v. 3, n. 21, 2023

Journal of
Engineering
Research

STRUCTURAL EVALUATION OF “UNIVERSITY OF VERACRUZ RECTORY OFFICE BUILDING” IN XALAPA, VERACRUZ, MEXICO

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Abstract: The “A” President´s office building is located the University area of the City of Xalapa, Veracruz. This building was built in the 80’s. In his time, for his height and features, it was a symbol of modernity of the state capital. The structure has a large response during earthquakes, even if earthquakes have their epicenter in remote locations and its magnitude is not large. Because of this phenomenon, the building had to be evacuated on multiple occasions and people working in the building have developed distrust and fear. Recent research is oriented to determine the structural behavior, measuring and processing environmental vibration. Recently, techniques have been used that consist of spectral analysis of vibration signals that provide insight into the actual behavior of the structure and are used to identify the fundamental modes of vibration, and moreover, the fundamental period of the foundation soil. Thus, anomalous responses in the structure and dynamics problems amplifications of movements because of the soil-structure interaction can be identified.
For structural evaluation of this building, we will consider their history, extensions or modifications; type of materials used in its construction, structural criteria and an experimental method will be used to infer structural dynamic response quickly and economically, through records of environmental vibration.
Keywords: Environmental vibration, dynamic characteristics, structural evaluation, vulnerability and risk.

INTRODUCTION

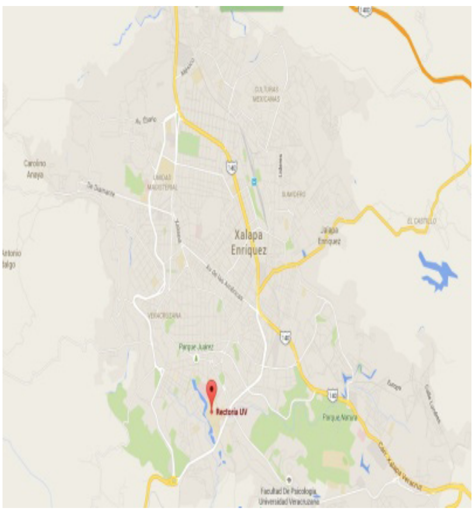
The “A” President´s office building of the Veracruz University is located in The Hills of the Stadium (S/N), university area, of the City of Xalapa-Enríquez, Veracruz (Fig.1). This building was built in the 80’s. In its time due to its height and characteristics, it was a symbol of modernity for the capital city of the State of Veracruz. The building throughout its history has presented a perceptible response by its occupants to seismic events, even when earthquakes have their epicenter in distant places and its magnitude is not very large, because of this it has had to be evacuated on multiple occasions. Thus, the people who work in the building have mistrust and fear that the structure may have some damage.

Due to the above, it was proposed to carry out a visual inspection of the structure, in addition, to make measurements of environmental vibration in the building and building. This paper presents the results obtained from the physical inspection and the analysis and interpretation of the environmental vibration records both in the structure and in the foundation soil (Torres *et al.,* 2010).

The President´s office building “A” is located on a hill that forms part of the hills of that area of the city of Xalapa, is a seven-story building two of which are basements and are partially underground. It occupies an approximate area of 631.18 m2. It presents a plant of regular form and is formed by a structure of reinforced concrete rigid frames with columns of 40 cm x80 cm. The mezzanine slabs have a ribbed slab system approximately 40 cm-thick whose finish varies, depending on the use. In addition to the stair area, there is also a 6.46 m2 area intended for two elevators. Each mezzanine has an approximate height of 2.38 m. The partition walls are mostly apparent and disconnected from the structural elements. For the lower levels, basements, intended for the use of cubicles and offices, there are retaining walls due to the unevenness that appears in the ground.

GEOLOGICAL AND GEOTECHNICAL CHARACTERISTICS

At present, there are advances in geological and geotechnical characteristics (Hernández *et al.*, 2007) in the conurbated zone Xalapa (ZCX) (Torres *et al.*, 2012a, 2015a), identifying different types of soil (Fig. 2). The building is located on deposits resulting from the volcanic activity in the area, the unit was identified as new ignimbrita. The composition of the subsoil in this zone is very complex due to the variation of the materials that go from basalts in their deep strata to silty loam soils or sandy silts in the superficial strata, resulting from the volcanic processes in this area.



