AQUILA, MICHOACÁN, MEXICO SEPTEMBER 19, 2022, M_w 7.6 EARTHQUAKE

PRELIMINARY VIRTUAL RECONNAISSANCE REPORT (PVRR)

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PREFACE

The Earthquake Engineering Research Institute (EERI) is the leading non-profit membership organization in the United States that connects those dedicated to reducing earthquake risk. Its multidisciplinary members include engineers, geoscientists, social scientists, architects, planners, emergency managers, academics, students, and other like-minded professionals. EERI has been bringing people and disciplines together since 1948. EERI's mission is to provide members with the technical knowledge, leadership and advocacy skills, collaborative networks, and multidisciplinary context to achieve earthquake resilience in their communities worldwide. EERI has members not only in the U.S. but worldwide.

This report has been produced by EERI's Learning From Earthquakes (LFE) program. The mission of the LFE Program is to accelerate and increase learning from earthquake-induced disasters that affect the natural, built, social and political environments worldwide. This mission is accomplished through field, remote or hybrid reconnaissance, data collection and archiving, and dissemination of lessons and opportunities for reducing earthquake losses and increasing community resilience. For more information on LFE, please visit http://www.learningfromearthquakes.org/about

Sociedad Mexicana de Ingeniería Sísmica, SMIS, (Mexican Society for Earthquake Engineering), founded in 1962, is a scientific and technical society, whose mission is to promote, disseminate and exchange knowledge, experiences and scientific and technological research on Earthquake Engineering in a multidisciplinary context. Its objectives include: (1) Investigate and develop technology to study, analyze, detect and evaluate seismic phenomena, prepare and develop projects to promote research, data collection and experiences related to Earthquake Engineering, Natural Risk Engineering and others; (2) Bring together people interested in earthquake engineering problems with the purpose of exchanging knowledge, experiences and technological research; (3) Organize scientific events, such as workshops, courses, seminars, round tables, conferences, congresses, symposiums, among others, to fulfill its mission; (4) Promote the publication of technical reports, newsletters, magazines or others; (5) Exchange, experiences derived from the occurrence of earthquakes and investigations with other interested associations or institutions, and participate in efforts to acquire data and knowledge and its subsequent applications; (6) Collaborate with related institutions in order to fulfill its mission. More details about SMIS can be found in https://smis.org.mx/

ACKNOWLEDGMENTS

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Special thanks are given to the Colombian Earthquake Engineering Research (CEER) Network who enthusiastically reached out to us immediately after the earthquake to offer their assistance. Many faculty members and students, all fully bilingual, from seven different Universities in Colombia doing research in Earthquake Engineering actively participated in gathering information and in producing this report. Their contributions are greatly acknowledged. To learn more about CEER please visit http://ceer.co/

Many individuals in Mexico in addition to those coauthoring this report also contributed with information and enthusiastic work in producing this reconnaissance report. In particular, we would like to thank the following students at UNAM who contributed to the section on geotechnical effects on this earthquake: Daniel De La Rosa Arenas and José Mauricio Alcaraz Barranco.

For more information about the Earthquake Engineering Research Institute please visit the EERI website: https://www.eeri.org/

In particular, for a full listing of resources including Virtual Earthquake Reconnaissance Team (VERT) reports, datasets, and publications for over 300 different earthquakes occurring in more than 50 countries during the last 70 years of EERI's Learning From Earthquakes program, please visit the EERI LFE earthquake archive:
https://learningfromearthquakes.org/archive/table-view

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EXECUTIVE SUMMARY

On September 19th, 2022, a moment magnitude 7.6 earthquake struck the Pacific coast of Mexico in the state of Michoacán between the cities of Manzanillo and Zihuantanejo. This is the third major earthquake that has occurred in Mexico on September 19th in the last 40 years. A large earthquake drill in Mexico City is carried out annually on the anniversary of the great Mw 8.0 September 19th 1985 earthquake. On September 19th 2017 a magnitude 7.1 occurred on the 32nd anniversary of the 1985 earthquake a few hours after the city wide earthquake drill. This magnitude 7.6 earthquake struck again on the anniversary of the 1985 earthquake but now only about 45 min after the city-wide earthquake drill. The Seismic Early Warning System of Mexico (SASMEX) was triggered as a result of this event working as expected and provided a 98 second warning in Mexico City.

The earthquake mechanism corresponds to a reverse faulting mechanism characteristic of earthquakes that occur on or near the plate boundary between the Cocos and North American Plates. USGS focal mechanism solutions indicate that rupture occurred on a shallowly dipping (i.e., 18.0°) thrust fault. The rupture of this earthquake is located approximately between the rupture of the great Mw8.0 September 19, 1985 to the South and the rupture of the great Mw8.0 October 9, 1995 to the North. The earthquake produced a small tsunami with a maximum measured wave amplitude of 1.7m in the port of Manzanillo.

Three deaths were reported as a result of the main shock, one of them a minor who was severely injured and subsequently died in the hospital as a result of the injuries. Additionally, two other persons in Mexico City died as result of an aftershock on September 22nd: one from injuries to the head when she fell on the stairs and another as a result of a heart attack. Several hundred injuries were reported as a result of the main earthquake.

