BASED ON THE RESULTS OF SEISMIC MICROZONATION, SEISMIC INTENSITY MAPS FOR THE CONURBAD AREA OF XALAPA

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ABSTRACT: The effects of earthquakes in Mexico have caused great disasters, which are accompanied by economic and human losses; in the State of Veracruz, throughout its history, important damages have been manifested due to earthquakes of great intensity. The State occupies the second and third place in the number of fatalities at the national level, with the Xalapa earthquakes of 1920 and the Orizaba earthquake of 1973, only after the Mexico City earthquake of 1985. The objective of this study was to create seismic intensity maps in terms of maximum accelerations for the metropolitan area of Xalapa, using the results of environmental vibration studies in the area. The seismic records obtained from the non-permanent seismic monitoring network of the Veracruz University in the Xalapa area, and the results of the environmental vibration analysis obtained for more than 500 vibration points taken in the seismic microzonation of the metropolitan area were used. A one-dimensional propagation methodology of the signal of the earthquakes recorded in the seismic monitoring stations of the metropolitan area was proposed, from the rock to the surface using a convolution operator, related to the empirical transfer function obtained from the seismic noise.

This study used acceleration records from various stations, within the earthquake catalog of the seismic monitoring network, both to validate the methodology and to generate seismic scenarios for each of the earthquakes under study. The maps were created for earthquakes of various magnitudes and seismogenic sources, to obtain maps of maximum amplification of the terrain in the metropolitan area, and thus establish areas of greater acceleration of the terrain and therefore of greater danger. The aforementioned methodology will be applied to obtain maps of the maximum accelerations in a practical and efficient way, which will be shown on internet sites and social networks, which will serve to delimit the areas with the greatest danger, with which the population and decision makers, such as civil protection authorities, will be able to take immediate actions after the occurrence of an earthquake and orient them where to direct the aid after the earthquake.
KEYWORDS: Microzoning, hazard, Vulnerability, Risk.

CON BASE EN LOS RESULTADOS DE MICROZONACIÓN SÍSMICA, MAPAS DE INTENSIDAD SÍSMICA PARA LA ZONA CONURBAD DE XALAPA

RESUMEN: Los efectos de los sismos en México han provocado grandes desastres, los cuales van acompañados de pérdidas económicas y humanas; En el Estado de Veracruz, a lo largo de su historia, se han manifestado importantes daños debido a sismos de gran intensidad. El Estado ocupa el segundo y tercer lugar en número de víctimas mortales a nivel nacional, con los terremotos de Xalapa de 1920 y el de Orizaba de 1973, sólo después del terremoto de Ciudad de México de 1985. El objetivo de este estudio fue generar mapas de intensidad sísmica en términos de aceleraciones máximas para el área metropolitana de Xalapa, utilizando los resultados de estudios de vibración ambiental en la zona. Se utilizaron los registros sísmicos obtenidos de la red de monitoreo sísmico no permanente de la Universidad Veracruz en la zona de Xalapa, y los resultados del análisis de vibraciones ambientales obtenidos para más de 500 puntos de vibración tomados en la microzonificación sísmica del área metropolitana. Se propuso una metodología de propagación unidimensional de la señal de los sismos registrados en las estaciones de monitoreo sísmico del área metropolitana, desde la roca hacia la superficie mediante un operador convolucional, relacionada con la función de transferencia empírica obtenida del ruido sísmico. Este estudio utilizó registros de aceleración de diversas estaciones, dentro del catálogo de terremotos de la red de monitoreo sísmico, tanto para validar la metodología como para generar escenarios sísmicos para cada uno de los terremotos en estudio. Los mapas fueron creados para sismos de diversas magnitudes y fuentes sismogénicas, para obtener mapas de máxima amplificación del terreno en el área metropolitana, y así establecer áreas de mayor aceleración del terreno y por tanto de mayor peligro. La metodología antes mencionada se aplicará para obtener de manera práctica y eficiente mapas de las aceleraciones máximas, los cuales serán mostrados en sitios de internet y redes sociales, los cuales servirán para delimitar las zonas de mayor peligro, con las que la población y tomadores de decisiones, como las autoridades de protección civil, podrán tomar medidas inmediatas después de que se produzca un terremoto y orientarles hacia dónde dirigir la ayuda después del terremoto.
PALABRAS CLAVE: Microzonificación, Peligro, Vulnerabilidad, Riesgo.

