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Seismic Microzonation of the City of Puebla, Mexico

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SYNOPSIS We gathered information concerning the seismic response of the city of Puebla including: surface geology and hydrology, bore-hole data, damage information for two destructive earthquakes, and earthquake records in four strong motion instruments that have operated in the city. Additional data was obtained from three experiments: microtremor measurements in 39 points within the urban zone; installation and operation of a temporal digital seismograph network; a small scale refraction experiment. Consideration of all data together allows to draw a coherent picture of site effects in the urban zone. Based on these results, we propose a preliminary seismic microzonation map for the city of Puebla.

INTRODUCTION

The city of Puebla is located 110 km to the SE of Mexico City, precisely at the limits between zones 1 and 2 of the seismic risk map of Esteva (1970). During its history, Puebla has suffered from several destructive earthquakes, with data going back to 1523 (Figueroa, 1974). The most important was that of August 28, 1973 ($m_b=6.8$, 500 casualties, 1600 wounded, Figueroa, 1974). The explosive growth of the city in recent years and the high probability of being affected by large earthquakes impose the need of a modern building code, that must include consideration of expected site effects.

In this paper we present the results of a site effect study in the city of Puebla. The objective was to map the differences of the seismic response within the urban area due to changes in local geology. To this end, we compiled pertinent information that included: surface geology and hydrology, bore-hole data, detailed damage information, and strong motion records. Additionally, we conducted experiments to acquire relevant data: microtremor measurements in 39 points within the city, installation of a temporal digital seismograph network, and a small scale refraction experiment. Based on all this, we propose a preliminary seismic microzonation map for the city of Puebla.

GEOLOGICAL AND GEOTECHNICAL DATA

Geological data for the city of Puebla was compiled from Auvinet (1976) and the different scale maps of INEGI. The basement of the geological sequence consists of Cretaceous limestones. On this basement lies a sequence of mixed volcanic (mainly tuffs) and sedimentary deposits. The volcanic activity that produced these deposits is related to the evolution of the Mexican Volcanic Belt. Within the city, outcrops of basalt and silty tuffs appear to the South and West. To the East of the city, reddish basaltic scoria forms a small hill. In the rest of the city outcrops consist of alluvial deposits interlayered with tuffs. Along the different rivers that cross the city, there are gravel layers in a silty sandy matrix. Finally, there are some outcrops of travertine. Geological data was concentrated in the map of Fig. 1.

Geotechnical data is scarce in Puebla. It was possible to obtain data from a total of 50 bore-holes from Auvinet (1976) and Jiménez (1994, pers. comm.) with a description of the soil column and SPT values. Depth of investigation seldom goes below 20 m. The soil column data allowed a

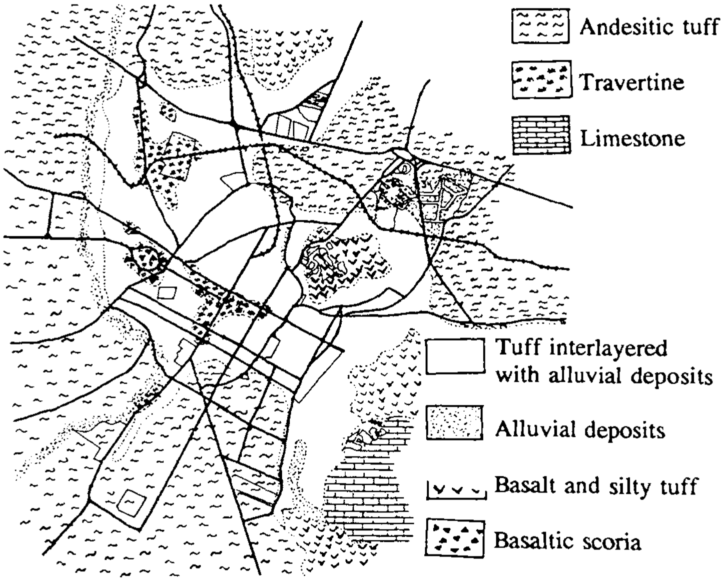

Fig. 1. Geological map of the city of Puebla. Thick lines are large avenues for reference.