1 Introduction

On September 19th, 2022, at approximately 1:05 pm local time, a moment magnitude 7.6 earthquake struck 37 km southwest of the Aquila municipality in the state of Michoacán, Mexico. The epicentral coordinates reported by the U.S. Geological Survey (USGS, 2022a) and the Servicio Sismológico Nacional de México (National Seismological System of Mexico) (SSN, 2022a) were 18.367°N 103.252°W and 18.22°N 103.290°W, respectively. The USGS reported a hypocenter depth of 15.1 km, almost the same as that reported by SSN which reported a depth of 15.0 km. At the time of the writing of this report, over 1229 aftershocks have occurred (SSN, 2022b).

The largest aftershock occurred on September 22nd, three days after the main event, at approximately 1:16 am local time. For this second event, the USGS reported a moment magnitude of 6.8. According to the USGS the epicenter was located at 18.308°N 102.923°W, approximately 39 km southeast of that of the September 19th earthquake.

A tsunami warning was triggered by the Mw 7.6 earthquake for Mexican Pacific Coast, and the earthquake triggered waves at various locations with the largest waves reported in the port of Manzanillo where an amplitude of 1.7m was measured.

The main event and its aftershocks caused moderate to extensive damage to structures near the epicenter, mainly affecting the states of Colima and Michoacán. Furthermore, reports of some damage were found in cities located farther away from the epicentral region, as far as Mexico City, which is located approximately 453 km from the epicenter of the main event.

There was a total of five fatalities reported as a result of the two events, three were caused by the main event on September 19th, and the other two occurred in Mexico City after the Mw 6.8 aftershock on September 22nd. Two of the fatalities produced by the main shock occurred during the earthquake, one as a result of the collapse of a large facade element and the other of a partial collapse of the roof of a gymnasium. The other was a minor who was injured as a result of a gas explosion triggered by the earthquake and subsequently died in the hospital as a result of his injuries. Of the fatalities produced by the aftershock one was produced by a heart attack and the other by head injuries to a person who fell on the stairs while evacuating her residence. Several hundred people have been reported injured (CNN, 2022).

2 Seismological Aspects

2.1 Tectonic summary

Mexico is located in a complex seismological region with active seismicity, as the result of the interaction between six tectonic plates: North American (where most of the country sits), Cocos, Rivera, Orozco, Pacific, and Caribbean plates, as shown in Figure 2.1. The high seismicity of the Pacific Coast of Mexico is mainly controlled by the subduction process of the Cocos plate beneath the North American plate, in a northeast direction, at an approximate rate of 70 mm/yr, with a relatively shallow dip angle (lower than 30°, according to Singh et al. 1981).

Since 1900, Mexico has experienced 235 earthquakes with magnitudes equal to or greater than 6.5 (USGS, 2022b), as shown in Figure 2.2. This gives an average of approximately two events with magnitudes equal to or greater than 6.5 per year. To put this seismicity into perspective, during the same period the contiguous United States have only experienced 45 earthquakes with magnitudes equal to or greater than 6.5, for an average of one every 2.7 years. Of the 235 earthquakes in Mexico, 83 had magnitudes between 7 and 8, and five had magnitudes equal to or greater than 8. Mexico, therefore, experiences roughly a magnitude 7 or larger event every 1.4 years.

The largest earthquakes in Mexico usually correspond to interplate thrust subduction events that occur in the interface between the Cocos and the North American Plates. Two recent examples of this type of event are the 1985 Mw 8.0 Michoacán earthquake and the 1995 Mw 8.0 Colima earthquake. Intermediate depth intraplate events, which occur within the subducted Cocos Plate, are also common in the region and have caused significant damage, as evidenced by the 2017 Mw 7.1 Puebla-Morelos earthquake (Galvis et al. 2020). An example of a subduction event between the Rivera and North American plates is the 1932 Mw 8.1 Jalisco earthquake (Singh et al. 1984). Meanwhile, in the northwest of Mexico, shallow crustal strike-slip earthquakes are also generated in the boundary between the Pacific and the North American plates, such as the 2010 Mw 7.2 El Mayor–Cucapah earthquake. Additionally, crustal events have occurred within the North American Plate, especially in the Trans-Mexican Volcanic Belt (e.g., the 1912 M~7.0 Acambay earthquake).

