Guadalajara, Jalisco: 420-458

Figueroa J. (1974). Sismicidad en Puebla; Macrosismo del 28 de Agosto de 1973, Informe 343, Instituto de Ingeniería, UNAM.

Gómez A., Ortega R., Guerrero J.J., González E., Paniagua J.P. e Iglesias J. (1989). Response and design spectra obtained from earthquake damaged buildings, *Earthquake Spectra*, V5, n1: 113-120.

Iglesias J., Robles F., De la Cera A. y González O.M. (1985). Reparación de estructuras de concreto y mampostería, Universidad Autónoma Metropolitana, México, D.F.

Iglesias J., Jara M., Aguilar J., Mota O., Terán A., Gómez A., Ortega R., González E., Guerrero J.J., Juárez H., Paniagua J.P. y Sordo E. (1987). Estudio de las intensidades del sismo del 19 de septiembre en la ciudad de México, Universidad Autónoma Metropolitana, México D.F.

Iglesias J., (1989). Evaluación de edificios de concreto en la ciudad de México. *Construcción y Tecnología*, IMCYC, V2, n15: 19-26.

Jara M., Aguilar J., Guerrero J.J. e Iglesias J. (1989). Vulnerabilidad sismica de la ciudad de Mexico. *VIII Congreso Nacional de Ingeniería Sísmica*, Acapulco, Guerrero: D76-D86.

Maison B.F. and Neuss C.F. (1985). Super Etabs. An enhanced version of the Etabs program, University of California, Berkeley.

Reglamento de Construcciones para la ciudad de Puebla, (1988), Gaceta Oficial.

Ruiz, C. (1992). Características geodinámicas de la ciudad de Puebla, Tesis de Maestría, Universidad Popular Autónoma del Estado de Puebla, Puebla, Puebla.

Seismic Workstation Software, (1988), Kinemetrics Systems, Pasadena California.

Trigos J.L. (1988). Riesgo sísmico construcciones y reglamentos en México. *Memorias del III Simposio Nacional Sobre Ingeniería Sísmica*, Guadalajara, Jalisco, 323-345.

Zeevaert L., (1988). *Sismo-geodinámica de la superficie del suelo*, Editorial e Impresora Int., México.