MAPS OF SEISMIC INTENSITY IN THE METROPOLITAN AREA XALAPA, VERACRUZ, MEXICO.

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SUMMARY:

On February 25, 2011 at 7:08 an earthquake shook the metropolitan area of Xalapa (ZCX), causing alarm in the population. The magnitude was 6.0 Mw, the epicenter (17.76N, 95.21W) was located between Oaxaca and Veracruz, 30 km southwest of Sayula, Veracruz, and its depth was 135 km.

The Center for Earth Sciences of the Universidad Veracruzana (CCTUV) has a network with seismic microzonation purposes in the ZCX, in which four broadband stations were working at the time. The quake saturated two stations located on soft ground, which generated a great deal of interest in knowing the perceived intensities, so surveys were conducted to define the intensities.

This paper presents the survey results as a map of intensities. This information relates to the results of a seismic microzonation in ZCX. Furthermore, the results are compared with the expected intensities for the city.

Keywords: Geological danger, risk, seismic prospection, seismic microzoning, vulnerability

1. INTRODUCTION

1.1 Location

The ZCX is located in the Central Region of the State of Veracruz, in the foothills of Macuiltepetl hill in the eastern foothills of the Cofre de Perote, a transition zone between the Sierra Madre Oriental and the coastal plain of the Gulf of Mexico. Its average altitude is 1,400 meters. The ZCX has over 450,000 inhabitants, its geographical coordinates are 19 ° 32 '24" north latitude and 96 ° 55' 39" west longitude. It has an approximate area of 118 km^2 (Fig. 1.1.1).

1.2 Seismicity in the ZCX

The State of Veracruz has suffered throughout its history major damage because of high intensity earthquakes. The first news of a major local earthquake near Xalapa dates from 1546. Historical reports of this event indicate the total destruction of the Convent of San Francisco, founded in 1534. Subsequent reports indicate that the city was affected by similar earthquakes with return periods of 100 years (Torres 2008).

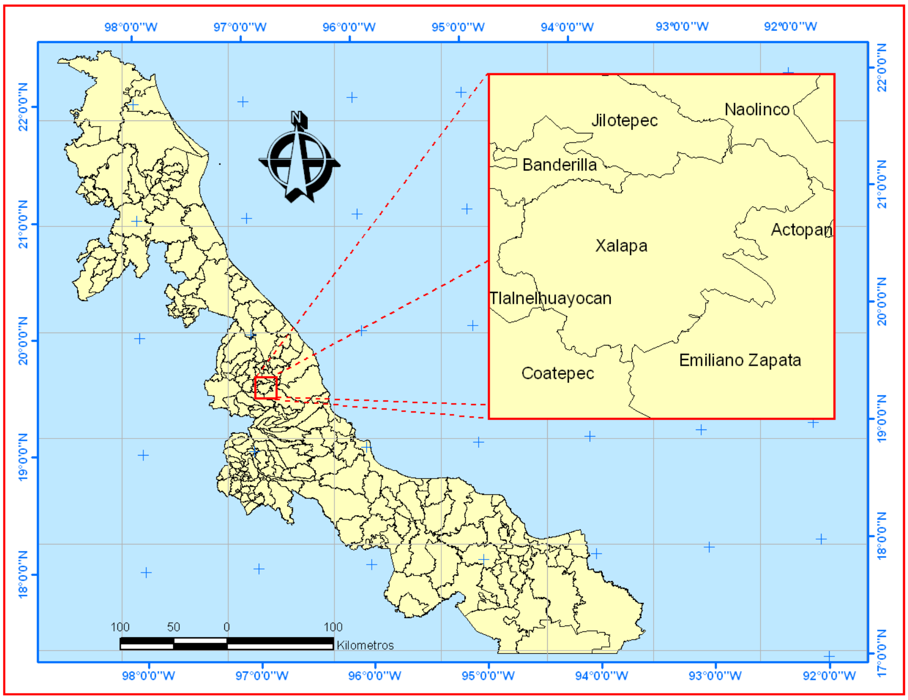


Figure 1.1.1 Location of ZCX

Veracruz State occupies the second and third place in number of fatalities nationwide, with Xalapa earthquakes of January 3, 1920 and Orizaba of August 28, 1973 respectively, only after the earthquake of September 19, 1985 with approximately 6,000 victims. The Xalapa earthquake (Ms = 6.2) ranked second nationally with 650 fatalities, 419 were killed by mudslides caused by the landslide material in ravines. The earthquake originated in the Sierra Madre Oriental, between the states of Puebla and Veracruz. The epicenter was located about 35 kilometers southwest of the city of Xalapa. The Orizaba earthquake (Mw = 7.0) caused 539 deaths. This earthquake occurred in the state of Puebla near the border with the state of Veracruz about 40 km southwest of Orizaba.

