11 WCEE

Paper No. 1239. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

SEISMIC ZONATION OF TUXTLA GUTIERREZ, MEXICO

G. ALONSO*, R. CRUZ*, M. RUIZ-SANDOVAL** and F. SANTOS*

*Escuela de Ingenieria Civil. Universidad Autonoma de Chiapas
Av. Belisario Dominguez s/n, Tuxtla Gutierrez, Chiapas, Mexico

**Departamento de Materiales, Universidad Autonoma Metropolitana
Av. San Pablo 180, Azcapotzalco, Mexico 02200 D.F.

ABSTRACT

Results form the first stage of the seismic risk study of Tuxtla Gutierrez, Chiapas, Mexico, are shown; they consist of an isoperiod map and a seismic zonation of the city and a seismic design spectra proposal. The results were obtained from ambient vibration measurements in 75 sites in the urban area, geotechnical information from ten boreholes, and the geological and topographical characteristics of the city, as well as information from a regional seismicity study.

KEYWORDS

Ambient vibration; code; isoperiod; Mexico; microzonation; modified Mercalli scale; Tuxtla; zonation.

INTRODUCTION

Tuxtla Gutierrez is the capital city of the Mexican state of Chiapas, which is located in one of the most important seismic regions of Mexico, besides Oaxaca, Michoacan and Guerrero states; this explains the interest in studying the dynamic characteristics of the soil and the seismic risk in the principal cities of this state. The building code in effect for Tuxtla Gutierrez (Reglamento, 1971) proposes seismic coefficients for three differents types of soils, which are classified according to load capacity criteria. This forced the preparation of maps of isoperiod curves, which allows to define the dynamic response of the soil during an earthquake and helps to establish a seismic zonation for the city. In the other hand, the acceleration values of the seismic design spectra proposed for Tuxtla Gutierrez (Trigos, 1988; Esteva *et. al.*, 1988; and CFE, 1993) do not take into account the specific conditions of the city. A suitable seismic zonation should consider the local geology to detect active faults, as well as the topographical characteristics which can generate amplifications of the seismic waves. Moreover, it is necessary to know the mechanical properties of soils in order to estimate the amplifications in relation to those on firm soil. In a common effort, the Universidad Autonoma de Chiapas (UNACH) and the Universidad Autonoma Metropolitana (UAM) signed an agreement in 1994 to study the seismic risk of Tuxtla Gutierrez and to propose seismic-resistant parameters for building design. This study has been organized with the following activities:

a) Gathering of the seismic, geological and geotechnical information available.
b) Ambient vibration measurements.

c) Estimates of soil natural periods using soil borings and ambient vibration information.
d) Definition of map of equal period curves for the city.
e) Proposal of a seismic zonation map.
f) Seismic risk analysis based on regional studies, historical information and professional expertise to, finally, propose a seismic design spectra.

REGIONAL GEOLOGY

Tectonism and Structural Geology

Tuxtla Gutierrez is located in the tectonic province of the Central Synclinal, which is surrounded by Transcurrence fault at north, and the Granitic Mass at south-west. The Central Synclinal is coincident with the physiographic region named Central Depression, because it is integrated by a topographic depression which is the result of the Grijalva Synclinal morphology. Other important structure which belongs to Central Synclinal is the Copoya´s Synclinal, a limestone structure just south of the city.

J. Figueroa and F. Mooser (1974) describe the Chiapas State faults observed from aerial photographs. The most important faults for Tuxtla Gutierrez are:

a) Chiapa de Corzo - Tuxtla Gutierrez - El Arenal.
b) Normal faults to Grijalva river - Sumidero - Chiapa de Corzo.
c) Ixtapa - Chicoasen - Copainala -Tecpatan.
d) Teran - Berriozabal - El Suspiro.
e) La Sombra - Trinitaria - Sur de Comitan - Soyatitlan - Venustiano Carranza.
f) West of Tuxtla Gutierrez - Comitan.