DELIMITATION OF THE STUDY AREA

The study area is the city of Xalapa and its main surrounding urban areas. For practical purposes the city has been divided into four delegations: the north, south, east, and west, which form the city of Xalapa, as well as the surrounding urban areas. For this reason, this research covers the city of Xalapa, as well as the urban areas of Banderilla and a part of San Andrés Tlalnelhuayocan (Figure 1), which are located to the north and west of Xalapa, respectively.

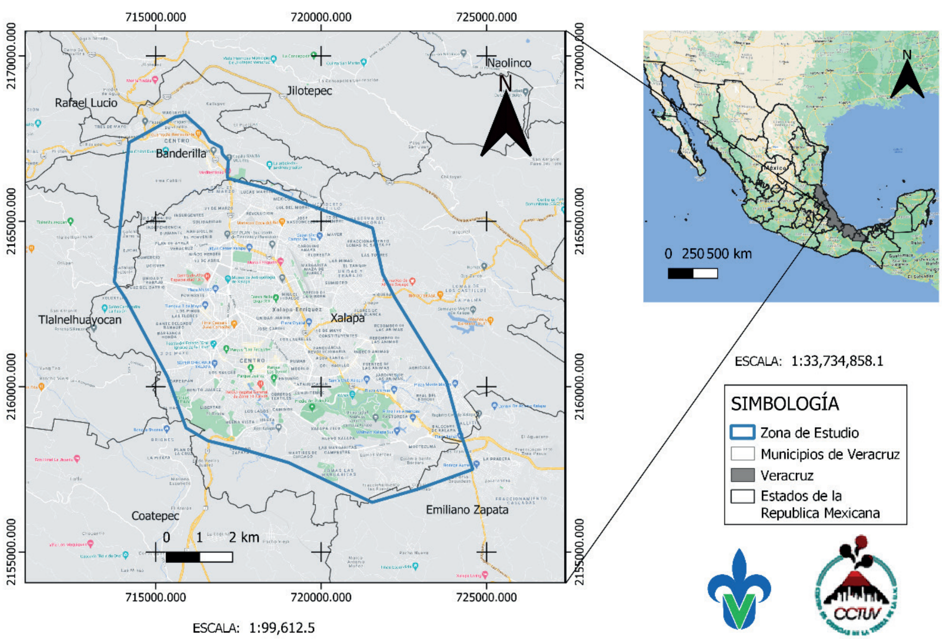

Figure 1. Map of the Xalapa Metropolitan Area (ZCX).

When reviewing existing studies on the geological, geotechnical, and geomorphological characteristics of the region, it was observed that a large part of the ZCX is composed of medium and high plasticity silts, sandy silts-clays, and alluvial deposits, making these areas more susceptible to longer periods of vibration. These studies provided us with guidelines for seismic microzonation and a more accurate understanding of how those zones would respond in the event of a seismic event. (Suarez, 2009)

DATA COLLECTION

Environmental vibration records were taken throughout the study area to carry out seismic microzonation of the Xalapa conurbation zone (Suarez, 2009). This fieldwork was carried out in 67 vibration campaigns on different dates, which resulted in a total of 517 vibration points, of which 214 points were taken from previous studies carried out in the study area where their location is shown on a map (Figure 2).

Analysis of information, Ambient Vibration Data Processing

Below are the steps to take to download and analyze the environmental vibration logs:

1. Obtaining the environmental vibration files recorded by the seismic equipment.
2. For GURALP brand equipment, the equipment is connected directly to a PC, and the data is extracted and saved to a GURALP hard drive using the Scream v4.6 program (Guralp systems 2007).
3. The data of each record is separated into its respective channel.
4. This way you can work independently with each of the accelerograph components, E2, N2 and Z2. Each component must be synchronized to GTM time at the beginning of each record (Figure 3).