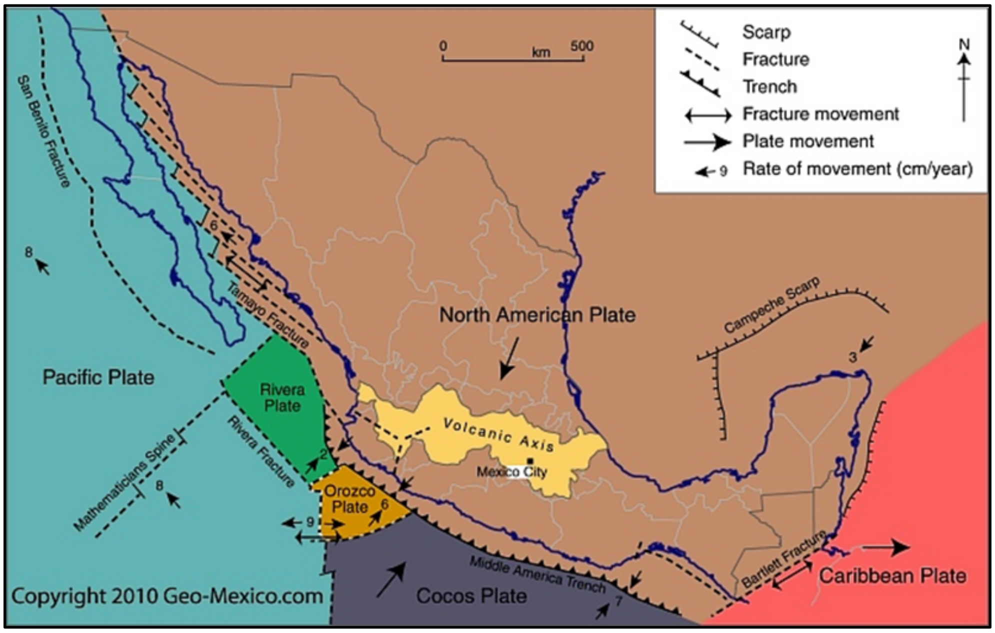


Figure 2.1. Tectonic setting around Mexico. Source: Geo-Mexico (2012).

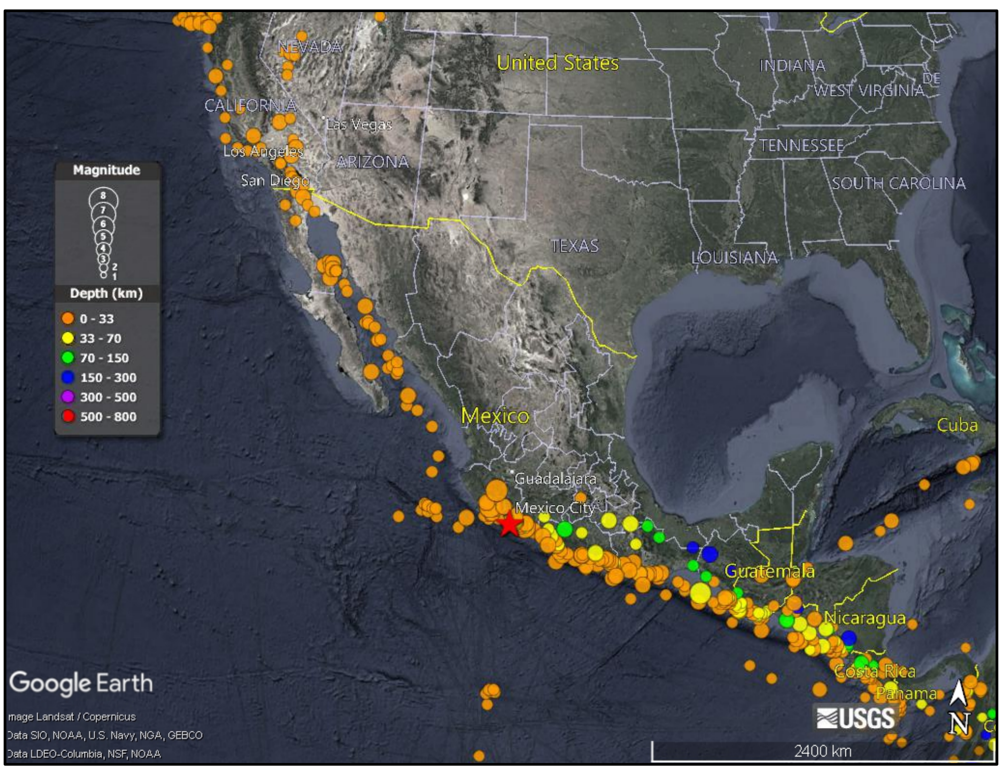


Figure 2.2. Epicenters of events with magnitudes greater than 6.5, since 1900 (USGS, 2022b).

Other significant interplate and intraplate earthquakes in Mexico, causing widespread damage in the country, are listed below:

- **1932**: A Mw 8.4 thrust earthquake occurred in the region of Jalisco, about 165 km to the northwest of the Michoacán September 19, 2022, Mw 7.6 earthquake.
- **1980**: On October 24, 1980, a Ms 7.0 earthquake severely damaged the city of Huajuapan de León, Oaxaca, where 90% of the built environment had some type of damage; particularly, 10 churches, 2 hotels, and the municipality building collapsed because of the earthquake. According to official reports, there were 50 deaths and more than 300 injured inhabitants.
- **1985**: The deadliest earthquake in Mexico happened on September 19, 1985, in the Michoacán region, approximately 90 km to the east of the September 19, 2022 event. This Mw 8.0 earthquake resulted in at least 9,500 fatalities, injured about 30,000 people, and left 100,000 people homeless.
- **1995**: On October 9, a Mw 8.0 earthquake struck the Colima-Jalisco region and resulted in at least 49 fatalities and left 1,000 people homeless.
- **2003**: A Mw 7.6 earthquake in Colima, Mexico, resulted in 29 fatalities, destroyed more than 2,000 homes, and left more than 10,000 people homeless.
- **2012**: A Mw 7.4 earthquake that occurred 560 km to the southeast of the 2022 Michoacán event killed two people and injured 11 others in the Oaxaca region.
- **2017**: On September 8th, a Mw 8.2 earthquake occurred offshore Chiapas, several hundred kilometers to the southeast of the 2022 Michoacán event. That earthquake caused at least 78 fatalities and 250 injuries in Oaxaca, and also 16 deaths in Chiapas. Eleven days later, a Mw 7.1 earthquake struck closer to Mexico City, 620 km to the southeast of the 2022 Michoacán earthquake, resulting in over 300 fatalities and significant damage in Mexico City and the surrounding region (Arteta et al. 2019; Galvis et al. 2020).
- **2018**: In February, a Mw 7.2 event struck 750 km to the southeast of the 2022 Michoacán earthquake that injured four people and damaged 1,000 homes in Oaxaca.
- **2020**: On June 23rd, a Mw 7.4 earthquake occurred in Oaxaca, producing 10 deaths, hundreds of injuries, damage to more than 2,000 residential buildings, and damage to several commercial structures and infrastructure.
- **2021**: On September 7th, a Mw 7.0 earthquake struck about 550 km to the southeast of the 2022 Michoacán event. This event killed 13 people and injured 23 others.

Figure 2.3 shows the location of the Mw ≥ 7.0 events that impacted Mexico in the last decade (USGS, 2022b), confirming the high seismicity rate of the region (i.e., 0.7 events/year). Except for the Puebla (2017) earthquake, the epicenter of these events aligns with the subduction zone along the Pacific Coast. The subduction events Northeast to the Tehuantepec Gulf are shallow, with depths in the range of 15-24 km (Table 2.1).

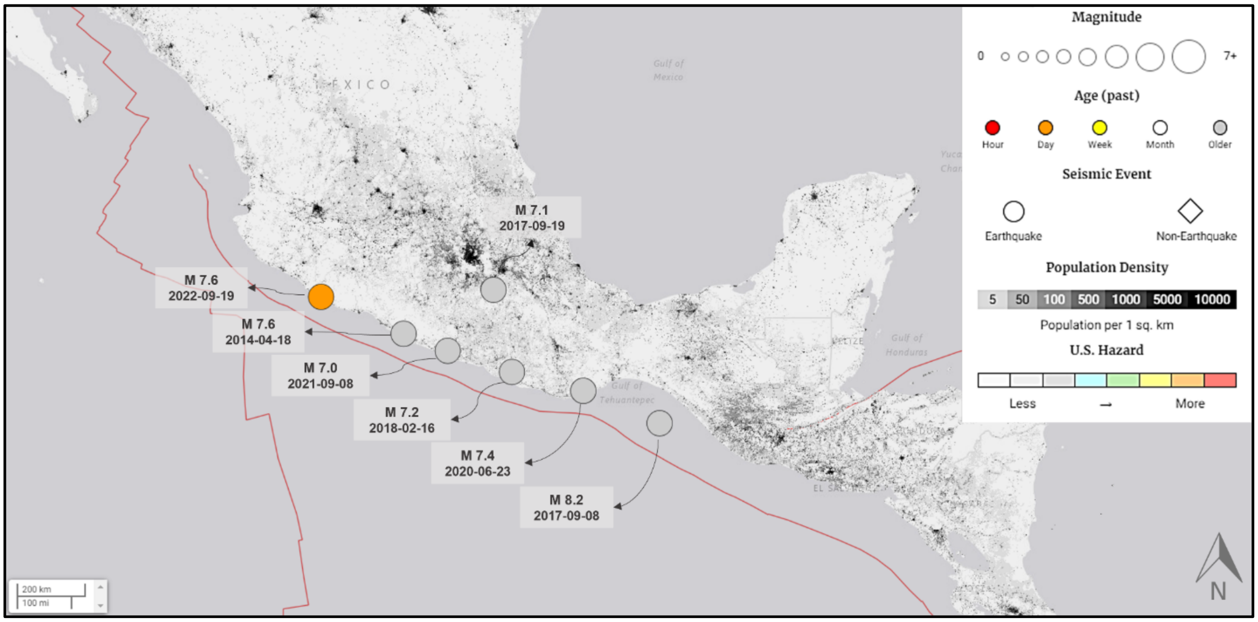


Figure 2.3. Epicenter of major events affecting Mexico in the last decade (adapted with data from USGS, 2022b).

Table 2.1. Major events in Mexico in the last decade.

