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Landforms Spatial Interference with Seismic Waves in the Area of Influence of the Cocos Plate, Mexico

Interferência Espacial da Topografia com as Ondas Sísmicas na Área de Influência da Placa de Cocos, México

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Abstract

Within the framework of the "site effect" study and the spatial impact of local geographic features on seismic waves, the maximum accelerations of 45 interplate and intraslab seismic events with magnitudes (Mw) in the range of 5.6 to 8.2 that occurred from 1985 to 2018 were spatially analyzed and processed. Averages and maximum acceleration values of 172 accelerographs distributed among the territories boundaries located in the most seismic region of Mexico, are replaced the data of the scale of seismic moment magnitude (Mw) in each of the epicenters of the 45 events studied. The differential seismic impact of the topography that four Significant Epicentral Zones (SEZ) identified exert in two important cities, two tourist poles and two commercial seaports is identified. Correspondingly, the predominant orientation, direction, spatial tendency at the lithosphere level, which follow seismic waves as a result of interaction with topography within each SEZ were identified.

Keywords: Earthquakes; North American Plate; Sierra Madre del Sur

Resumo

No âmbito do estudo de "efeito local" e do impacto espacial das feições geográficas locais nas ondas sísmicas, foram analisadas e processadas espacialmente as acelerações máximas de 45 eventos sísmicos interplaca e intraplaca com magnitudes (Mw) na faixa de 5,6 a 8,2 que ocorreram de 1985 a 2018. Os valores médios e máximos de aceleração de 172 acelerógrafos distribuídos entre os limites dos territórios localizados na região mais sísmica do México, são substituídos pelos dados da escala de magnitude do momento sísmico em cada um dos epicentros dos 45 eventos estudados. É identificado o impacto sísmico diferencial da topografia que quatro Zonas Epicentrais Significativas (ZES) identificadas exercem em duas cidades importantes, dois polos turísticos e dois portos comerciais. Correspondentemente, foram identificadas a orientação, direção, tendência espacial predominante ao nível da litosfera, que seguem as ondas sísmicas como resultado da interação com a topografia dentro de cada ZES.

Palavras-chave: Terremotos; Placa Norte-americana; Sierra Madre del Sur

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1 Introduction

The area most seismically at risk in any region of the world is regularly represented by a seismicity map, which spatially distributes epicenters and, better of cases, the focal mechanisms of a particular area at an appropriate scale. While these maps are an important contribution that give details where the greatest regional seismic activity is concentrated. However, the magnitude, epicenter and hypocenter of an earthquake, are not synonymous with surrounding linear affectation as seismic waves move away from their center of origin, considering the immediate interaction these waves have with the surrounding regional topography, which can act as an amplifier or attenuator of frequency and amplitude of seismic waves. Therefore, characterizing the topography-seismic wave interaction can help to identify regions that favor or not the passage of seismic waves, in the same way it can reveal the predominant sense, direction and preferred trend.

In regions of high seismicity, the opportunities that a citizen living in a mega-city has to save his life in the face of the manifestation of an earthquake are dependent on several factors. The main ones is related to the earthquake intrinsic characteristics, such as magnitude, depth (hypocenter), the epicenter distance and topographic location (Armendáriz 2006; Montalvo Arrieta, León Gómez & Valdés González 2006).

Another factor is related to the "site effect" or local seismic response of terrain, associated to the relief inherent characteristics of the of the site where the individual is located (Gutiérrez-Martínez et al. 2014; Torres-Álvarez 2017). The interaction with the surrounding environment and the energy released by a seism produces terrain acceleration due to the waves transit through the surface, being more evident in unconsolidated soil such as the plains, this contact increase the urban and suburban infrastructure damage by matching its vibration periods (Tsige & García Flórez 2006).

One more factor is the opportunity time, multiplier component associated with the distance at which the epicenter is located, technically it concerns the time lapse between the start of notification of a seismic alert until the start of arrival of the cutting waves: between 30 seconds if the event occurs at a distance of 120 kilometers; 60 seconds when presented at a distance of 320 kilometers; and 120 seconds for events occurring at a distance of 580 kilometers (APCDMX 2017).

In physiographic terms, another factor involved is the terrestrial mega-forms surrounding (provinces and sub-provinces), which contribute at best to mitigating the consequences of seismic waves. In the case of Mexico Country, examples of these are the Sierra Madre del Sur and the Neovulcanic Axis (López-Blanco 2007). Under other conditions, the topography contributes to increase the waves frequency as in the Balsas River basin happens.

2 Background

With support in the catalogues and historical seism records, the Mexican Republic is divided into four seismic regions, (Gutiérrez-Martínez et al. 2014). And for the systematic record of the telluric events, Mexico has the National Seismological Service (Servicio Sismológico Nacional, SSN) founded on September 5, 1910, whose seismic oldest registration was obtained on Thursday, June 7, 1911 (Armendáriz 2006; Montalvo Arrieta, León Gómez & Valdés González 2006).

Through the Mexican Seismic Alert System (SASMEX), Mexico is considered a global pioneer in how to warn the population in case of a seism event, in this regard it has the Center for Seismic Instrumentation and Registration, A.C. (Centro de Instrumentación y Registro Sísmico, A.C., CIRES), founded in 1988, an institution that serves seismic emergencies for Ciudad de México, "CDMX" abbreviated name (Armendáriz 2006; Juárez-García et al. 2012). With the incorporation of innovative sensory technologies (García et al. 2009), it is continuously updated with new instruments distributed in the coastal borders of Michoacán, Colima, Jalisco, Oaxaca and Chiapas and Veracruz too (Armendáriz 2006; Montalvo Arrieta, León Gómez & Valdés González 2006). CIRES also works by applying "portable alerts" in schools, hospitals and sites, primarily in CDMX (country's capital metropolitan zone).

Dispose of the longest anticipation time before an strong earthquake is fundamental, but it is definitely conditioned by the place distance where an earthquake (epicenter) is generated, shorter distance to the telluric event represent less opportunity time to save the lives of citizens (APCDMX 2017). For example, events occurring in areas very close to CDMX between the boundaries of the states of Morelos and Puebla States, 110 kilometer away to south, the alert time is significantly reduced (SSN (UNAM) 2017a).

However, when talking about earthquakes, the regional landscape surrounding also plays a very important role in the natural protection provided to large cities. Particularly for Mexico, two physiographic provinces contribute to dissipating the energy generated with the earthquakes: the Neovulcanic Axis and the Sierra Madre del Sur (López-Blanco 2007). 85% of the telluric events occurred in Mexico are interplate, these occur throughout the coastal border between the states of Colima to Chiapas (Figures 1–6 included below), area where Cocos plate subduct to the North America continental plate, but much of the energy of these telluric events is attenuated by these two provinces, particularly to North.

15% of the least frequent events occurred in Mexican territory are intraslab earthquakes but are considered the most harmful, are presented under the continental plate due to ruptures within the Cocos ocean plate, the best known are those occurred in 1985 and 2017 whose sequels still remain in the memory of the inhabitants of the Mexico central region (García-Acosta, 2004), particularly of CDMX and the states of Puebla and Morelos (SSN (UNAM) 2017a; UIS-UNAM, CIS-IIGEN & FCT-UALN 2018).

3 Methodology

National Seismic Service historical record of 45 seismic events from 1985 to 2018 obtained from the earthquake Catalogue is analyzed (http://www2.ssn.unam.mx:8080/catalogo/). In a complement, the maximum acceleration (Max Accel) data of 172 accelerographs are thoroughly examined, data distributed between the states of Guerrero, Guanajuato, Michoacán, Puebla, Distrito Federal, Jalisco, Chiapas, Colima, State of Mexico, Oaxaca, Veracruz, Tlaxcala, Tabasco, obtained from the database of accelerographic records of RAII-UNAM (http://aplicaciones.iingen.unam.mx/AcelerogramasRSM/Consultas/FiltroAv.aspx).

Acceleration files (csv format) for the period 1985 to 2018 were obtained, processing the "Maximum acceleration" values of 45 earthquakes in the range of 6 to 9 degrees on the seismic moment magnitude scale (Mw). The data chosen from each file corresponded preferably to the averages and occasionally, to the highest records for each of the stations involved, in particular within the urban area boundaries of the cities in Mexico City (CDMX), Puebla, Puebla; Lázaro Cádenas, Michoacán and Salina Cruz, Oaxaca, and the resorts of Acapulco, Guerrero and Puerto Escondido, Oaxaca.

From the tabular information (xlsx format) were generated and processed on the platform of a geographic information system, SIG ArcMap™, the base files for drawing up maps of interest using ASCII files of delimited text with geographic locations in decimal degrees, similar activity was performed in each seismic event using numeric fields of the coordinates "X, Y", to generate a tabular feature and layer of point features, spatially viewable and representable.

To GIS-generated file, layers of city and state boundaries were added, as well as a raster color shading map (map flat, with elevations colored only) obtained from a digital terrain model (ASTER-GDM v2, 1 arc-second resolution), acquired from the website https://asterweb.jpl.nasa.gov/gdem.asp, and processed in "Global Mapper™ (Blue Marble Geographics)".

The final maps were obtained from GIS processing of layer properties selecting the acceleration field (maximum acceleration, abbreviated Max Accel) contained in the tabular feature, as result each map does not spatially represent the moment magnitude (Mw) of seismic events at the epicenter, but the spatial impact of the average or higher maximum acceleration (Max Accel). To the data interpretation for the movement perception analysis (ground motion and shaking intensity) the shakemap criteria from the Earthquake Hazards Program of the United States Geological Survey were used.

From this process six tables and six individual maps were obtained, spatially represent the "Max Accel" recorded at the epicenter for each event and their influence on the cities of CDMX; Acapulco, Guerrero; Puebla, Puebla; Lázaro Cárdenas, Michoacán; Puerto Escondido, Oaxaca and Salina Cruz, Oaxaca.

4 Results

Tables 1–6 summarize the analysis of the historical records of 45 seismic events that occurred in the period 1985 to 2018 and the maximum acceleration records (Max Accel) of each event in the 172 accelerographs distributed in the D and C seismic regions (Gutiérrez-Martínez et al. 2014), distributed over a large part of the coastal boundaries of the from Jalisco to Chiapas states, as well as the territorial limits of the State of Mexico, CDMX, Morelos, Puebla and Veracruz. In Figures 1–6 particularly depict the mapping of regional spatial impact in the cities and metropolises of CDMX, Puebla, Acapulco, Lázaro Cárdenas, Puerto Escondido and Salina Cruz ANO, related to the maximum acceleration records of the 45 seismic events studied. More detailed intensity maps of the aforementioned seismic events can be consulted at: http://www2.ssn.unam.mx:8080/mapas-de-intensidades/.

In the subsequent chapter paragraphs, the influence of surface seismic waves of 45 events during the period of

1985 to 2020 in the six cities mentioned in the previous paragraph is analyzed in detail. For this analysis, the shakemap criteria from the Earthquake Hazards Program of the United States Geological Survey were used.

Data analysis of the CDMX, Table 1 and Figure 1, shows that when seismic waves reach megalopolis, 2.2% are perceived as extreme, with facing and direction predominant W-E coming from the state limits of Michoacán and Guerrero 400 km away. Another 2.2% of seismic waves are perceived as violent and originate from a region very close to 100 km away, between the boundaries of Morelos and Puebla. 45.6% seismic waves are perceived as strong to severe and originate in the coastal borders of Guerrero and Oaxaca State. The remaining 40.0% of seismic waves are imperceptible or perceived as moderate, coming from the states of Chiapas and Veracruz. With reference to potential damage only 4.4% of seismic waves are perceived from strong to very strong.

For the city of Puebla, Puebla, Table 2 and Figure 2, numbers analysis indicates that when seismic waves reach the city, 4.0% are perceived as extreme, they originate 100 km away, in very contiguous regions to the south of the state and near the limits of the state Morelos. Another 4.0% of seismic waves are perceived as severe and come from the state limits of Michoacán and Guerrero 400 km away, with facing and direction with a predominant W-E trend. 27.0% of the waves are perceived from strong to very strong and originate in the coastal borders within the state of Oaxaca near the limits of the state of Guerrero. The remaining 64.0% of seismic waves are imperceptible to moderate and come from the Veracruz plains, the Tehuantepec Isthmus and adjacent continental slope. The potential damage of seismic waves for this megalopolis is 8.8% and is perceived from strong to very strong.

