

EMPIRICAL TRANSFER FUNCTIONS TO BUILD SOIL CLASSIFICATION MAPS FOR SEISMIC DESIGN

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ABSTRACT :

Most important cities in Mexico lack geotechnical zonation maps as aids for seismic design. This paper proposes a methodology for combining those maps with spectral shapes obtained applying Nakamura's technique (HVNR) on microtremor records. The technique also uses the parameter $V_{s, 30}$ and the code from The National Earthquake Hazard Reduction Program, NEHRP-2000. The technique was applied to the city of Puebla where five distinct spectral shape types were identified corresponding to an equal number of soil-type sites. Results validate the usefulness of $V_{s, 30}$ as a parameter and also allowed for the construction of a zone map for foundation design.

KEYWORDS: Site effects, microtremors, microzonation, classification of sites for seismic design, $V_{S, 30}$.

1. INTRODUCTION

Seismic design of structure requires the consideration of site effects. For decades, design codes have included geotechnical criteria for defining specific seismic design spectra. In Mexico City, for example, design spectra have been differentiated ever since the 1960's in term of soil deposit thickness and a simple classification of soil types. Following basically the same approach, Seed (1976) suggested that soil or soil deposits could grossly be grouped into: a) rocks or hard soils, b) firm soils or rocks, c) soft soils. Presently, site classification in many current building codes is based on average shear wave velocity and dominant period which can be applying Nakamuras technique to ambient vibration records. Some international codes now use V_{s30} as an additional zoning criterion parameter, as suggested in the National Earthquake Hazard Reduction Program, NEHRP-2000 (Dobry et al., 2000) and in the Eurocode 8, 2004 (Sousa et al., 2006). In what follows we have adapted the same basic approach to obtain geotechnical zoning maps for the city of Puebla in central Mexico.

2. METHOD

The geotechnical zoning map for the city of Puebla shown in the upper part of Figure 1 was produced by Azomoza et al (1998) from a collection of geological, geophysical and geotechnical soundings. The lower part of the figure shows in detail a portion of the larger map, the historical center of the city which is our study area. There are eight geotechnical zones in Puebla but only four of them are present in the study zone namely, hydrothermal deposits (travertine), eolic soils of volcanic origin, basaltic tuff and alluvial deposits (Auvinet, 1976). Travertine has also been mapped by Azomoza et al (1998) and is also indicated in the lower part of the figure.

Our method requires five other steps: 1) recording microtremors or earthquakes; 2) identification of families of empirical transfer functions (ETFs); 3) calculation of theroretical transfer functions (TTF); 4) classification of soil types within each microzone; 5) correlation of data to define seismic microzones. These steps are succinctly described in the following paragraphs:





Figure 1 Upper part: Geothechnical Map of the City of Puebla (Azomoza, et al, 1998). Lower part: study zone with geotechnical zones within.

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First step: recording microtremors or earthquakes. This is used to obtain quantitative estimates of site effects from the spectral shapes of ETFs derived applying the Nakamura HVNR technique for microtremors or, in the case of earthquakes, either the standard technique (SSR) or the Nakamura HVSR technique (Lermo et al., 1993; 1994a,b; 1995). Typical empirical transfer functions (HVNR) are illustrated in Figure 2 from a collection of microtremor records obtained at a site in the study zone. Thin colored lines are spectral ratios for several time windows and the thick dark line is the average spectral ratio.



Figure 2 Empirical transfer ratios from a collection of microtremor records obtained at a site in the study zone. Thin colored lines are spectral ratios for several time windows; the thick dark line is the average spectral ratio.

Second step: identification of families of empirical transfer functions (ETFs). This process leads to defining seismic microzones in which the seismic response of soil deposits is similar. The plots in Figure 3 show the families of ETFs that we identified as well as their spatial distribution in the corresponding map. It should be Note that each spectral family does indeed display a particular spectral shape and also note that their spatial distribution is closely linked to the presence of different soil types: alluvial deposits, altered travertine and sound travertine as well as volcanic basalts.

Third step: calculation of theroretical transfer functions (TTF). These are meant to be representative of average seismic movements in a given seismic zones. Actual shear wave velocity profiles determined in Puebla from twelve downhole soundings, were used to define average soil and rock profiles at each of the microzones identified in the previous step from ETF families (Ovando et al, 2000; Azomoza et al, 1998). Geological and geotechnical data included thicknesses of relevant strata as well as densities, internal damping ratios as well as their corresponding shear wave velocities. Damping ratios were assigned following suggestions put forth by Avilés and Trueba (1991). TTFs were then obtained applying Haskell's (1962) method to a representative average stratified media, one for each of the four microzones defined previously. In applying this method, horizontally polarized shear waves were assumed to propagate vertically. Geotechnical and stratigraphical parameters were adjusted by trial and error until a best fit ETF was obtained.