Name	Date	Location	Depth
M 7.6 - 37 km SE of Aquila, Mexico	2022-09-19	18.367°N, 103.252°W	15.1 km
M 7.0 - Acapulco, Mexico	2021-09-08	16.947°N, 99.753°W	20.0 km
M 7.4 - 9 km SE of Santa María Xadani, Mexico	2020-06-23	15.886°N, 96.008°W	20.0 km
M 7.2 - 4 km S of Pinotepa de Don Luis, Mexico	2018-02-16	16.386°N, 97.979°W	22.0 km
M 7.1 - 1 km S of Matzaco, Mexico	2017-09-19	18.550°N, 98.489°W	48.0 km
M 8.2 - Near the coast of Chiapas, Mexico	2017-09-08	15.022°N, 93.899°W	47.4 km
M 7.2 - 9 km ENE of Coyuquilla Norte, Mexico	2014-04-18	17.397°N, 100.972°W	24.0 km

2.2 Earthquake Details

On September 19, 2022 on the annual commemoration of the 1985 earthquake that caused the largest death toll in the country, at 01:05 pm local time, a subduction earthquake occurred at the interface between the Cocos and North America plates on the pacific coast of Mexico. According to the USGS (2022a) the epicenter was located at 18.367°N, 103.252°W, 37 km southwest of the Aquila municipality in the state of Michoacán, while the reported moment magnitude and hypocenter depth are Mw 7.6 and 15.1 km, respectively. On the other hand, the SSN (2022a) reported a Mw 7.7 for the event and a hypocenter located at 18.22°N 103.29°W with a 15 km depth. According to SSN, the earthquake was followed by more than 1436 aftershocks having moment magnitudes up to Mw 6.8 (up to 12 h of September 22, 2022). The location of the event along with the stations used for the preliminary report developed by UIS (2022a) are presented in Figure 2.4.

Figure 2.4. Map of the epicenter and stations reported by UIS (2022a).

The earthquake mechanism reported by SNN corresponds to a reverse faulting mechanism characteristic of earthquakes on or near the plate boundary between the Cocos and North American Plates. USGS focal mechanism solutions indicate that rupture occurred on either a shallowly dipping (i.e., 18.0°) thrust fault striking towards the West or on a steeply dipping (i.e., 72.0°) reverse fault striking towards the ESE (**Error! Reference source not found.**). A summary of these mechanism solutions is shown in Table 2.2 along with principal axes information displayed in Table 2.3. Although earthquakes of this magnitude have rupture areas of about 70 x 35 km (length x width), the USGS computed a larger rupture plane of about 100 x 90 km (USGS, 2022a). The rupture plane found by USGS also had a strike of 295.0° and a dip angle of 18.0°, with a maximum slip of 1.2 m (USGS, 2022a). Figure 2.6 shows the dimensions of the fault plane and the slip distribution, as well as its surface projection.

Table 2.2. Nodal Planes.

Plane	Strike	Dip	Rake
NP1	287°	18°	86°
NP2	112°	72°	91°

Table 2.3. Principal Axes.

Axis	Value	Plunge	Azimuth
T	2.735e+20 N-m	63°	24°
N	-0.127e+20 N-m	1°	292°
P	-2.609e+20 N-m	27°	201°

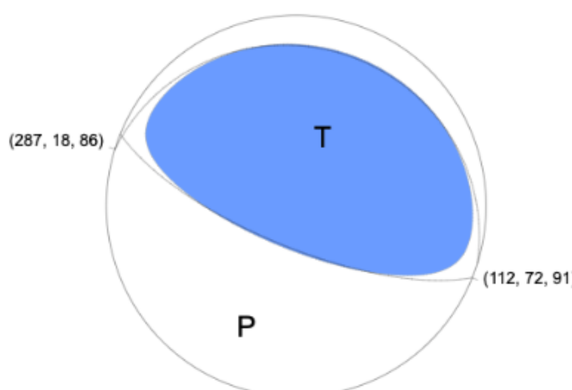


Figure 2.5. Fault plane solutions by USGS (2022a).

The finite fault model developed by USGS (2022a) indicates maximum slip values along the fault plane of 1.2 m towards the Northwest of the epicenter. The reported seismic moment estimate is M_0 = 2.7 x10^{20} Nm