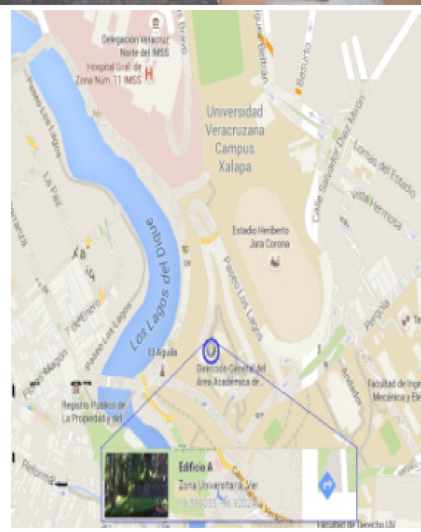
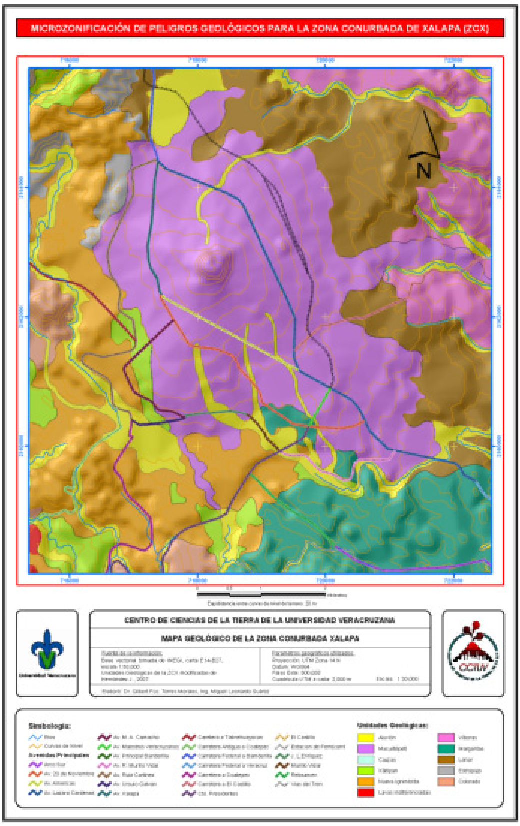


Figure 1. Location and images of Building A of President´s office of UV in the city of Xalapa, Veracruz.

The material where the building is cemented is not known with accuracy, but according to some studies of mechanics of nearby soils, is clayey silt material in the superficial strata and in deeper strata the existence of basalts is presumed, not knowing with exactitude the depth of the resistant layer, ignoring its thickness and if there is a different material at a greater depth.

Geological-geotechnical studies are very important to accurately identify the dynamic amplifications of soils and infer their response to an earthquake. Therefore, a more detailed study, geotechnical or geophysical, is being prepared to be able to better identify the characteristics of the soils.



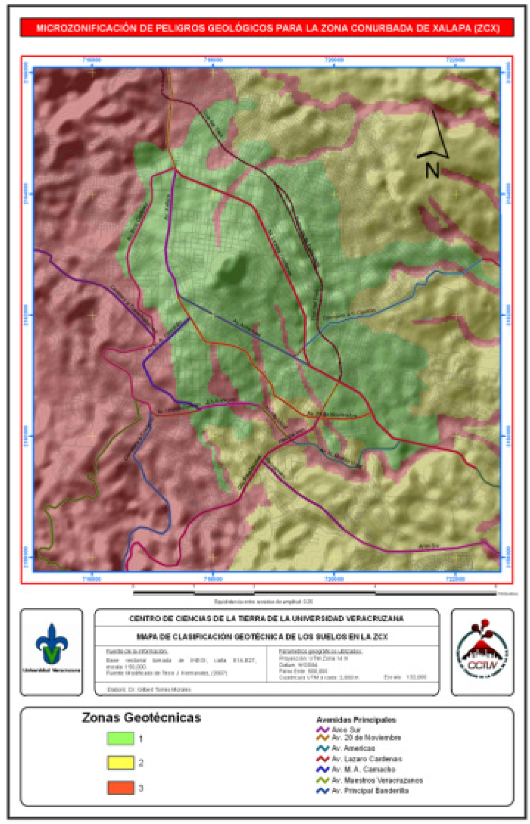


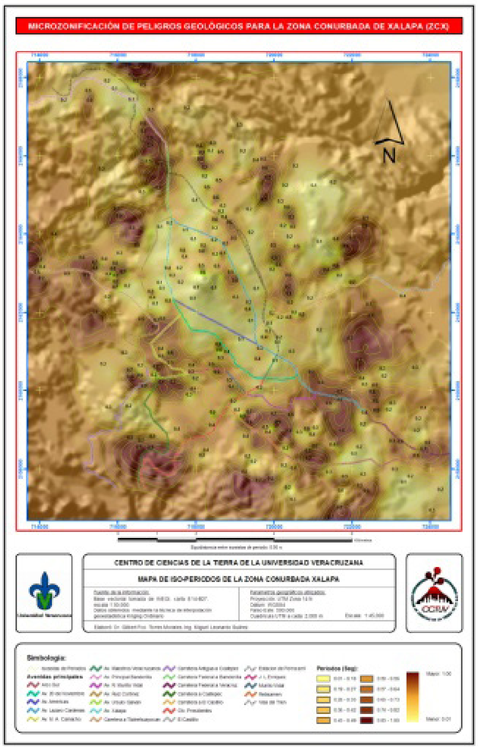
Figure 2. Geological and geotechnical map of ZCX. https://sites.google.com/view/microzoneuv/.