Other earthquakes that damaged major cities in the state were: The earthquake of January 14, 1931 Huajuapan de León, Oaxaca., (Ms = 7.8), which caused damage to the city of Veracruz; the earthquake of July 25 Nopatltepec of 1937, Ver, (Ms = 7.3), affecting the cities of Veracruz, Xalapa, Orizaba and Córdoba; the earthquake in Jáltipan of August 26, 1959 (Ms = 6.4), which completely destroyed the city and affected the cities of Acayucan, Minatitlan and Coatzacoalcos and, the earthquake of March 11, 1967 (Mw = 5.7), known as the Veracruz earthquake which damaged about 50 buildings.

Clearly, the state of Veracruz and the ZCX, which have been affected by earthquakes in the past, and have become an important tourist center, with ever stronger industrial and commercial investment in infrastructure, require studies on the effects that the natural phenomena would have on its urban areas and population. The increase in population, industrial activity and the high probability of impact by natural phenomena, show the importance of defining the hazards in urban areas, in order to take steps to prevent damage or disasters and with the aim of carrying out urban planning in consonance with nature. Often, the lack of financial resources together with the lack of more precise information about the area has meant that many homes and even large structures are built without the appropriate technical advice (Torres, 2000).

2. Seismic Microzonation of ZCX

For the planning of an urban area to aspire to promote sustainable development, it is essential to have a great deal of the details on the pertinent information and the most important is that that has to do with the degree of exposure to natural phenomena. In general, microzonation investigations consider all natural phenomena that could potentially affect an area of interest, such as earthquakes, floods, landslides, erosion, tsunamis, etc., and hazard maps for each of potential hazards are prepared. These maps are superimposed and then the area considered is divided in areas with different degrees of danger. Geographic information systems (GIS) are useful for these tasks.

Seismic microzonation studies are a branch of microzonation studies and are the most important ones for areas or cities exposed to earthquakes; these are interdisciplinary studies of Earth sciences, that when properly synthesized and drawn, allow preparation of the seismic hazard map. These studies cover a few square kilometers, including the existing urban area and its possible expansion, and consider the effects that an earthquake would have, taking into account the site effects, shown by isoperiod curves and areas of amplification on solid ground, to define seismic microzones; this is a document easier to interpret and apply to land use plans for natural disaster reduction, as well as to building regulations.

For seismic microzonation the ZCX data on a total of 517 points of vibration was recorded, in different geological and geotechnical areas to determine its dynamic characteristics and site effects using the Nakamura technique. We used mainly two triaxial accelerometers, a Refteck 130-anss/02 model and the CMG-5TD from Guralp System. After orientation and leveling of the apparatus at each point, about fifteen to thirty minutes at ambient vibration were recorded in the internal memories of the equipments, and then downloaded to a computer for analysis.

We also installed seismic monitoring stations, on solid ground (reference station) and on soft ground, according to geological and geotechnical characteristics, using broadband seismometers Guralp, model CMG-6TD, running up to eight seismic monitoring stations, recording to date 138 earthquakes, which has allowed us to apply the technique of standard spectral ratios, to corroborate the results obtained with the Nakamura technique. Analyses were performed with the help of programs Degtra (Ordaz, 1990) and Geopsy (Geopsy, 2007).

The seismic monitoring network has served the ZCX to detect seismogenic sources affecting the area and earthquakes of many seismic sources of the Mexican Republic have been recorded. The most important seismogenic sources that generate the greatest danger are the most active ones and which are at a shorter distance and that are associated with historical earthquakes that have caused damage to the ZCX; the earthquake could be grouped into four groups: subduction earthquakes, the deep subduction ones, those from the crustal neovolcanic axis and those of local and Gulf origin. The return periods go also in that order.

The most important earthquakes that have been recorded on the network since 2007 which have been perceived by the population and caused alarmed: The Oaxaca earthquake of February 12, 2008 (M = 6.6); the Puebla earthquake of May 22, 2009 (M = 5.7); that of September 8, 2009 (M = 5.1), located in Isla, Veracruz; another on April 7, 2011 (M = 6.7), located 83 km from the Choapas, Ver.; that of February 25, 2011 (M = 6.0), which was located southwest of Sayula, Veracruz; one more on September 28, 2011 (M = 4.1), located 32 km southeast of Misantla; one more, on February 14, 2012 (M = 4.1), located 10km from Sayula, Veracruz; and the most recent one, on March 20, 2012 (M = 7.4), 29 km south of Ometepec, Gro., the strongest so far and that has generated the greatest velocities and accelerations, a = 9 gals and V = 0.31 m/s.