For the city of Lázaro Cárdenas, Michoacán, Table 3 and Figure 3, 20.0% of seismic waves are perceived from strong to extreme and have a very local origin between 60 and 120 km away. Another 66.7% of seismic waves are imperceptible and 13.3% are light to moderate, coming from the southeastern state of Guerrero and the rest of the country. With reference to potential damage, the waves that reach this city correspond to 15.6% and are perceived as strong to very strong.

For the Acapulco city, Guerrero state, Table 4 and Figure 4, seismic wave analysis exhibits that 66.7% are perceived from strong to extreme and come from an adjoining area between 50 and 280 km above the coastal border, within the subduction zone between the continental and oceanic plates (Cocos and North American). 33.3% of the remaining waves range from imperceptible to moderate coming from the rest of the country, 450 km away. For this resort 24.4% of the waves are perceived from strong to very strong. With reference to potential damage, 33.0% of seismic waves are perceived from moderate to very heavy.

The diagnosis of seismic waves for the city of Puerto Escondido, Oaxaca, Table 5 and Figure 5, shows that 11.1% are perceived from strong to moderate, coming from a surrounding area between 20 and 240 km along the coastal border. 88.9% of the remaining waves are imperceptible to moderate from the rest of the country. As for the potential damage of seismic waves in this city, 4.4% are perceived from strong to very strong.

Finally, for the city of Salina Cruz, Oaxaca, Table 6 and Figure 6, the information analysis shows that 15.6% are perceived from strong to extreme and originate mainly in the platform and continental slope of the Tehuantepec Isthmus, as well as in the coastal limit, accumulation plains and minor elevations within the area of influence of the Isthmus and Veracruz territory. The seismic waves have an orientation and direction with a preferential trend SSE-NNE between 30 and 200 km away. 84.4% of the remaining waves are perceived from imperceptible to moderate, coming from the rest of the country. In this port city the 8.9 of the seismic waves are perceived from violent to extreme.

Summaries of spatial information and mapping contained in Tables 1 – 6 and Figures 1 – 6, give evidence of the interaction of seismic energy and geological formation, this reciprocal action has allowed to delimit four "*Significant Epicentral Zones* (SEZ)", thus nominated for considering are areas with sufficient energy to generate earthquakes with magnitude, sensitive and instrumental perception capable of causing differential degrees of impact to human settlements immersed in the topography of the central region, southern and southeastern Mexico.

For this identification and demarcation, the processed and analyzed data of each accelerograph were essential. Therefore, the RAII-UNAM database information could be considered an *index* for each registration station, as it summarizes the information of the interaction among seismic energy, local geology and the surrounding topography in several kilometers around, horizontally and vertically.

Table 1 Level of perception of apparent ground motion and shaking potential damage of seismic waves to the CDMX megalopolis.

No	Date	Hour	Latitude	Longitude	Mw	Depth	Near Dist	Max Accel	Locality	State	Perceived Shaking	Potential Damage
1	09/19/1985	07:17:49	18.42	-102.47	8.10	15.0	366.10	161.63	45 km NORTHWEST of LA MIRA	MICH	Extreme	Very heavy
2	09/20/1985	19:37:14	17.83	-101.68	7.60	17.0	310.80	34.96	25 km NORTHWEST of ZIHUATANEJO	GRO	Severe	Moderate/ Heavy
3	04/30/1986	01:07:19	18.36	-103.05	7.00	22.0	426.60	32.27	48 km SOUTH of COCOMAN	MICH	Severe	Moderate/ Heavy
4	07/13/1986	03:12:15	16.08	-94.20	6.00	90.0	619.30	1.00	36 km SOUTHWEST of ARRIAGA	CHIS	Not felt	None
5	07/15/1987	01:16:13	17.39	-97.26	6.00	68.0	274.20	1.00	46 km NORTHEAST of H TLAXIACO	OAX	Not felt	None
6	04/25/1989	08:29:03	16.80	-99.28	6.80	23.0	261.00	42.35	12 km EAST of SAN MARCOS	GRO	Severe	Moderate/ Heavy
7	05/14/1993	21:11:56	16.47	-98.72	6.00	15.0	298.70	9.37	41 km SOUTHWEST of OMETEPEC	GRO	Moderate	Very light
8	10/24/1993	01:52:19	16.77	-98.77	6.60	30.0	265.10	12.91	40 km WEST of OMETEPEC	GRO	Strong	Light
9	03/14/1994	14:51:26	15.98	-92.43	6.80	160.0	784.50	0.76	42 km SOUTHEAST of VENUSTIANO CARRANZA	CHIS	Weak	None
10	12/10/1994	10:17:40	17.98	-101.52	6.60	53.0	285.80	15.66	37 km NORTH of ZIHUATANEJO	GRO	Strong	Light
11	09/14/1995	08:04:33	16.75	-98.67	7.30	21.0	268.00	38.69	29 km NORTHWEST of OMETEPEC	GRO	Severe	Moderate/ Heavy
12	10/09/1995	09:35:54	18.99	-104.25	8.00	25.0	538.30	13.11	10 km SOUTHEAST of MANZANILLO	COL	Strong	Light
13	10/12/1995	10:53:04	19.04	-103.70	6.10	11.0	480.20	2.85	21 km SOUTHEAST of COQUIMATLAN	COL	Light	None
14	10/20/1995	20:38:58	16.81	-93.47	7.10	160.0	641.60	3.19	12 km NORTHWEST of OCOZOCOAUTLA	CHIS	Light	None
15	07/15/1996	16:23:34	17.50	-101.12	6.60	22.0	279.10	11.61	17 km EAST of PETATLAN	GRO	Strong	Light
16	01/11/1997	14:28:26	18.34	-102.58	7.10	40.0	374.00	31.43	43 km NORTHWEST of LA MIRA	MICH	Severe	Moderate/ Heavy
17	05/22/1997	02:50:55	18.41	-101.81	6.00	59.0	294.30	6.04	61 km NORTHEAST of LAS GUACAMAYAS	MICH	Moderate	Very light
18	02/02/1998	21:02:01	15.69	-96.37	6.40	33.0	472.60	5.17	12 km SOUTHEAST of S PEDRO POCHUTLA	OAX	Moderate	Very light
19	06/15/1999	15:42:04	18.13	-97.54	7.00	63.0	195.70	32.51	29 km SOUTHWEST of S GABRIEL CHILAC	PUE	Severe	Moderate/ Heavy
20	06/21/1999	12:43:05	17.99	-101.72	6.20	54.0	301.10	8.52	42 km NORTHWEST of ZIHUATANEJO	GRO	Strong	Light

Table 1 Cont.

No	Date	Hour	Latitude	Longitude	Mw	Depth	Near Dist	Max Accel	Locality	State	Perceived Shaking	Potential Damage
21	09/30/1999	11:31:13	16.06	-97.00	7.40	39.0	400.60	32.24	22 km NORTHEAST of PUERTO ESCONDIDO	OAX	Severe	Moderate/ Heavy
22	12/28/1999	23:19:46	18.02	-101.68	6.10	82.0	295.40	5.16	44 km NORTHWEST of ZIHUATANEJO	GRO	Moderate	Very light
23	07/21/2000	01:13:39	18.09	-98.97	6.00	48.0	116.90	21.88	45 km SOUTHWEST of CHIAUTLA of TAPIA	PUE	Very strong	Moderate
24	08/09/2000	06:41:47	17.99	-102.66	7.00	16.0	390.10	16.66	35 km WEST of LA MIRA	MICH	Very strong	Moderate
25	10/07/2001	21:39:19	16.94	-100.14	6.10	4.0	263.80	30.63	9 km SOUTHWEST of COYUCA of BENITEZ	GRO	Very strong	Moderate
26	11/28/2001	08:32:36	15.41	-93.64	6.40	36.0	695.80	1.00	55 km SOUTHWEST of PIJIJIAPAN	CHIS	Not felt	None
27	06/14/2004	17:54:21	16.22	-98.16	6.40	10.0	331.50	6.79	18 km SOUTHWEST of PINOTEPA NAL.	OAX	Moderate	Very light
28	04/13/2007	00:42:23	17.13	-100.38	5.60	34.0	256.40	11.63	10 km SOUTHWEST of ATOYAC DE ALVAREZ	GRO	Strong	Light
29	07/05/2007	20:09:21	16.32	-94.02	6.20	94.0	606.10	1.00	16 km NORTHWEST of ARRIAGA	CHIS	Not felt	None
30	06/30/2010	02:22:27	16.24	-97.99	6.00	4.0	334.00	8.37	13 km SOUTHEAST of PINOTEPA NAL.	OAX	Strong	Light
31	02/25/2011	07:07:28	17.69	-95.21	6.00	135.0	428.10	1.00	34 km SOUTHWEST of SAYULA of EMAN	VER	Not felt	None
32	04/07/2011	08:11:22	17.22	-94.32	6.70	171.0	532.00	1.00	80 km SOUTHWEST of LAS CHOAPAS	VER	Not felt	None
33	12/10/2011	19:47:25	17.84	-99.96	6.50	54.0	167.70	21.84	50 km NORTHWEST of ZUMPANGO ofL RIO	GRO	Very strong	Moderate
34	03/20/2012	12:02:48	16.26	-98.46	7.50	18.0	317.60	36.99	46 km SOUTH of OMETEPEC	GRO	Severe	Moderate/ Heavy
35	04/02/2012	12:36:43	16.29	-98.54	6.00	12.0	312.50	8.67	45 km SOUTHWEST of OMETEPEC	GRO	Strong	Light
36	11/15/2012	03:20:22	18.18	-100.53	6.10	45.4	180.80	6.00	24 km SOUTHEAST of CD TAMIRANO	GRO	Moderate	Very light
37	08/21/2013	07:38:29	16.75	-99.58	6.00	5.0	262.70	11.05	21 km WEST of SAN MARCOS	GRO	Strong	Light
38	04/18/2014	09:27:21	17.01	-101.46	7.20	18.0	333.90	34.11	61 km SOUTHWEST of PETATLAN	GRO	Severe	Moderate/ Heavy
39	05/08/2014	12:00:14	16.99	-100.92	6.50	10.0	297.70	22.91	40 km SOUTHWEST of TECPAN	GRO	Very strong	Moderate
40	07/29/2014	05:46:15	17.70	-95.64	6.40	117.2	383.60	3.51	38 km SOUTHWEST of ISLA	VER	Moderate	Very light

Table 1 Cont.

No	Date	Hour	Latitude	Longitude	Mw	Depth	Near Dist	Max Accel	Locality	State	Perceived Shaking	Potential Damage
41	05/08/2016	02:33:59	16.32	-97.88	6.00	7.4	326.60	3.71	19 km EAST of PINOTEPA NAL.	OAX	Moderate	Very light
42	09/08/2017	23:49:17	14.76	-94.10	8.20	45.9	692.80	23.66	133 km SOUTHWEST of PIJIJIAPAN	CHIS	Very strong	Moderate
43	09/19/2017	13:14:39	18.33	-98.67	7.10	51.1	98.00	88.60	8 km NORTHWEST of CHIAUTLA of TAPIA	PUE	Violent	Heavy
44	09/23/2017	07:53:04	16.50	-95.15	6.10	22.0	489.90	1.00	9 km SOUTHWEST of CD IXTEPEC	OAX	Not felt	None
45	02/16/2018	17:39:39	16.22	-98.01	7.20	16.0	330.60	19.39	14 km SOUTHEAST of PINOTEPA NAL.	OAX	Very strong	Moderate

