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PRELIMINARY SEISMIC ZONATION OF CHILPANCINGO, GUERRERO, MEXICO

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ABSTRACT

The results presented were obtained from the first stage of the project of seismic zonation of the city of Chilpancingo, Guerrero, based on the estimation in the field of the dynamic characteristics of the soil, the structural analysis of several buildings damaged in recent earthquakes and the study of local geology and regional seismicity.

KEYWORDS

Seismic zonation; dynamic structural analyses, seismic design parameters; dynamic characteristics of soils.

INTRODUCTION

The city of Chilpancingo, capital of the state of Guerrero, is located in one of the zones of highest seismic hazard in the country of Mexico (and in the world). For this reason, the Universidad Autonoma de Guerrero and the Universidad Autonoma Metropolitana established a working agreement in 1991 for the purpose of studying the seismic hazard of the city of Chilpancingo and propose seismic design parameters for use in seismic-resistant design of construction within the city, in accord with the zonification derived from the available information.

Although a seismic design regulation exists for the State of Guerrero, it is based on information obtained in the city of Acapulco (about 100 km distant) and the city of Mexico (about 200 km distant). This study is the first stage considered necessary to realize an investigation that addresses cultural and geological characteristics particular to the city of Chilpancingo.

This paper presents the results of the first phase of the project, and includes the geodynamic characterization of the city based on the determination in the field of the dynamic characteristics and local geology of the terrain. These characteristics, combined with estimates of maximum intensities produced in the study area by historical earthquakes, are used as the basis to propose seismic design parameters for the seismic zoning of the city.

TECTONICS AND SEISMICITY

The principal tectonic mechanism producing earthquakes which affect the city of Chilpancingo is subduction in the Mexican trench, where the Cocos plate is being consumed below the North American plate at the rate of about 7 cm/yr (A.A.P.G., 1980; Nishenko and Singh, 1987). In particular, Chilpancingo is strongly affected by intermediate depth earthquakes generated on the three closest segments of the shallowly dipping trench, the Central Guerrero, the San Marcos and the Petatlan, which include the trench between about 99.3°W and 101.8°W longitude. Although these are generally of moderate magnitude, resultant accelerations and intensities in Chilpancingo are relatively high because of the proximity of the epicenters to the city, and local geologic conditions promoting amplification within the city. Note that the Guerrero segment has not had a large earthquake since 1911 and is considered the one of the most dangerous seismic gaps in the world. Table 1 (from Figueroa, 1972) presents some of the major historical earthquakes of the Guerrero segment that have affected Chilpancingo with magnitude given in the Richter scale and intensities in the Modified Mercalli scale.

Table 1. Major Historical Earthquakes that have affected Chilpancingo. Richter Magnitudes and Modified Mercalli Intensities (Figueroa, 1972)

DATE	MAGNITUDE	INTENSITY	DATE	MAGNITUDE	INTENSITY
7 APR 1845	7.0	VIII	31 OCT 1909	7.0	V
19 JUL 1889	7.5	VI	31 MAY 1910	6.5	VI
16 JAN 1902	7.0	IX	16 DEC 1911	7.0	VII
26 MAY 1908	7.5	VI	28 JUL 1957	7.5	VIII
30 JUL 1909	7.7	VIII			

LOCAL GEOLOGY AND SUBSURFACE CONDITIONS

Geology of the Chilpancingo area (Fig. 1) was refined in the field using the original units of Leon (1976). Two bedrock and two superficial geologic deposits are present; limestone conglomerates of the Balsas Formation, clastic continental deposits of the Chilpancingo Formation, and older and younger alluvial deposits. Subsurface conditions are based on the work of Gama (1992), which includes 16 shallow and 7 deep borings within the city. Table 2 lists the location for the 7 deep borings and the locations of all are shown on the isoperiod map (Fig. 2).