2.1 Determining the shear velocity Vs in the ZCX

Seismographs arrangements were made with multichannel broadband in order to apply SPAC techniques to obtain the shear velocity profiles in the ZCX. The experiment was designed to optimize time and use of the equipment installed. Prospection seismographs GEODE and SARA of 24 and 16 channels respectively, were used for the experiment at each site with vertical geophones between 4.5 and 125 Hz, recording for a half hour at each site. In addition, three sensors were placed with bandwidth between 0.1 and 50 Hz on the same geophones laid out in a linear arrangement, placing the equipment on the ends and center. In some sites we used regular and irregular triangular arrangements depending on the available space. In addition, an active test was performed taking advantage of the laying of the geophones, Rayleigh surface waves were generated repeatedly hitting a plate with a hammer of 10 kg, in three different locations of the arrangement (at the beginning, middle and end). This test provides information on surface layers.

The measurements of scattering of the phase velocity are made by extending the technique of spatial autocorrelation in two stations to a line (2sSPAC, for short English; Aki, 1957 and Morikawa *et al.*, 2004). The process includes initially calculating the spatial autocorrelation between the recordings obtained in possible pairs of stations. Then, the calculated correlations are taken to the domain of the phase velocity and the frequency to identify the resulting image in the dispersion curve of phase velocity. The dispersion curves were constructed and inverted to phase velocity profiles, Vs.

2.2 Summary of results in the ZCX microzonation

From the spectral analyses of the records of ambient vibration, seismic and technical implementation of the SPAC we found that the frequencies in the ZCX are in the range of 0.9 to 13 Hz, the dominant periods of 0.07 to 1.14 sec. And, amplification of 1 to 6 times compared to solid ground, that in all ZCX, but correlated with the type of land classified in the geological-geotechnical maps. Also, we could distinguish 3 zones: the hard zone I, the intermediate zone II and soft zone III. Data analyses allowed us to find that for the hard zone I, at a depth of 15 m Vs of 400 m/s; at 30 m, Vs of 800 m/s. For the intermediate zone II, we found at a depth between 20 m and 25 m, a velocity Vs of 400 m/s, reaching 500 m/s at depths of 35 m. For the soft zone III, it was found that at a depth between 20 m and 25 m, the velocity Vs is 200 m/s

The results were integrated in a geographic information system (GIS), creating thematic maps in all conurbations such as: points of vibration, geological isofrequency, isoperiods, and isoamplifications, as an example, some of the results are shown (Fig. 2.2.1.), (Torres *et al.*, 2009, 2011), these are important products because they integrate the main features of the ZCX and its management in a GIS allows it to be susceptible to updating, which makes the study a dynamic one. It is also possible to query details for any point of the above characteristics and are made available to anyone who may need them at an internet portal, which will be helpful for building professionals, civil protection officials, appraisers, insurers, etc.