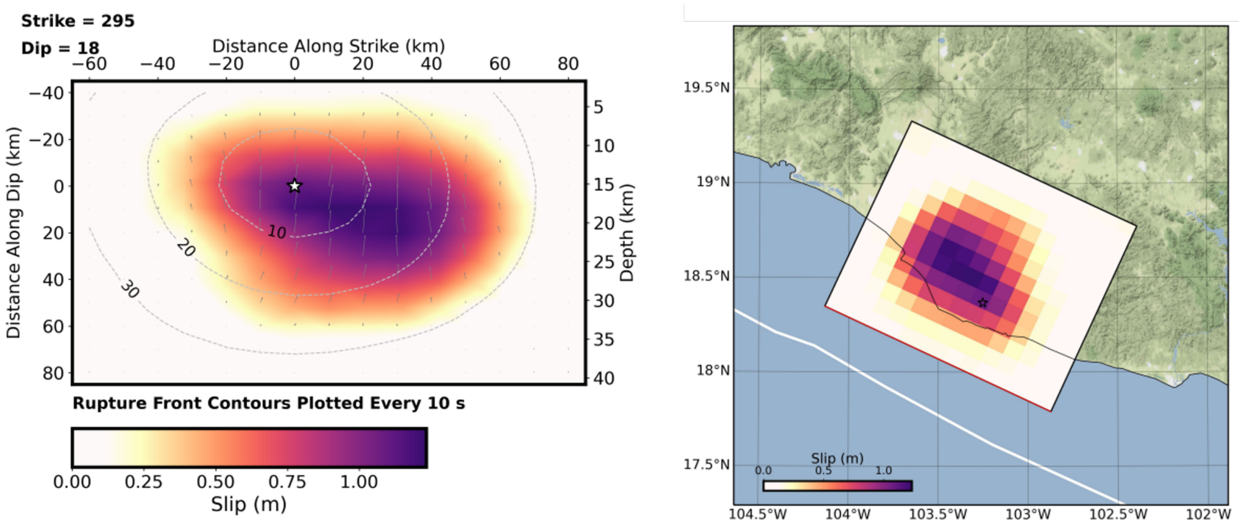
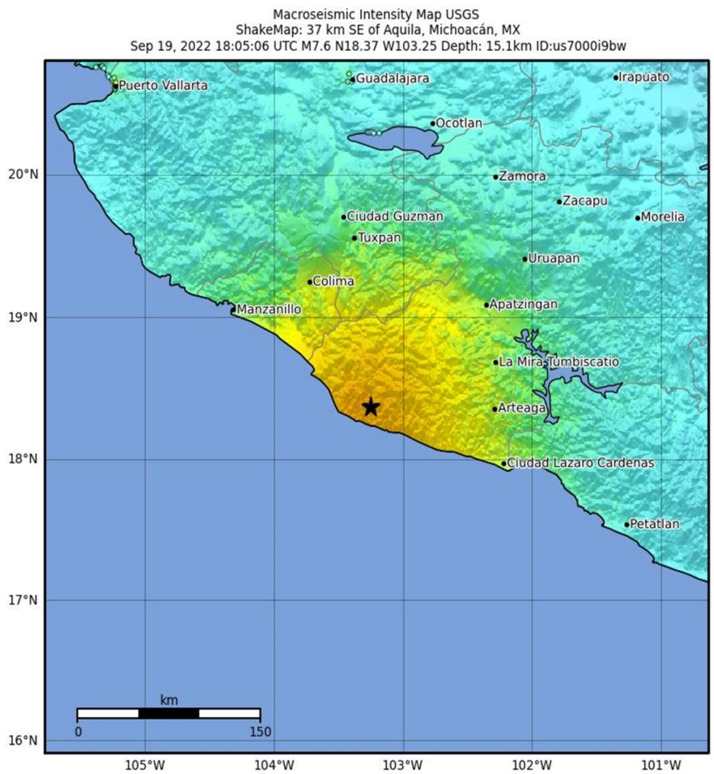


Figure 2.6. Cross-section and surface projection of slip distribution (USGS, 2022a).

The USGS Shakemap estimates a MMI of VII around the epicenter as presented in Figure 2.7. Similarly, Figure 2.8 presents the contours for PGA, PGV, and Sa(T=1s). Both PGA and Sa(T=1s) values estimated around the epicenter are close to 0.5g while the estimated PGV is approximately 20.



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0464	0.297	2.76	6.2	11.5	21.5	40.1	74.7	>139
PGV(cm/s)	<0.0215	0.135	1.41	4.65	9.64	20	41.4	85.8	>178
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Worden et al. (2012) Version 3: Processed 2022-09-19T20:06:11Z
△ Seismic Instrument ○ Reported Intensity ★ Epicenter

Figure 2.7. Intensities estimated from ShakeMap (USGS, 2022a).

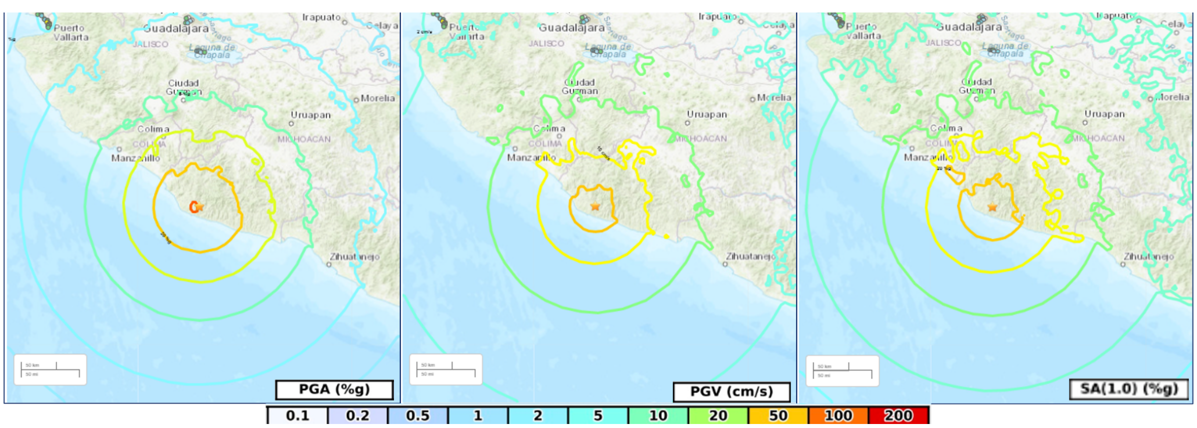


Figure 2.8. Intensity map estimated from recorded PGAs, PGVs, and Spectral acceleration at T =1s estimated from ShakeMap (USGS, 2022a).