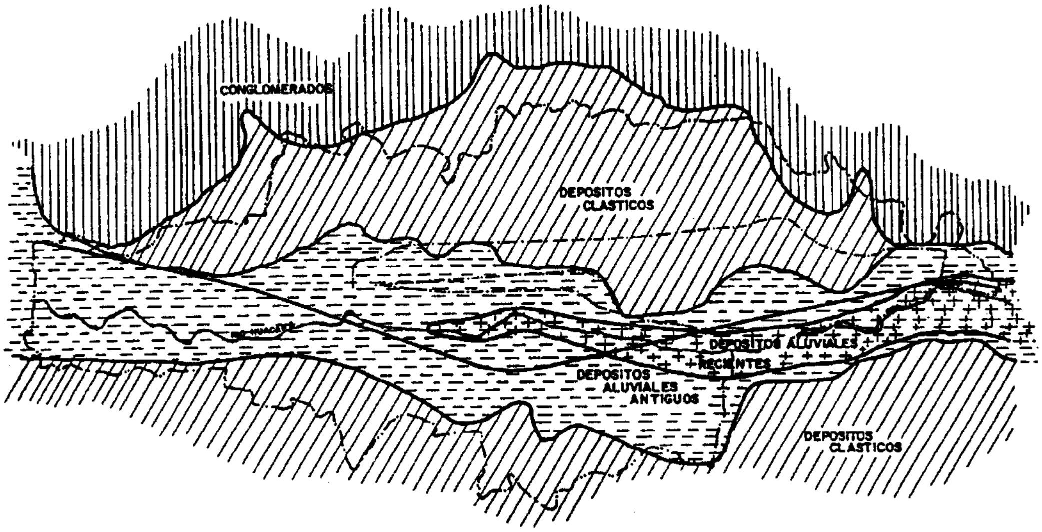

Fig. 1. Local Geology of Chilpancingo

GEODYNAMIC CHARACTERISTICS

It is possible to estimate the approximate natural period of soft deposits, **T**, using information provided by a deep borings using the elastic model of shear wave propagation following methods described by Zeevaert (1988).
where:

$$T=4\ \Sigma H_i/V_i \qquad (1)$$

H_i = Thickness of ith strata
V_i = Shear wave velocity in ith strata, or $V_i = (G_i / \rho_i)^{0.5}$
G_i = Dynamic shear module of ith strata
P_i = Density of material of strata i

Table 2 shows the results obtained for T in the 7 deep borings from Gama (1992). The values of G for the different strata were between 180 and 600 kg/cm^2. This is considered as firm material because the number of hits for a standard penetration test exceeded 50 in each case.

To extend the coverage of the geodynamic information, the values of the natural period of the terrain, T, determined from the deep borings were compared to the natural vibration of the terrain. The equipment used for this consisted of a Kinemetrics SSR-1 solid state digital recorder with a resolution of 16 bits, three access channels and a of 200 sps per channel, and two Kinemetrics WR-1 field seismic geophones with a nominal frequency of 20 Hz and an efficient response interval for periods of 0.05 to 5.00 seconds, controlled by a Toshiba 1000 laptop computer and corresponding software (Kinemetrics, 1988).

Table 2. Location of Intermediate Depth Boring sand Calculated Periods (Gama, 1992).

BORING	LOCATION	T(sec)
S-17	Ave. Hidalgo & Ave. V. Guerrero	0.51
S-18	Plaza de las Banderas	0.72
S-19	Ave. Rufo Figueroa	0.52
S-20	Ave. Benito Juarez & Quintana Roo	0.66
S-21	Ayuntamiento	0.66
S-23	Zocalo	0.47
S-24	Ave. B. Dominguez & 5 Febrero	0.72

Thirty sites were selected for sampling along the valley of the Huacapa river (Fig.2). At each station ten events of thirty second duration were registered in two orthogonal directions, N-S and E-W, utilizing a Butterworth filter that eliminated the frequencies higher than 15 Hz. The registers were recovered for all stations except at station #26, which were lost because of equipment malfunction. For the twenty events registered at each station (ten in each direction) the Fourier spectra of the signals was obtained, and a natural vibration period for the station was estimated by statistical analyses. The periods calculated from the information of the deep borings was used as a reference for comparison to the values obtained from the statistical analyses. These values were used to construct the isoperiod map (Fig. 2) using values of 0.35, 0.40, 0.50 and 0.60 second.