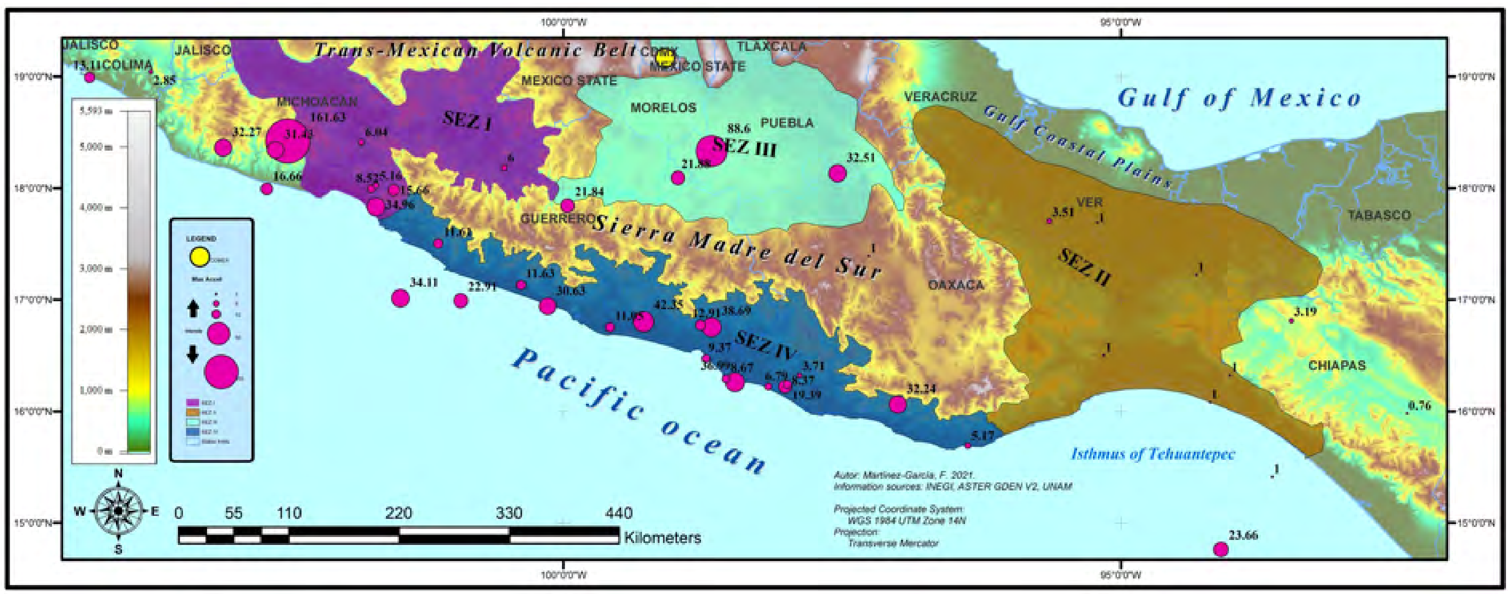

Figure 1 Spatial distribution of maximum acceleration data and degree of influence for CDMX megalopolis

Table 2 Level of perception of apparent ground motion and shaking potential damage of seismic waves to the megalopolis of Puebla, Puebla.

No	Date	Hour	Latitude	Longitude	Mw	Depth	Near Dist	Max Accel	Locality	State	Perceived Shaking	Potential Damage
1	09/19/1985	07:17:49	18.42	-102.47	8.10	15.0	454.6	32.6	45 km NORTHWEST of LA MIRA	MICH	Severe	Moderate/ Heavy
2	09/20/1985	19:37:14	17.83	-101.68	7.60	17.0	390.6	24.6	25 km NORTHWEST of ZIHUATANEJO	GRO	Very strong	Moderate
3	04/30/1986	01:07:19	18.36	-103.05	7.00	22.0	516.3	0.1	48 km SOUTH of COCOMAN	MICH	Not felt	None
4	07/13/1986	03:12:15	16.08	-94.20	6.00	90.0	538.3	0.1	36 km SOUTHWEST of ARRIAGA	CHIS	Not felt	None
5	07/15/1987	01:16:13	17.39	-97.26	6.00	68.0	209.4	0.1	46 km NORTHEAST of H TLAXIACO	OAX	Not felt	None
6	04/25/1989	08:29:03	16.80	-99.28	6.80	23.0	273.5	0.1	12 km EAST of SAN MARCOS	GRO	Not felt	None
7	05/14/1993	21:11:56	16.47	-98.72	6.00	15.0	290.5	0.1	41 km SOUTHWEST of OMETEPEC	GRO	Not felt	None
8	10/24/1993	01:52:19	16.77	-98.77	6.60	30.0	259.1	0.1	40 km WEST of OMETEPEC	GRO	Not felt	None
9	03/14/1994	14:51:26	15.98	-92.43	6.80	160.0	702.8	0.1	42 km SOUTHEAST of VENUSTIANO CARRANZA	CHIS	Not felt	None
10	12/10/1994	10:17:40	17.98	-101.52	6.60	53.0	369.0	0.1	37 km NORTH of ZIHUATANEJO	GRO	Not felt	None
11	09/14/1995	08:04:33	16.75	-98.67	7.30	21.0	259.1	0.1	29 km NORTHWEST of OMETEPEC	GRO	Not felt	None
12	10/09/1995	09:35:54	18.99	-104.25	8.00	25.0	636.3	0.1	10 km SOUTHEAST of MANZANILLO	COL	Not felt	None
13	10/12/1995	10:53:04	19.04	-103.70	6.10	11.0	578.1	0.1	21 km SOUTHEAST of COQUIMATLAN	COL	Not felt	None
14	10/20/1995	20:38:58	16.81	-93.47	7.10	160.0	560.7	0.1	12 km NORTHWEST of OCOZOCOAUTLA	CHIS	Not felt	None
15	07/15/1996	16:23:34	17.50	-101.12	6.60	22.0	352.2	6.2	17 km EAST of PETATLAN	GRO	Moderate	Very light
16	01/11/1997	14:28:26	18.34	-102.58	7.10	40.0	467.6	6.6	43 km NORTHWEST of LA MIRA	MICH	Moderate	Very light
17	05/22/1997	02:50:55	18.41	-101.81	6.00	59.0	386.2	0.1	61 km NORTHEAST of LAS GUACAMAYAS	MICH	Not felt	None
18	02/02/1998	21:02:01	15.69	-96.37	6.40	33.0	420.1	5.2	12 km SOUTHEAST of S PEDRO POCHUTLA	OAX	Moderate	Very light
19	06/15/1999	15:42:04	18.13	-97.54	7.00	63.0	123.9	279.0	29 km SOUTHWEST of S GABRIEL CHILAC	PUE	Extreme	Very heavy
20	06/21/1999	12:43:05	17.99	-101.72	6.20	54.0	388.7	0.1	42 km NORTHWEST of ZIHUATANEJO	GRO	Not felt	None

Table 2 Cont.

No	Date	Hour	Latitude	Longitude	Mw	Depth	Near Dist	Max Accel	Locality	State	Perceived Shaking	Potential Damage
21	09/30/1999	11:31:13	16.06	-97.00	7.40	39.0	354.9	22.6	22 km NORTHEAST of PUERTO ESCONDIDO	OAX	Very strong	Moderate
22	12/28/1999	23:19:46	18.02	-101.68	6.10	82.0	383.6	0.1	44 km NORTHWEST of ZIHUATANEJO	GRO	Not felt	None
23	07/21/2000	01:13:39	18.09	-98.97	6.00	48.0	133.1	13.0	45 km SOUTHWEST of CHIAUTLA of TAPIA	PUE	Strong	Light
24	08/09/2000	06:41:47	17.99	-102.66	7.00	16.0	484.3	2.6	35 km WEST of LA MIRA	MICH	Light	None
25	10/07/2001	21:39:19	16.94	-100.14	6.10	4.0	310.2	2.3	9 km SOUTHWEST of COYUCA of BENITEZ	GRO	Light	None
26	11/28/2001	08:32:36	15.41	-93.64	6.4	36	631.9	0.1	55 km SOUTHWEST of PIJIJIAPAN	CHIS	Not felt	None
27	06/14/2004	17:54:21	16.22	-98.16	6.40	10.0	313.2	0.1	18 km SOUTHWEST of PINOTEPA NAL.	OAX	Not felt	None
28	04/13/2007	0:42:23	17.13	-100.38	5.60	34.0	312.8	4.6	10 km SOUTHWEST of ATOYAC DE ALVAREZ	GRO	Moderate	Very light
29	07/05/2007	20:09:21	16.32	-94.02	6.20	94.0	538.0	0.1	16 km NORTHWEST of ARRIAGA	CHIS	Not felt	None
30	06/30/2010	02:22:27	16.24	-97.99	6.00	4.0	311.8	16.9	13 km SOUTHEAST of PINOTEPA NAL.	OAX	Very strong	Moderate
31	02/25/2011	07:07:28	17.69	-95.21	6.00	135.0	351.1	15.4	34 km SOUTHWEST of SAYULA of EMAN	VER	Strong	Light
32	04/07/2011	08:11:22	17.22	-94.32	6.70	171.0	459.1	11.1	80 km SOUTHWEST of LAS CHOAPAS	VER	Strong	Light
33	12/10/2011	19:47:25	17.84	-99.96	6.50	54.0	228.2	21.2	50 km NORTHWEST of ZUMPANGO of RIO	GRO	Very strong	Moderate
34	03/20/2012	12:02:48	16.26	-98.46	7.50	18.0	309.8	36.5	46 km SOUTH of OMETEPEC	GRO	Severe	Moderate/ Heavy
35	04/02/2012	12:36:43	16.29	-98.54	6.00	12.0	307.4	6.3	45 km SOUTHWEST of OMETEPEC	GRO	Moderate	Very light
36	11/15/2012	03:20:22	18.18	-100.53	6.10	45.4	263.0	3.5	24 km SOUTHEAST of CD TAMIRANO	GRO	Moderate	Very light
37	08/21/2013	07:38:29	16.75	-99.58	6.00	5.0	292.9	4.5	21 km WEST of SAN MARCOS	GRO	Moderate	Very light
38	04/18/2014	9:27:21	17.01	-101.46	7.20	18.0	411.5	14.6	61 km SOUTHWEST of PETATLAN	GRO	Strong	Light
39	05/08/2014	12:00:14	16.99	-100.92	6.50	10	366.4	16.5	40 km SOUTHWEST of TECPAN	GRO	Very strong	Moderate

Table 2 Cont.

No	Date	Hour	Latitude	Longitude	Mw	Depth	Near Dist	Max Accel	Locality	State	Perceived Shaking	Potential Damage
40	07/29/2014	05:46:15	17.70	-95.64	6.40	117.2	310.1	12.8	38 km SOUTHWEST of ISLA	VER	Strong	Light
41	05/08/2016	02:33:59	16.32	-97.88	6.00	7.4	304.1	5.7	19 km EAST of PINOTEPA NAL.	OAX	Moderate	Very light
42	09/08/2017	23:49:17	14.76	-94.10	8.20	45.90	646.4	25.1	133 km SOUTHWEST of PIJIJIAPAN	CHIS	Very strong	Moderate
43	09/19/2017	13:14:39	18.33	-98.67	7.10	51.1	93.3	206.0	8 km NORTHWEST of CHIAUTLA of TAPIA	PUE	Extreme	Very heavy
44	09/23/2017	07:53:04	16.50	-95.15	6.10	22.0	430.2	4.0	9 km SOUTHWEST of CD IXTEPEC	OAX	Moderate	Very light
45	02/16/2018	17:39:39	16.22	-98.01	7.20	16.0	313.8	24.0	14 km SOUTHEAST of PINOTEPA NAL.	OAX	Very strong	Moderate

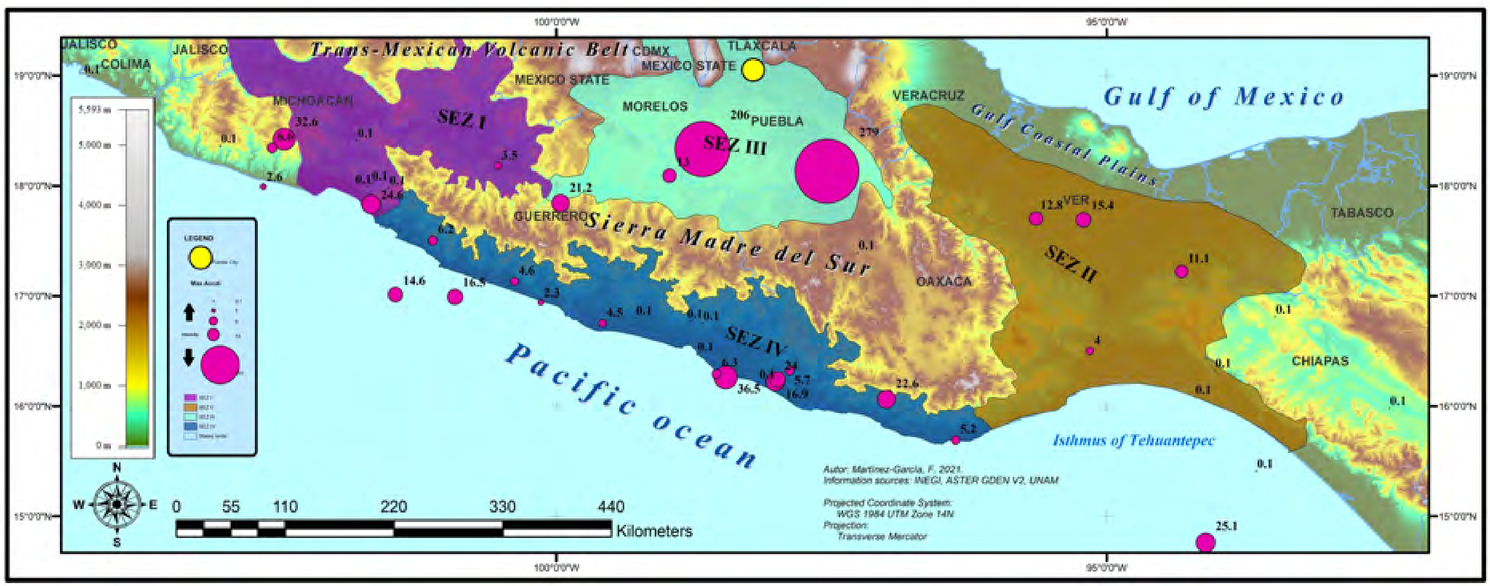

Figure 2 Spatial distribution of maximum acceleration data and degree of influence for the megalopolis of Puebla, Puebla

Table 3 Level of perception of apparent ground motion and shaking potential damage of seismic waves to the commercial seaport of Lazaro Cardenas, Michoacán.

