Estimation of the underground structure in Manzanillo, Colima, through use of microtremors

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SUMMARY:
This paper presents a methodology to estimate the velocity structure of de subsurface shear wave in the urban zones of Manzanillo city, which consist in to seek for HVSR theoretical model that fits to the observed HVSR obtained from records of microtremors. The theoretical model applied estimates the transfer function of the horizontal viscoelastic layers of S wave incident vertically overlaying the bedrock. I addition, in four selected sites of the studying area was done multichannel seismic refraction survey with the objective to confirm these results. This information is generated maps of dominant periods and thickness of the soft soil en the study area, which can be incorporated into regulations structural design to earthquake effects.

Keywords: Microtremors, Seismic microzonification, Earthquake effects and Site effects

1. INTRODUCTION

Because Colima is one of the states of Mexico most affected by the high seismic activity, it is necessary that their major cities have more information on the dynamic behavior of soil in which these cities are developing, establishing a microzonation seismic by maps showing areas with different levels of seismic hazard.

Manzanillo is one of the municipalities and county seat from the state of Colima. It is the main seaport of Mexico's Pacific coast. It is a tourist port, industrial and commercial with a great growth potential. Comprising Manzanillo bays are built from the tip of Campos in the south to the north Juluapan. This territory includes the towns of Campos, Manzanillo, Tapeixtles, Salagua and Santiago currently part of the urban area. The region is bordered to the north by the southern Sierra Madre, characterized by mountain ranges with elevations of around 2700 meters above sea levels and descending abruptly to the Pacific coast. The plain is very narrow and sometimes there is the proximity of the hills to the coast. Outcrops in the region extending from the Cretaceous to the Pleistocene, the oldest formations are granite K (Igea). The lithological sequence continues in the Pleistocene and Holocene sedimentation in the alluvial deposits Q (al) located on the coast. In the Santiago and Salagua area alluvial deposits consist of accumulations heterogeneous gravel, sand and silt. Along the coast there are deposits of bar Q (II) consists of sand of different particle sizes, the gaps separating the sea. East of these bars were formed during the Pleistocene, saltwater lagoons that were deposited in clay high in organic matter and peat, lake deposits denominated Q (la). The thickness of lacustrine deposits is highly variable within the area and can be found at the San Pedrito, Tapeixtles, Valley of the Herons and Cuyutlán e.g. see Fig. 1.