The area within the curve of the 0.60 second isoperiod corresponds to the central portion of the city (Fig. 2), which has developed in the central, low lying portions of the valley. This area is underlain by the oldest and deepest alluvial deposits. The isoperiod curve for 0.50 second follows the geology of the valley and has a longitudinal axis which closely follows the bed of the Huacapa River. In the northeast and southeast of the city, this curve invades the region of clastic deposits of the Chilpancingo Formation adjacent to areas where the thickness of the alluvial deposits of the river decreases abruptly. The limit of the 0.40 second isoperiod curve extends beyond the limits of the city and is principally in the region underlain by the clastic deposits of the Chilpancingo Formation. Locally it extends into alluvial areas where the deposits are a surface veneer over the clastics. Station 23 was located in a zone of firm terrain underlain by the well cemented limestone conglomerates of the Balsas Formation, outside the urban zone of the city on the highway to Tixtla. The natural period obtained at this station, 0.11 second, is representative of the firmest terrain of the region. Values of the natural period of vibration in Mexico City are delineated as firm terrain for values of T over 0.40 second, intermediate for values of T between 0.40 and 1.00 second, and soft for values of T longer than 1.00 second (Iglesias *et al.*, 1987). Using these guidelines, the valley of Chilpancingo only contains firm and intermediate terrain.