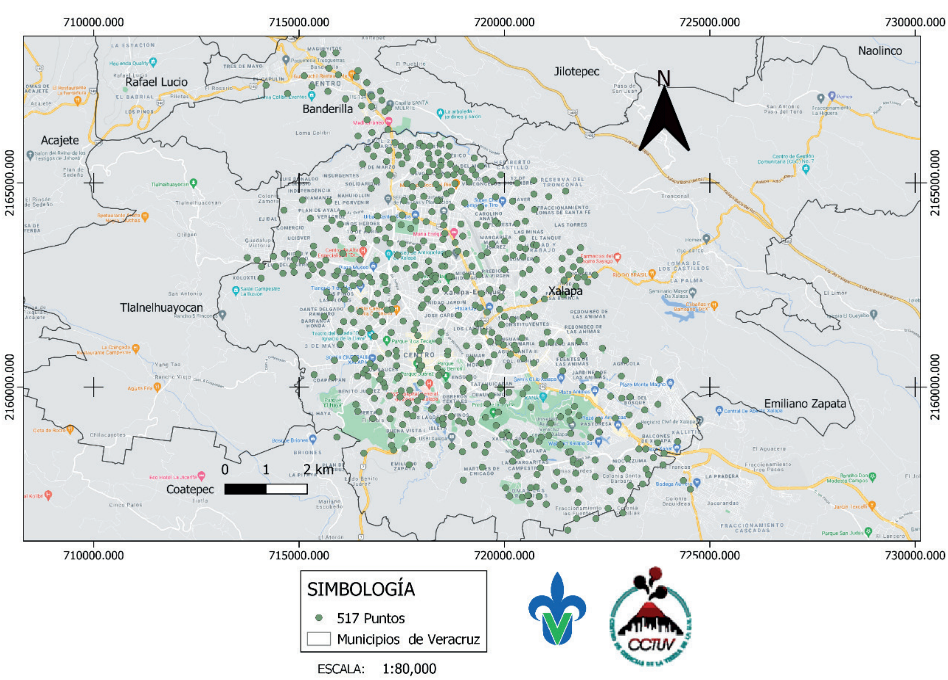

Figure 2. Map of Environmental Vibration Points in the study area.

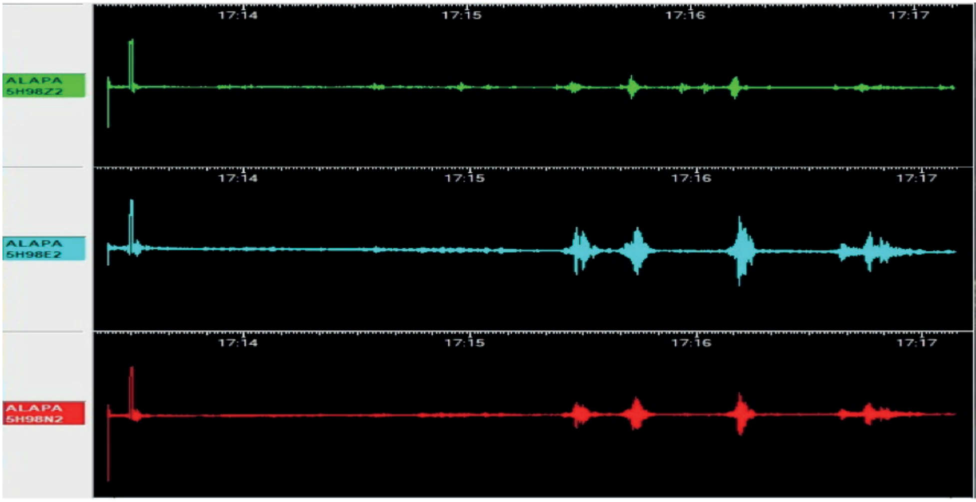

Figure 3. View of the Scream 4.6 Program showing the ambient vibration records.