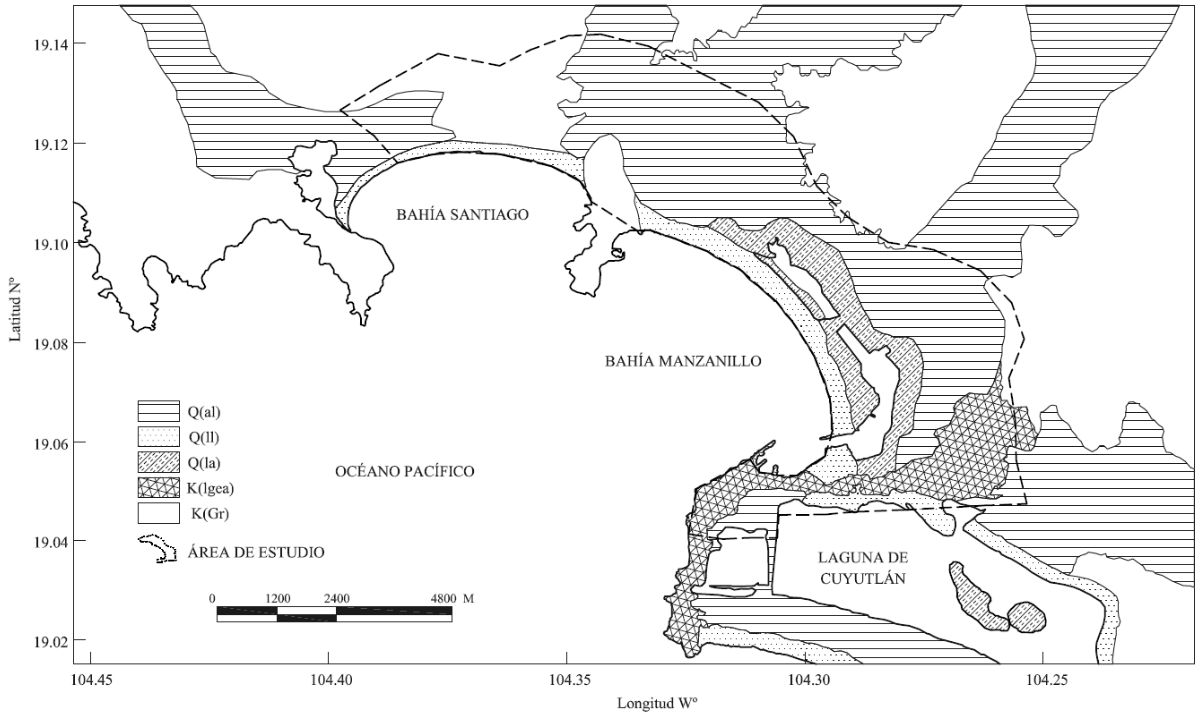

Figure 1. Geological map of Manzanillo (adapted INEGI)

Large earthquakes have occurred in the Mexican Pacific Ocean coastline. It can be stated that the most recent earthquakes in Mexico have occurred off the coast of Colima and examples of this are the Manzanillo earthquake of 1995 (Pacheco et al., 1997) that caused significant damage in Manzanillo, and Santiago and Salagua Tecomán 2003 (Nuñez-Cornu et al., 2004) also caused extensive damage in the state of Colima.

The seismic microzonation is the most usual technique to reduce the seismic hazard. The effects of site due to local geology of the subsoil usually determine the distribution of damage in urban areas during major earthquakes (Bard, 1999). For this reason, it is necessary to identify areas with important amplification index correlated with their dominant period, and it is used to be incorporated into building codes. These maps help to prevent serious harm to the new buildings during strong earthquakes. The local amplification is usually the result of certain soft soil deposits overlying stiff soils. The impedance contrast between these deposits and the base amplifies the ground motion and catches the wave energy.

This work aims to draw maps of dominant period and thickness of the subsoil, which characterize the site effects in the suburbs of Manzanillo, Salagua, Santiago, and Tapeixtles e.g. see Fig. 2. These results were based on the determination of HVSR of microtremor and small earthquakes, and in determining the structure of S-wave velocities obtained at certain points with multichannel seismic refraction data, and a method which adjusts a theoretical HVSR the observed HVSR (Herak, 2010).

Due to the low level of environmental vibration in the area, conditioned the use of seismographs instead of accelerometers to estimate the site effects and avoid the effect of self-noise of these instruments or electronic (Chavez-Garcia and Tejeda - Jacome, 2010).