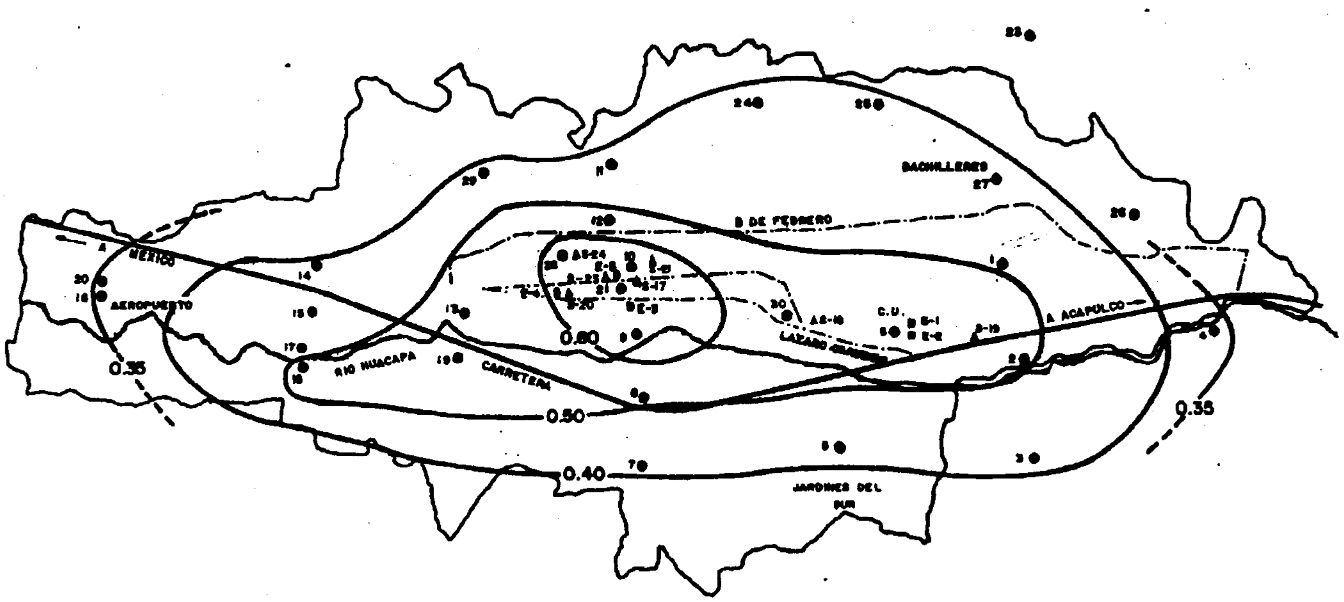

Fig. 2. Isoperiod curves map proposed for Chilpancingo

STUDY OF LOCAL INTENSITIES

An estimate of the maximum intensities in Chilpancingo from the September 19 and 20, 1985 Mexican trench earthquakes was used to determine the seismic resistance of five concrete buildings in the city which had available the necessary data of design and construction and were damaged during the principal shock and/or the largest aftershock of the 1985 earthquake sequence. The location of the five buildings is shown on Fig. 2. For each of the buildings, the coefficient of resistance, K (which is the coefficient of basal shear, c/Q, determined by the damages to the buildings), was derived using the simplified evaluation method proposed by Iglesias (1989).

To associate the maximum seismic intensity with the coefficient of resistance, the earthquake damages observed to a structure should be very serious following the classification of Iglesias *et. al.* (1985). However, the five buildings analyzed only suffered serious (i.e., not very serious) structural damage. A conversion factor of 0.75 was used to extrapolate the relationship from serious to very serious damage, based on the large number of analyses of damaged buildings in Mexico City in the 1985 events (Iglesias *et al.*, 1987). Additionally, for three of the buildings where detailed structural information was available, an evaluation was accomplished using the computer program SUPER-ETABS (Maison and Neuss, 1985). The values of K obtained from this procedure correspond to the seismic coefficient, c, if a reduction factor of Q = 4 is used. The values from both the simplified evaluation method (SEM) of Iglesias (1989) and from SUPER-ETABS is presented in Table 4. Using the historical earthquake information given in Table 1 which shows repeated MMI intensities of VIII in the city of Chilpancingo, and also considering that the event of 1902 resulted in MMI intensities of IX in the city, the data in Table 5 was derived, extrapolated from the values determined in Mexico City for the 1985 event. The intensity IX of 1902 corresponds to a coefficient of resistance, K, in the range of 0.11 to 0.14.

SEISMIC RISK ANALYSIS

The first approximation of the seismic risk to Chilpancingo was the evaluation of the scenarios possible. From this point of view, the 1985 Mexican Trench earthquake, whose maximum intensity was K = 0.10 (c = 0.40) from Table 2, can be considered as a representative shallow main event of the subduction zone. Considering the MMI intensity of IX from the 1902 earthquake, which corresponds to K = 0.14 (Table 4) with a corresponding c = 0.56, values were derived for what is considered the worst possible scenario from subduction zone events of intermediate depth. These latter events are more damaging to the city because the trench geometry (dipping northward) dictates that intermediate depth events on a trench segment will be closer to the city. The seismic hazard study of Trigos (1988) used general attenuation relationships to derive maximum values of acceleration and velocity for hard rock (firm) terrain in the city. These yielded a value of c = 0.48 for 5% dampening. Esteva and Ordaz (1988) presented a regional seismic risk analysis for the Republic of Mexico which employed general relationships of attenuation of the seismic intensity. They proposed a division of the country into four zones and proposed coefficients of seismic design without differentiating hard, intermediate and soft terrain sites, based on the intensities in Mexico City from the 1985 Mexican Trench earthquakes and considering an estimation of the local amplification factor.