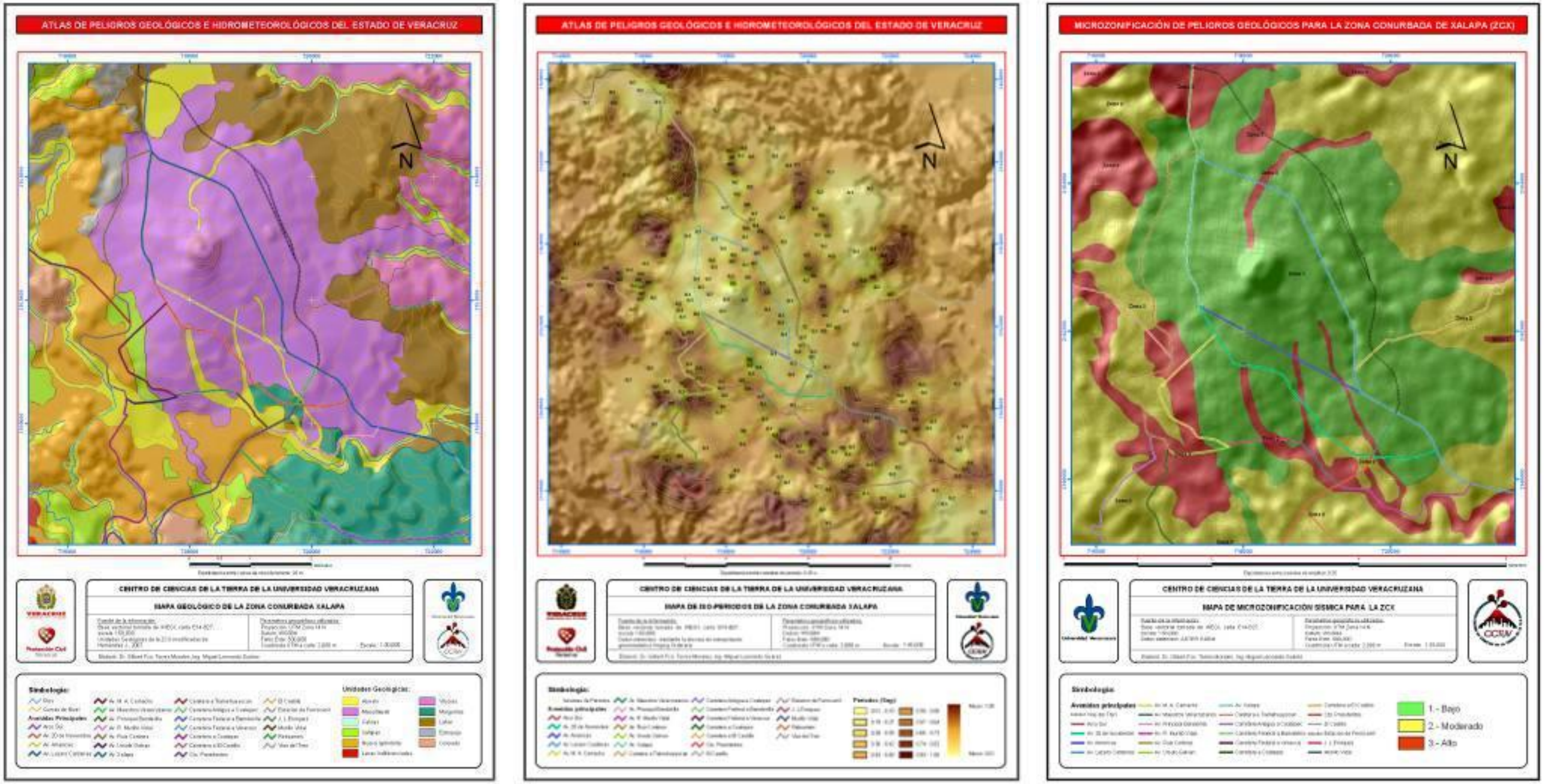


Figure 2.2.1. Geology maps, isoperiods, and seismic microzonation of ZCX.

3. Intensity Map

3.1 Earthquake of February 25, 2011

The earthquake of February 25, 2011 of magnitude 6.0, occurred at 7:07 hours time in central Mexico. The coordinates of the epicenter were 17.76 N latitude and 95.21 W longitude, on the border between Oaxaca and Veracruz, 30 km southwest of Sayula de Alemán, Veracruz and its depth was 135 km. (Fig. 3.1.1). This earthquake was felt in much of the state of Veracruz, causing alarm in the population. Due to its characteristics, it corresponds to a deep subduction earthquake with a focal mechanism showing a normal fault according to the SSN

Figure 3.1.1 Location and characteristics of earthquake 25.02.2011 (SSN)

The previous earthquake is similar to the earthquake occurred on July 25, 1937, with magnitude 7.3, whose epicenter was located 22 km northeast of Nopaltepec Veracruz, near the border between the states of Oaxaca and Veracruz. In Xalapa, numerous houses were damaged and in poor neighborhoods, some houses collapsed. The State Government Palace suffered cracks in its towers, which were later demolished to prevent its collapse into the street; this led to the relocation of the government offices to the Preparatory College. The city was without power.

The earthquake of 25/02/2011 was recorded at all stations of the seismic monitoring network of ZCX, the stations which recorded the quake were: Cerro (reference station), CCTUV, Psychology, Language School, and only in the Language School and CCTUV stations, the record were saturated. The records at the stations are shown in (Fig.3.1.2) and a table with maximum velocities and accelerations of the stations that were saturated (Table 3.1.1).