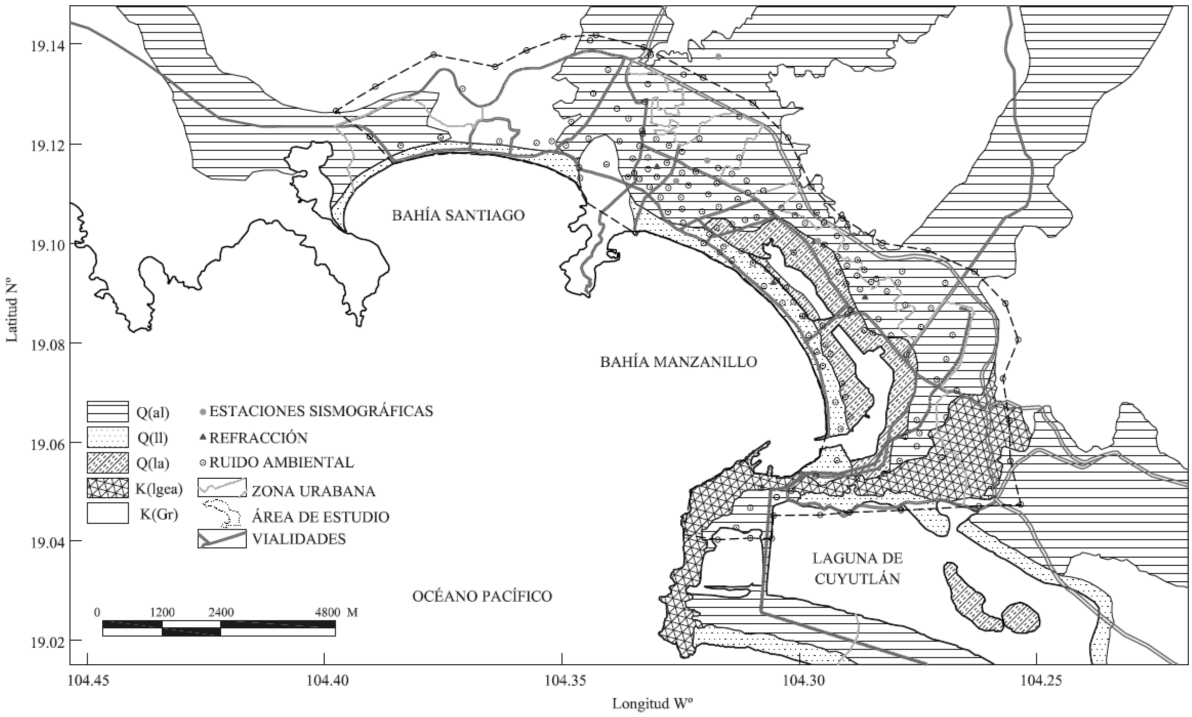

Figure 2. Indicates the study area boundary. Circles show the microtremor recording points, triangles define multichannel seismic refraction and squares the location of temporally seismic station

2. METHODOLOGY

It is well known that seismic ground can be amplified significantly in sedimentary deposits. In Colima, the consequences of this phenomenon in urban areas close to the seismic sources have been demonstrated recently in the damage patterns observed in Manzanillo earthquake of 1995 (Pacheco et al. 1997), and Tecomán 2003 (Singh et al. 2003; Nunez - Cornu et al. 2004). The subsurface impedance contrast can amplify significantly the level of vibration and increase the duration of the movement. One way to prevent the destructive effects during large earthquakes is the identification of different areas with homogeneous seismic response and mapping these areas at the scale of a city. The seismic microzonation of the city is based on the determination of the maximum amplification of the movement that can occur in each area with respect to a reference site is generally rock. Additionally, it is desired to determine the periods of which is presented such amplification.

The amplification of the seismic motion due to the presence of soft soils is estimated using theoretical and experimental approaches. Among the techniques are theoretical modeling procedures soil from knowledge of their mechanical properties and its geometry. Among the experimental techniques include log analysis procedures of microtremor records of earthquakes and obtained temporary stations in the study site.

Modeling one-dimensional (1D) geometry and mechanical properties from geotechnical data is the simplest. It is assumed that the subsoil consists of horizontal strata characterised by its thickness, density, damping coefficient and Court wave velocity. The thickness and density can be known from geotechnical surveys and laboratory tests carried out on samples taken on them. In addition, the velocities of shear wave surface can be estimated through correlations between parameters obtained from geotechnical tests and these speeds, or dynamic tests such as suspended probe test. When velocities of shear wave surface in the different layers of soil are not determined by dynamic tests, tend to apply empirical expressions that relate, for example, the speed with the number obtained from a standard penetration test (e.g., Ovando and Romo, 1990, 1991). However one-dimensional geotechnical models are not always able to reproduce accurately the response of the soil due to the effects of lateral heterogeneities in the soil. In these cases one must resort to 2D and 3D models, or experimental procedures as microtremor measurements, recording of tremors or multichannel refraction techniques (Kagami et al., 1986). Once there is a geotechnical soil model can calculate its transfer function (TF).

3. DATA AND RESULTS

To draw the maps of dominant period and subsoil thickness overlying the bedrock in the urban area of the municipality of Manzanillo were used essentially microtremor measurement data with a single mobile station by about 180 points for the spectral ratios horizontal components with respect to the vertical on the site, HVSR (Nakamura, 1989; Palermo and Chavez - Garcia, 1994). The duration of records was 10 to 15 minutes and was performed with a seismometer Lennartz 1s of natural period and a wideband sensor Güralp. However, to ensure the reliability of this procedure in some common sites were compared these results with the calculation of spectral ratios of the S-wave seismic records of three temporary seismographic stations and the obtained TF-dimensional modeling of soil , using data from microtremors with a multichannel seismic refraction equipment. Additionally, another method was used (Herak, 2010) which is to seek a theoretical model based on strata HVSR horizontal planes and vertical incidence of S waves with the observed HVSR obtained from microtremor measurements.