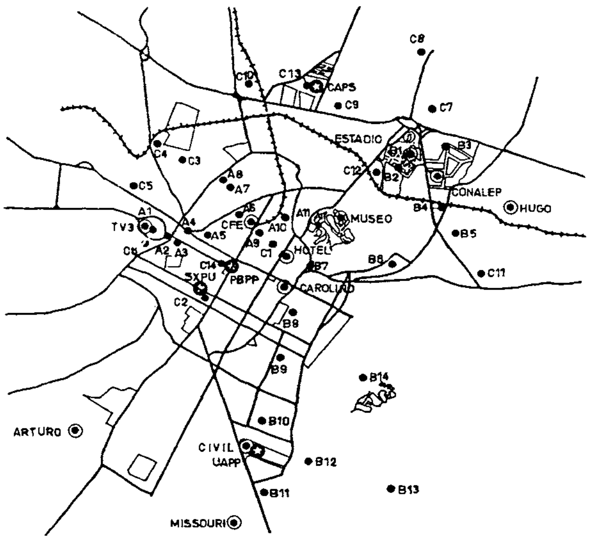

Fig. 2. Measurement points of microtremors, together with location of digital seismographs and accelerographs.

better understanding of the uppermost geological structure and was very useful in the elaboration of Fig. 1. SPT data was used to estimate shear wave velocity (Vs) against depth for the first few meters. To this end, we used empirical correlations between SPT and Vs proposed in the literature.

RESULTS FROM MICROTREMOR MEASUREMENTS

Microtremor measurements is a well established technique for the evaluation of dominant period (T_0) of surface sediments. A review of the application of microtremor data in Mexico was presented in Lermo and Chávez-García (1994). These authors compared different processing techniques and showed that the best results were obtained using Nakamura's technique (Nakamura, 1989), which consists in computing spectral ratios of horizontal relative to vertical motion recorded at one site. This technique allowed not only a reliable estimate of T_0, but also a first estimate of the maximum amplification factor (A_r). In this paper we have used this technique to analyze microtremor records.

We measured microtremors at 39 sites in the city of Puebla. The equipment used was a DR100 seismograph by Sprengnether, coupled to three seismometers of 5 s natural period by Kinemetrics. The location of the measurement points is given on Fig. 2. At each point, we recorded ambient ground vibration for two minutes, and selected 4 to 6 windows of 20 s duration for the analysis. An example of the results is shown on Fig. 3. We observe a good agreement between both horizontal components, where a clear peak appears with small standard deviation. Fig. 4 presents the distribution of T_0 based on microtremor measurements. T_0 is comprised between 0.2 and 2.5 s. Longest periods appear to the NE of the city, while in most of downtown T_0 varies between 0.3 and 0.8 s. The empirical transfer functions obtained from microtremor measurements were also used to determine A_r. Most of the observations indicate A_r between 2 and 5, with only two points showing amplitudes larger than 10. This suggests that there are no significant differences in amplification between different geological formations.

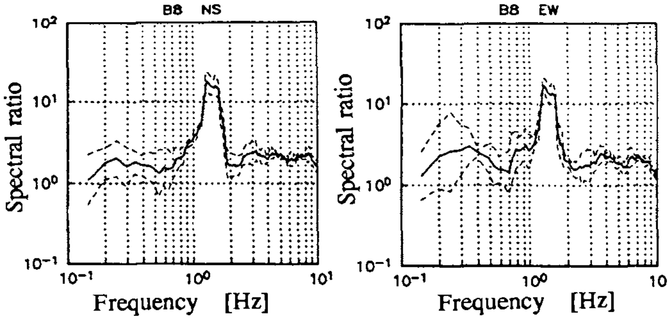

Fig. 3. Example of transfer function from microtremor data. Continuous line: average for several data windows. Dashed lines: average plus or minus one standard deviation.

SITE EFFECTS FROM STRONG MOTION DATA

Four accelerographs have operated within Puebla. The stations are labelled UAPP, PBPP, CAPS and SXPU on Fig. 2. There are in total 18 strong motion records from 15 events to date. However, these records are not useful for computation of standard spectral ratios (Borcherdt, 1970) due to two problems: only two events were recorded by more than one instrument, and no accelerograph is located on firm ground. In face of these problems, we applied again Nakamura's technique. Lermo and Chávez-García (1993) showed that this technique allowed to estimate local amplification using earthquake records on only one station.

We computed spectral ratios of the horizontal relative to the vertical components of acceleration for each strong motion record. We compared T_0 obtained from strong motion records with that obtained from microtremor records at the same sites and found very good agreement in all four cases.

SITE EFFECTS FROM WEAK MOTION DATA

Spectral ratios of weak motion data have been used to estimate site effects caused by local geology (Borcherdt, 1970). We installed a temporal seismograph network to record small earthquakes on different types of soil. The stations used were 6 PRS-4 digital seismographs by Scintrex, with triaxial, 1 Hz seismometers LE-3D by Lennartz. 11 sites were instrumented, keeping always one station at site MUSEO (Fig. 2), the reference station. During its operation, this network recorded 7 events in three or more stations.