Using version 2.6.3 of the Geopsy® processing program (SESAME European Project, 2007) and the H/V tool, methodology described by (Nakamura, 1989), the predominant frequency in Hertz (Hz) and the relative amplitude were sought in the location of environmental vibration points, as well as in the seismic monitoring stations.

For each station and point, three consecutive records were analyzed, each with a minimum time of 30 minutes. These recordings were chosen in windows of 25 seconds to 50 seconds, with a frequency range of 0.1 to 10 Hz. Geopsy® uses the mean square to calculate the Fourier transform (FFT) and obtains the value of H using the equation 1:

$$H = \sqrt{\frac{NS^2 + EO^2}{2}} \quad (1)$$

H/V is then obtained in the frequency domain and smoothed (Konno, 1998). With a frequency range of 0.1 to 10 Hz, calculate the mean of the H/V spectral coefficient and +/- the standard deviation (Figure 4).

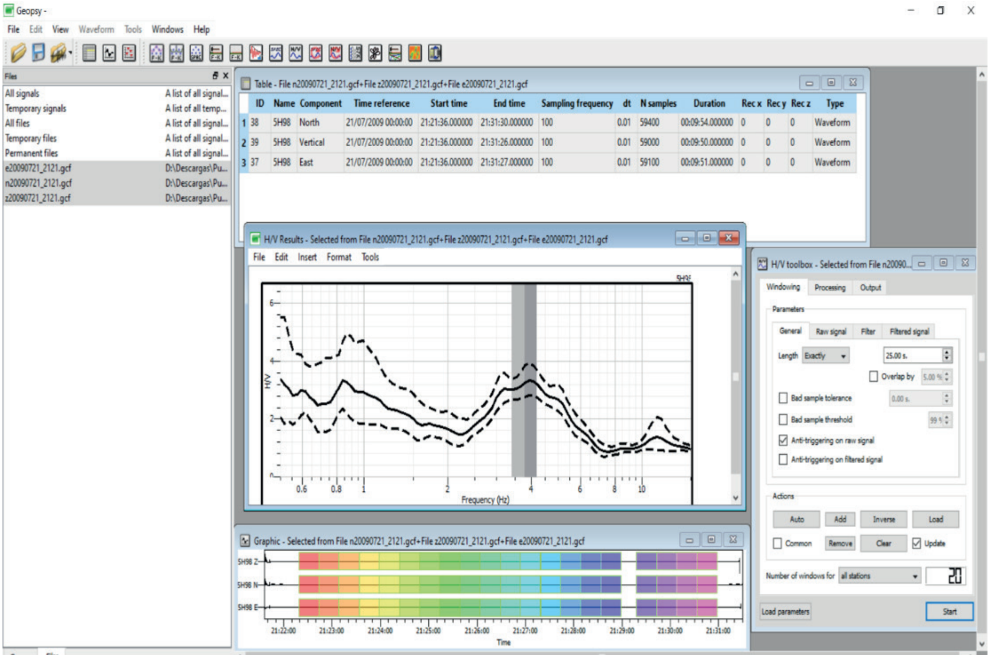

Figure 4. Example of vibration point processing in Geopsy®.

Processing of earthquake data recorded by the Xalapa seismic monitoring network

Up to 13 seismic monitoring stations were installed at some point in the Xalapa conurbation area; the main stations have been recording earthquakes since June 2007, not all stations continue to operate, because only six pieces of seismic equipment are permanently available; these must be removed and installed in other places to instrument the largest possible area of the city, and thus be able to compare the results obtained from the environmental vibrations with the analysis of the seismic records, in addition to the real seismic intensities in each zone of the city. The only station that has recorded continuously is the Cerro Station (Reference Station). This is located on the slopes of the monogenetic Macuiltépetl Volcano, which has the most consolidated soils, from which we can apply the standard spectral quotient technique and one-dimensional propagations to the other installed stations and environmental vibration points.