The use of spectral ratios of S-wave window of seismic records is a valid alternative (Palermo and Chavez - Garcia 1994). Also, in recent years has increased the use of correlation techniques in the frequency domain and time records of multichannel refraction (eg, MAM) for the surface structure of the soil. Since the structure can be obtained representing the TF amplification and dominant frequency (f0) of the site under study. The curves obtained with microtremors HVSR, small earthquakes and the method that fits a theoretical model with the noise HVSR calculated for two sites in the study area are shown in Fig. 3. Fig. 4 shows the same described above but also shows the curves corresponding to the data obtained with TF multichannel refractive ECEX site.

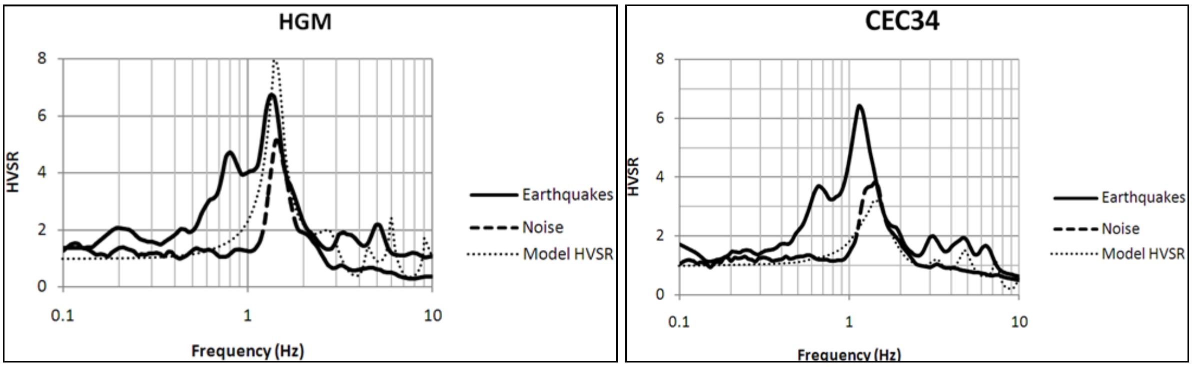

Figure 3. HVSR curves obtained from records of earthquakes, microtremor and a theoretical model for two recording sites in the study area

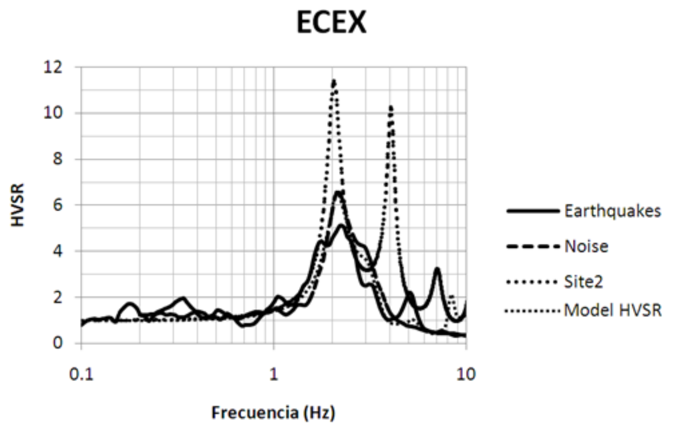

Figure 4. HVRS curves obtained from records of earthquake, microtremor, seismic refraction and a theoretical model for the ECEX site

As can be seen in Fig. 3 and 4, the curve is closer to ModelHVSR HVSR microtremor to the earthquake. However, the coincidence of the dominant frequencies of all curves at the three sites is almost perfect. The amplifications vary according to the technique used is a matter which has not yet been fully resolved.

At present, the characterization of the geology in a given site is generally reduced to the specification of a single parameter, Vs_{30} or the shear wave velocity averaged from the surface to a depth of 30 meters. This parameter is used in some building codes to identify the effects of site and also to predict empirically, the ground motion attenuation models using a given site. To obtain this number or its generalization to other depths, most methods for assessing site effects attempt to derive the shear wave velocity as a function of depth. The use of the theoretical model sites adjusted HVSR measured ambient noise, allows to obtain the structure of body-wave velocities, and thus to reliably estimate the depth of the bedrock, or the depth from which the Vs exceeds a predefined threshold. In the present study, using a threshold wave propagation velocity Vs = 760 m/s and from this value until the surface is calculated depth of sediment from the point under consideration. From this information from all sites of measurement noise, we obtained a thickness map that correlates well with dominant period map. The map of dominant period for the study area e.g. see Fig.5 and the thickness map of the strata overlying sediments with Vs values greater than 760 m / s e.g. see Fig.6. This information must be validated with the study of deep boreholes and analysis of suspended probe Vs, which until now was not possible to do.