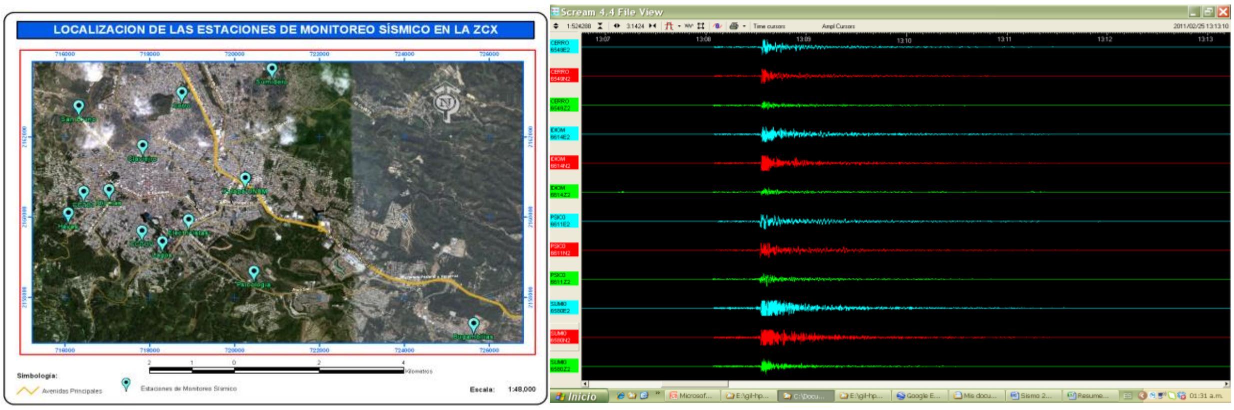
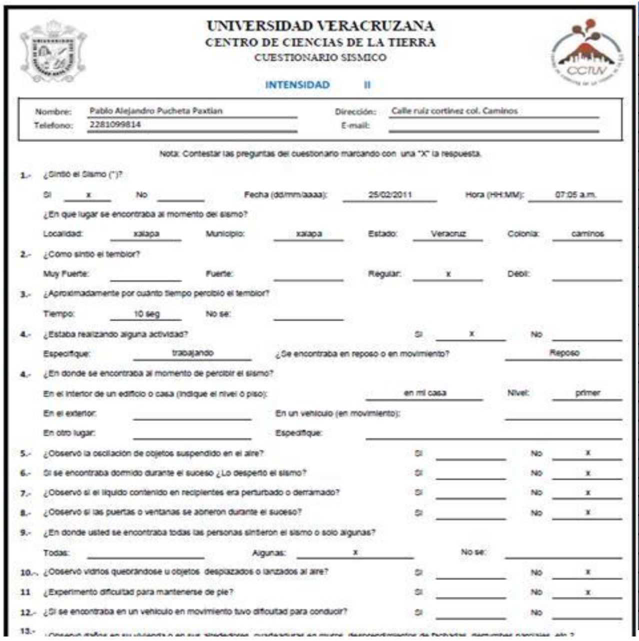


Figure 3.1.2 Location map of stations and station records in earthquake of 25.02.2011 at ZCX.

Table 3.1.1 Accelerations and maximum velocity in earthquake of 25.02.2011 ZCX						
Station	Velocity (cm / s)			Acceleration (cm/sec2)		
	EST	**NORTH**	**VERTICAL**	**EST**	**NORTH**	**VERTICAL**
CERRO	3.16E-01	3.04E-01	1.73E-01	6.51E+00	7.93E+00	3.50E+00
PSYCHOLOGY	2.97E-01	3.20E-01	2.52E-01	3.95E+00	3.76E+00	3.60E+00

3.2. Survey to establish the seismic intensity in the ZCX

The earthquake caused great alarm in the population, although no damage was reported, but it generated that some broadband stations located in the soft ZCX saturated their record, which caused great interest in knowing what were the intensities of earthquakes felt by the population. For several years the CTTUV has tried to apply the survey every time an earthquake occurs, and has tried to get the state's civil defense authorities involved, but it has not been successful so far. For this earthquake we invited students in the school of civil engineering at the Universidad Veracruzana Xalapa to implement the survey, achieving over 100 surveys completed in the city (Fig.3.1.2).



UNIVERSIDAD VERACRUZANA
CENTRO DE CIENCIAS DE LA TIERRA
CUESTIONARIO SISMICO

INTENSIDAD II

Nombre: Pablo Alejandro Pucheta Paxtian — Dirección: Calle ruiz cortinez col. Caminos
Telefono: 2281099814 — E-mail:

Nota: Contestar las preguntas del cuestionario marcando con una "X" la respuesta.

1.- ¿Sintió el Sismo (")?
Si: x No: Fecha (dd/mm/aaaa): 25/02/2011 Hora (HH:MM): 07:05 a.m.
¿En que lugar se encontraba al momento del sismo?
Localidad: xalapa Municipio: xalapa Estado: Veracruz Colonia: caminos

2.- ¿Como sintio el temblor?
Muy Fuerte: Fuerte: Regular: x Débil:

3.- ¿Aproximadamente por cuánto tiempo percibio el temblor?
Tiempo: 10 seg No se:

4.- ¿Estaba realizando alguna actividad? Si: x No:
Especifique: trabajando ¿Se encontraba en reposo o en movimiento? Reposo

4.- ¿En donde se encontraba al momento de percibir el sismo?
En el interior de un edificio o casa (indique el nivel ó piso): en mi casa Nivel: primer
En el exterior: En un vehiculo (en movimiento):
En otro lugar: Especifique:

5.- ¿Observó la oscilacion de objetos suspendido en el aire? Si: No: x
6.- Si se encontraba dormido durante el suceso ¿Lo desperto el sismo? Si: No: x
7.- ¿Observó si el liquido contenido en recipientes era perturbado o derramado? Si: No: x
8.- ¿Observó si las puertas o ventanas se abrieron durante el suceso? Si: No: x
9.- ¿En donde usted se encontraba todas las personas sintieron el sismo o solo algunas?
Todas: Algunas: x No se:
10.-. ¿Observó vidrios quebrándose u objetos desplazados o lanzados al aire? Si: No: x
11 ¿Experimento dificultad para mantenerse de pie? Si: No: x
12.- ¿Si se encontraba en un vehiculo en movimiento tuvo dificultad para conducir? Si: No:
13.-

#Encuesta original	# Encuesta	Nombre	Grado de intensidad	Grado de intensidad	Coordenada Este	Coordenana Norte
1	1	Margarita Dominguez	VII	7	719750.32	2162495.34
2	2	Marco A. Dobledo	VI	6	719424.74	2164483.37
3	3	Maricela Lara lopez	VII	7	719894.73	2163894.84
4	4	Ana Karen Ramos	II	2	718819.7	2163944.93
1	5	Gerardo Diaz	V	5	720326.92	2164001.57
2	6	Margarita Sanchez Enriquez	VII	7	720458.08	2163586.95
3	7	Francisco Ceballos Soto	V	5	720378.6	2163451.88
4	8	Abraham Escobar Garcia	IV	4	720240.59	2164690.35
5	9	Arlen Zapata	II	2	720336.03	2163216.61
6	10	Jose David Monje Gonzalez	II	2	720612.35	2162760.92
7	11	Ilano O. Fernandez	V	5	720342.62	2162970.54
8	12	Marco Hernandez	II	2	720339.19	2163028.08
9	13	Ema Garcia Perez	VI	6	719746.14	2161266.54
10	14	Alicia Andrade Ortega	X	10	721097.67	2163354.64
11	15	Antonia Garcia	VI	6	720464.81	2163688.68
12	16	Juan Samuel Soto	II	2	715420.61	2164040.22
13	17	Arturo G.H.	II	2	721011.1	2161790.96
14	18	Isidro Aguilar Loeza	VI	6	720615.91	2163205.76
15	19	Rocio Aguilar Herrera	V	5	720261.5	2162806.44
16	20	Martina Mersildo Pelayo	II	2	720660.96	2162358.57
17	21	Juan Carlos Perez	II	2	714866.49	2164086.62
18	22	Victor Alfonso Tibera	IV	4	719737.29	2165462.39
19	23	Jose Antonio Nieto Galan	II	2	721014.25	2162704.52
20	24	Jose Manuel Trinidad Gonzales	II	2	721180.62	2162782.08
21	25	Roberto A. C.	VII	7	717772.33	2160797.5
22	26	Ruben Martinez Vargas	II	2	715629.13	2164086.35
23	27	Alizon	VIII	8	720866.58	2162992.48
24	28	Hector	V	5	719693.28	2163888.17
25	29	Humberto	V	5	716863.4	2166375.67
26	30	Antonia Garcia	V	5	720464.81	2163688.68
27	31	Maria Teresa	V	5	719693.15	2160706.04

Figure 3.2.1. Example of seismic survey undertaken and summary of results.

3.3. Seismic map of intensities

The results of seismic surveys were integrated into a table where data is placed; among the most important ones are the name of the person, the resulting intensity and coordinates of where they stood when the quake happened. Using a GIS we generated a map of intensities (Fig.3.1.2). On this map are located the places where people who answered the survey were when the earthquake occurred and we made an interpolation of the obtained values of intensity.

The method to interpolate the values was the method of inverse distance weighted (IDW), this is an interpolation method for point-type data base. The inverse distance weighted assumes that each input point has a local influence that diminishes with distance. Interpolation with GIS generated a raster, which is an image where each pixel represents a value, in this case of intensity; from these values isointensities curves were generated, identifying the areas most susceptible to the amplification of seismic waves according to the survey, as intensity minima I and maxima X in MM scale.