Local Geology

The city is located on the southern side of Copoya´s Synclinal. Late in the Tertiary and around the beginnings of the Quaternary, in Tuxtla Gutierrez valley were deposited continental clastic sediments, product of rock erosion. Last geologic events are represented by alluvial deposits that are located along the Sabinal River, which flows from west to into the Sumidero Canyon, near Tuxtla Gutierrez (Fig. 1). In the north-west side of the city, limestones are presented, and according to the geologic maps, this limestone extension belongs to the Angostura Formation and it continues to the north-east side. It exists a Tertiary formation constituted by rough sands with gravel and limestones, which were probably deposited in the Eocene period, due to the elevations occurred in the region and which cover permanently the limestones. The contact between the alluvial and the clastic continental deposits is not well defined. In some places limestones with gravel or rough sands with gravel are observed, e.g. the contact between this formation and the limestones located on the San Fernando road, at north-west.

Three morphological zones can be observed:
a) A strong slope zone where it exists an increasing urban development, at the northern part of the city.
b) A smooth slope zone, where most of the modern buildings are located, at the south and south-west.
c) An almost horizontal zone, at the center of the valley, constituted by firm alluvial soils. This is the historical zone of the city.

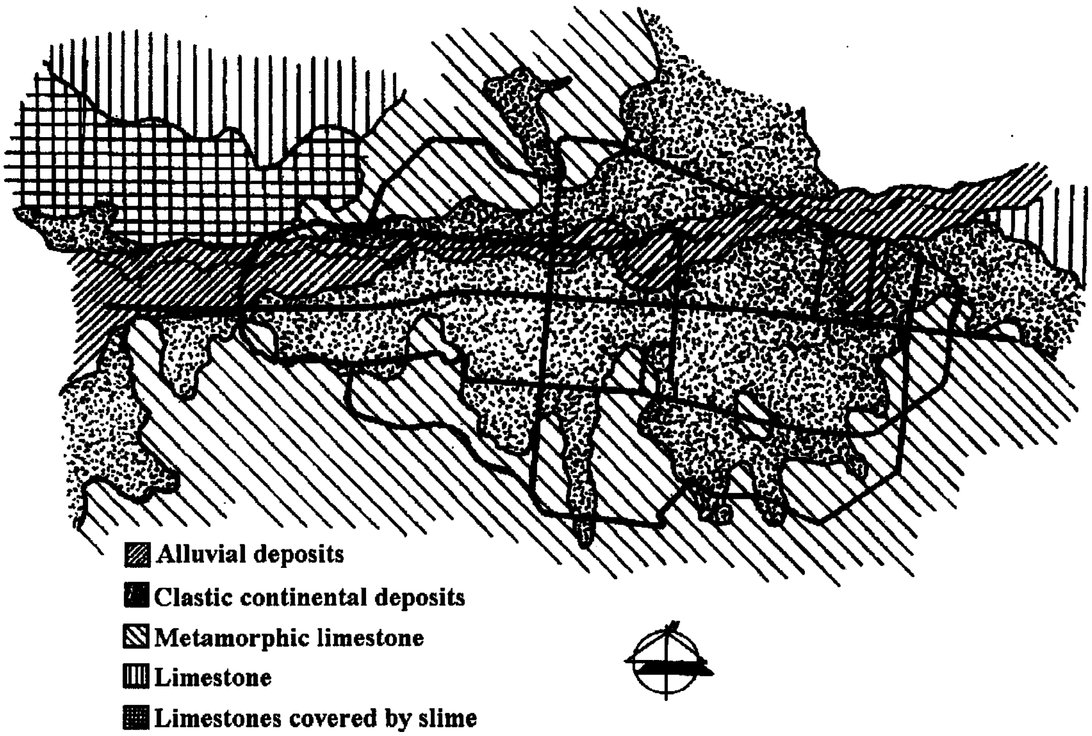

Fig. 1. Local geology of Tuxtla Gutierrez

SEISMICITY

All the Chiapas area is under the influence of actives foci associated with the subduction of the Cocos plate under the North-American plate, as well as continental focus, in which several important earthquakes have occurred, like in 1902 ($Ms = 7.8$), 1935 ($Ms = 7.3$), 1949 ($Ms = 6.5$), 1968 ($Ms = 6.0$), 1970 ($Ms = 5.6$) and 1995 ($Mb = 6.3$). In Chiapas there are superficial foci near the Pacific coast as well as deep foci (between 100 to 300 Km), which are abnormal for other seismic regions in Mexico. Most of the epicenters observed in the seismic map of the state are located near the Guatemala border and in front of the Pacific coast. Nevertheless, importants earthquakes have occurred in other zones.