DYNAMIC CHARACTERISTICS (SITE EFFECT)

In the study of seismic microzoning where the hazard classification goes in ascending order according to the number, it is necessary to calculate the number of seismic microzonings in the city of Xalapa (Torres *et al.*, 2012b, 2015b). In other words, zone I was considered a zone of little danger and zone 3 as the one of greater danger. According to the above, the building property is located in zone 2 (Fig. 3). In addition, recent studies have been able to better characterize this area by determining that the land is located over a zone of periods between 0.5 to 0.6 seconds of dominant soil. These values will be reviewed with environmental vibration record taken on the building's premises.

Seismic microzonation studies are

multidisciplinary studies whose objective is to identify, through information collected and generated, areas with amplification in urban areas, which is closely linked to the characteristics of the foundation soil. Spectral analysis techniques for seismic signals have been developed to infer the dynamical characteristics of soils by obtaining frequency, period and amplification. Some of the most recognized techniques are the H/V technique and standard spectral ratios used in previous studies in the conurbation of the city of Xalapa.



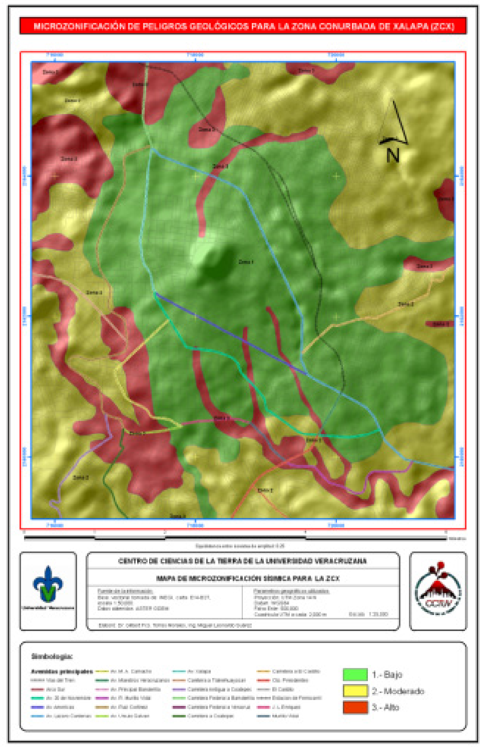


Figure 3. Left side, map of isoperiods of the ZCX. Right side, ZCX seismic microzoning map. https://sites.google.com/view/microzoneuv/.

LOCATION OF SENSORS

In President´s office Building A three broadband seismographs were placed, which is the minimum number of equipment recommended to identify their basic dynamic characteristics, such as the fundamental frequency of the floor and the structure. The seismographs were located in the central part and in a corner of the fifth level, which corresponds to the last level of the original project, or the roof plant, which over time, at this level was placed a light sheet cover supported in light-frame steel elements (Fig. 4). In addition, to complement the seismograph arrangement, a seismograph was placed at the base of the structure at a free field at the level of the basement entrance of the building (Fig. 5).

Figure 4. Location of the seismographs in the fifth-story level of the building, indicated with a red star.

Figure 5. Photos of the location of the seismographs at the base of the building and the last level of the building, and the simultaneous monitoring of the three teams.

ACQUISITION AND PROCESSING OF DATA

The acquisition of data was done with three seismographs of broad band Guralp model 6td, that acquires and records data of speed in 3 orthogonal directions in an internal memory, the dynamic range of this equipment is of 120 dB and 24 bits of resolution. The sampling rate of the equipment can be 40, 50, 100, 125, 200, 250, 500 and 1000mps and for this experiment was set at 100 mps and the seismographs were registered simultaneously for about two hours, where they were monitoring their operation through a router and a laptop connected to WiFi network, since the equipment has this type of communication (Fig. 6). The equipment was oriented the north component in the longitudinal direction and in the short sense the east component.