Analysis of the data was done using the standard spectral ratio technique as well as Nakamura's tecnique. In almost all the cases we observe a very good agreement between both techniques. However, in some cases, Nakamura's technique showed a spurious maximum, larger than the maximum determined from the standard technique. In these cases, the spurious peak could be easily identified as it occurred at frequencies below the natural frequency of the seismometer. Table 1 shows the resulting values of T_0 and A_r determined for each of the sites from weak motion records. We confirmed that microtremor measurements at the sites of the weak motion instruments yielded the same values of T_0.

TABLE 1. Dominant period and maximum amplification from weak motion records

STATION	Weak motion records			
	Standard		Nakamura	
	T_0	A_r	T_0	A_r
TV3	0.5	4	0.5	4
CAROLINO	0.7	4	2.0	3
CONALEP	1.1	4	2.2	4
CFE	0.75	2		
CIVIL	0.6	3	0.6	2
MISSOURI	0.75	7	0.75	6
ARTURO	1.0	3	2.0	3
HUGO	0.9	3	0.7	3
HOTEL	0.9	3	0.8	3

SMALL SCALE REFRACTION STUDY

As an additional effort to collect relevant data we performed a small scale refraction experiment. The selected site coincides with C12 on Fig. 2. As it was not possible to use explosives, we used weight drop and hammer as energy sources. The recording equipment were the same PRS-4 used for the seismograph network. Two profiles were recorded, testing different source types each time. We could estimate P and S wave velocities for a two layer model. The first layer has a thickness of 10 m, S wave velocity (Vs) of 200 m/s and P wave velocity (Vp) of 350 m/s. The underlying material has Vs of 450 m/s and Vp of 600 m/s.

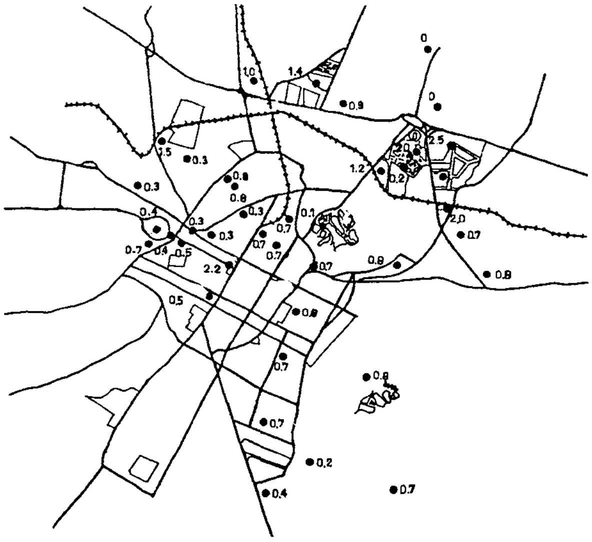

Fig. 4. Isoperiod map from microtremor data.

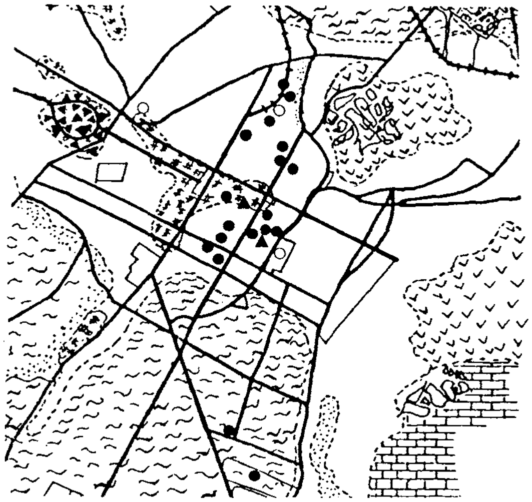

Fig. 5. A detail of Fig. 1. We have superposed damage distribution for two earthquakes. Open circles: light damage. Filled circles: heavy damage. Filled triangles: collapse.

We also estimated an attenuation factor (Q) from the regression of the largest amplitudes recorded at each station for each component of motion and for different frequency bands. This means that we cannot discriminate between intrinsic attenuation and scattering. However, the Q values we determined are indicative of overall attenuation effects in the topmost layers. These values are, in average, 2 around 1 Hz, 5 around 3 Hz, and 10 around 6 Hz. These low values suggest large attenuation of waves propagating in the topmost soft soil layers. This may explain the low to moderate amplification factors determined throughout the city.