Adjusted shear wave velocity (Vs) profiles for each microzone are shown in Figure 4 together with the profiles obtained from the results of down-hole tests. The plots in Figure 5 allow for comparisons of actual transfer functions obtained from measurements at zones having alluvial deposits, altered travertine and basalts with the corresponding TTFs obtained as explained above.

Relative amplifications of ETFs derived from microtremors are usually underestimated (Lachet and Bard, 1994; Bard, 1995), and it is therefore necessary to modify these to get better estimates of actual amplifications. In order to assess how important is this underestimation, we obtained standard spectral ratios (SSR) from actual seismic

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signals from a magnitude 7.0 event recored on 15 June, 1999 (Singh et al, 1999) in a few sites within the study zone, in the zones with altered travertine and alluvial deposits as well as in a rock outcrop out of the city. As seen in Figure 5, SSRs obtained during that event and indicated with thick green lines, define an envelope that follows transfer functions obtained from microtremos (FTE) as well as the theortical transfer functions (TTF). Hence, the reliability of our proposed TTFs can in general be ascertained.



Figure 3 Map of the study zone with the spatial distribution of the families of ETFS we identified.





Figure 4 Adjusted shear wave velocity profiles from obtained from the results of down-hole tests.



Figure 5 Plots allow for comparisons of actual transfer functions obtained from measurements at zones having alluvial deposits, altered travertine and basalts with the corresponding TTFs obtained as explained above.

Fourth step: classification of soil types within each microzone. According to criteria developed by The National Earthquake Hazard Reduction Program NEHRP-2000 (Dobry et al., 2000), soils may be classified in terms of $V_{s, 30}$ as expressed by equation 1. $V_{s, 30}$ is defined from the time taken for a shear wave to traverse the first 30 m of a soil or rock deposit. Table 1 shows the classification suggested by NEHRP.

$$V_{S30} = \frac{\sum_{i=1}^{n} d_i}{\sum_{n=1}^{n} \frac{d_i}{V_{si}}}$$
(1)

Where d_i is the thickness of the i^{th} layer between 0 and 30 m and V_{si} is the shear ware velocity layer in the i^{th} layer (Boore, 2004).



Soil Profile Type	Rock/Soil Description	V _{S, 30} (m/s)
А	Hard rock	>1500
В	Rock	760 - 1500
С	Very dense soil/soft rock	360 - 760
D	Stiff soil	180 - 360
E	Soft soil	<180
F	Special soils requiring, site-specific	-
	evaluation	

Table 1	Site clas	sifications	using V	$V_{S_{30}}$ as	an i	ndicator	of site	response	(NEHRP	-2000).
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Values of $V_{S,30}$ were determined from de adjusted shear wave velocity profiles shown in red in Figure 4 with the exception of the sound-travertine microzone where they were taken from the results of down hole soundings. Table 2 summarizes the $V_{S,30}$ values we found for the study zone in the historic center of Puebla

Table 2 Site classifications using $V_{S, 30}$ as an indicator of site response (NEHRP-2000), for the study zone in the historic center of Puebla.

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MICROZONE	V _{S, 30} (m/s)	SOIL TYPE	DESCRIPCIÓN				
Sound Travertine	1028.0	В	Rock				
Volcanic-basaltic	434.0	С	Hard soil				
Alluvial	224.0	D	Sandy soil				
Altered Travertine	170.0	E	Loose/soft soils				

Fifth step: correlation of data to define seismic microzones. Geological and geotechnical data were correlated with geophysical information (transfer functions from microtremores and earthquakes) to produce the map given in Figure 6 which can be used as an aid for seismic design of structures in Puebla's historic center.

3. CONCLUSIONS

We have presented an alternative method for mapping a classification of soil types useful for the seismic design of structures. The map developed for the historical center of the city of Puebla was based on empirical transfer functions obtained from microtremor records and on pre-existing geotechnical zoning maps. The code proposed by the the National Earthquake Hazard Reduction Program, NEHRP-2000 and the V_{s. 30} parameter were also used.

As a result, soils in our study zone were grouped on the basis of four families of distinct spectral shapes which correspond to an equal number of soil types (sound travertine, altered travertine, alluvial soils, volcanic basaltic deposits). These, in turn, correspond to groups B, C, D and E according to the NEHRP-2000.

Finally, the results presented here suggest that empirical transfer functions can be applied as a useful geophysical prospection tool for extending the microzonation study to the whole of the urban area of Puebla and to other cities elsewhere.





Figure 6 New soil classification map for seismic design in the historical center of Puebla

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