# Geoseismic Microzonation of the Metropolitan area of Colima-Villa de Alvarez, México 

E.P. Sánchez-Sánchez, J.C. Tejeda-Jácome, T. Domínguez-Reyes \& M.F. Cabrera-Sandoval



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#### Abstract

SUMMARY: This paper presents a geoseismical classification of the ground in the metropolitan area of Colima-Villa de Álvarez. The technique of HVSR was used with data from measurements of microtremors and small earthquakes obtained from seismographic stations in the area. Maps of dominant periods for two frequency ranges (periods) and a map with ground classification were drawn. The information of the high and low frequencies was correlated with S wave velocity structure using a method that adjusts the HSVR observed with a theoretical model. In accordance with the results, the earthquakes with energy of high frequency or near field are the most dangerous for most of the buildings in the study area.


Keywords: Microzonation, Microtremors, H/V Spectral Ratio

## 1. INTRODUCTION

The city of Colima is located on the southern slope of the volcanic complex Cántaro-Colima, where it has been developed an intense volcanic activity throughout its history thereby forming canyons and valleys product of the mixtures of avalanche deposits, lahars and volcanic sediment, see Fig. 1.1. At the same time, seismic activity associated with the subduction of the Cocos and Rivera plates beneath the North American plate has affected the city in recent years. The earthquakes of 1941, 1973, 1995 and 2003 are those that have caused more damage in the city that is currently growing at a rate above the national average. It is therefore necessary to carry out studies to evaluate the seismic and volcanic hazard in the city to take actions to minimize the risk of catastrophic damage to the infrastructure of the growing city.


Figure 1.1. Study area southerly the Fuego de Colima volcano

The aim of this study is to classify the ground in the metropolitan area of Colima-Villa de Álvarez, using maps of dominant periods and an estimate of the surface velocity structure (Vs), based on the provisions of the building regulations of Colima.

We analyze the ground motion in the metropolitan area of Colima-Villa de Álvarez and its relationship to the surface geology of the subsoil. We take into consideration the results of previous studies (Lermo et al., 1991; Gutiérrez et al., 1996 and Chávez-García et al., 2007) and previous seismic data (20062008) recorder by a temporary network of seismic stations. Additionally, we use records of microtremors obtained from a station located in the urban area, with duration of 14 hours. We also use records of environmental noise from 258 points of the urban area (Kagami et al., 1986, Gutiérrez et al., 1992). The data were analyzed with the technique of horizontal to vertical spectral ratio HVSR (Nakamura, 1989; Lermo et al., 1994; Bard, 1999 and Field et al., 1995) obtained with a Lennartz sensor of 1s and a Guralp broadband sensor of 30s, coupled with a SARA recorder and a K2 recorder respectively. Our results are consistent with those reported by the previous studies and show that the site response has to do with the geology of the surface structure and the geology of the deep volcanic deposits that form the valley of Colima, which form an irregular stratigraphy both vertically and horizontally. The maps of periods at low and high frequencies are based on the dynamic response of deep volcanic deposits ( $>800 \mathrm{~m}$ ) with respect to the bedrock and the stratigraphy of superficial sediments ( 30 to 115 m ).

### 1.1. Geology

The city of Colima is set on a plateau on the southern slope of the Fuego de Colima volcano and has a slight inclination ( $11^{\circ}$ approx.) to the south and south-west. The area is drained by parallel rivers (Pereyra, Manrique, Colima, etc.) that cross the city and discharge their waters into the river Armería, which is the largest in the state. According to the geological map of the study area, the city is built on four types of rocks and surface materials: to the northeast of city is andesitic volcanic breccia (Bva) extending southward as major tongues, to the northwest emerges a conglomerate of andesitic gravels in a silty sandy matrix known as sandstone-conglomerate ( $\mathrm{ar}-\mathrm{cg}$ ), in the east of the city are clastic deposits with lesser amounts of sand that are classified as conglomerate $(\mathrm{cg})$, and finally to the south, there are deposits of alluvial soils (at) derived from materials transported by the streams that cross the city, see Fig. 1.2. These formations are probably interspersed with respect to each other forming a single unit over approximately 700 meters thick (López and Gutiérrez, 1977).