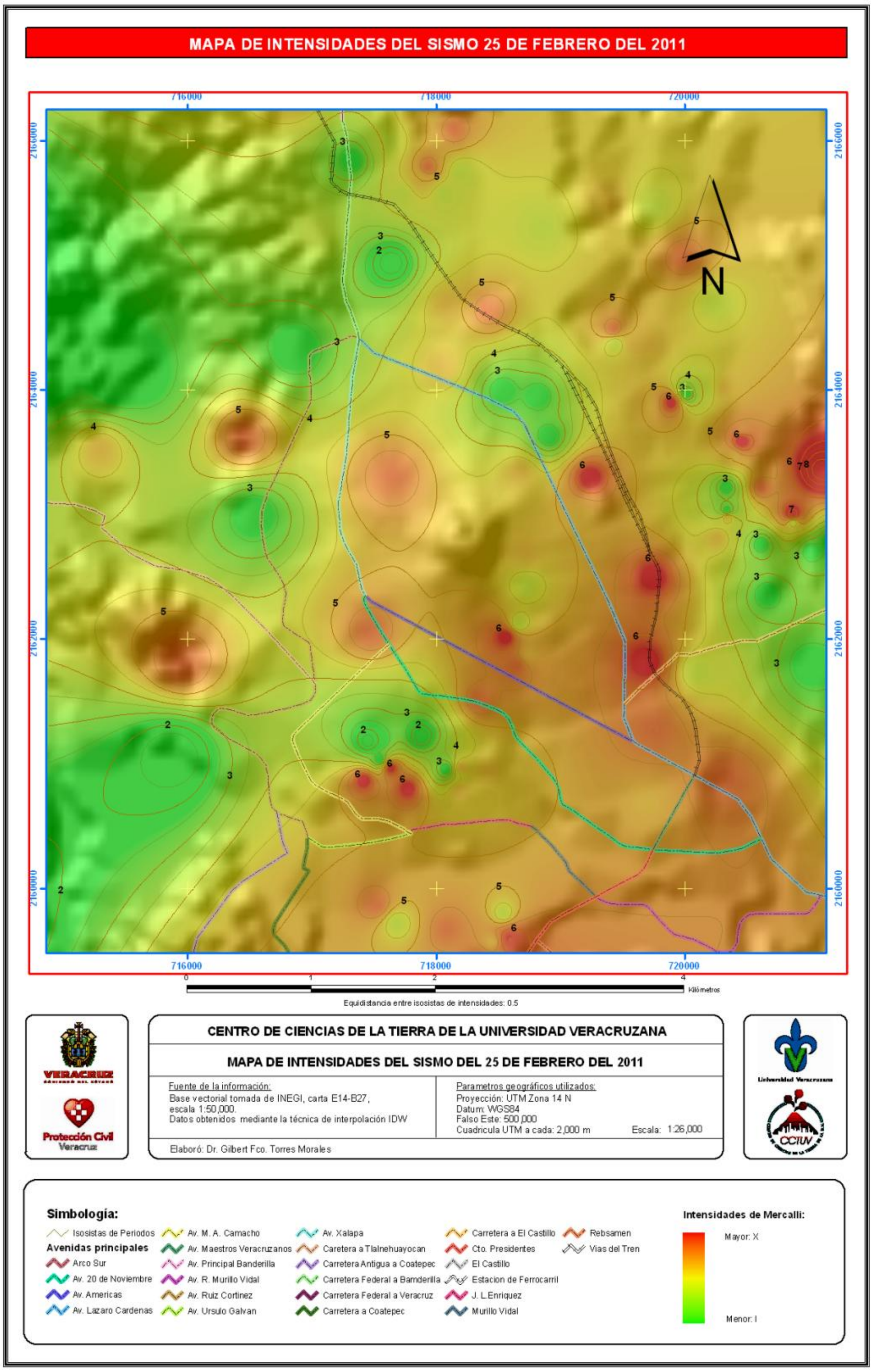


Figure 3.3.1 Map of seismic intensities for the 25.02.2011 at ZCX.

The result of the interpolation of the intensities obtained in the surveys was compared with the results of the seismic microzonation, this is done more easily if we superimpose the maps in a system like Google Earth, so that the maps generated in CCTUV are transformed into a format that can be displayed in the program free to use Google Earth, this greatly facilitates any analysis and comparison of results, this information is also available online at CTUV page and on that of a few collaborators,

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http://sites.google.com/site/hdjmdjdyj/home/microzonificacion-de-peligros.