GEOTECHNICAL PROPERTIES

In general, two kinds of deposits can be considered: one of them is formed by clastic continental deposits, constituted by limes an compact sand deposits, and other is formed by alluvial deposits, of compacted clay less than 5m deep. Alluvial sediments are located along the Sabinal river. Superficially this deposits are constituted by a black - high plasticity organic soil, under which organic soil with limes and sand limes can be founded. Rough sand and gravel only can be found at river bed (Fig. 1). For the analytical estimation of the natural period of the soil, information from ten soil borings was utilized. With the use of the elastic model of shear wave propagation, it can be assumed the incidence of S waves considering the deposits as formed by a single layer (Newmark and Rosenblueth, 1976), thus the natural period can be calculated by:

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

where:

H_i = Thickness of the ith layer.
V_i = Mean shear wave velocity of the ith layer = $(G_i / \rho_i)^{0.5}$

G_i = Shear modulus of the ith layer.
ρ_i = Mass density of the ith layer

This procedure was applied considering those superficial layers which have less than 50 blows per foot according to the standard penetration test. The period values and their location are displayed in table 1 and Fig. 2.

Table 1.- Periods obtained analytically

Soil-boring identification	Location	T (sec)
S-A	Lib. Nte. esq. Limón	0.21
S-B	Av. Central Ote. esq. 12 OteNte	>0.08
S-C	Tribunal Superior de Justicia	0.12
S-D	Libramiento "La Mexicanidad"	0.27
S-E	Blvd.Lic.Salomon Gonzalez B	0.25
S-F	Belisario Dominguez esq.18 PteSur	0.25
S-G	IMSS Col. el Periodista	0.20
S-H	Pemex	0.16
S-I	Cia. PICSUR	0.15
S-J	Cia. Cervecera Superior	0.20

AMBIENT VIBRATION AND ISOPERIOD MAP

Ambient vibration measurements were conducted on 75 sites distributed in the urban area (Fig. 2). The equipment used consisted of a SSR-1 Kinemetrics digital recorder with 16 bits of resolution, three channels and 200 samples per second. In addition, two WR-1 Kinemetrics seismic sensors with natural frequency of 20 Hz and a portable computer were used. Each site measurement consisted of ten events of 30sec each, which were registered in two orthogonal directions. A digital low-pass Butterworth filter, which eliminates frequencies greater than 15Hz, was used. Fourier spectrum was obtained for every one of the 20 events registered on each place by using the Seismic Workstation Software (Kinemetrics, 1989). From these spectra, natural frequency of the soil on each site was determined using a statstical analysis. To determine the natural period it was essential to know the analyticals period calculated from the borehole information. The greatest period founded was 0.33 sec, which corresponds to sites 10 and 22, which are located in the lowest part of the valley, an alluvial deposit zone, the lowest period of 0.11sec (site 17) is located on the clastic deposits.

An accelerometric station was recently placed by Red Interuniversitaria de Instrumentacion Sismica (Aguilar *et. al.*, 1996) near the Engineering School, at the University campus, which corresponds to site 75. The natural period obtained with ambient vibration measurements was 0.23 sec, that could be compared with the 0.18sec period obtained from a major earthquake occurred on October, 1995 (a_{max} = 450 gals). From these results, an isoperiod map was obtained for 0.15, 0.20 and 0.25 sec (Fig. 3).

SEISMIC RISK ANALYSIS

To estimate the seismic risk, it is necessary to evaluate several scenarios. According with the seismic history of the region, in 1902 occurred the most destructive earthquake for Tuxtla Gutierrez as well as other cities (Ms = 7.8). Figueroa assigned to this earthquake an intensity of X in the Modified Mercalli scale, for the town of Venustiano Carranza, and VIII for Tuxtla Gutierrez (Figueroa *et. al.*, 1974). Figueroa also assigned an intensity of VIII for Tuxtla Gutierrez to the 1935 earthquake (Ms = 7.3).