2.2.1 M 6.8 – Michoacán Aftershock

Only three days after the M7.6 Aquila earthquake, at around 01:16:09 am local time, a M6.8 earthquake hit the state of Michoacán on the Pacific coast of Mexico. According to the USGS (2022c), the earthquake is also a subduction event at the interface between the Cocos and North America Plate and is considered an aftershock of the main event. The epicenter location reported by the USGS is 18.308°N, 102.923°W, and had a 24.1 km depth. The SSN (2022a) reported a moment magnitude of 6.9 and a hypocentral depth of 12 km with an epicenter located at 18.01°N, 103.18°W. Table 2.4 summarize the focal mechanism solutions estimated by USGS, the solutions indicate that the rupture occurred on either a steeply dipping (i.e., 72.0°) reverse fault striking towards the ESE or a shallowly dipping (i.e., 18.0°) thrust fault striking towards the West. Lastly, the principal axes information for the M6.8 earthquake is presented in Table 2.5, and the fault plane solution provided by the USGS is presented in Figure 2.9.

Table 2.4. Nodal Planes.

Plane	Strike	Dip	Rake
NP1	291°	18°	90°
NP2	111°	72°	90°

Table 2.5. Principal Axes.

Axis	Value	Plunge	Azimuth
T	1.909e+19 N-m	63°	24°
N	-0.012e+19 N-m	1°	292°
P	-1.897+19 N-m	27°	201°

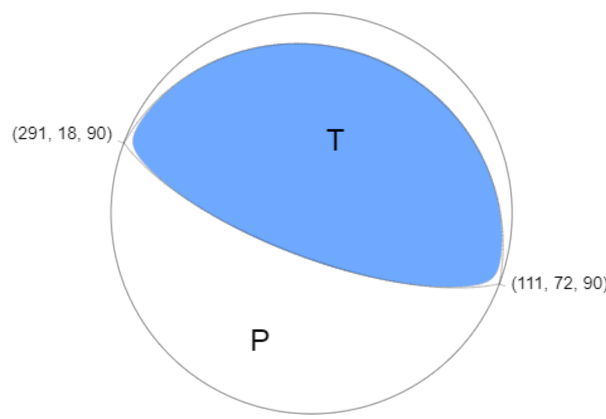
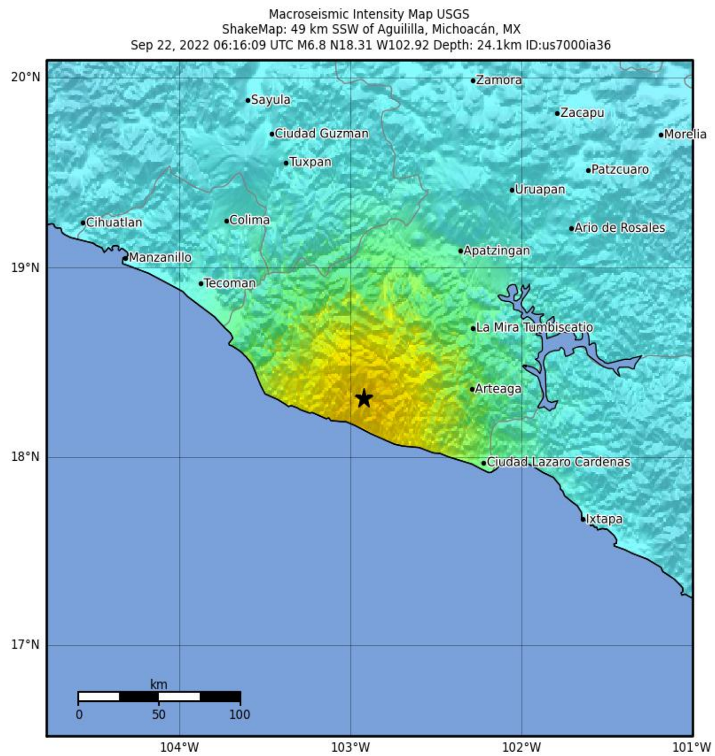


Figure 2.9. Fault plane solutions by USGS (2022c).

The USGS ShakeMap products for the M6.8 aftershock are presented in Figure 2.10 (MMI) and Figure 2.11 (PGA, PGV, and Sa(T=1s). Although the released energy during this earthquake is considerably lower than the energy released during the M7.6 earthquake, the estimated MMI around the epicenter for both earthquakes is the same (VII). Furthermore, the estimated PGA, PGV, and Sa(T=1s) are 0.5g. 20 cm/s and 0.2g, respectively.



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0464	0.297	2.76	6.2	11.5	21.5	40.1	74.7	>139
PGV(cm/s)	<0.0215	0.135	1.41	4.65	9.64	20	41.4	85.8	>178
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Worden et al. (2012) Version 3: Processed 2022-09-22T08:17:24Z
△ Seismic Instrument ○ Reported Intensity ★ Epicenter

Figure 2.10. Intensities estimated from ShakeMap for the M6.8 Michoacán earthquake (USGS, 2022c).