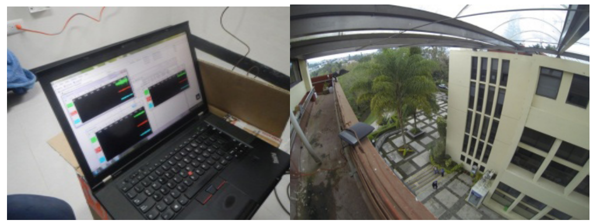


Figure 6. Simultaneous monitoring of seismographs and router location for the equipment's WiFi communication.

ESTIMATION OF THE EFFECT OF SITE WITH ENVIRONMENTAL VIBRATION IN THE BUILDING

The use of microtremors (environmental vibration) to obtain the estimate of the response of a site was introduced in Japan in the 1950s (Kanai *et al,* 1954). Microtremor measurements are highly attractive for the characterization of the site response, due to its simplicity of operation, low cost and fast results. The most popular technique for estimating site effects using environmental vibration records is the spectral ratio between the horizontal and vertical components of a single register, originally proposed by Nakamura (1989).

For the processing of the soil records, the GEOPSY program was used and the H/V tool was used, for which the files were transformed into SAC format. We proceed to open the GEOPSY program (GEOPSY, Marc Wathelet, 2002), record the signals, and proceeded to implement the tool.

IDENTIFICATION OF DOMINANT FREQUENCIES IN STRUCTURES

To identify the fundamental frequency of the structure it was used an analogous methodology to the standard spectral ratios technique used in soils. In our case the reference station was considered to be the station located in the foundation soil and the stations to identify the dynamic characteristics were those located in the structure. It is considered as a linear system subject to an input signal or excitation, to which it responds with an output signal. We then proceeded to obtain spectral ratios of the horizontal signals recorded in last level of the structure with respect to the records obtained in the base.

The Geopsy program was used by applying the standard technique and using the H/V tool, the components to be analyzed were the horizontal components (east and north) of the registers in the structure between its corresponding horizontal component (east and north) at the base of the structure, also known as free field.

The parameters of the registers were modified to be able to occupy the H/V tool since it always has to have the three components to perform the analysis. With this we obtained an analysis for each East and North component for each equipment placed in the structure with respect to the one placed at the base of the structure. The results are shown in Figures 8 through 11 and a summary in Table 1.

For the equipment placed in the center of the last level in the north-center component (n-c) we obtained:

For the equipment placed in the center of the last level in the east-center component (e-c) we obtained:

For the team placed in the corner of the last level in the north component we obtained:

For the equipment placed in the corner of the last level in the component this we obtained:

Location	Frequency (F)	Period (T)	Amplification (A)
Ground	1.67	0.6	2.5
Structure			
Center North	2.21	0.45	23
Center East	1.75	0.57	23
Corner North	2.23	0.45	23
Corner East	2.36	0.42	20

Table 1 - Summary of the results of spectral analysis techniques of environmental vibration, for soil and structure.

ANALYSIS OF CONTENTS

The analysis of the contents in the building was considered an important aspect in its vulnerability due to the response of the structure during seismic events, and that can cause damage to the people who work inside. In addition, it will contribute to the reduction of vulnerability by correcting identified problems. A visual inspection of the contents that represent a danger for the workers of the building was performed with the help of the students of the Civil Engineering school. The results are the following:

Basement 1: Desks obstruct the emergency exit. In addition, there are some file cabinets in bad condition that obstruct the passage of the emergency exit. We also located gates that are not embedded in the structure

Basement 2: In this area, we found file cabinets and shelves of poor quality, which can overturn. In addition, there are cubicles with glass shutters, which are not embedded in the structure and have a chance of falling. On the part of illumination fixtures, we found lamps without protection, which can fall on the workers.

Access plant: In the access floor, we found a small refrigerator placed on top of afile cabinet, which we consider to be at risk of