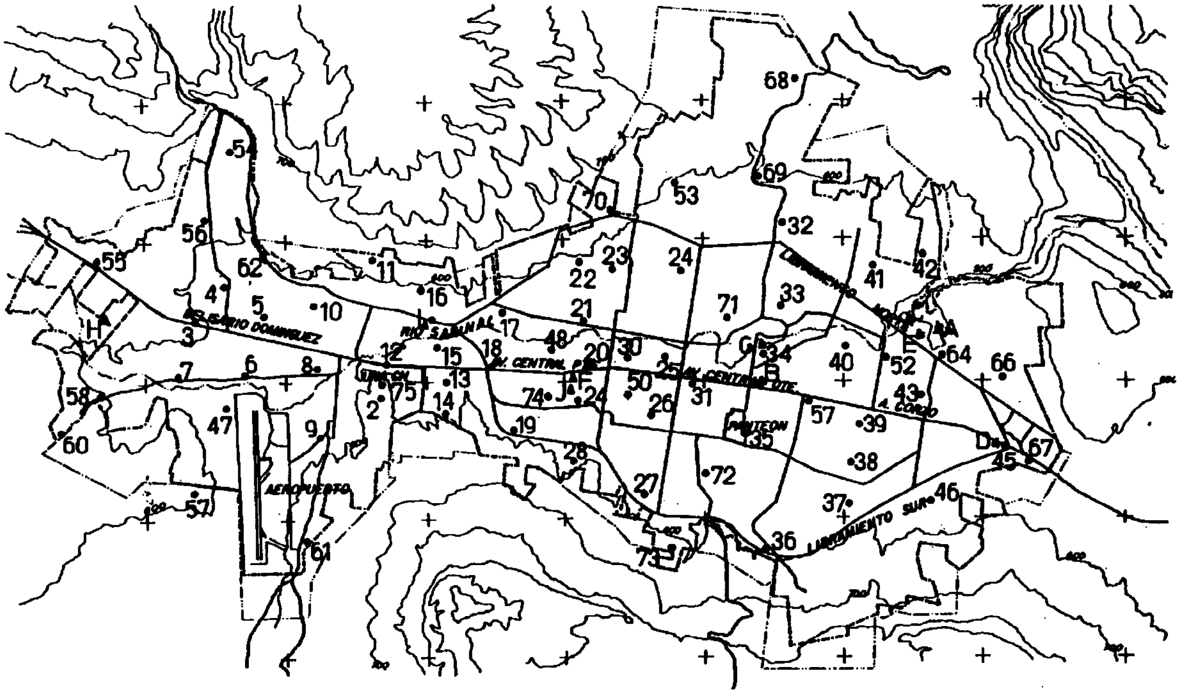

Fig 2. Location of soil-borings and ambient vibration measurements

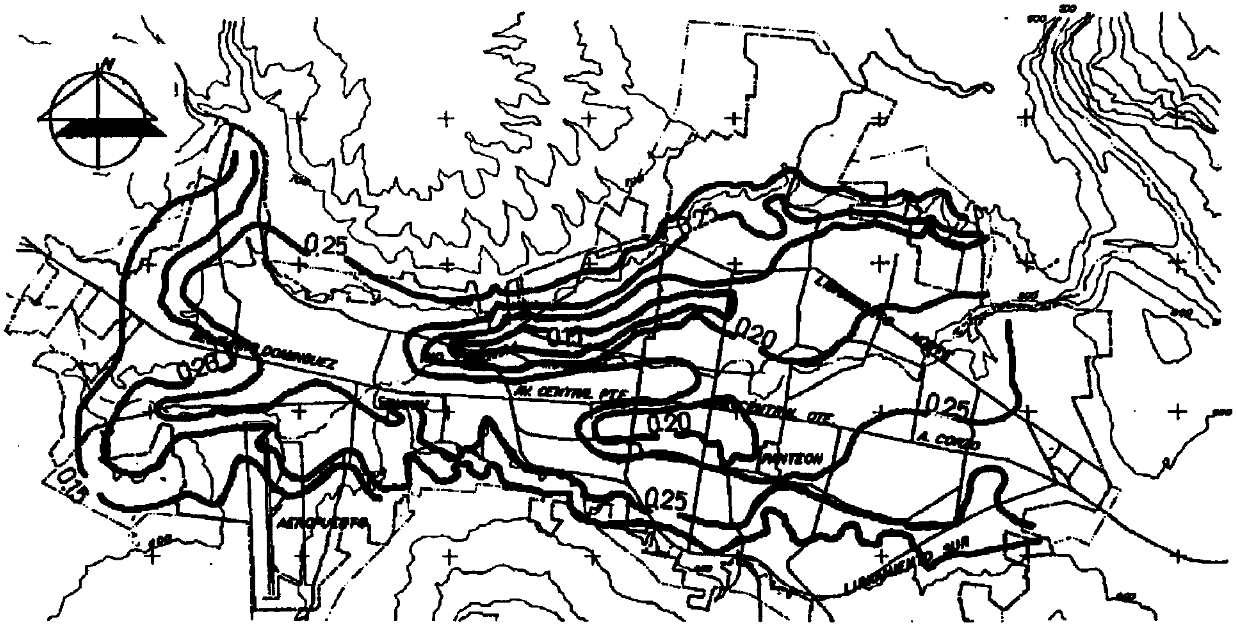

Fig. 3. Isoperiod map.

Recently, in October, 1995, a Mb = 6.3 earthquake which epicenter was located at 40Km from Tuxtla Gutierrez, produced some damages in buildings. This event, that is the most important ground motion recorded in Tuxtla Gutierrez, produced a modified Mercalli intensity of VII in the city. These three events have been the most important events for the city.

According to the relation between the modified Mercalli intensity and the base shear resistant coefficients k obtained from the study of the damages induced in Mexico City during the 1985 earthquakes (table 2), the k value corresponding to an intensity of VIII is in the 0.08 to 0.11 range, and is equivalent to a maximum spectral ordinate c = 0.44g, considering a ductility factor of Q = 4. Values presented in table 2 are related with the static analysis method, which produces shear forces approximately 72% of those obtained with the dynamic analysis, for typical mid-rise concrete buildings (Gomez *et. al.*, 1989), so the corresponding values derived from resistant coefficients were divided by 0.72 in order to obtain the maximum spectral ordinate assigned to Tuxtla Gutierrez: 0.61g for firm soil, the only soil type existing in the city.

Table 2. Modified Mercalli scale vs. base shear resistant coefficient, k (Jara, 1989)

Modified Mercalli scale	k
VI	$k < 0.06$
VII	$0.06 < k < 0.08$
VIII	$0.08 < k < 0.11$
IX	$0.11 < k < 0.14$
X	$k > 0.14$

Trigos (1988) presents seismic design spectras in firm soil for 116 cities in Mexico, obtained from a seismic risk study which uses general attenuations laws for peak acceleration and velocity values. His seismic coefficient proposal for Tuxtla Gutierrez is 0.72, corresponding to 5% damping and a return period of 50 years. Esteva and Ordaz (1988) proposed general attenuation laws of the seismic intensity and also proposed the division of the country in four seismic zones. According to these, Tuxtla Gutierrez is located in the highest seismicity