Figure 1.2. Geological map of the metropolitan area Colima-Villa de Alvarez (adapted from INEGI)

### 1.2. Previous studies

There are previous studies in which the site effects in Colima city have been estimated. Among them we can mention Lermo et al., 1991; Gutiérrez et al., 1996 and Chavez-Garcia et al., 2007. Lermo et al., 1991, estimated dominant periods in about 38 sites in the city using potency spectra of microtremors records, the results show a variation between 0.25 s and 0.33 s in the formations of Bva and ar-cg, while for cg and al there were estimated higher values than 2.0 s . Lermo et al., 1991, classified the city in four microzones, based on the estimates described and the geological information of the four types of outcrops described above, see Fig. 1.3.a.


Figure 1.3. Dominant periods by a) Lermo et al., 1991; b)Gutierrez et al., 1996
In the study of Gutierrez et al., 1996, to verify and complement the previous findings, there was installed a temporary seismic network, managing to record a total of 65 regional and local earthquakes at six sites within the urban area and one in the hill of La Cumbre, which served as a reference station. They also measured microtremors in a profile of 24 km from the hill La Cumbre in the east to the town of Zacualpan in the west. Their results are similar to those obtained by Lermo et al., 1991, however, draws the attentions that the dominant frequency values along the profile are near 0.3 Hz , see Fig. 1.3.b.

Finally, Chávez-García (Chávez-García et al., 2007) made a study of site effects based on microtremor measurement with a station and vertical arrays of seismometers. He applied the technique of horizontal to vertical spectral ratio (HVSR) at 310 sites within the city using accelerometers to measure microtremors. However, only in 125 sites were identified the fundamental frequency, see Fig. 1.4. The results of this technique showed that a seismic zoning based solely on the measurement of microtremors with a single station is not a reliable alternative when the local geology is complex and the site effects are not the result of a simple impedance contrast. For this reason, he applied the SPAC and REMI analysis techniques, measuring microtremors in array-stations. He use lineal arrays with 25 s duration records at eight sites within the city. The results of both of these techniques are dispersion curves of phase velocity, which were inverted to obtain a profile of S-wave velocity. These profiles showed a good fit with previous measurements of suspended probe (Gutierrez et al., 1996) in one of two sites and a poor fit in the other. Transfer functions calculated with the inverted soil profiles agree with previous estimates of local amplification of spectral ratios analysis of seismic records.


Figure 1.4. Dominant periods by Chávez-García et al., 2007.

## 2. METHODOLOGY

The evaluation of the site effects depends strongly on the local geology and its mechanical properties with depth. That is, the greater the variation in the stratigraphy of a sedimentary deposit, the greater the number of expected spectral peaks in the seismic response of the deposit. Based on previous studies of site effects (Lermo et al., 1991; Gutiérrez et al., 1996; Chavez-Garcia et al., 2007) and records of small earthquakes, we carried out a microtremor measurement campaign throughout the metropolitan area of Colima-Villa de Álvarez.

We recorded microtremors at 335 sites in the study area with two measuring equipments, see Fig. 2.1. One of the equipment was a broadband sensor CMG-40T Guralp (natural period of 30s) attached to a recorder K2, the other one was a Lennartz short period sensor (natural period of 1s) coupled with a SARA recorder. The reason for using two equipments was to assess the reliability of the results obtained in previous studies and those obtained in this study. This allowed the analysis of HVSR curves with sensors that have different instrumental responses (natural frequency) and can be affected by the electronic noise of the instrument. The effect of electronic noise is very important in places where the ambient noise level is low (Chávez-García and Tejeda-Jácome, 2010) and represents a limitation in studies of site effects using only the spectral relations HVSR technique.

In addition to calculating HVSR with the records obtained with the Guralp and Lennartz sensors, we obtained the relations $\mathrm{H} / \mathrm{V}$ of the S -wave records of small earthquakes recorded in 7 temporary stations located in the urban zone, see Fig. 2.1. With the data from HVSR noise measurements on these sites and the results of $\mathrm{H} / \mathrm{V}$ of earthquakes, we could confirm that there are at least two periods of significant resonance in the valley and, that only with the Guralp sensor and the H/V of earthquakes, is possible to see these spectral peaks at high and low frequencies reliably. From this information it was possible to draw maps for periods shorter than 1 s and for periods longer than 1 s using data from both equipments.