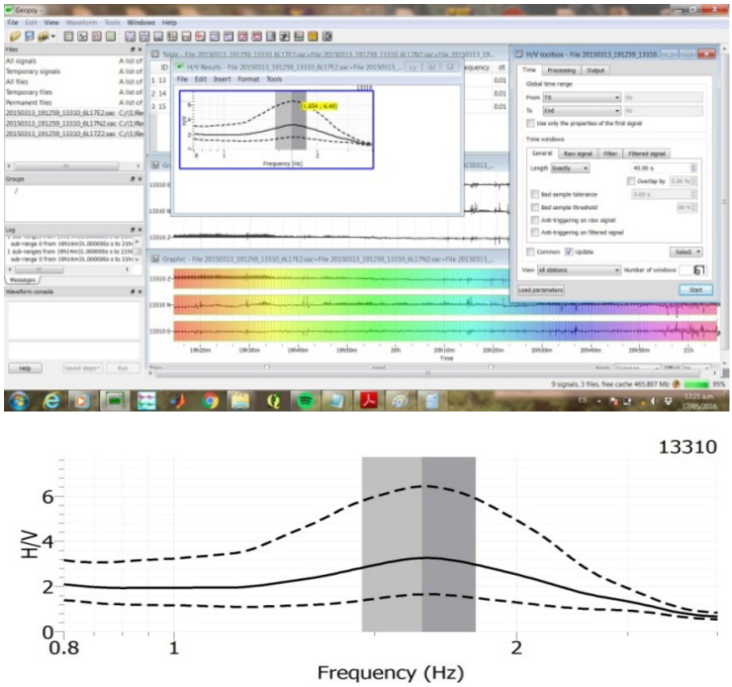


Figure 7. Application of H/V to the soil using GEOPSY and the resulting spectral quotient, F = 1.65, T = 0.6, A = 2.5.

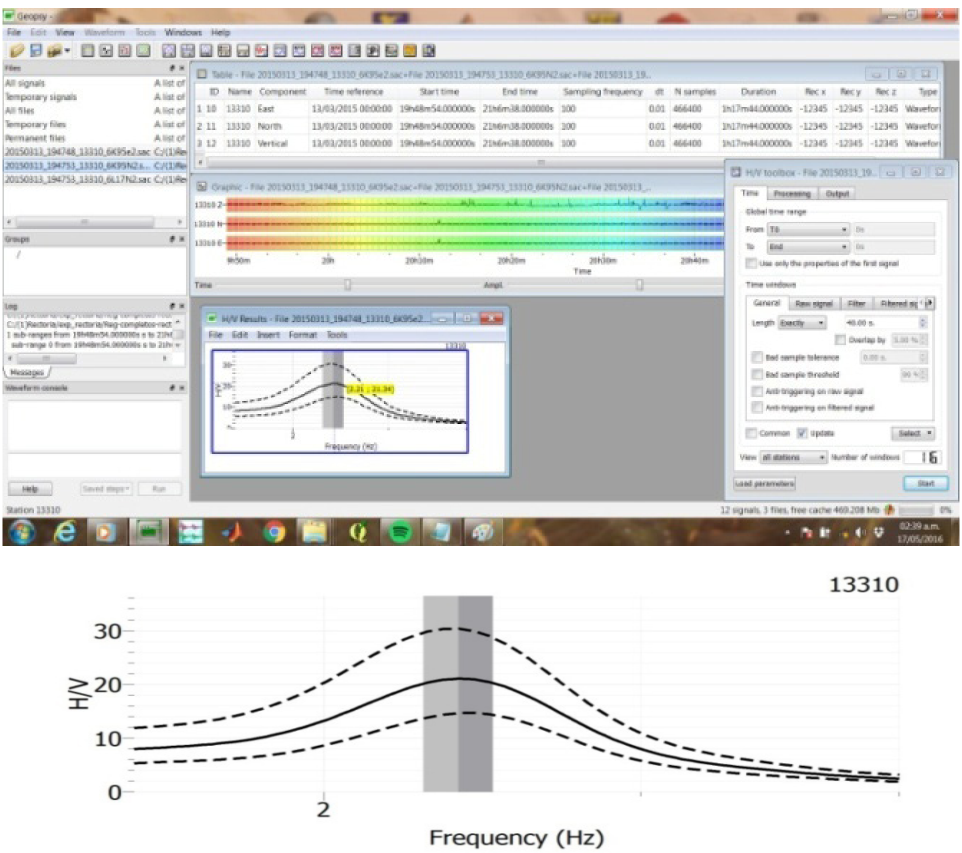


Figure 8. Standard technique application using GEOPSY (H/V) and the resulting quotient, (n-c) F = 2.21, T = .45, A = 23