zone, type D, which recommends seismic design values for firm, intermediate and soft soils, based on Mexico's city experience for local amplifications. So the seismic coefficient recommended in that study for the firm soil in Tuxtla Gutierrez is c = 0.44. The Handbook of Civil Constructions of the Federal Commission of Electricity (CFE, 1993) also uses general attenuation laws as well as optimal spectra; the country had also been divided in four zones, but Tuxtla Gutierrez is located on the seismic zone C. Their proposal establishes seismic design values for three kinds of soil: soft or type III, medium or type II and firm or type I; besides, it establishes a procedure which classifies a particular site according with those layers which are upper to the firm bed defined as the layer which shows shear velocities greater than 700m/s. According with their procedure, all boreholes correspond to type III or soft soil. Nevertheless, this is not consistent with the analytical nor experimental evidence given by the borehole information as well as by the ambient vibration measurements. Thus, a variant of this proposal is considered, adopting soil type I, or firm soil for Tuxtla Gutierrez which in this case lead to c = 0.36.

The Tuxtla Gutierrez building code establishs parametres for three different zones: c = 0.12 for firm soil, c = 0.24 for medium soil and c = 0.30 for soft soil. It can be noted that this proposal is based on load capacity criteria instead of dynamic behavior of the soil. Based on all previously indicated studies, displayed in table 3, a seismic design value of c = 0.60 is finally proposed, which cover the historical intensities as well as almost all the seismic risk studies considered. It is important to note that the response spectra for 5% damping recently obtained (Alonso, 1996) from the October 1995 earthquake (Fig. 5) shows a maximum spectral amplitude of 2.1g associated with T = 0.18sec, while for T > 0.30sec spectral amplitudes are lesser than 0.6g. This explains the absence of collapses in concrete structures of the city, which normally have a structural period greater than 0.3 sec.