Figure 2.1. Location of microtremor measurement points and temporary stations

## 3. DATA USED AND RESULTS

Horizontal to vertical spectral ratio HVSR has been widely used to determine the site response to the environmental vibration. In Colima it has been sought to establish whether the use of microtremor HVSR is a reliable technique to estimate site response in areas with complex stratigraphic characteristics. The first two studies discussed previously used a number of very small microtremor measurements and found dominant periods in high and low frequencies. Moreover, the third study was made with microtremor records of an accelerograph station at 310 points, of which only 125 of them showed some relevant information. The results of that study showed only peaks at high frequencies with low amplitude. In firsts studies the seismometers used were of 1 and 5 s of natural period, so they only can found periods shorter than 1s, consistently and eventually longer than 1 s , the third study used an accelerometer ETNA with a FBA sensor and found no dominant periods at low frequencies (high periods).

The previous information and a database with records of small earthquakes (Borcherdt, 1970, ChavezGarcia et al., 1990) obtained from 7 temporary seismographic stations located in the study area, see Fig. 2.1, made possible the realization of this work. Our study consisted in an array of 335 microtremor measurement points, lasting 15 minutes each one of the records, taking information in each point with the two equipments aforementioned. Additionally, we used data from a 14 hours record of microtremors obtained in the station CASA1, in 2007 with a Guralp broadband sensor and a FBA accelerometer attached to a K2 recorder. Moreover, the existence of data from local and regional earthquakes recorded by 7 temporary stations, consisting in 4.5 Hz of natural frequency seismometers and digital recorders SARA-Mariotti, allowed us to analyze the dynamic response of sediments in the valley of Colima, see Fig. 3.2.


Figure 3.1. HVSR curves of earthquakes and ambient noise recorded at station CASA1
In order to assess the reliability of microtremor measurements recorded with different equipment, HVSR curves were calculated for the stations where we had data from weak earthquakes. For example, the Fig. 3.1 shows the HVSR curves of the station CASA1 obtained with the records of various instruments located in the place. This station is the same in which we recorder 14 hours of microtremors, and there stood a temporary station that recorded a large number of local and regional earthquakes. As can be seen in Fig.3.1, only the curves obtained with the Guralp seismometer and from small earthquakes show spectral peaks at low frequencies (high periods) and high frequencies (low periods). In the records obtained with the Guralp, the peak at low frequencies is the dominant one. Another important aspect is that the measurement with the Lennartz seismometer of 1 s and with the FBA accelerometer don't show the low frequency peaks on this site. However, the curves obtained with the Guralp seismometer show this peak in low frequencies, as well as the one in the high frequencies corresponding to the second mode and usually seen in the curves obtained with the Lennartz seismometer records. This suggests that the Guralp sensor is most suitable for measures of microtremors in Colima and that the results shown in the HVSR curves, let us see the behavior of the entire sedimentary deposit that overlies the bedrock in the valley of the city.


Figure 3.2. HVSR curves from the recorders of the 7 temporary stations
Figure 3.2 shows the results of HVSR calculated from the S-wave part of the seismic records obtained in the 7 temporary stations. Here the spectral peaks are observed at short and long periods confirming the shown in Fig. 3.1. In the Fig. 3.2 it can be observed that the peaks at short periods vary from 0.16 s to 0.4 s and the long periods vary from 2 to 3.5 s . Figures 3.1 and 3.2 show that the response of soil in the urban zone of the metropolitan area of Colima-Villa de Álvarez has two ranges of periods that may affect the dynamic response of buildings.

The previous statement can be observed in the following maps. In the first case, see Fig. 3.3, curves vary from 0.1 s to 0.9 s and in the second case, see Fig. 3.4, the curves have a range between 1 and 4 seconds. With this information and the estimate of the theoretical transfer function calculated using a model of horizontal flat strata and the vertical incidence of the S-wave, adjusted to the HVSR curves (Herak, 2008) representative of the site, we obtain an estimate of the Vs for strata surface, see Fig. 3.6, and for all the sediment overlying the bedrock in Colima, see Fig. 3.5.