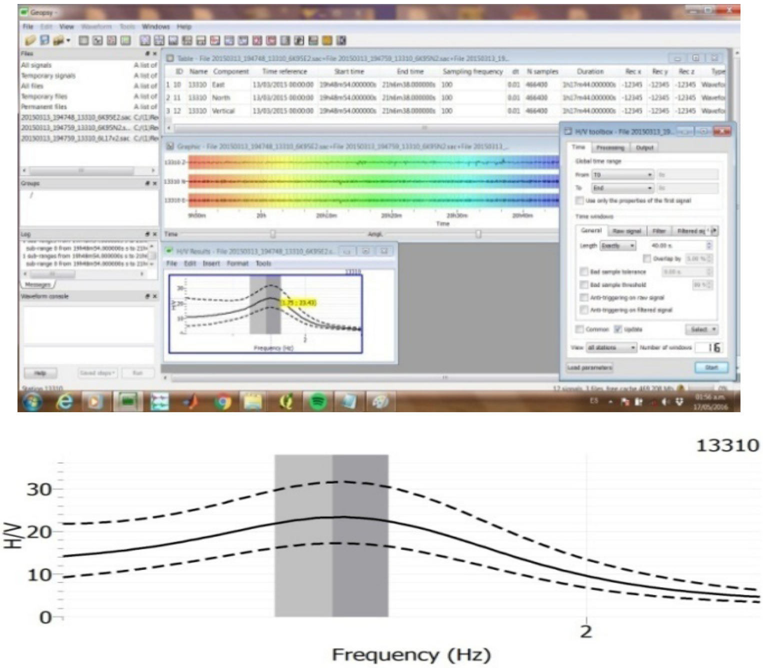


Figure 9. Standard technique application using (H/V) of GEOPSY and the resulting quotient,(e-c) F = 1.75, T = .57, A = 23

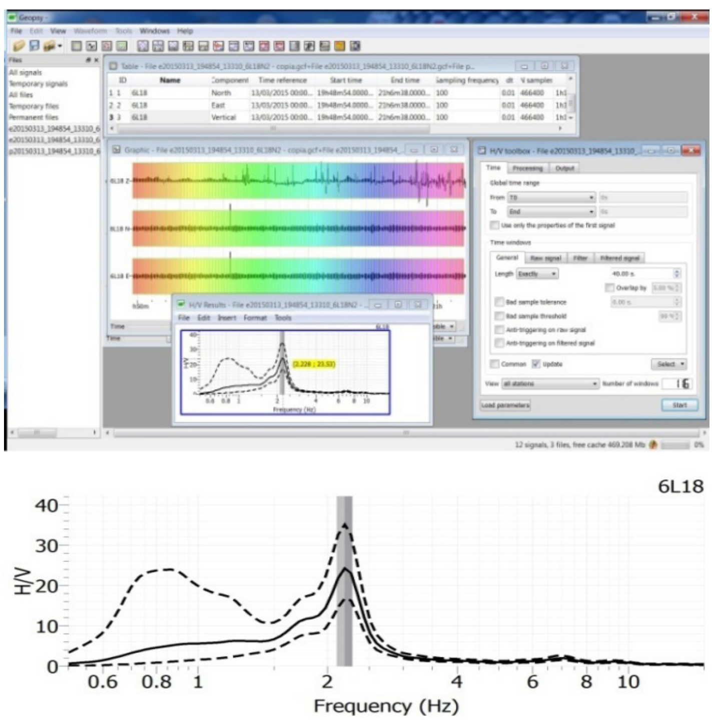


Figure 10.Standard technique application using GEOPSY (H/V) and the resulting quotient,(n-corner) F = 2.23,T = .45, A = 23

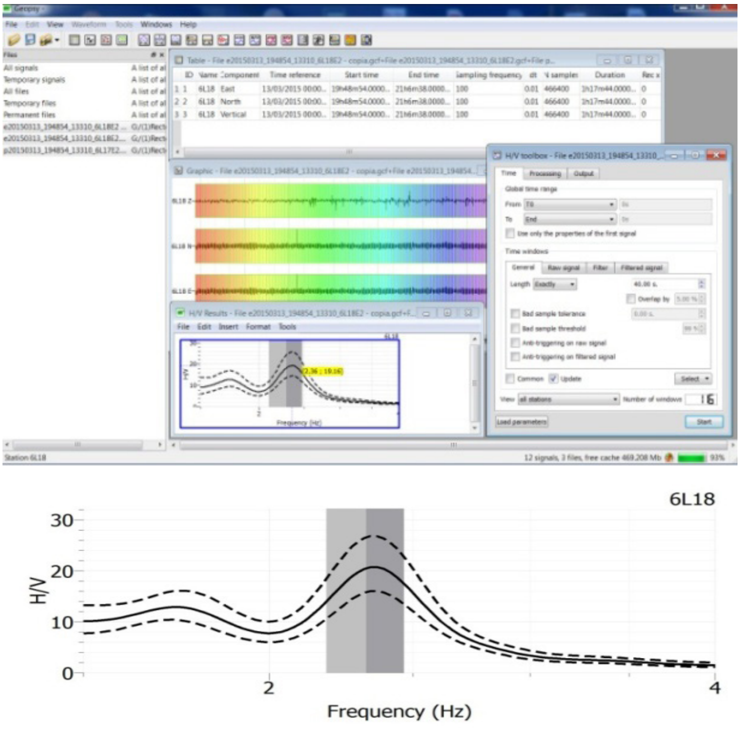


Figure 11. Standard technique application using GEOPSY (H/V) and the resulting quotient, (e-corner) F = 2.36, T = .42, A = 20

falling in the event of an earthquake.