Figure 5 shows the seismic monitoring stations installed in the Xalapa area, some of which remain working to date.

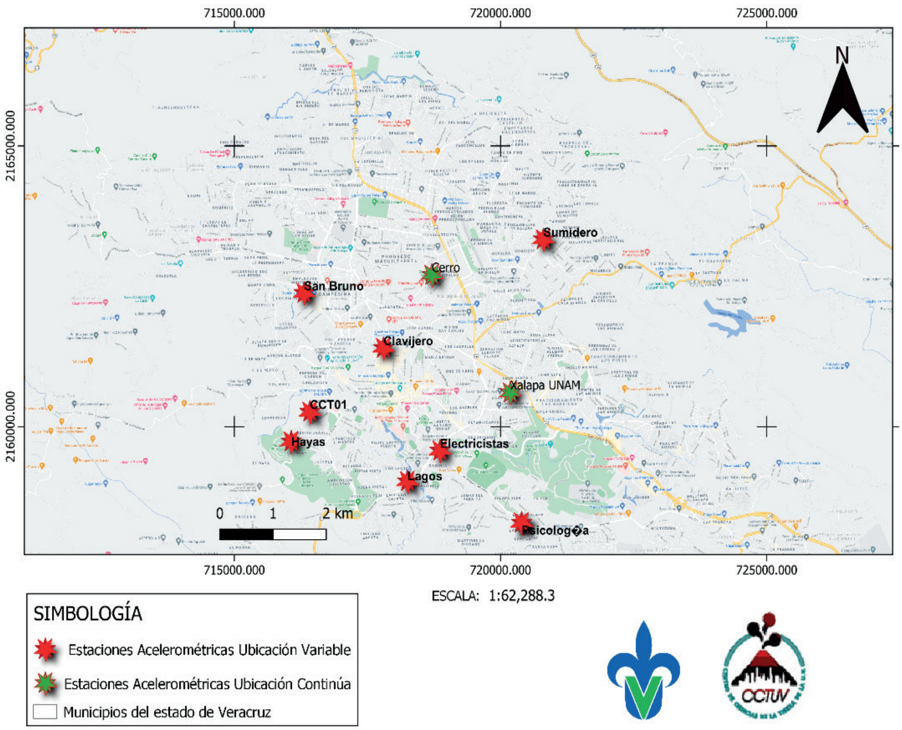

Figure 5. Location of the seismic logging stations in the ZCX.

DETAILS ABOUT THE METHODOLOGY

In this work, the empirical transfer function (H/V) is used to estimate the level of amplification in synthetic signals that is calculated with the procedure mentioned in section 3.1. At this point it is time to show the series of steps that were implemented to make the maximum acceleration maps for different earthquakes, which are shown below.

1. Over the years, acceleration signals have been recorded in the three components of the reference station, ideal for calculating the empirical transfer function (H/V) with the help of the Geopsy® software (SESAME European Project, 2007) to determine his site effect, this is eliminated in the next step (Álvarez, 2016).

2. To correct the signal for the effect of the site, the fast Fourier transform is used in the recording of the seismic signal at the reference station; thus, we work with two signals in the frequency domain, which are, the amplitude spectrum of the signal in rock and the spectral ratio H/V. These signals are deconvoluted to subtract the amplification of the site in the signal of the reference station; it is relevant to note that the Fourier spectrum of the reference station only considers the amplitude spectrum, sometimes the phase spectrum is used to calculate the synthetic signal in the time domain, however, in this project we only worked with the real part of the Fast Fourier Transform.

3. Correction of the site effect produces a Fourier spectrum of the rock record; this synthetic signal no longer has the amplification caused by the site effect, and the rock record of the earthquake can be obtained by applying the inverse Fourier transform.
4. To propagate the signal from the rock basement to the surface of the unknown point, we again use the Fourier amplitude spectra of 2 signals, requiring a spectral ratio that represents the degree of amplification and the dominant period characteristic of that point and the Fourier spectrum of the rock record. With these signals, the convolution operation is performed to multiply the effect of the amplitude to the seismic signal.
5. After performing the convolution, we obtain as a result the signal in the frequency domain in its periphery, and, since for the purposes of the project we need to know the maximum accelerations of a signal in the time domain, thus, we perform the inverse Fourier transform.
6. Finally, we calculate the maximum acceleration of the synthetic signal calculated with this process, leaving only to record it in a table format.