DISCUSSION

We will now discuss the correlations among data of different kinds. Let us compare surface geology with damage informations for destructive earthquakes. There are only two events for which detailed data is available: August 28, 1973, (epicentral distance 90 km), and September 19, 1985, (epicentral distance more than 400 km). For the 1973 event, and starting from the report by Figueroa (1974), we revised the newspaper accounts and made a list of damaged structures, together with its precise location. As regards the second event, only three buildings were affected in Puebla. Damage data from these events is shown on Fig. 5, together with surface geology from Fig. 1. We are aware that some

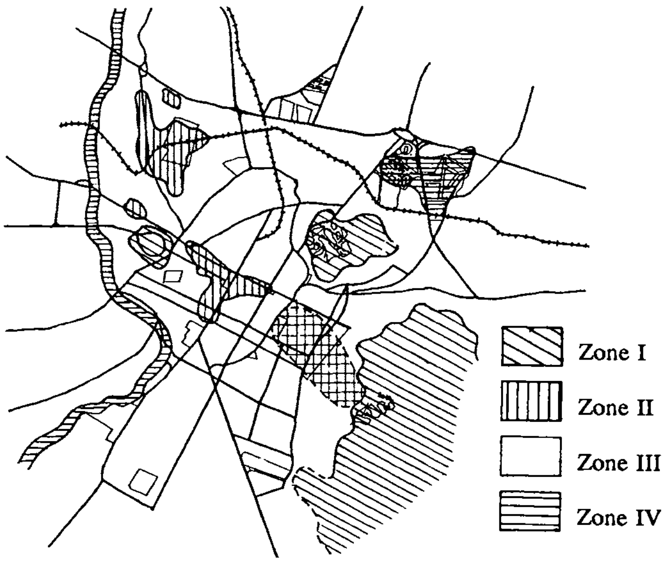

Fig. 6. Preliminary seismic microzonation map for the city of Puebla. The crossed vertical and horizontal lines show the zone where large amplification was observed.

of the damages may have resulted from defective structures with no direct relation to ground shaking. Most of the damages occurred on the more recent formation (shown in white). No damage appears to the NE of the city, where we observed long periods, but this may be due to the fact that this zone has developed only recently and then most of the structures are small houses, rigid relative to dominant period of the ground. Fig. 5 suggests that there are significant differences between ground shaking on alluvial deposits and that on travertine, where no damaged structures appear. The travertine outcrops in the historical center of the city, where density of buildings has been high, and structures are homogeneous as regards its height, structuring and materials.

As regards distribution of T_0, the largest values (2 to 2.5 s) appear to the NE, on sands and silts. At site MUSEO, where basalt outcrops, T_0 is very low, 0.1 s. In the rest of the city we observe no systematic tendency, although, in average, T_0 is smaller on tuffs than that on the mixture of tuffs and alluvial deposits. The results of 1D modeling (not shown) suggest that the transfer functions obtained from microtremors, and weak and strong motion data are coherent with the computed response of the topmost layers of soil. Therefore, we have confidence on the robustness of Fig. 4.

Taking into account all the data, we propose the seismic microzonation map of Fig. 6. We do not claim this map to be final and regard it as preliminary. We have differentiated four zones. Zone I is considered firm soil (limestones and basalts) with low dominant period (0.1 to 0.3 s). Zone II consists of the travertine outcrops, based on the damage observations discussed above. Zone III comprises the largest part of the city, where outcrops consist of alluvial deposits and volcanic tuff and dominant periods are around 0.8 s. We propose a zone IV in two parts of the city: the NE zone, reported by Auvinet (1976) as consisting of compressible soils, where dominant period reaches 2.5 s, and the river bed of Atoyac river, based on results for station ARTURO, extrapolated to all the river bed given the hydrographic importance of this river. Finally, we have differentiated with dotted line part of Zone III. This is due to the results for two microtremor measurements which indicate amplification larger than a factor 10. We suggest that particular care should be taken in this zone until we have additional data.

CONCLUSIONS

We have presented a study of the seismic response of the city of Puebla. We used information from surface geology and hydrology, bore-hole data, damage information for past destructive earthquakes, and strong motion records from four instruments. Additionally, we measured microtremors at 39 points within the city, installed and operated a digital seismograph network, and performed a small scale refraction experiment. Putting all the data together, we were able to propose a preliminary seismic microzonation map for Puebla. Our results stress the necessity of incorporating data of different kinds in a microzonation study. Different data is complementary and allows to draw a coherent picture of site effects caused by local geology within the city.

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