Second Level: On the second level, we found offices that obstruct the exit. In addition to archivists in poor condition. In the cubicles, we found gypsum board walls that are not embedded in the structure.

Third Level (President's office): A bust and a sculpture placed in this area were found, which are not fixed and can be easily detached.

Fourth Level: In the fourth level, the greatest danger we identified were two large book shelves that we consider are not properly fixed and can fall in case of earthquake.

Fifth Level: In the fifth level, we found an archives area, with 24 file cabinets, which represent an excessive weight for the floor slab, which, besides we consider are not properly fixed and have the possibility of falling in case of earthquake. In Figure 12 we show some problems with the contents.

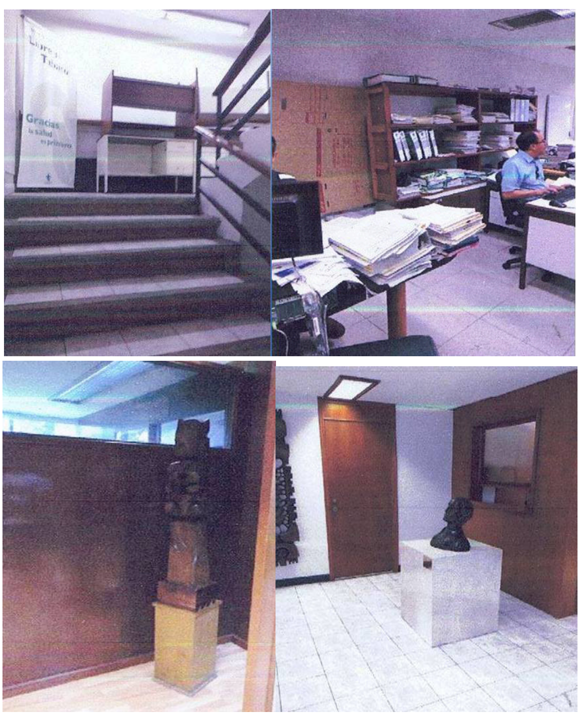
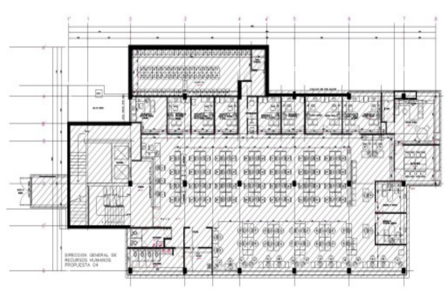


Figure 12. Some examples of problems with the contents of the building, such as partial obstruction of corridors and stairs, bad shelves and some ornate objects that may fall.

CONCLUSIONS

In an analysis of geology and geotechnics, it was found that the building is located in an area of silty loam deposits, typical of the south-central region of the city of Xalapa. Preliminary analyzes of the dynamic behavior of these soils show dominant frequencies between 0.5 and 0.6 seconds, with amplifications smaller than 3 times. This could be verified by the analysis of the environmental vibration records taken on the foundation floor of the building. It gave a dominant period of 0.6 seconds, with relative amplification of 2 times. This result indicates that the resistant layer is deep and that the hill where the building is located has a site effect, which will present the problem of amplifying the seismic waves during earthquakes.

The building has a regular shape both in plan and elevation (Figure 13), which is favorable for its behavior in the event of an earthquake. The values of the dominant periods for the horizontal components are: for the longitudinal (N) of 0.45 sec and for the transversal (E) of 0.6 seconds. If we observe that the band of the dominant period of the soil is 0.6 seconds, it means that the building is vibrating in the transverse direction at the same period as the floor, which represents a severe problem. With this, the building is expected to undergo dynamic amplification due to a possible resonance effect with the floor.



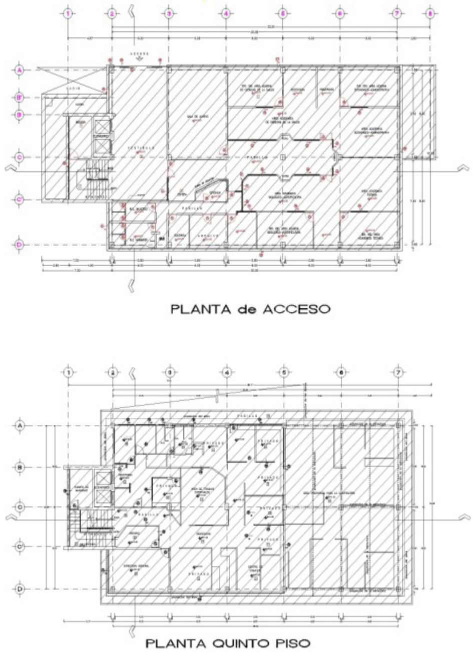


Figure 13. Plants of the President´s office building from left to right from the basement to upper mezzanines where plant regularity is observed.