Systematic methodology for the generation of intensity maps. Summary of the methodology for the generation of intensity maps.

1. An earthquake recorded at the XAL rock station (reference station) is chosen.
2. The accelerograms of the earthquake are cutting out in each of the three components.
3. Deconvolution of the accelerograms is performed to eliminate possible site effects.
4. The one-dimensional propagation of the signal is calculated without site effects that was determined in the previous step. The spectral ratio is calculated at each study point and one-dimensional propagation is carried out based on the spectral ratio and the effect-free signal. In this case, the result of interest from one-dimensional propagation is the maximum value of the ground surface acceleration (PGA).
5. From the results of the PGA, a map of maximum accelerations determined for each of the 517 points studied is generated.

The above methodology can be automated to generate intensity maps within minutes of an earthquake, for use in civil protection activities, etc.

SELECTION OF STUDY EARTHQUAKE

Axochiapan earthquake (Morelos) of September 19, 2017

The earthquake struck at 1:14:40 p.m. and was strongly felt throughout the country. The epicenter was located at 18.40 N latitude and -98.72 W latitude, with a depth of 57 kilometers (Figure 6). Six aftershocks had been recorded as of 6:00 p.m. on September 19. The National Seismological Service (SSN) reported a 7.1 magnitude earthquake on September 19, 2017, near the state border between Puebla and Morelos, 12 kilometers southeast of Axochiapan, Morelos, and 120 kilometers from Mexico City.

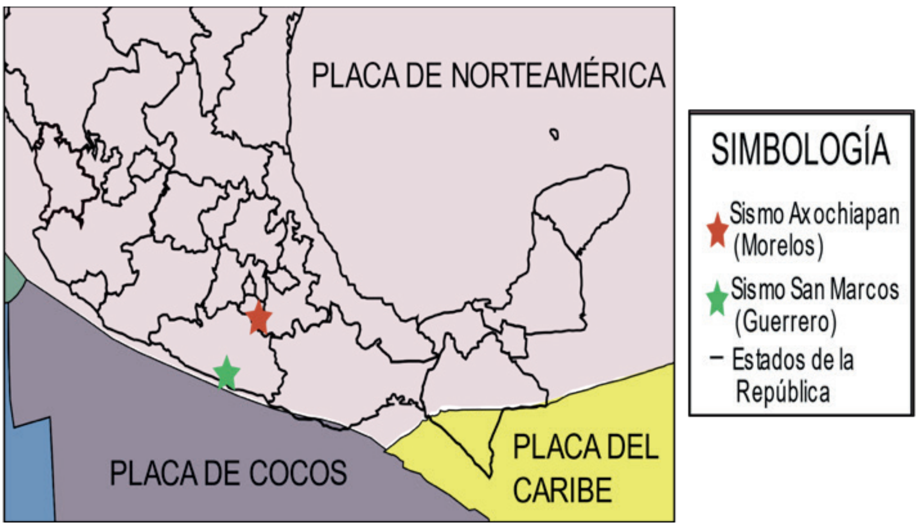

Figure 6. Epicenters of the earthquakes under study. Modified from the National Seismological Service.

San Marcos earthquake (Guerrero) of April 27, 2009

The earthquake struck at 11:46:27 a.m. and was strongly felt throughout the country. The epicenter was located at 16.90 N latitude and -99.58 W latitude, with a depth of 7 kilometers (Figure 10). There were no aftershocks with great influence on the population. The National Seismological Service (SSN) reported a 5.7 magnitude earthquake on April 27, 2009, 23 km northeast of San Marcos, Guerrero.