It is important to note that the study area suffered major damage after the earthquake of 1995 and during the same liquefaction were problems and the collapse of the Hotel Costa Real in 9 levels, whose fundamental period of vibration fits well the period Resonance of the soil at the site.

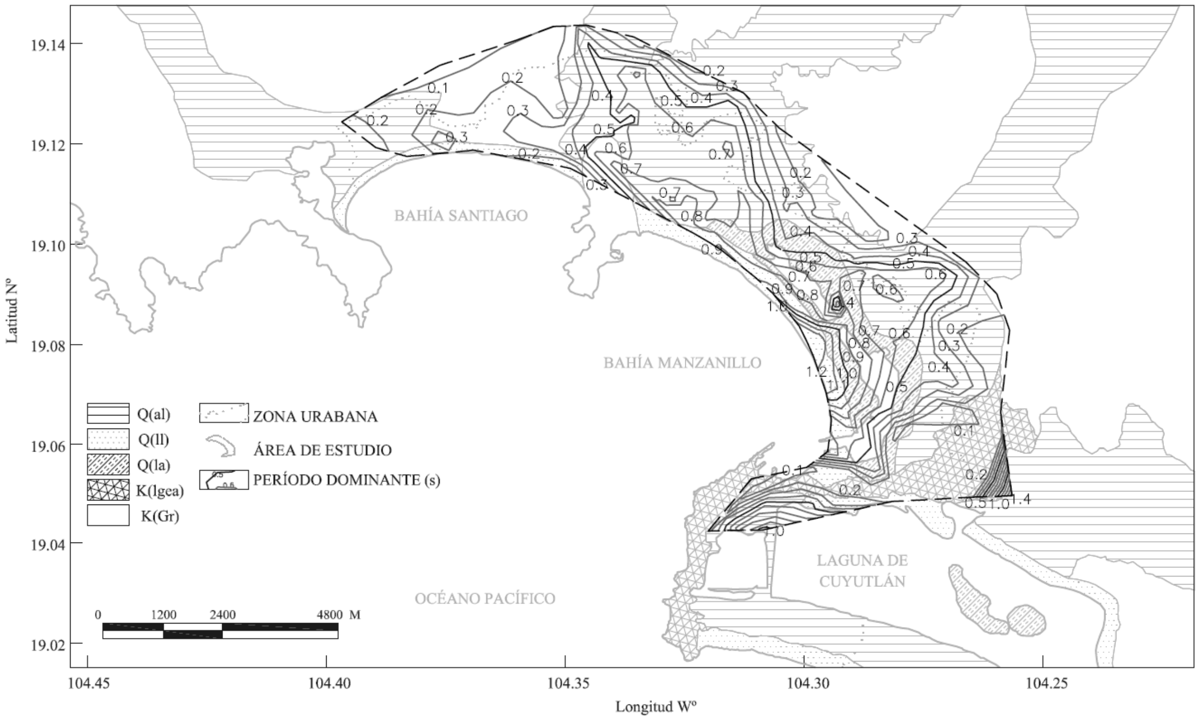

Figure 5. Dominant periods map of the study area

Stratigraphic profiles shown in Figure 7 correspond to those indicated in the map of thickness in Figure 6, the thickness of the soft soil layer that overlies to the stiff layer. The stiff layer is considering that soil presents a shear wave velocity greater than or equal to 760 m/s, which although is not rock but is adequate enough to be considered stiff.