The rotational periods found with the corner logs are smaller than those of the ground and are in the proper ranges of this type of structure, considering that it is a regular structure and the levels above the foundation soil.

Regarding the contents we found that there are partially blocked exits with office furniture in poor condition or that is unused, as well as, that the panels of the divisions of the office cubicles have large crystals that are not embedded in the ceiling, which represents a danger to the occupants of this area in case of a strong earthquake. Also, we found sculpture murals whose fixing to the walls must be verified because they are only supported in the floor and some points on the wall without some limitation in its movements.

Another observation is that there is only an exit for the upper levels and does not have an emergency exit, so that in case of fire or earthquake this could present a problem by the large number of people who would have to evacuate the building.

From the results, we can conclude that the building is deployed in an area with a site effect that amplifies the seismic waves. In addition, the period of the cross-section of the building is the same as that of the ground which represents a problem because of the possibility that during an earthquake the building could resonate with the ground.

It is recommended to unblock the exits, stairs and corridors as well as fasten panels, and ornaments on walls and floors, discard furniture in poor condition, do not place heavy equipment on furniture not resistant, as well as the possibility of creating an alternate emergency exit, and make further studies to see the possibility of stiffening the short direction of the building to prevent that the periods of soil and structure coincide.

ACKNOWLEDGEMENTS

This work is based on Raymundo Hernández Cruz´s master's thesis. We thank the authorities of the University of Veracruz for the help and support to carry out the study, to the students of the Faculty of Civil Engineering Zone Xalapa, who participated in the work, especially Miguel Ángel Hernández Flores and Jesús Eduardo Gutiérrez Ángel who carry out their social service and thesis in the CCTUV of the Veracruz University. In addition, Dr. Rolando Salgado for his valuable observations and suggestions.

REFERENCES

Aki, K. (1957). **Space and time spectra of stationary stochastic waves with special reference to microtremors**, *Bull. Earthq. Res. Inst.*, 35, 415-457.

Hernández J., Rodríguez S., Torres G. (2007), **Integración de Sondeos de Mecánica de Suelos en la Zona Urbana de Xalapa, Veracruz**, Como Base para elaborar un Mapa Geotécnico. *Tesis de Licenciatura UV*.

Geopsy. Sesame European (Neries) (Geopsy, Marc Wathelet, 2002)

Kanai K., and Tanaka (1954), **Measurement of the microtremor**, *Bull Earthquake Res Inst*. Tokyo Univ. 32, 199-209.

Nakamura Y. (1989), **A method for dynamic characteristics estimation of subsurface using microtremors on the ground surface**, *QR of RTRI, 30*, No.1, 25-33.

Torres, G., Dávalos, R., Castillo, S., Mora, I., Suárez, M. (2015a). **Microzonificación de zonas urbanas, elemento básico para el ordenamiento territorial, gestión de riesgos y desarrollo sostenible**. *Metodologías aplicadas a las ciencias de la tierra* Vol. 1(p. 124). ISBN: 978-607-9091-49-1.México: Universidad Veracruzana.

Torres, G., Dávalos, R., Castillo, S., Mora, I., Suárez, M. (2015b). **Microzonificación sísmica estandarizada y amenaza sísmica probabilística en zonas conurbadas de Veracruz México**. *Academia Journals 2015*, 1, pp.118-123.

Torres, G., Samaniego, J., Rodríguez, M., Aguirre, J., Dávalos, R., Castillo, S., Córdoba, F. (2012a). **Microzonificación de peligros en áreas urbanas**. *Revista Científica Guarruco*, 137, ISSN: 1657-4605, pp.111-140.

Torres, G., Mora, I. (2012b). **Peligro sísmico.** ***Peligros geológicos e hidrometeorológicos en el Estado de Veracruz*** (p. 99). ISBN:978-607-9090-12-8. México: Consejo Veracruzano de Investigación Científica y Desarrollo.

Torres, G., Dávalos, R., Castillo, S., Mora, I., Suárez, M. (2010); **Evaluación Estructural del Antiguo Edificio del Instituto de Pensiones del Estado de Veracruz, (IPE), Xalapa, Ver**., ISBN: 978-607-950425-0, *Memorias IV Congreso Nacional ALCONPAT 2010*, CENTRO DE INVESTIGACIÓN EN MATERIALES AVANZADOS, Vol. 1.