VISUALIZATION OF THE RESULTS

As a result of this work, we produced the maps of maximum accelerations for the Xalapa conurbation area (ZCX) where they show us the approximate accelerations to the physical reality as shown for the two earthquakes registered in the Xalapa Accelerometric Network.

Earthquake of September 19, 2017

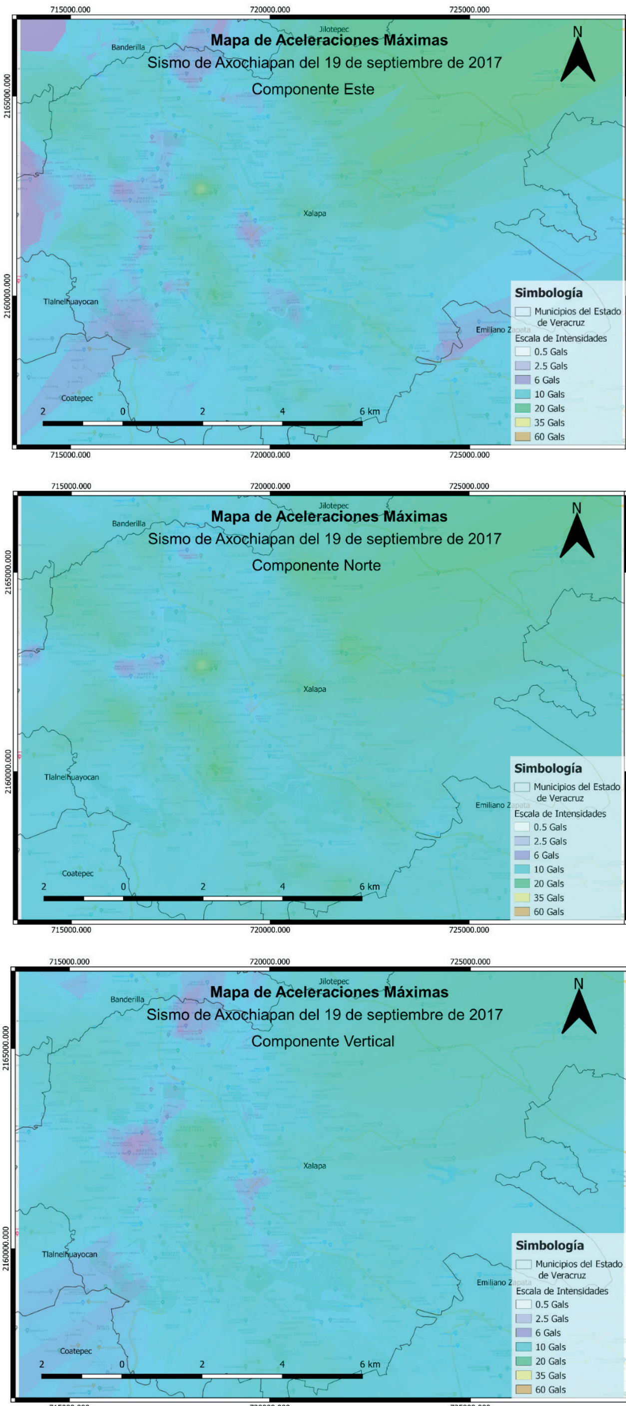

Figure 7. Intensity maps for the September 17, 2017, earthquake.