No	Date	Hour	Latitude	Longitude	Mw	Depth	Near Dist	Max Accel	Locality	State	Perceived Shaking	Potential Damage
1	09/19/1985	07:17:49	18.42	-102.47	8.10	15.0	58.1	165.29	45 km NORTHWEST of LA MIRA	MICH	Extreme	Very heavy
2	09/20/1985	19:37:14	17.83	-101.68	7.60	17.0	57.3	158.23	25 km NORTHWEST of ZIHUATANEJO	GRO	Extreme	Very heavy
3	04/30/1986	01:07:19	18.36	-103.05	7.00	22.0	99.8	0.1	48 km SOUTH of COCOMAN	MICH	Not felt	None
4	07/13/1986	03:12:15	16.08	-94.20	6.00	90.0	874.9	0.1	36 km SOUTHWEST of ARRIAGA	CHIS	Not felt	None
5	07/15/1987	01:16:13	17.39	-97.26	6.00	68.0	526.1	0.1	46 km NORTHEAST of H TLAXIACO	OAX	Not felt	None
6	04/25/1989	08:29:03	16.80	-99.28	6.80	23.0	334.6	0.1	12 km EAST of SAN MARCOS	GRO	Not felt	None
7	05/14/1993	21:11:56	16.47	-98.72	6.00	15.0	403.2	0.10	41 km SOUTHWEST of OMETEPEC	GRO	Not felt	None
8	10/24/1993	01:52:19	16.77	-98.77	6.60	30.0	385.3	0.10	40 km WEST of OMETEPEC	GRO	Not felt	None
9	03/14/1994	14:51:26	15.98	-92.43	6.80	160.0	1056.3	0.1	42 km SOUTHEAST of VENUSTIANO CARRANZA	CHIS	Not felt	None
10	12/10/1994	10:17:40	17.98	-101.52	6.60	53.0	71.8	92.91	37 km NORTH of ZIHUATANEJO	GRO	Violent	Heavy
11	09/14/1995	08:04:33	16.75	-98.67	7.30	21.0	394.8	0.1	29 km NORTHWEST of OMETEPEC	GRO	Not felt	None
12	10/09/1995	09:35:54	18.99	-104.25	8.00	25.0	242.1	0.1	10 km SOUTHEAST of MANZANILLO	COL	Not felt	None
13	10/12/1995	10:53:04	19.04	-103.70	6.10	11.0	196.0	0.1	21 km SOUTHEAST of COQUIMATLAN	COL	Not felt	None
14	10/20/1995	20:38:58	16.81	-93.47	7.10	160.0	925.3	0.1	12 km NORTHWEST of OCOZOCOAUTLA	CHIS	Not felt	None
15	07/15/1996	16:23:34	17.50	-101.12	6.60	22.0	124.1	0.1	17 km EAST of PETATLAN	GRO	Not felt	None
16	01/11/1997	14:28:26	18.34	-102.58	7.10	40.0	57.0	258	43 km NORTHWEST of LA MIRA	MICH	Extreme	Very heavy
17	05/22/1997	02:50:55	18.41	-101.81	6.00	59.0	63.7	13.03	61 km NORTHEAST of LAS GUACAMAYAS	MICH	Strong	Light
18	02/02/1998	21:02:01	15.69	-96.37	6.40	33.0	659.4	0.1	12 km SOUTHEAST of S PEDRO POCHUTLA	OAX	Not felt	None
19	06/15/1999	15:42:04	18.13	-97.54	7.00	63.0	485.3	0.1	29 km SOUTHWEST of S GABRIEL CHILAC	PUE	Not felt	None
20	06/21/1999	12:43:05	17.99	-101.72	6.20	54.0	50.3	101.04	42 km NORTHWEST of ZIHUATANEJO	GRO	Violent	Heavy

Table 3 Cont.

No	Date	Hour	Latitude	Longitude	Mw	Depth	Near Dist	Max Accel	Locality	State	Perceived Shaking	Potential Damage
21	09/30/1999	11:31:13	16.06	-97.00	7.40	39.0	581.0	0.1	22 km NORTHEAST of PUERTO ESCONDIDO	OAX	Not felt	None
22	12/28/1999	23:19:46	18.02	-101.68	6.10	82.0	54.7	0.1	44 km NORTHWEST of ZIHUATANEJO	GRO	Not felt	None
23	07/21/2000	01:13:39	18.09	-98.97	6.00	48.0	335.3	0.1	45 km SOUTHWEST of CHIAUTLA of TAPIA	PUE	Not felt	None
24	08/09/2000	06:41:47	17.99	-102.66	7.00	16.0	47.5	97.29	35 km WEST of LA MIRA	MICH	Violent	Heavy
25	10/07/2001	21:39:19	16.94	-100.14	6.10	4.0	240.9	0.1	9 km SOUTHWEST of COYUCA of BENITEZ	GRO	Not felt	None
26	11/28/2001	08:32:36	15.41	-93.64	6.4	36	933.1	0.1	55 km SOUTHWEST of PIJIJIAPAN	CHIS	Not felt	None
27	06/14/2004	17:54:21	16.22	-98.16	6.40	10.0	459.6	0.1	18 km SOUTHWEST of PINOTEPA NAL.	OAX	Not felt	None
28	04/13/2007	0:42:23	17.13	-100.38	5.60	34.0	208.8	5.3	10 km SOUTHWEST of ATOYAC DE ALVAREZ	GRO	Moderate	Very light
29	07/05/2007	20:09:21	16.32	-94.02	6.20	94.0	865.6	0.1	16 km NORTHWEST of ARRIAGA	CHIS	Not felt	None
30	06/30/2010	02:22:27	16.24	-97.99	6.00	4.0	473.4	0.1	13 km SOUTHEAST of PINOTEPA NAL.	OAX	Not felt	None
31	02/25/2011	07:07:28	17.69	-95.21	6.00	135.0	720.4	0.1	34 km SOUTHWEST of SAYULA of EMAN	VER	Not felt	None
32	04/07/2011	08:11:22	17.22	-94.32	6.70	171.0	815.8	0.1	80 km SOUTHWEST of LAS CHOAPAS	VER	Not felt	None
33	12/10/2011	19:47:25	17.84	-99.96	6.50	54.0	230.7	4.68	50 km NORTHWEST of ZUMPANGO ofL RIO	GRO	Moderate	Very light
34	03/20/2012	12:02:48	16.26	-98.46	7.50	18.0	426.6	2.31	46 km SOUTH of OMETEPEC	GRO	Light	None
35	04/02/2012	12:36:43	16.29	-98.54	6.00	12.0	417.3	0.1	45 km SOUTHWEST of OMETEPEC	GRO	Not felt	None
36	11/15/2012	03:20:22	18.18	-100.53	6.10	45.4	172.8	6.2	24 km SOUTHEAST of CD TAMIRANO	GRO	Moderate	Very light
37	08/21/2013	07:38:29	16.75	-99.58	6.00	5.0	298.7	1.73	21 km WEST of SAN MARCOS	GRO	Light	None
38	04/18/2014	9:27:21	17.01	-101.46	7.20	18.0	127.0	76.22	61 km SOUTHWEST of PETATLAN	GRO	Violent	Heavy

Table 3 Cont.

No	Date	Hour	Latitude	Longitude	Mw	Depth	Near Dist	Max Accel	Locality	State	Perceived Shaking	Potential Damage
39	05/08/2014	12:00:14	16.99	-100.92	6.50	10	167.4	10.7	40 km SOUTHWEST of TECPAN	GRO	Strong	Light
40	07/29/2014	05:46:15	17.70	-95.64	6.40	117.2	670.2	0.1	38 km SOUTHWEST of ISLA	VER	Not felt	None
41	05/08/2016	02:33:59	16.32	-97.88	6.00	7.4	475.5	0.1	19 km EAST of PINOTEPA NAL.	OAX	Not felt	None
42	09/08/2017	23:49:17	14.76	-94.10	8.20	45.90	898.9	0.1	133 km SOUTHWEST of PIJIJIAPAN	CHIS	Not felt	None
43	09/19/2017	13:14:39	18.33	-98.67	7.10	51.1	360.9	6.1	8 km NORTHWEST of CHIAUTLA of TAPIA	PUE	Moderate	Very light
44	09/23/2017	07:53:04	16.50	-95.15	6.10	22.0	735.8	0.1	9 km SOUTHWEST of CD IXTEPEC	OAX	Not felt	None
45	02/16/2018	17:39:39	16.22	-98.01	7.20	16.0	465.6	0.1	14 km SOUTHEAST of PINOTEPA NAL.	OAX	Not felt	None

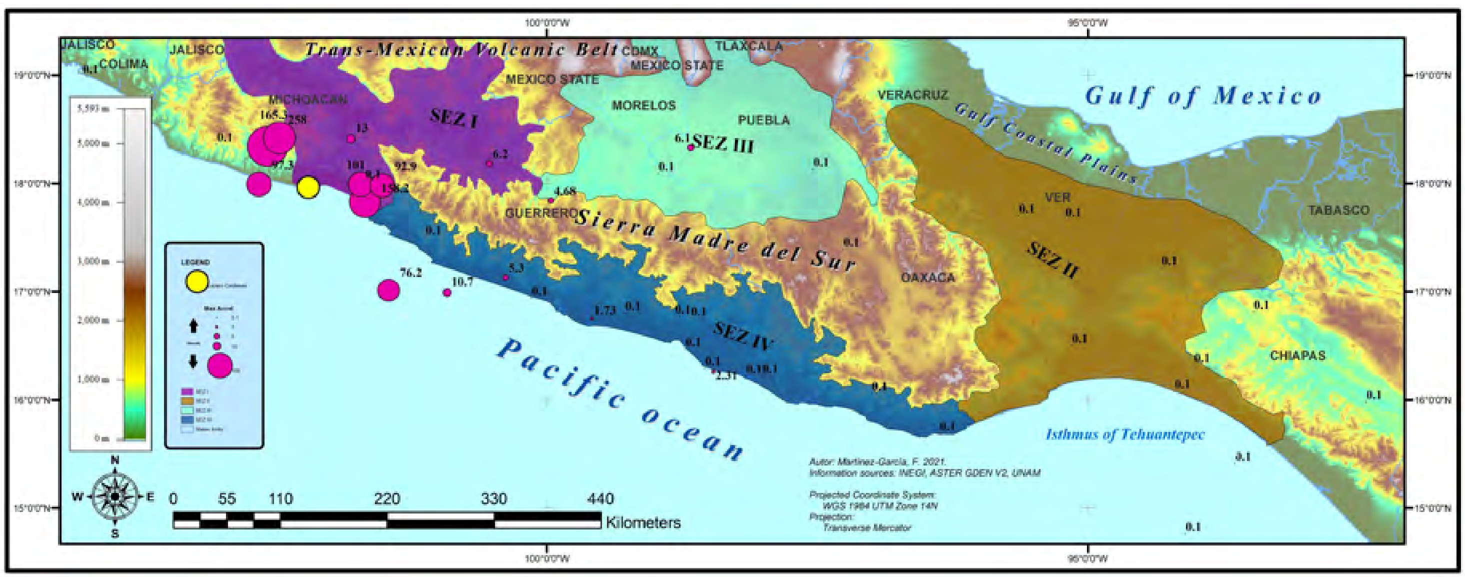

Figure 3 Spatial distribution of maximum acceleration data and degree of influence for the commercial seaport of Lazaro Cardenas, Michoacán

Table 4 Level of perception of apparent ground motion and shaking potential damage of seismic waves to the tourist pole of Acapulco, Guerrero.