Table 3. Coefficients of Resistance of the Buildings Evaluated (Gama, 1992). SEM = Simplified Evaluation Method, S-ETABS = SUPER-ETABS Software Program

BLDG	# of FLOORS	TYPE OF DAMAGE	K=c/Q SEM	K=c/Q S-ETABS	c SEM	c S-ETABS
E-1	3	Serious Struct.	0.09	0.07	0.36	0.28
E-2	4	Serious Struct.	0.10	----	0.40	----
E-3	5	Serious Struct.	0.07	0.08	0.28	0.32
E-4	7	Serious Struct.	0.08	0.10	0.32	0.40
E-5	8	Serious Struct.	0.09	----	0.36	----

Table 4. Modified Mercalli Intensities vs. Coefficients of Resistance (Jara *et. al.*, 1989).

MMI	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	$0.14 < K$

Table 5 presents a review of the values of the seismic coefficients derived from the scenarios considered and from the previously described building studies in Chilpancingo. Gomez and others (1989) report that the values of coefficients of seismic resistance obtained from static analyses are on the order of 72% of those derived from dynamic analyses for typical buildings of concrete of moderate height. The values in Table 6 are divided by 0.72 to present a correct comparison.

Likewise, considering that the values of the maximum intensities observed correspond to intermediate type terrain sites and the seismic hazard study yielded results only in firm terrain sites, to obtain in each case the values corresponding to the other type of soil, a factor of amplification of 1.50 was used on the values at firm soil sites to convert to those of intermediate, derived from the distribution of intensities observed in the city of Mexico in 1985 (Iglesias *et al.*, 1987).

Finally, in this study, seismic coefficients of 0.52 and 0.80 were adopted for firm and intermediate terrains respectively, values that cover the maximum observed intensities in the city of Chilpancingo and are compatible with the results of seismic risk studies available from other sources. If the coefficient of 0.86 proposed by Esteva and Ordaz (1988) is considered, with a factor of amplification of almost two for some sites, the resultant intensity is very high, similar to that observed Mexico City in 1985.

Table 5. Seismic Coefficients for 5% Damping.

SOURCE	c/T FIRM TERRAIN	c/T INTERMEDIATE
Actual Regulations	0.50	0.86
Maximum Intensity, 1985 Event	0.40/0.72/1.5 = 0.37	0.40/0.72 = 0.56
Maximum intensity, 1902 Event	0.56/0.72/1.5= 0.52	0.56/0.72 = 0.78
Trigos, 1988	0.48	0.48 x 1.50 = 0.72
Esteva and Ordaz, 1988 - Zone D	0.44	0.86

SEISMIC ZONATION

Similar to isoperiod maps for Mexico City, Fig. 2, the isoperiod map for Chilpancingo, permits the delineation of two zones; the higher lying, firm terrain, with periods less than 0.40 second, and the lower lying portions of the valley where the period is over 0.40 second with the highest determined of 0.72 second (see Table 3). The isoperiod curve for 0.40 second also nearly coincides with the outer edge or urbanization as well as the geologic contact between bedrock and superficial deposits (Fig. 1). Because of the nearness of the 0.40 second isoperiod to the limit of development, the seismic zonification map given in Fig. 3 is proposed. This map shows a zone of firm terrain (Zone I) and another of intermediate terrain (Zone II), conservatively adopted as the existing edge of development of the city, except in the southern portions, where the 0.40 second isoperiod curve was used.

To conclude this study of seismic-resistant design, the use of the spectra of design defined by the following relationships (2 and 3) and in Table 6 is proposed, based on the seismic coefficients derived above. The values proposed for the highest dominant period of vibration of the terrain, Tb, was obtained by multiplying by 1.50 the highest periods corresponding to each of the two zones defined above (0.40 and 0.70 second), for conservation to offset possible errors in the estimation of the natural period of buildings. The values of the exponent of the descending limb of the spectrum, r, corresponds to the regulations now in use.

In this manner, the spectral order, a, as a percentage of the acceleration of gravity, is given by the following expressions:

$$a = c, \text{ if } T \leq Tb \qquad (2)$$

and,

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

where T is the period of the structure being assessed.