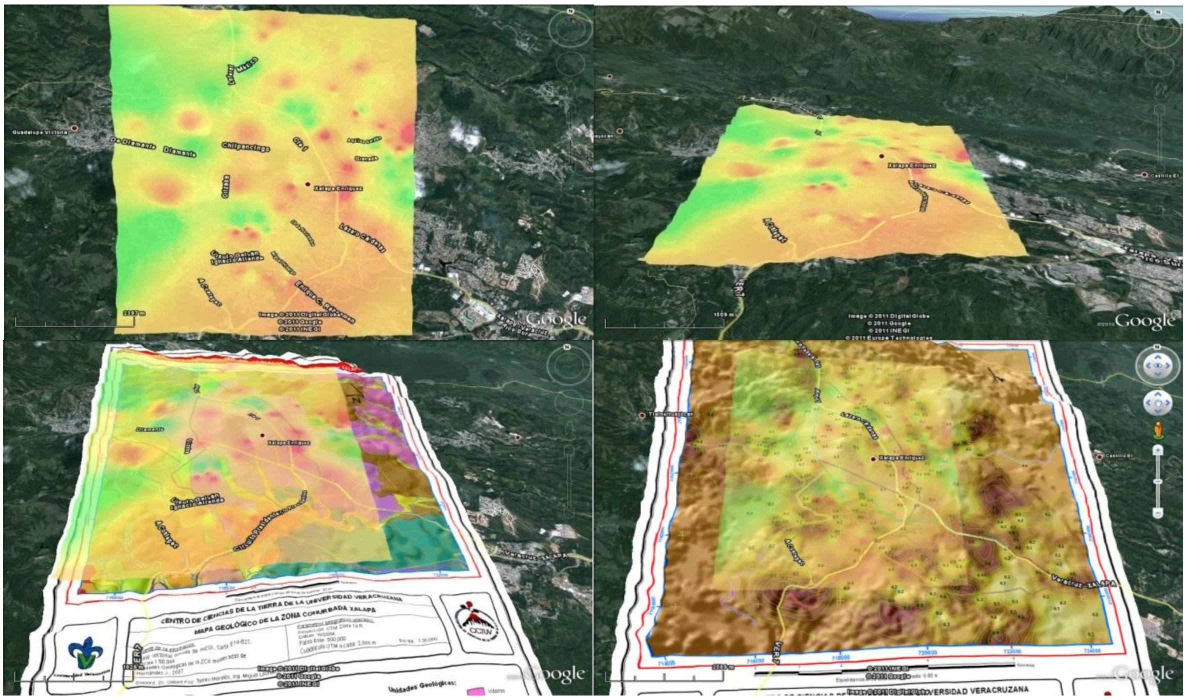

Figure 3.3.2 Map of intensities displayed on Google Earth along with other outcome of the microzonation maps for comparison of results.

We can observe a good correlation of results from the interpolation of intensity values with the results of the seismic microzonation, we note that the areas where the periods of vibration are higher and are considered the areas of greatest amplification of seismic waves, are the areas where the intensity perceived by the people was stronger. Furthermore, apart from this earthquake for which the intensities map was drawn, there have been other earthquakes, for which the survey was applied and new maps of intensities.

In a preliminary way, we obtained a seismic hazard map for the state of Veracruz with the CRISIS program (Ordaz *et al.* 2007), according to the main seismogenic sources affecting the state of Veracruz and the Greater Xalapa area, with which we obtained hazard maps with seismic probability of exceedance of 2%, 10%, 33% in 50 years, which correspond to return periods (Tr) of 2475, 475 and 125 years respectively, the intensity values of acceleration for these Tr, are 290 , 135 and 65 gals respectively, which are very large values compared to values recorded by the seismic monitoring network of ZCX (Fig. 3.3.3).

We are currently working to integrate the information resulting from the seismic microzonation CRISIS program and to obtain the seismic hazard map considering the site effect (Huerta *et al.* 2011), which will allow us to obtain expected intensity maps for different geological and geotechnical areas and both products, can be compared.

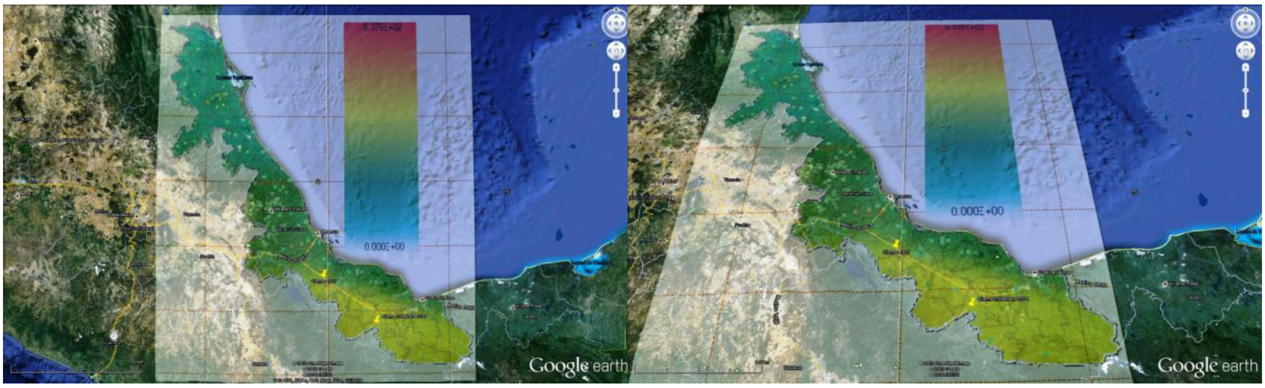

Figure 3.3.3 Map of seismic hazard with probability of exceedance of 2% in 50 years, and T = 0.15 where the maximum intensity for ZCX is 290 gals.

AKCNOWLEDGEMENT

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