No	Date	Hour	Latitude	Longitude	Mw	Depth	Near Dist	Max Accel	Locality	State	Perceived Shaking	Potential Damage
1	09/19/1985	07:17:49	18.42	-102.47	8.10	15.0	324.3	27.72	45 km NORTHWEST of LA MIRA	MICH	Very strong	Moderate
2	09/20/1985	19:37:14	17.83	-101.68	7.60	17.0	218.8	35.77	25 km NORTHWEST of ZIHUATANEJO	GRO	Severe	Moderate/ Heavy
3	04/30/1986	01:07:19	18.36	-103.05	7.00	22.0	374.3	0.1	48 km SOUTH of COCOMAN	MICH	Not felt	None
4	07/13/1986	03:12:15	16.08	-94.20	6.00	90.0	611.1	0.1	36 km SOUTHWEST of ARRIAGA	CHIS	Not felt	None
5	07/15/1987	01:16:13	17.39	-97.26	6.00	68.0	283.4	9.51	46 km NORTHEAST of H TLAXIACO	OAX	Strong	Light
6	04/25/1989	08:29:03	16.80	-99.28	6.80	23.0	63.9	335	12 km EAST of SAN MARCOS	GRO	Extreme	Very heavy
7	05/14/1993	21:11:56	16.47	-98.72	6.00	15.0	130.4	63.75	41 km SOUTHWEST of OMETEPEC	GRO	Violent	Heavy
8	10/24/1993	01:52:19	16.77	-98.77	6.60	30.0	117.8	128.24	40 km WEST of OMETEPEC	GRO	Violent	Heavy
9	03/14/1994	14:51:26	15.98	-92.43	6.80	160.0	796.3	0.1	42 km SOUTHEAST of VENUSTIANO CARRANZA	CHIS	Not felt	None
10	12/10/1994	10:17:40	17.98	-101.52	6.60	53.0	211.5	20.1	37 km NORTH of ZIHUATANEJO	GRO	Very strong	Moderate
11	09/14/1995	08:04:33	16.75	-98.67	7.30	21.0	128.2	70.28	29 km NORTHWEST of OMETEPEC	GRO	Violent	Heavy
12	10/09/1995	09:35:54	18.99	-104.25	8.00	25.0	514.1	0.1	10 km SOUTHEAST of MANZANILLO	COL	Not felt	None
13	10/12/1995	10:53:04	19.04	-103.70	6.10	11.0	465.6	0.1	21 km SOUTHEAST of COQUIMATLAN	COL	Not felt	None
14	10/20/1995	20:38:58	16.81	-93.47	7.10	160.0	674.8	0.1	12 km NORTHWEST of OCOZOCOAUTLA	CHIS	Not felt	None
15	07/15/1996	16:23:34	17.50	-101.12	6.60	22.0	147.3	20.82	17 km EAST of PETATLAN	GRO	Very strong	Moderate
16	01/11/1997	14:28:26	18.34	-102.58	7.10	40.0	325.0	16.9	43 km NORTHWEST of LA MIRA	MICH	Very strong	Moderate
17	05/22/1997	02:50:55	18.41	-101.81	6.00	59.0	262.5	10.53	61 km NORTHEAST of LAS GUACAMAYAS	MICH	Strong	Light
18	02/02/1998	21:02:01	15.69	-96.37	6.40	33.0	390.4	0.1	12 km SOUTHEAST of S PEDRO POCHUTLA	OAX	Not felt	None
19	06/15/1999	15:42:04	18.13	-97.54	7.00	63.0	279.8	21.88	29 km SOUTHWEST of S GABRIEL CHILAC	PUE	Very strong	Moderate
20	06/21/1999	12:43:05	17.99	-101.72	6.20	54.0	227.4	11.69	42 km NORTHWEST of ZIHUATANEJO	GRO	Strong	Light

Table 4 Cont.

No	Date	Hour	Latitude	Longitude	Mw	Depth	Near Dist	Max Accel	Locality	State	Perceived Shaking	Potential Damage
21	09/30/1999	11:31:13	16.06	-97.00	7.40	39.0	313.8	35.9	22 km NORTHEAST of PUERTO ESCONDIDO	OAX	Severe	Moderate/ Heavy
22	12/28/1999	23:19:46	18.02	-101.68	6.10	82.0	225.2	0.1	44 km NORTHWEST of ZIHUATANEJO	GRO	Not felt	None
23	07/21/2000	01:13:39	18.09	-98.97	6.00	48.0	162.5	20.86	45 km SOUTHWEST of CHIAUTLA of TAPIA	PUE	Very strong	Moderate
24	08/09/2000	06:41:47	17.99	-102.66	7.00	16.0	313.4	0.1	35 km WEST of LA MIRA	MICH	Not felt	None
25	10/07/2001	21:39:19	16.94	-100.14	6.10	4.0	28.2	309.15	9 km SOUTHWEST of COYUCA of BENITEZ	GRO	Extreme	Very heavy
26	11/28/2001	08:32:36	15.41	-93.64	6.4	36	670.3	0.1	55 km SOUTHWEST of PIJIJIAPAN	CHIS	Not felt	None
27	06/14/2004	17:54:21	16.22	-98.16	6.40	10.0	191.9	17.28	18 km SOUTHWEST of PINOTEPA NAL.	OAX	Very strong	Moderate
28	04/13/2007	0:42:23	17.13	-100.38	5.60	34.0	59.1	202.87	10 km SOUTHWEST of ATOYAC DE ALVAREZ	GRO	Extreme	Very heavy
29	07/05/2007	20:09:21	16.32	-94.02	6.20	94.0	611.4	0.1	16 km NORTHWEST of ARRIAGA	CHIS	Not felt	None
30	06/30/2010	02:22:27	16.24	-97.99	6.00	4.0	207.2	9.55	13 km SOUTHEAST of PINOTEPA NAL.	OAX	Strong	Light
31	02/25/2011	07:07:28	17.69	-95.21	6.00	135.0	490.1	0.1	34 km SOUTHWEST of SAYULA of EMAN	VER	Not felt	None
32	04/07/2011	08:11:22	17.22	-94.32	6.70	171.0	575.5	0.1	80 km SOUTHWEST of LAS CHOAPAS	VER	Not felt	None
33	12/10/2011	19:47:25	17.84	-99.96	6.50	54.0	104.6	66.49	50 km NORTHWEST of ZUMPANGO ofL RIO	GRO	Violent	Heavy
34	03/20/2012	12:02:48	16.26	-98.46	7.50	18.0	160.4	36.17	46 km SOUTH of OMETEPEC	GRO	Severe	Moderate/ Heavy
35	04/02/2012	12:36:43	16.29	-98.54	6.00	12.0	151.3	13.38	45 km SOUTHWEST of OMETEPEC	GRO	Strong	Light
36	11/15/2012	03:20:22	18.18	-100.53	6.10	45.4	155.4	10.22	24 km SOUTHEAST of CD TAMIRANO	GRO	Strong	Light
37	08/21/2013	07:38:29	16.75	-99.58	6.00	5.0	33.2	457.54	21 km WEST of SAN MARCOS	GRO	Extreme	Very heavy
38	04/18/2014	9:27:21	17.01	-101.46	7.20	18.0	163.1	99.6	61 km SOUTHWEST of PETATLAN	GRO	Violent	Heavy

Table 4 Cont.

No	Date	Hour	Latitude	Longitude	Mw	Depth	Near Dist	Max Accel	Locality	State	Perceived Shaking	Potential Damage
39	05/08/2014	12:00:14	16.99	-100.92	6.50	10	107.6	98.24	40 km SOUTHWEST of TECPAN	GRO	Violent	Heavy
40	07/29/2014	05:46:15	17.70	-95.64	6.40	117.2	442.7	5.16	38 km SOUTHWEST of ISLA	VER	Moderate	Very light
41	05/08/2016	02:33:59	16.32	-97.88	6.00	7.4	213.2	14.9	19 km EAST of PINOTEPA NAL.	OAX	Strong	Light
42	09/08/2017	23:49:17	14.76	-94.10	8.20	45.90	635.9	20.98	133 km SOUTHWEST of PIJIJIAPAN	CHIS	Very strong	Moderate
43	09/19/2017	13:14:39	18.33	-98.67	7.10	51.1	198.1	60.82	8 km NORTHWEST of CHIAUTLA of TAPIA	PUE	Violent	Heavy
44	09/23/2017	07:53:04	16.50	-95.15	6.10	22.0	485.3	0.1	9 km SOUTHWEST of CD IXTEPEC	OAX	Not felt	None
45	02/16/2018	17:39:39	16.22	-98.01	7.20	16.0	203.0	43.42	14 km SOUTHEAST of PINOTEPA NAL.	OAX	Severe	Moderate/ Heavy

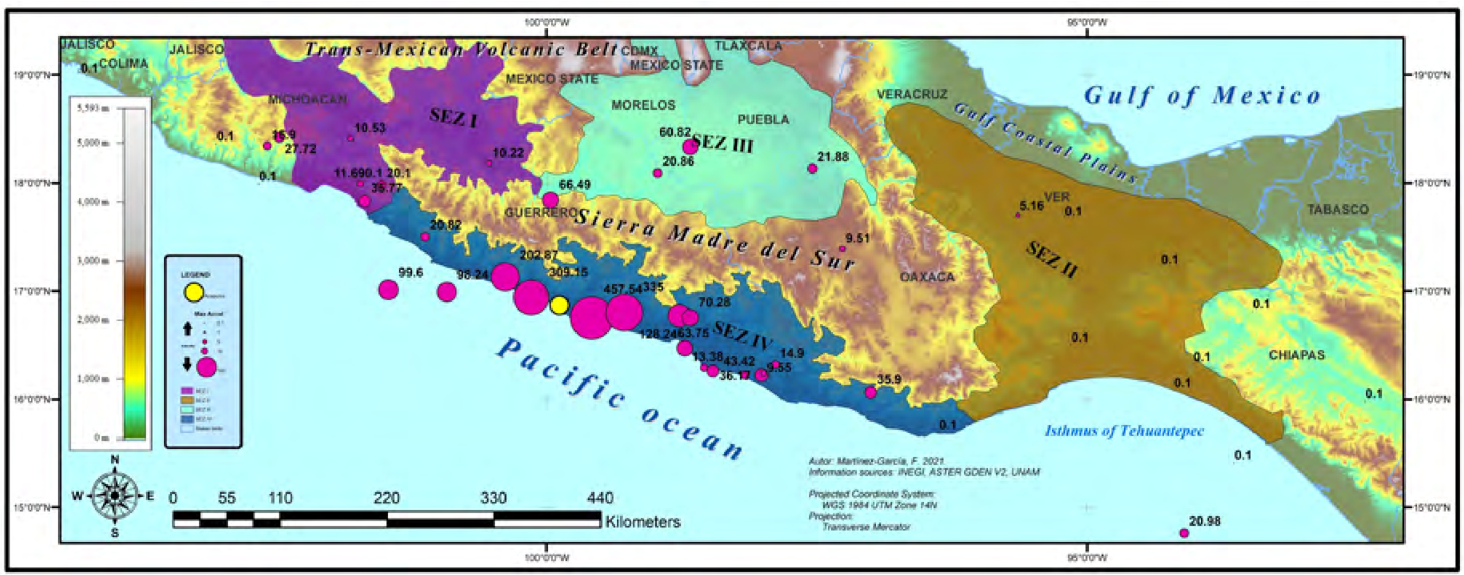

Figure 4 Spatial distribution of maximum acceleration data and degree of influence for the tourist pole of Acapulco, Guerrero

Table 5 Level of perception of apparent ground motion and shaking potential damage of seismic waves for the tourist pole of Puerto Escondido, Oaxaca.