Table 3. Seismic coefficients proposed for 5% damping

SOURCE	C
Present building code	
Soil type I	0.12
Soil type II	0.24
Soil type III	0.36
Maximum intensity (VIII)	0.60
Trigos	0.72
Esteva y Ordaz, 1988	0.44
CFE-93 (Soil I)	0.36

SEISMIC ZONATION

Because of the fact that greater than 0.33 sec were not found, and that the great mayority of the city presented periods less than 0.25sec, all the city was considered as firm soil, which borders are the municipal limits for urban projection considerated until the year 2010 (Secretaria, 1995), (Fig. 4).

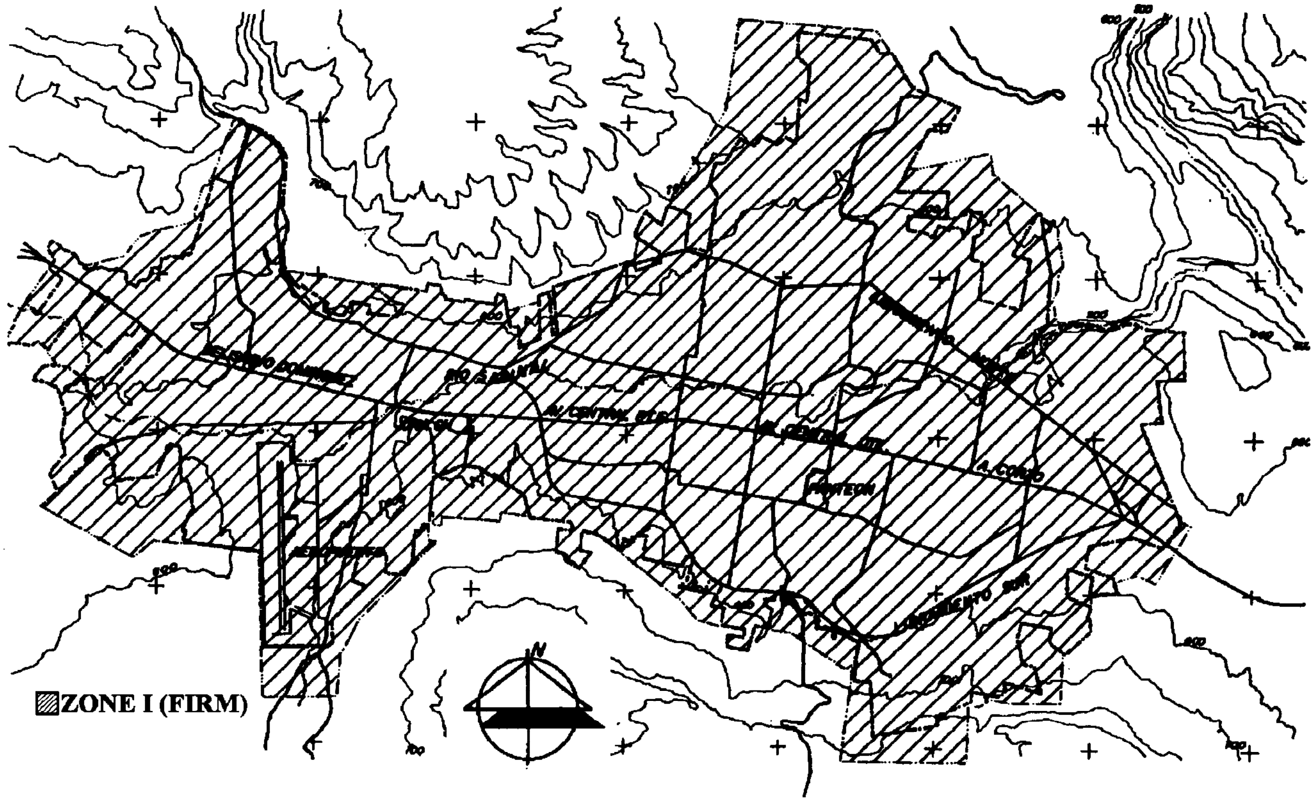

Fig. 4. Seismic zonation map.