Earthquake of April 27, 2009

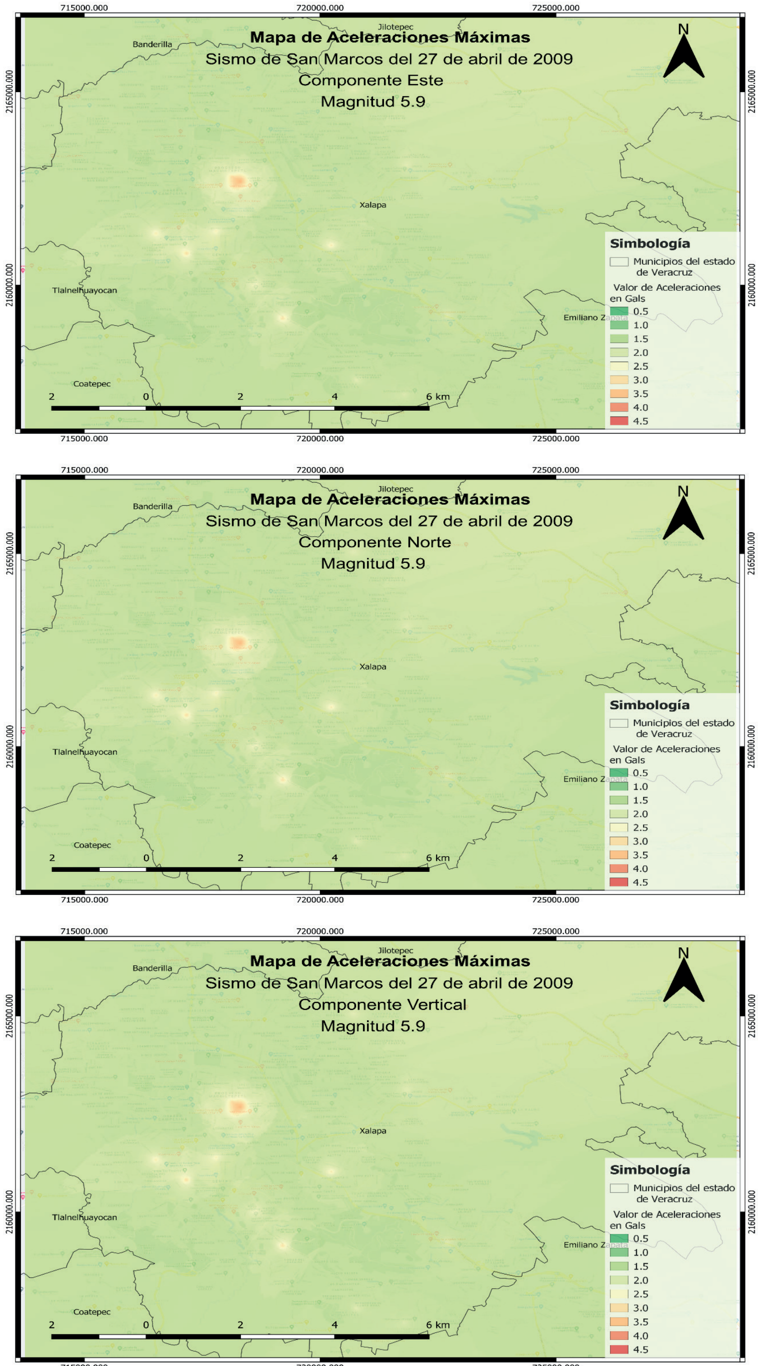

Figure 8. Intensity maps for the April 27, 2009, earthquake.

CONCLUSIONS

Few cities in Mexico have the necessary tools and studies to understand the dynamic behaviour of the soil on which they are built. The high monetary cost of an accelerograph network or the performance of sufficient geotechnical studies to study each area has led to the development and continuous improvement of methodologies such as those described in this work.

We conclude with some necessary considerations for a correct analysis of soil dynamics and seismic risk in terms of the methodology of the H/V spectral ratios, numerous studies recommend that in order to achieve a reliable analysis spectrum from 0.2 to 20 Hz it is necessary to perform the environmental vibration recordings with broadband tests and try to achieve the longest possible recording time (not to exceed 60 minutes), since in this way, the amplitude clearly shows the peaks of higher amplification; it is necessary to carry out the measurements and processing of the H/V coefficients.

In terms of surface accelerations, the methodology used in this project successfully attempts the process of amplification and attenuation of seismic signals, allowing the accelerations caused by an earthquake to be reproduced at multiple points of interest from a single signal recording station.

Finally, despite considering only the amplitude of the signal and not modifying its duration, a reliable result is obtained. It is also necessary to correct the site effect of the propagating seismic signal to avoid overestimating the calculated accelerations.

RECOGNITIONS

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