No	Date	Hour	Latitude	Longitude	Mw	Depth	Near Dist	Max Accel	Locality	State	Perceived Shaking	Potential Damage
1	09/19/1985	07:17:49	18.42	-102.47	8.10	15.0	638.9	0.1	45 km NORTHWEST of LA MIRA	MICH	Not felt	None
2	09/20/1985	19:37:14	17.83	-101.68	7.60	17.0	535.2	0.1	25 km NORTHWEST of ZIHUATANEJO	GRO	Not felt	None
3	04/30/1986	01:07:19	18.36	-103.05	7.00	22.0	690.9	0.1	48 km SOUTH of COCOMAN	MICH	Not felt	None
4	07/13/1986	03:12:15	16.08	-94.20	6.00	90.0	308.8	0.1	36 km SOUTHWEST of ARRIAGA	CHIS	Not felt	None
5	07/15/1987	01:16:13	17.39	-97.26	6.00	68.0	168.3	0.1	46 km NORTHEAST of H TLAXIACO	OAX	Not felt	None
6	04/25/1989	08:29:03	16.80	-99.28	6.80	23.0	255.0	0.1	12 km EAST of SAN MARCOS	GRO	Not felt	None
7	05/14/1993	21:11:56	16.47	-98.72	6.00	15.0	186.1	0.1	41 km SOUTHWEST of OMETEPEC	GRO	Not felt	None
8	10/24/1993	01:52:19	16.77	-98.77	6.60	30.0	204.5	0.1	40 km WEST of OMETEPEC	GRO	Not felt	None
9	03/14/1994	14:51:26	15.98	-92.43	6.80	160.0	495.4	0.1	42 km SOUTHEAST of VENUSTIANO CARRANZA	CHIS	Not felt	None
10	12/10/1994	10:17:40	17.98	-101.52	6.60	53.0	522.4	0.1	37 km NORTH of ZIHUATANEJO	GRO	Not felt	None
11	09/14/1995	08:04:33	16.75	-98.67	7.30	21.0	193.6	0.1	29 km NORTHWEST of OMETEPEC	GRO	Not felt	None
12	10/09/1995	09:35:54	18.99	-104.25	8.00	25.0	827.3	0.1	10 km SOUTHEAST of MANZANILLO	COL	Not felt	None
13	10/12/1995	10:53:04	19.04	-103.70	6.10	11.0	776.4	0.1	21 km SOUTHEAST of COQUIMATLAN	COL	Not felt	None
14	10/20/1995	20:38:58	16.81	-93.47	7.10	160.0	395.1	0.1	12 km NORTHWEST of OCOZOCOAUTLA	CHIS	Not felt	None
15	07/15/1996	16:23:34	17.50	-101.12	6.60	22.0	460.3	0.1	17 km EAST of PETATLAN	GRO	Not felt	None
16	01/11/1997	14:28:26	18.34	-102.58	7.10	40.0	636.2	0.1	43 km NORTHWEST of LA MIRA	MICH	Not felt	None
17	05/22/1997	02:50:55	18.41	-101.81	6.00	59.0	567.0	0.1	61 km NORTHEAST of LAS GUACAMAYAS	MICH	Not felt	None
18	02/02/1998	21:02:01	15.69	-96.37	6.40	33.0	77.6	0.1	12 km SOUTHEAST of S PEDRO POCHUTLA	OAX	Not felt	None
19	06/15/1999	15:42:04	18.13	-97.54	7.00	63.0	250.0	0.1	29 km SOUTHWEST of S GABRIEL CHILAC	PUE	Not felt	None
20	06/21/1999	12:43:05	17.99	-101.72	6.20	54.0	536.6	0.1	42 km NORTHWEST of ZIHUATANEJO	GRO	Not felt	None

Table 5 Cont.

No	Date	Hour	Latitude	Longitude	Mw	Depth	Near Dist	Max Accel	Locality	State	Perceived Shaking	Potential Damage
21	09/30/1999	11:31:13	16.06	-97.00	7.40	39.0	22.0	279.8	22 km NORTHEAST of PUERTO ESCONDIDO	OAX	Extreme	Very heavy
22	12/28/1999	23:19:46	18.02	-101.68	6.10	82.0	533.1	0.1	44 km NORTHWEST of ZIHUATANEJO	GRO	Not felt	None
23	07/21/2000	01:13:39	18.09	-98.97	6.00	48.0	310.4	0.1	45 km SOUTHWEST of CHIAUTLA of TAPIA	PUE	Not felt	None
24	08/09/2000	06:41:47	17.99	-102.66	7.00	16.0	624.4	0.1	35 km WEST of LA MIRA	MICH	Not felt	None
25	10/07/2001	21:39:19	16.94	-100.14	6.10	4.0	339.2	0.1	9 km SOUTHWEST of COYUCA of BENITEZ	GRO	Not felt	None
26	11/28/2001	08:32:36	15.41	-93.64	6.4	36	364.0	0.1	55 km SOUTHWEST of PIJIJIAPAN	CHIS	Not felt	None
27	06/14/2004	17:54:21	16.22	-98.16	6.40	10.0	118.5	7.2	18 km SOUTHWEST of PINOTEPA NAL.	OAX	Moderate	Very light
28	04/13/2007	0:42:23	17.13	-100.38	5.60	34.0	368.6	0.1	10 km SOUTHWEST of ATOYAC DE ALVAREZ	GRO	Not felt	None
29	07/05/2007	20:09:21	16.32	-94.02	6.20	94.0	322.7	0.1	16 km NORTHWEST of ARRIAGA	CHIS	Not felt	None
30	06/30/2010	02:22:27	16.24	-97.99	6.00	4.0	102.4	0.1	13 km SOUTHEAST of PINOTEPA NAL.	OAX	Not felt	None
31	02/25/2011	07:07:28	17.69	-95.21	6.00	135.0	275.2	0.1	34 km SOUTHWEST of SAYULA of EMAN	VER	Not felt	None
32	04/07/2011	08:11:22	17.22	-94.32	6.70	171.0	320.8	0.1	80 km SOUTHWEST of LAS CHOAPAS	VER	Not felt	None
33	12/10/2011	19:47:25	17.84	-99.96	6.50	54.0	364.4	0.1	50 km NORTHWEST of ZUMPANGO ofL RIO	GRO	Not felt	None
34	03/20/2012	12:02:48	16.26	-98.46	7.50	18.0	148.7	26.0	46 km SOUTH of OMETEPEC	GRO	Severe	Moderate/ Heavy
35	04/02/2012	12:36:43	16.29	-98.54	6.00	12.0	157.4	3.6	45 km SOUTHWEST of OMETEPEC	GRO	Moderate	Very light
36	11/15/2012	03:20:22	18.18	-100.53	6.10	45.4	432.0	0.1	24 km SOUTHEAST of CD TAMIRANO	GRO	Not felt	None
37	08/21/2013	07:38:29	16.75	-99.58	6.00	5.0	274.2	0.1	21 km WEST of SAN MARCOS	GRO	Not felt	None
38	04/18/2014	9:27:21	17.01	-101.46	7.20	18.0	466.9	0.1	61 km SOUTHWEST of PETATLAN	GRO	Not felt	None

Table 5 Cont.

No	Date	Hour	Latitude	Longitude	Mw	Depth	Near Dist	Max Accel	Locality	State	Perceived Shaking	Potential Damage
39	05/08/2014	12:00:14	16.99	-100.92	6.50	10	412.4	0.1	40 km SOUTHWEST of TECPAN	GRO	Not felt	None
40	07/29/2014	05:46:15	17.70	-95.64	6.40	117.2	244.6	5.1	38 km SOUTHWEST of ISLA	VER	Moderate	Very light
41	05/08/2016	02:33:59	16.32	-97.88	6.00	7.4	94.9	13.4	19 km EAST of PINOTEPA NAL.	OAX	Strong	Light
42	09/08/2017	23:49:17	14.76	-94.10	8.20	45.90	330.0	53.3	133 km SOUTHWEST of PIJIJIAPAN	CHIS	Severe	Moderate/ Heavy
43	09/19/2017	13:14:39	18.33	-98.67	7.10	51.1	307.2	5.8	8 km NORTHWEST of CHIAUTLA of TAPIA	PUE	Moderate	Very light
44	09/23/2017	07:53:04	16.50	-95.15	6.10	22.0	209.1	2.6	9 km SOUTHWEST of CD IXTEPEC	OAX	Light	None
45	02/16/2018	17:39:39	16.22	-98.01	7.20	16.0	102.0	61.4	14 km SOUTHEAST of PINOTEPA NAL.	OAX	Violent	Heavy

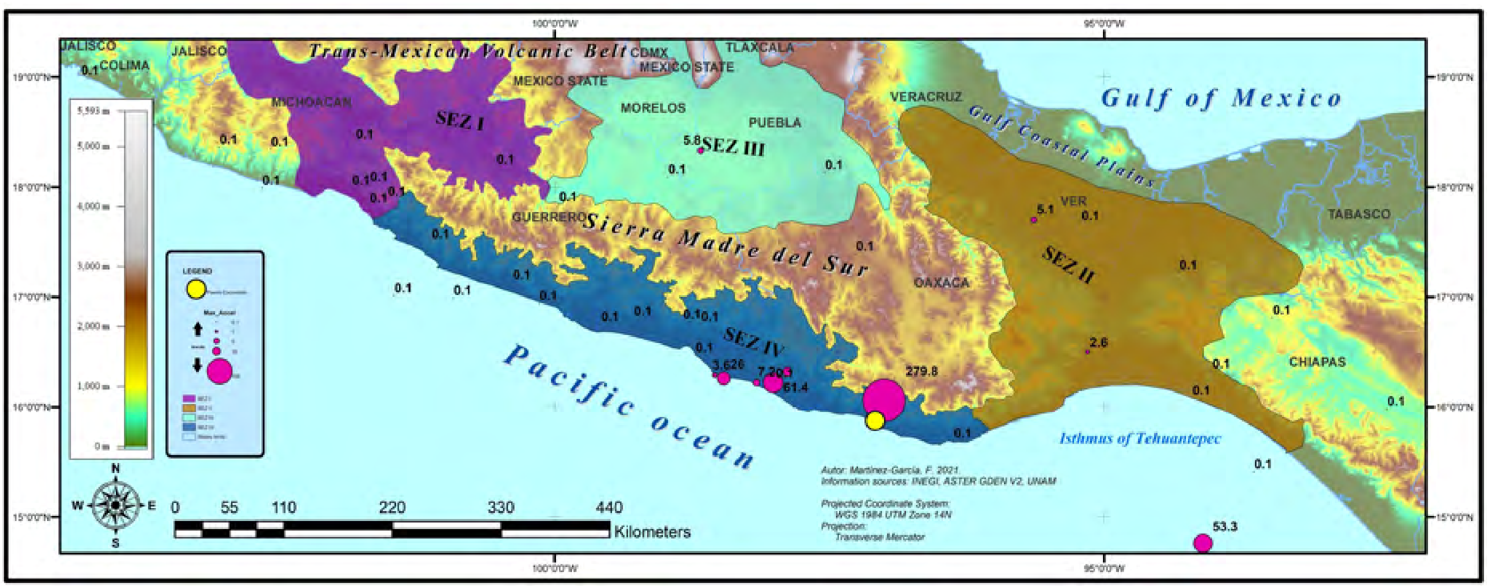

Figure 5 Spatial distribution of maximum acceleration data and degree of influence for the tourist pole of Puerto Escondido, Oaxaca

Table 6 Level of perception of apparent ground motion and shaking potential damage of seismic waves to the commercial seaport of Salina Cruz, Oaxaca.