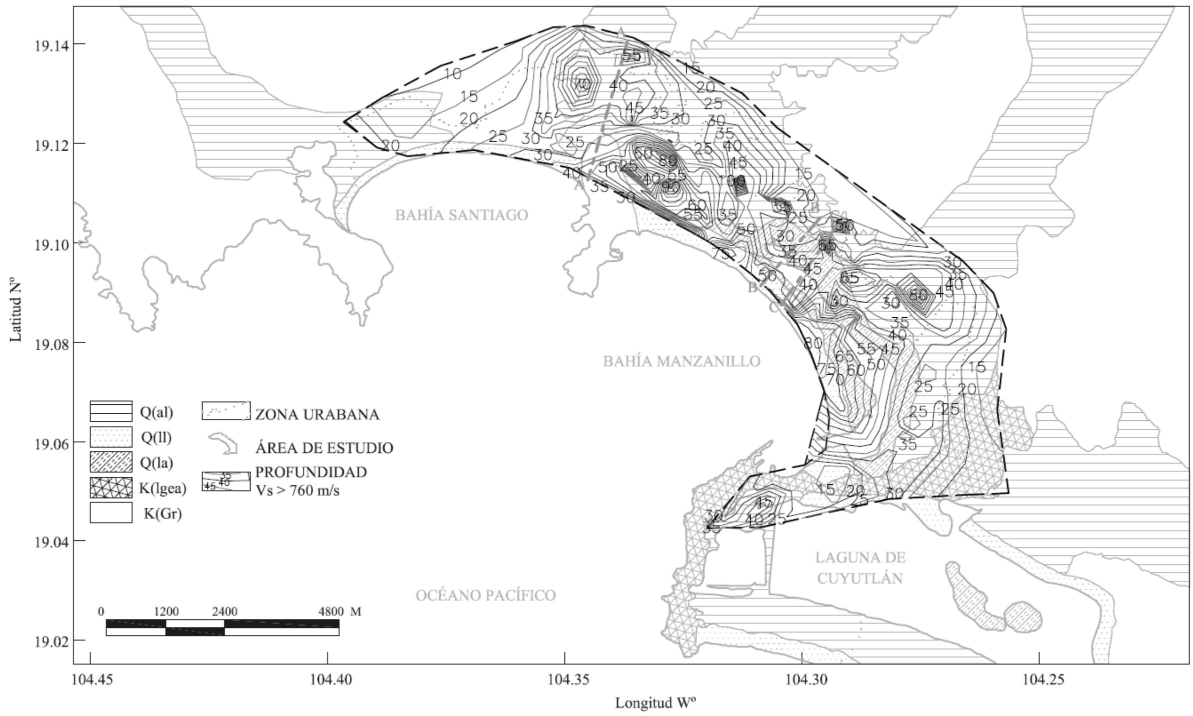

Figure 6. Thickness map soft soild of the urban zone of Manzanillo city

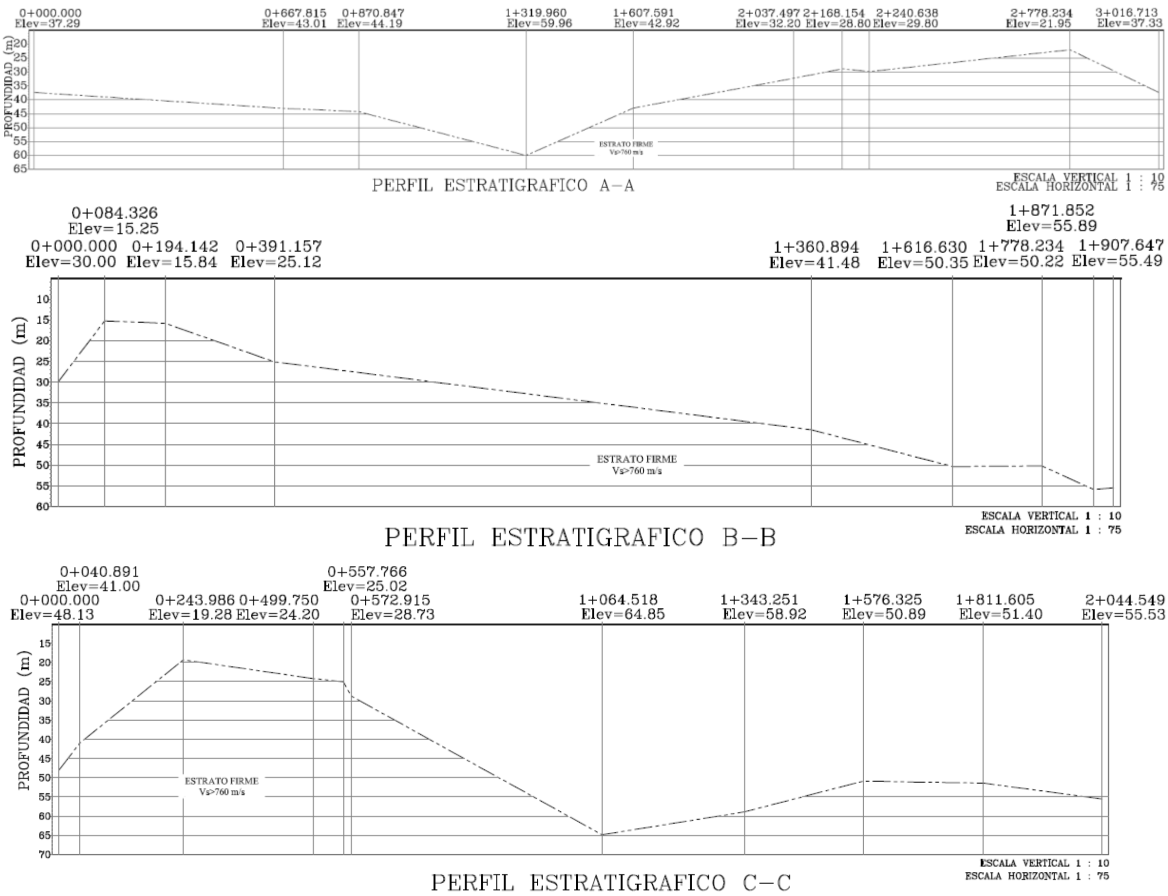

Figure 7. Stratigraphic profiles of the sections A-A, B-B and C-C, shown above

In Fig. 8 is shown the structure of S-wave velocities of the points 16, 17 and 42 calculated from measurements of microtremors and after a post-processing with software was obtained ModelHVSR the estimated transfer function corresponding stratigraphy the spectral ratio H / V of the above points.

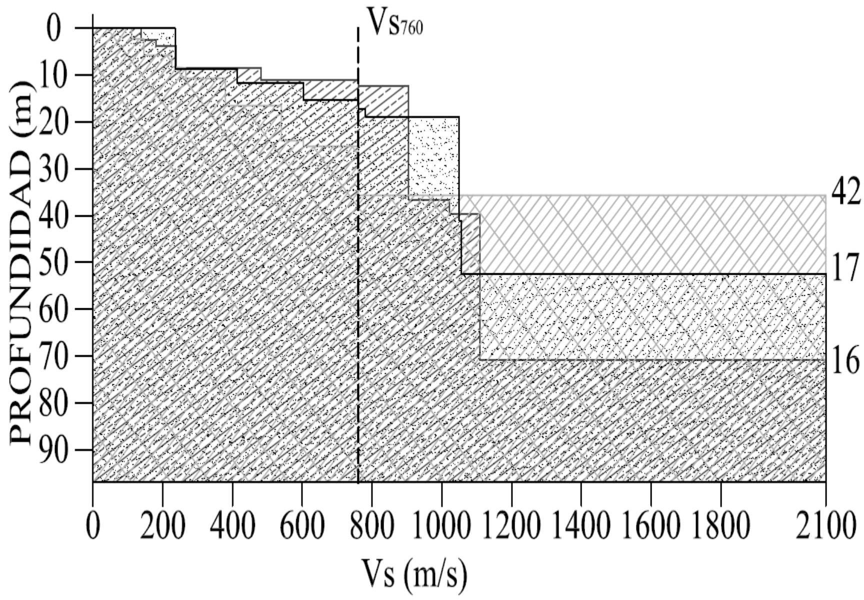

Figure 8. Vs wave velocities estimated with the ModelHVSR using the microtremor records of the sites 16, 17 and 42

4. CONCLUSIONS

The use of theoretical and experimental methods for estimating the effects of urban site is necessary to obtain an accurate assessment of the dominant periods and the amplifications of the soil. The estimation of the average propagation velocity of shear wave is a tool that can function properly if you know the actual depth of the bedrock. The use of the technique is reliable spectral relationships when compared with other estimates to clarify the shortcomings of the method.

We performed a study where maps were developed dominant periods and thickness of alluvial sediments overlying a base of hard soil with a threshold of wave propagation velocity Vs equal to 760m/s, in the urban area of the municipality of Manzanillo, Colima. The results reflect adequately the seismic response of soils in an area where major damage occurred after the earthquake of October 1995. The dominant periods map can be referenced in the seismic design of buildings in the area, which has grown significantly in recent years. The average thickness map geotechnical data should be validated with deep wells and suspended probe to estimate liquefaction potential and its possible inclusion in the current building code.

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