For seismic design spectra, the parameters considered are the same to those traditionally used in Mexico codes for firm soil:

$$a = c, \text{ if } T < Tb \quad (2)$$

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

where:

T = Structural period
Tb = Maximum period which has assigned the seismic design value of c.
r = 0.5

Tb value, defined according to the maximum period obtained with ambient vibration is fixed to 0.50 considering a 50% increment in order to cover any uncertainty in the analysis of the structure period. Finally Tb was defined as Tb = 0.6sec taking into account the proposals of several other authors. Seismic design spectra finally recommended are shown in Fig. 5.

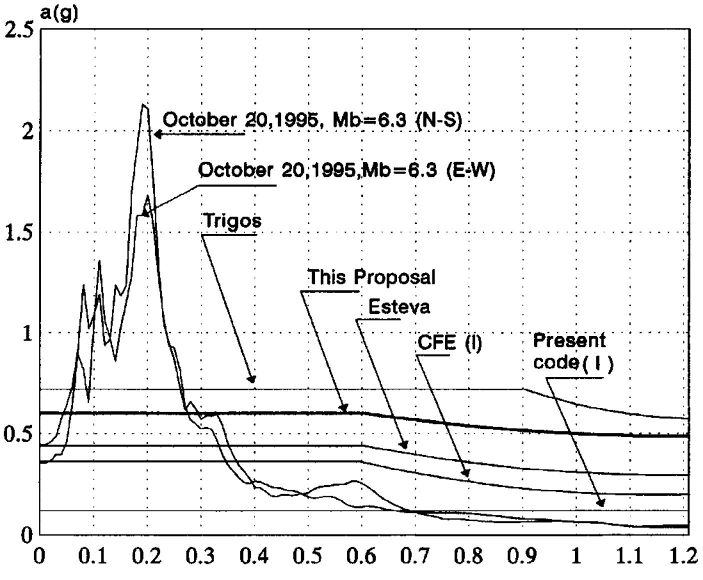

Fig. 5. Design spectra proposed

CONCLUSIONS AND RECOMMENDATIONS

A seismic zonation for Tuxtla Gutierrez obtained using ambient vibration techniques, the geotechnical information available, the topographical and geologic characteristics as well as the regional seismicity is presented. The recent earthquake occurred on October 1995 gives new data that allows to support the need to increment the present code's of the seismic coefficients. The response spectra corresponding to this event is covered by the design spectra proposed for periods greater than 0.30sec, range in which most structures pertain. New information from recent accelerometer installed in the city will allow to enhance the proposal presented in this work.

REFERENCES

Aguilar, J., Sordo E., Fernandez, A., Iglesias, J. (1996). Interuniversity strong motion accelerometric network in Mexico. *Proc. 11th World Conference on Earthquake Engineering*, Acapulco, Mexico (Accompanying paper).

Alonso G., R. Cruz, J.Juarez, T. Perea, R. Guinto, E. Sordo and A. Fernandez, (1996). Sismo del 20 de Octubre de 1995. *Reporte RIIS-05.* Mexico

Comision Federal de Electricidad (CFE), (1993). *Manual de Diseño de Obras Civiles, Estructuras, C.1.3. Diseño por sismo, CFE,* Instituto de Investigaciones Electricas.

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

Figueroa, J. y F. Mooser (1974). Sismicidad en Chiapas. Informe del Instituto de Ingenieria, UNAM.

Gomez A., Ortega R., Guerrero J.J., Gonzalez E., Paniagua J.P. and Iglesias J., (1989). Response and design spectra obtained from earthquake damage buildings. *Earthquake Spectra,* V5, nl: 113-120

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

Kinemetrics Systems, (1979). Seismic Workstation Software, Pasadena, California.

Newmark, N. y Rosenblueth, E., (1976). *Fundamentos de Ingenieria Sismica,* Editorial Diana, Mexico

Reglamento de Construcciones y Servicios Urbanos de los Municipios de Tuxtla Gutierrez, Tapachula, San Cristobal de las Casas, Comitan, Tonala y Villaflores (1971). *Periodico Oficial.* Gobierno del Estado de Chiapas.

Secretaria de Desarrollo Urbano y Comunicaciones, (1995). Actualizacion del Plan de Desarrollo Urbano del Centro de Poblacion de Tuxtla Gutierrez, Chiapas. H. Ayuntamiento de Tuxtla Gutierrez, 1992-1995

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