No	Date	Hour	Latitude	Longitude	Mw	Depth	Near Dist	Max Accel	Locality	State	Perceived Shaking	Potential Damage
1	09/19/1985	07:17:49	18.42	-102.47	8.10	15.0	811.3	0.1	45 km NORTHWEST of LA MIRA	MICH	Not felt	None
2	09/20/1985	19:37:14	17.83	-101.68	7.60	17.0	712.7	0.1	25 km NORTHWEST of ZIHUATANEJO	GRO	Not felt	None
3	04/30/1986	01:07:19	18.36	-103.05	7.00	22.0	866.9	0.1	48 km SOUTH of COCOMAN	MICH	Not felt	None
4	07/13/1986	03:12:15	16.08	-94.20	6.00	90.0	107.6	0.1	36 km SOUTHWEST of ARRIAGA	CHIS	Not felt	None
5	07/15/1987	01:16:13	17.39	-97.26	6.00	68.0	255.7	0.1	46 km NORTHEAST of H TLAXIACO	OAX	Not felt	None
6	04/25/1989	08:29:03	16.80	-99.28	6.80	23.0	438.7	0.1	12 km EAST of SAN MARCOS	GRO	Not felt	None
7	05/14/1993	21:11:56	16.47	-98.72	6.00	15.0	375.3	0.1	41 km SOUTHWEST of OMETEPEC	GRO	Not felt	None
8	10/24/1993	01:52:19	16.77	-98.77	6.60	30.0	383.9	0.1	40 km WEST of OMETEPEC	GRO	Not felt	None
9	03/14/1994	14:51:26	15.98	-92.43	6.80	160.0	296.0	0.1	42 km SOUTHEAST of VENUSTIANO CARRANZA	CHIS	Not felt	None
10	12/10/1994	10:17:40	17.98	-101.52	6.60	53.0	695.0	0.1	37 km NORTH of ZIHUATANEJO	GRO	Not felt	None
11	09/14/1995	08:04:33	16.75	-98.67	7.30	21.0	372.0	0.1	29 km NORTHWEST of OMETEPEC	GRO	Not felt	None
12	10/09/1995	09:35:54	18.99	-104.25	8.00	25.0	998.7	0.1	10 km SOUTHEAST of MANZANILLO	COL	Not felt	None
13	10/12/1995	10:53:04	19.04	-103.70	6.10	11.0	944.5	0.1	21 km SOUTHEAST of COQUIMATLAN	COL	Not felt	None
14	10/20/1995	20:38:58	16.81	-93.47	7.10	160.0	194.9	0.1	12 km NORTHWEST of OCOZOCOAUTLA	CHIS	Not felt	None
15	07/15/1996	16:23:34	17.50	-101.12	6.60	22.0	638.4	0.1	17 km EAST of PETATLAN	GRO	Not felt	None
16	01/11/1997	14:28:26	18.34	-102.58	7.10	40.0	807.9	0.1	43 km NORTHWEST of LA MIRA	MICH	Not felt	None
17	05/22/1997	02:50:55	18.41	-101.81	6.00	59.0	732.7	0.1	61 km NORTHEAST of LAS GUACAMAYAS	MICH	Not felt	None
18	02/02/1998	21:02:01	15.69	-96.37	6.40	33.0	134.9	0.1	12 km SOUTHEAST of S PEDRO POCHUTLA	OAX	Not felt	None
19	06/15/1999	15:42:04	18.13	-97.54	7.00	63.0	323.0	0.1	29 km SOUTHWEST of S GABRIEL CHILAC	PUE	Not felt	None
20	06/21/1999	12:43:05	17.99	-101.72	6.20	54.0	708.5	0.1	42 km NORTHWEST of ZIHUATANEJO	GRO	Not felt	None

Table 6 Cont.

No	Date	Hour	Latitude	Longitude	Mw	Depth	Near Dist	Max Accel	Locality	State	Perceived Shaking	Potential Damage
21	09/30/1999	11:31:13	16.06	-97.00	7.40	39.0	189.5	0.1	22 km NORTHEAST of PUERTO ESCONDIDO	OAX	Not felt	None
22	12/28/1999	23:19:46	18.02	-101.68	6.10	82.0	703.9	0.1	44 km NORTHWEST of ZIHUATANEJO	GRO	Not felt	None
23	07/21/2000	01:13:39	18.09	-98.97	6.00	48.0	443.2	0.1	45 km SOUTHWEST of CHIAUTLA of TAPIA	PUE	Not felt	None
24	08/09/2000	06:41:47	17.99	-102.66	7.00	16.0	800.3	0.1	35 km WEST of LA MIRA	MICH	Not felt	None
25	10/07/2001	21:39:19	16.94	-100.14	6.10	4.0	521.2	0.1	9 km SOUTHWEST of COYUCA of BENITEZ	GRO	Not felt	None
26	11/28/2001	08:32:36	15.41	-93.64	6.4	36	184.1	38.15	55 km SOUTHWEST of PIJIJIAPAN	CHIS	Severe	Moderate/ Heavy
27	06/14/2004	17:54:21	16.22	-98.16	6.40	10.0	308.6	0.1	18 km SOUTHWEST of PINOTEPA NAL.	OAX	Not felt	None
28	04/13/2007	0:42:23	17.13	-100.38	5.60	34.0	547.5	0.1	10 km SOUTHWEST of ATOYAC DE ALVAREZ	GRO	Not felt	None
29	07/05/2007	20:09:21	16.32	-94.02	6.20	94.0	123.8	11.12	16 km NORTHWEST of ARRIAGA	CHIS	Strong	Strong
30	06/30/2010	02:22:27	16.24	-97.99	6.00	4.0	290.1	4.65	13 km SOUTHEAST of PINOTEPA NAL.	OAX	Moderate	Very light
31	02/25/2011	07:07:28	17.69	-95.21	6.00	135.0	161.2	13.01	34 km SOUTHWEST of SAYULA of EMAN	VER	Strong	Strong
32	04/07/2011	08:11:22	17.22	-94.32	6.70	171.0	143.3	34.87	80 km SOUTHWEST of LAS CHOAPAS	VER	Severe	Moderate/ Heavy
33	12/10/2011	19:47:25	17.84	-99.96	6.50	54.0	522.0	0.1	50 km NORTHWEST of ZUMPANGO ofL RIO	GRO	Not felt	None
34	03/20/2012	12:02:48	16.26	-98.46	7.50	18.0	337.6	7	46 km SOUTH of OMETEPEC	GRO	Moderate	Very light
35	04/02/2012	12:36:43	16.29	-98.54	6.00	12.0	345.6	0.1	45 km SOUTHWEST of OMETEPEC	GRO	Not felt	None
36	11/15/2012	03:20:22	18.18	-100.53	6.10	45.4	587.6	0.1	24 km SOUTHEAST of CD TAMIRANO	GRO	Not felt	None
37	08/21/2013	07:38:29	16.75	-99.58	6.00	5.0	455.4	0.1	21 km WEST of SAN MARCOS	GRO	Not felt	None
38	04/18/2014	9:27:21	17.01	-101.46	7.20	18.0	650.1	0.1	61 km SOUTHWEST of PETATLAN	GRO	Not felt	None
39	05/08/2014	12:00:14	16.99	-100.92	6.50	10	594.2	0.1	40 km SOUTHWEST of TECPAN	GRO	Not felt	None

Table 6 Cont.

No	Date	Hour	Latitude	Longitude	Mw	Depth	Near Dist	Max Accel	Locality	State	Perceived Shaking	Potential Damage
40	07/29/2014	05:46:15	17.70	-95.64	6.40	117.2	167.1	42.64	38 km SOUTHWEST of ISLA	VER	Severe	Moderate/ Heavy
41	05/08/2016	02:33:59	16.32	-97.88	6.00	7.4	276.0	0.1	19 km EAST of PINOTEPA NAL.	OAX	Not felt	None
42	09/08/2017	23:49:17	14.76	-94.10	8.20	45.90	190.2	293.29	133 km SOUTHWEST of PIJIJIAPAN	CHIS	Extreme	Extreme
43	09/19/2017	13:14:39	18.33	-98.67	7.10	51.1	420.8	4.18	8 km NORTHWEST of CHIAUTLA of TAPIA	PUE	Moderate	Very light
44	09/23/2017	07:53:04	16.50	-95.15	6.10	22.0	33.1	85.54	9 km SOUTHWEST of CD IXTEPEC	OAX	Violent	Violent
45	02/16/2018	17:39:39	16.22	-98.01	7.20	16.0	288.0	6.68	14 km SOUTHEAST of PINOTEPA NAL.	OAX	Moderate	Very light

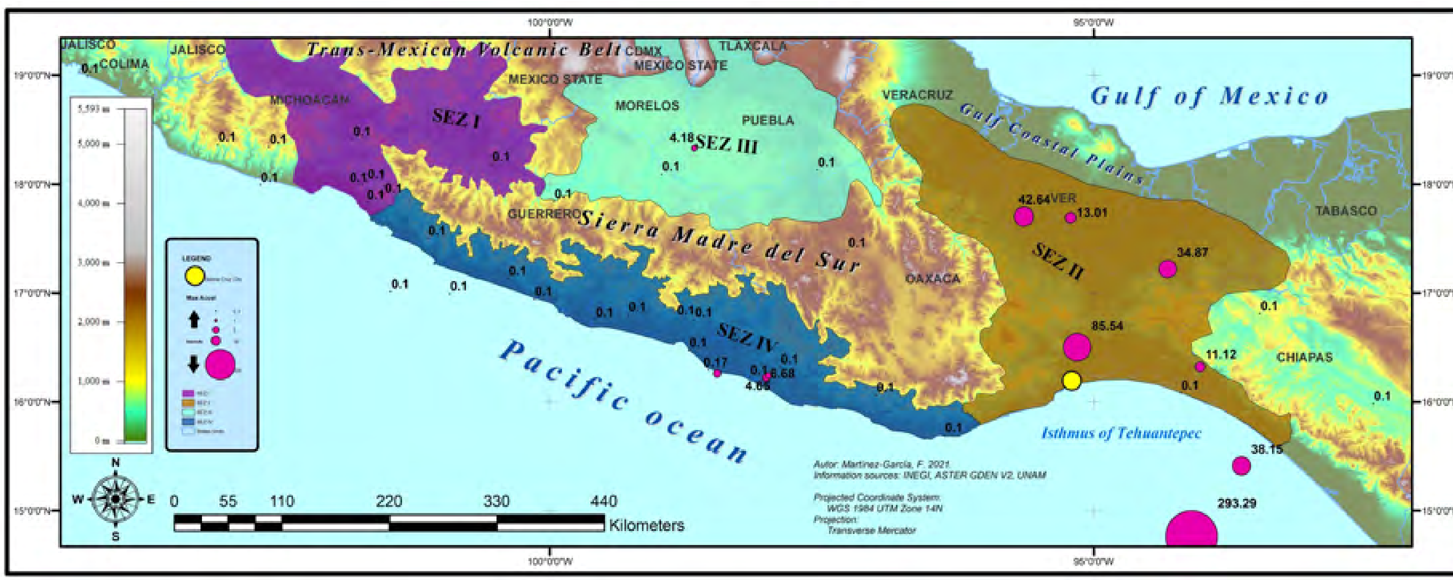

Figure 6 Spatial distribution of maximum acceleration data and degree of influence for the commercial seaport of Salina Cruz, Oaxaca

5 Discussion

The effects produced by an earthquake within its surrounding geographical space are subject to physical laws of refraction, reflection and damping of the terrain, these being characteristics exclusive for each seismic event according to the position of the epicenter and the adjacent topographic conditions. Measuring the effects of the earthquake implies knowing exhaustively the accelerations of the terrain throughout the area where the seismic waves of the event radiate, but this task is a list of inconceivable detailed multidisciplinary studies in all that territorial extension. That is why the efforts to elucidate these effects, in previous era were based on the assumption of the effects that seismic waves have on the environment through field work, verifying structural damage to the construction, as well as evaluations among the population; the results gave as a product intensities maps representing hypothetical lines (isosistas) around the epicenter according to intensity scales (Mercalli), the lines are highly correlated with the nature of the earthquake fault lines and geological conditions of density and elasticity of the materials it crosses (Figueroa 1963; Navarro-de-Fuentes 1943). Some examples of the maps mentioned can be consulted at: https://datosabiertos.unam.mx/CCUD_DOR_WS-war/resources/doil/6f84a8fd7d27186b.

For planning purposes of a seismic emergency attention, derived from the mission of the National Seismological Service (SSN acronym in Spanish) to record, store and distribute data about earthquakes that occur in Mexico, the first information previously analyzed, that reaches the citizens concerning an earthquake, is the geographical location of the epicenter of the telluric event, as well as the date, time, magnitude, location and its depth (http://www.ssn.unam.mx/).

Nowadays this information is collected through a series of seismographs distributed in wide regions where seismic activity is frequent (Gutiérrez-Martínez et al. 2014); as a result, the information is plotted into a seismogram that represent the magnitude data (Mw) or amount of energy released during an earthquake. Regarding the effects produced by an earthquake, its estimation is recorded in the intensity maps by means of isosists that delimit around the epicenter of an earthquake, regions with the same seismic intensity (Sandoval et al. 2012). For this map, the Modified Mercalli Scale (MM) is used and provides indirectly, indications on the nature and characteristics of the affected region materials.

In the case of Mexico at the present time, the advances obtained in terms of seismic records with institutions such as the SSN, CIRES and having more sensitive instruments, has made it possible to have seismic alerts almost in real time (SASMEX), (Allen & EERI Reconnaissance Team 2017; Montalvo Arrieta, León Gómez & Valdés González 2006) and intensity maps as reliable as possible (Quaas et al. 1996; Sandoval et al. 2012), maps that no longer depend entirely on opinions and surveys, but on digital information that is stored in the instruments memory. Each instrument placed in strategic sites within the national territory has a seismometer, an accelerometer, GPS, as well as a datalogger, with the capacity to record a wide range of magnitudes and accelerations of local earthquakes and distant earthquakes (Montalvo Arrieta, León Gómez & Valdés González 2006).