Figure 3.3. Periods map, considering periods shorter than 1 s


Figure 3.4. Periods map, considering periods longer than 1s


Figure 3.5. Theoretical transfer function for the site CASA1 (dark line), adjusted to the HVSR curve (red line) calculated with data of the Guralp seismoghrapher. In the bottom left the structure of Vs obtained is shown


Figure 3.6. Theoretical transfer function for the site CASA1 (dark line), adjusted to the HVSR curve (red line) calculated with data of the Lennartz seismographer. Vs structure is shown in the bottom left

## 4. GROUND CLASSIFICATION MAP

As defined by the Article 170 of the Chapter VIII of Title Sixth of the Building Regulations for the city of Colima, and by the end of the Complementary Technical Standards for Design and Construction of Foundations, the sites in the city of Colima is divided into five types with the following general characteristics:

Type I. Rock, composed of healthy rock or weathered rock, with periods shorter than 0.2 s and $\mathrm{Vs} \geq$ $720 \mathrm{~m} / \mathrm{s}$.
Type II. Dense or very stiff soil, formed generally by firm soils that were deposited outside the lacustrine environment. Have periods between 0.3 and 0.6 s ; Vs between 720 and $360 \mathrm{~m} / \mathrm{s}$ and thicknesses of 6 to 30 m . In this area, there may be the presence of voids, caverns and tunnels to mine sand and uncontrolled landfills.
Type III. Intermediate or transitional, where the deep deposits are between 30 m and 60 m deep, and is comprised predominantly of sand and silt layers interspersed with layers of sandy clay lake, the thickness of these varies from tens of centimeters and few meters. Times will vary between 0.8 and 1.4 s and Vs is between 360 and $180 \mathrm{~m} / \mathrm{s}$.

Type IV. Lakeside or soft, composed by deposits of clay highly compressible, separated by layers containing different sandy silt or clay. These sandy layers are usually firm to very hard and variable thickness from centimeters to several meters. The lacustrine deposits are often covered by shallow alluvium and artificial fill, the thickness of the whole can be greater than 60 m . The periods are greater than 1.4s.
Type V. Special, soil characteristics are different from those mentioned above and should be specifically evaluated, such as liquefiable soils, highly sensitive clays, peat and/or highly organic clays with $\mathrm{H}>3 \mathrm{~m}$ high plasticity clays with $\mathrm{H}>8 \mathrm{~m}$ and $\mathrm{IP}>75$, etc.

Based on this classification, we drew a map of ground types for the metropolitan area of Colima-Villa de Álvarez, which is shown in Figure 4.1. This classification does not include the dynamic response of flood sediment throughout its thickness (> 800 m ) whose dominant period is longer than 2 s . In these cases must be assessed whether these periods will have some influence with the fundamental periods of vibration of the buildings to be built in the near future.


Figure 4.1. Map of ground types for the metropolitan area of Colima-Villa de Álvarez

## 5. CONCLUSIONS

We carried out a study to classify the urban land in the metropolitan area of Colima-Villa de Álvarez based on previous studies, a microtremors measurement campaign with two different seismographs and using of data from small earthquakes registered in the city of Colima. We found that the HVSR analysis of small earthquakes and microtremosr with a Guralp broadband seismometer are those with the most reliable for estimating the dynamic response of the avalanche that forms the valley of Colima. There were significant spectral peaks at high and low frequency (low and high periods). However, low frequency are dominant in most cases, with significant amplitudes (greater than 4) and high frequencies correspond to the second mode of vibration of the ground and whose amplitudes are not very high (from 2 to 3.5 units on average). Periods maps were drawn for high and low frequencies that were used as reference to build a map of classification of the urban ground, useful for seismic design purposes as defined by the new Building Regulations of Colima, (in approval process). Like most buildings in the city of Colima are of low height (periods shorter than 1s), we considered classify the soil based on the range of high frequencies (low periods), which are frequencies that have caused more damage in the city after the recent earthquakes.

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