Table 6. Seismic Coefficients of Design Recommended for Chilpancingo

ZONE	c	Tb(sec)	r
I	0.52	0.60	1/2
II	0.80	1.00	2/3

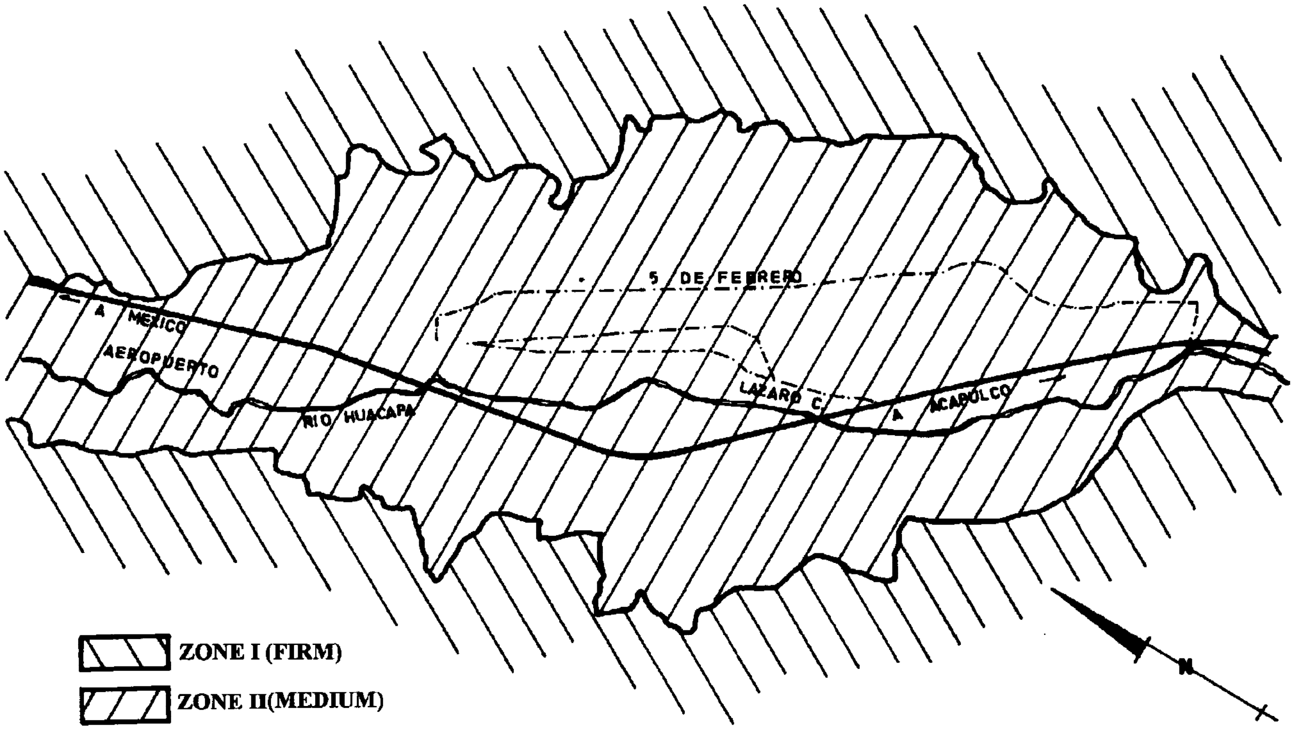

Fig. 3. Seismic Zonation map of Chilpancingo.

CONCLUSIONS AND RECOMMENDATIONS

This study presents a proposed seismic zonification for the city of Chilpancingo obtained from the available geological and geotechnical data complimented with the use of measurements of the natural vibration of the soil. The study of the historical seismicity of the region and the investigation of five buildings in the city damaged in the September 19-20, 1985 Mexican trench earthquakes indicates the vulnerability of the city, and allows quantification of earthquake effects, resulting in the preliminary determination of design spectra corresponding to the zonification.