In high-seismicity countries such as Mexico, having time to shelter in a safe structure during an earthquake is imperative and the difference to saving the citizen lives of the mega cities, for example, Puebla and in particular CDMX. In anticipation of earthquakes, this responsibility is attributable to institutions such as CENAPRED and CIRES with the implementation of technologies as innovative as possible and with the greatest coverage.

However, the transit of seismic waves through the Earth's crust is also determined by the interaction that seismic energy has with local and regional topography, particularly with the monumental formations of the relief, main natural barriers where the frequency of waves of telluric movements is decreased and attenuated. In this context, the accelerographic records of the RAII-UNAM database, obtained during the transit of seismic waves on the Earth's surface analyzed in this work, are clear and blunt evidence of such interaction. The examination, analysis and processing of this spatial information of these instruments in large regions, has resulted in the demarcation of four regions where earthquakes are generated with significant magnitude, sensitive and instrumental perception, areas called "*Significant Epicentral Zones* (SEZs)"; their geographical nature and geomorphology, as well as the spatial interference they exert on seismic waves is very variant.

The SEZ I is located on the coastal boundaries of the states of Michoacán and Guerrero, the EQs occurring on this area certainly have their irrefutable repercussions at the local level within the coastal border, but they can also be perceived exceptionally more than 400 km away, as seismic waves move easily through the Balsas River basin, a depression that owes its geomorphology to the presence of two mountain ranges, the Trans-Mexican Volcanic Belt (TMVB) to the north and the Sierra Madre del Sur (SMS) (López-Blanco 2007), Table 3 and Figure 3 . An example of this influence was the 1985 interplate seism of Mw 8.1 (Rosenblueth 1992; Cruz-Atienza et al. 2016), which recorded fluctuating accelerations in CDMX, the country's capital, 35 to 165 PGA (cm/s^2). This seism is considered the most serious natural disaster in the recent history of Mexico and is a milestone in the seismological history of the country, further demonstrating the insufficient knowledge gathered until then on the subject (Astiz, Kanamori & Eissler 1987; García-Acosta 2004).

SEZ II is located in the Gulf and Isthmus of Tehuantepec, where they highlight a geomorphology typical of accumulation plains; mountains and lower elevations; sedimentary rocks; slope and continental slope (Lugo-Hubp & Condoba-Fernández 2007). The earthquakes occurred in this part of the country exert their influence about 400 kilometers away from the epicenter, the seismic waves coming from this region maintain an orientation and direction with SSE-NNW trend, Table 6 and Figure 6, some of these telluric events occur on the platform and continental slope (Lugo-Hubp & Condoba-Fernández 2007), example of such events is the intraplate earthquake occurred on September 7, 2017 at 23:49:17 hours (04:49 UTM), with an 8.2-degree Mw at 45.9 km deep (SSN (UNAM) 2017a).

SEZ III involves the center of the country, particularly between the limits of Puebla and Morelos, Tables 1–2 and Figures 1–2, any seism greater than 5.5 Mw occurred in this area will undoubtedly affect this area of the country with seismic waves moving in a range of 120 km around, involving the CDMX, Cuernavaca, Morelos and Puebla, Puebla, an example is the intraslab EQ of 7.1 Mw, occurred 57 km deep, on September 19, 2017 at 13:14:40 hours (SSN (UNAM) 2017b).

SEZ IV is located between the coastal boundaries of the state of Guerrero with Oaxaca, with a strongly local seismic influence particularly between the municipal boundaries of Ometepec and Pinotepa Nacional, decreasing significantly to north no later than 120 km around the coastline, such attenuation is due to presence of the Sierra Madre del Sur (SMS), Table 4 and Figure 4.

The coastal border where the Cocos plate subducts with the North American plate, is the area of influence involving in its entirety to SEZ I, III and IV, Figures 1–6; to the southeast involves SEZ II along with the Caribbean plate. Seismic energy interaction and surrounding topography in this subduction zone are responsible for nearly 100% of the country's earthquakes (85% interplate events and the rest, intraslab).

The contributions of this research work are in agreement with the estimation of the potential effects caused by seismic waves to infrastructure, populations and natural environment, but unlike the intensity maps, the epicenter of the earthquake is not the center of attention, but each of the six populations involved by 45 earthquakes occurred in the period from 1985 to 2018: CDMX, Puebla, Acapulco, Lázaro Cárdenas, Puerto Escondido and Salina Cruz.

The approach used with replacing magnitude data (Mw) at the epicenter with maximum acceleration data (Max Accel) is considered novel and unprecedented and is potentially applicable to other urban centers in Mexico and other world seismic regions. This approach links concepts such as "site effect" by indirectly showing the interaction that exists between large topoforms and seismic waves (refraction, reflection and damping). In the same way, it emphasizes the importance of the origin (epicenter), the direction and orientation of the seismic waves of the event in the identification of potential affectations, mainly for urban and suburban centers, a very useful information for prevention purposes, in the design of development plans at the local and regional level.

Under this reasoning and in addition to the description of the SEZ I included in this section, the CDMX without being entirely the Mexican city most affected by seismic waves, this area of great urban concentration with almost 10 million inhabitants (22 million in total, in the metropolitan area of the Valley of Mexico) is the most important for being the country capital that houses or is the seat of the powers of the Union (Mexico) and main political nucleus, economic, social, academic, financial, business, tourism, cultural, communications and entertainment. Inserted in the Valley of Mexico basin, the CDMX is evidently the most significant outlier of the analysis carried out in this document since, in terms of seismic intensities, a good part of this megalopolis behaves like an "Island", because it is an enclosure that is separated from the surrounding space (Figueroa 1963, page 51, 59, 60, 62, 65; II-UNAM 2020). The reasons and answers of this condition are, without a doubt, the historical advance of the urban spot towards the lake ancient zone, an unconsolidated stratified area where seismic waves are amplified by the presence of different wavelength or overtones (Cruz-Atienza et al. 2016), a phenomenon that strongly affects constructions (Stone et al. 1987), as well as the geographical location of the epicenter, predominating the waves that arrive from the limits of the states of Puebla and Morelos (EQ 2017, 7.1 Mw), as well as the seismic waves that arrive from the coastal limits of the states of Michoacán and Guerrero (EQ 1985, 8.1 Mw). Figure 7 represents the seismic zoning of the CDMX created from amplification data related to a certain period (II-UNAM 2020), this map shows the variation of values that exists from the lake area (5.9 s) to the mountains, hills and volcanoes (0.1 s) that limit the ancient lake within of the Valley of Mexico Basin.

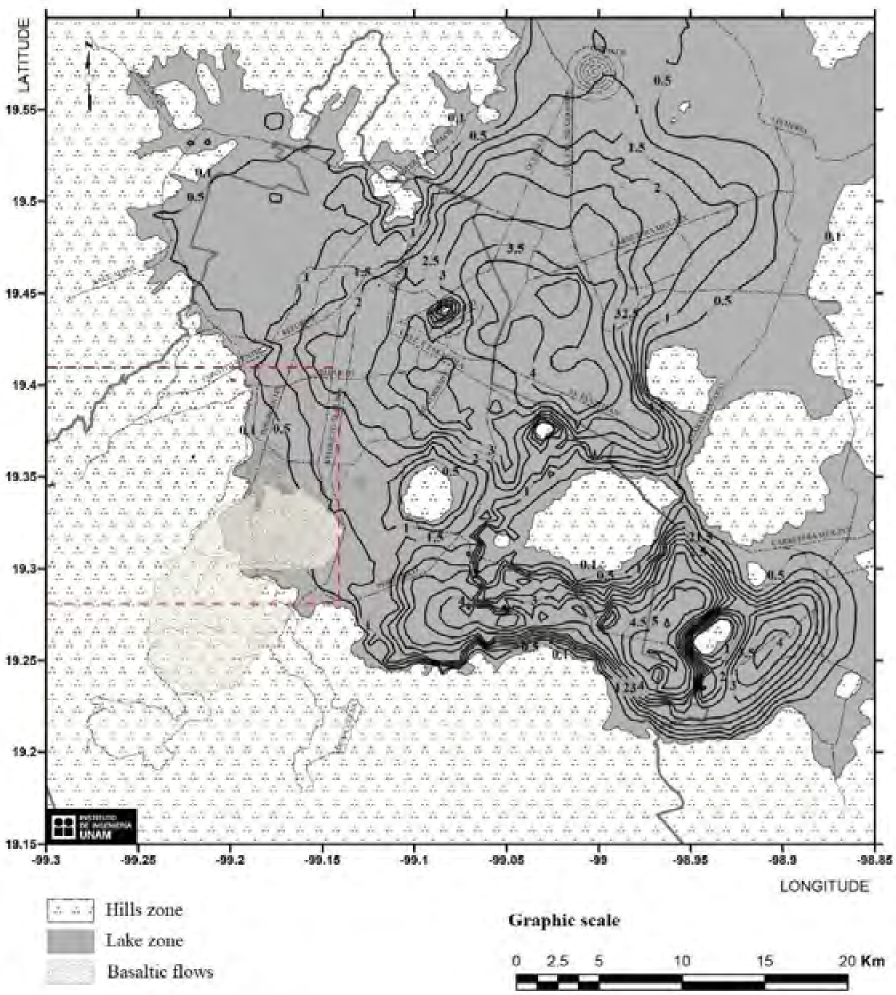

Figure 7 Relative amplification Map of the CDMX, (II-UNAM 2020).

6 Conclusions

Saving life during a telluric event is undoubtedly correlated with the earthquake own characteristics, the features of the local relief and the terrestrial route where seismic waves transit. Also, from the distance at which it occurs and the resistance of the buildings inhabited by citizens of seismic zones.

According with the information time period and the amount of data processed, spatial replacement of seismic moment "*Mw*" data with "*Max Accel*" gives an alternative spatial perspective of the differential site effect (regional perspective focus) and impact seismic waves have on the physical and social environment. The four SEZ identified give evidence of the role of local topography in attenuating or accelerating seismic waves influence, and also reveals the path and predominant route followed by the waves and the degree of vulnerability of certain regions of the country arising from the formal interaction between seismic waves and local topography.

Earthquakes in SEZ I and IV have a very local influence due to topography in a surrounding range between 70 and 120 kilometers, but in terms of frequency, events occurring in SEZ IV are more periodic because they are located where the Cocos plate subducts to the American plaque between the state coastal boundaries of the states of Guerrero and Oaxaca.

Earthquakes in SEZ I and II have a wider range of influence, greater than 400 km, but have a different path and direction, in SEZ I it is W-E trend, unlike the SEZ II whose trend is SSE-NNW. The geomorphology of these two regions is characterized by the presence of depressions, one corresponding to the basin or depression of the Balsas River which owes its shape to the presence of large mountain ranges, TMVB-SMS. The other depression corresponds to the Isthmus of Tehuantepec, characterized by the presence of plains, minor elevations and continental shelf.

Earthquakes occurred in SEZ I are primarily of strong local influence but the waves produced when transiting through the Balsas River basin maintain sufficient intensity and wave amplitude to cause impacts when reaching the lake area of the Metropolitan Zone of CDMX (MZMC) within the Basin of Mexico. The lake area is the most susceptible area the passage of seismic waves, is characterized by an unconsolidated complex structure of soft clays of high compressibility consisting of alternating clay strata with dissecting soils and layers of ash and pumice.

In constructive terms the CDMX Metropolitan Zone can be considered the worst choice, because while the rocky areas vibrate at the same frequency and amplitude as seismic waves, the unconsolidated areas in the lake area amplify the waves and the phenomenon of liquefaction occurs too, having a strong impact on the foundations of the buildings causing their collapse. This condition of affectation in CDMX is likewise considered unusual, as they rarely occur 400 km away from a telluric event of any magnitude. Undoubtedly, CDMEX is an atypical city since the condition of the ground on which it sits makes the entity more vulnerable to seismic waves from SEZ I mainly, in the same way as SEZ III for its proximity, SEZ IV too, although with a degree of significant attenuation by the southern presence of the Sierra Madre del Sur.

According to the data analysis, taking as a reference the CDMEX, the presence of the Sierra Madre del Sur is key in the attenuation of seismic waves, even for this great city. It is mainly important for the central region where the states of Morelos and Puebla are located; for these demarcations has more influence the seismic activity that occurs in SEZ I than the SEZ IV, despite being 310 km away, Figures 2–3.

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Author contribution

Fidel Martínez García: conceptualization; formal analysis; funding acquisition; investigation; methodology; resources; validation; visualization; writing – original draft; writing – review and editing.

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