This study should be considered as preliminary, with the intent to incorporate local available data to derive seismic-resistant design parameters for constructions in the city. As such, it is recommended that more precise geological and geotechnical information be obtained and a more detailed study be completed. The necessity of obtaining local registers of ground movement is emphasized, which requires the installation of additional accelerographs in the city (two are now in operation). Another recommendation is that more deep borings be made near the central, vulnerable portion of the city, to permit the conformation of the values obtained in the measurements of natural vibration of the soil accomplished in this study. With all of this information it will be possible to do an analysis of seismic hazard that considers the properties of local attenuation, to refine the characteristics of amplification present between the firm terrain and the softer alluvial deposits of the valley.

Finally, it is important to continue with the evaluation of the seismic capacity of the buildings and other structures in the city of Chilpancingo to determine their vulnerability, and to refine the seismic risk studies sufficiently to permit rational decisions at the governmental level for adopting regulations for new construction and rehabilitation of existing structures.

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REFERENCES

American Association of Petroleum Geologists (A.A.P.G.), (1980), Plate tectonic map of the circum-Pacific region, southeast quadrant, *American Assoc. of Petrol. Geol.*, Tulsa, Oklahoma, 5sh.

Esteva, L., and Ordaz, M., (1988), Riesgo sismico y espectros de diseño en la Republica Mexicana, *Memorias del III Simposio Nacional Sobre Ingenieria Sismica*, Guadalajara, Jalisco, 420-458.

Figueroa, J., (1972), Sismicidad en el Estado de Guerrero, *Revista Ingenieria*, 42, 1, 3-19.

Gama, A., (1992), Propuesta de microzonificacion para la ciudad de Chilpancingo, Guerrero, , Escuela Superior de Ingenieria y Arquitectura, Instituto Politecnico Nacional, México.

Gomez, A., Ortega, R., Guerrero, J.J., Gonzalez, E., Paniagua, J. P., and Iglesias, J., (1989), Response and design spectra obtained from earthquake damaged buildings, *Earthquake Spectra*, 5, 1, 113-120.

Iglesias, J., Robles, F., De La Cera, A., and Gonzalez, O. M., (1985), Reparacion de estructuras de concreto y mamposteria, *Internal Bulletin*, Universidad Autonoma Metropolitana, México D. F.

Iglesias, J., Jara, M., Aguilar, J., Mota, O., Teran, A., Gomez, A., Ortega, R., Gonzalez, E., Guerrero, J. J., Juarez, H., Paniagua, J. P., and Sordo, E., (1987), Estudio de las intensidades del sismo del 19 de septiembre en la ciudad de México, *Internal Bulletin*, Universidad Autonoma Metropolitana, México.

Iglesias, J., (1989), Evaluacion de edificios de concreto en la ciudad de México; Construccion y Tecnologia, *IMCYC*, 2, 15, 19-26.

Jara, M., Aguilar, J., Guerrero, J. J., and Iglesias, J., (1989), Vulnerabilidad sismica de la Ciudad de México, *VIII Congreso Nacional de Ingenieria Sismica*, Acapulco, Guerrero, D76-D86.

Leon, J. L., (1976), Estudio de mecanica de suelos para la ciudad de Chilpancingo, *Memorias de la VIII Reunion Nacional de Mecanica de Suelos*, Guanajuato, Guanajuato, 2, 71-81.

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

Nishenko, S. P., and Singh, S. K., (1987), Conditional probabilities for the recurrence of large and great interplate earthquakes along the Mexican subduction zone, *Bull. Seis. Soc. of America*, 77, 6, 2095-2114.

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

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

Zeevaert, L., (1988), *Sismo-Geodinamica de la Superficie del Suelo*, Editorial e Impresora Internacional, México.