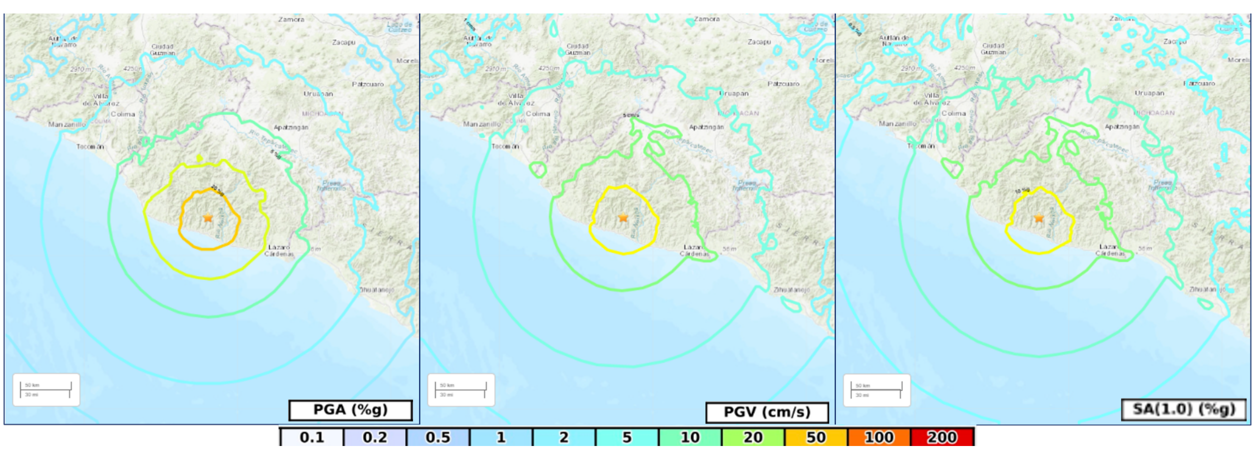


Figure 2.11. Intensity map estimated from recorded PGAs, PGVs, and, and Spectral acceleration at T =1s estimated from ShakeMap for the M6.8 Michoacán earthquake (USGS, 2022c).

2.3 Earthquake Early Warning (EEW)

Mexico's EEW system is one of the oldest in the world, which began operating in 1991 with Mexico's strong-motion accelerometer network that monitors the subduction zone on the western coast and was originally designed just to alert citizens in Mexico City of earthquake shaking (Allen et al., 2009). The Mexican Seismic Warning System (SASMEX by its acronym in Spanish) currently sends alerts to Mexico City, and the cities of Oaxaca, Acapulco, Chilpancingo, and Morelia via TV, AM/FM radio, National Oceanic and Atmospheric Administration weather radios, and the Mexican Hazard Alert System (Suarez et al., 2018). Similar to the other EEW systems, SASMEX detects the occurrence of an earthquake and sends this information to the managers of different infrastructure operating systems. As an example, the Public Electric Transportation System and the METRO have used the Seismic Alert System (SAS) warnings by means of radio receivers in their control center since 1992, but they do not share the warning with the passengers.

The SASMEX was triggered in both the main event and the Mw 6.8 aftershock that occurred on 22 September 2022. The main shock was registered on 26 stations of the system while the aftershock was registered at 35 seismic sensor stations and generated a Seismic Alert warning for Mexico City and other cities. Table 2.6 lists the warning times that were issued for different locations before the arrival of s-waves and the beginning of strong motion in both events. These warning times are long primarily because of the large distances between the epicenter and the listed locations but also because of a relatively fast algorithm that is used as soon as the earthquake is detected in recording stations near the epicenter.

Table 2.6. Warning times for different locations during the main event.

Location	Warning time (sec) on the Mw7.6 9/19/2022 event	Warning time (sec) on the Mw 6.8 9/22/2022 event
Morelia	58	56
Acapulco	84	76
Chipalcingo	88	80
Cuernavaca	94	87
Mexico City	98	92
Puebla	120	113
Oaxaca	159	151

2.4 Tsunami and Tsunami Warning

The earthquake triggered variations of the sea level along the Mexican Pacific coast causing a relatively small tsunami. The effects of these variations were observed as anomalous waves breaking on beaches and floods affecting portions of Manzanillo City, in the State of Colima. Tsunami wave observations from coastal and/or deep-ocean sea level gauges, reported by the Pacific Tsunami Warning Center (PTWC), determined a maximum tsunami height of 79 cm, measured with respect to the normal tide level, in the coast of Manzanillo, MX. Details of these measures are listed in Figure 2.12. The PTWC broadcasted tsunami warnings starting at 1:09 PM local time (Figure 2.13). Furthermore, the National Autonomous University of Mexico reported that the monitoring stations in the region near the earthquake, in the Mexican Pacific, recorded an increase in the sea level, as shown in Figure 2.14 and

Table 2.7. In particular, the Manzanillo station detected the maximum amplitude. Similarly, Figure 2.15 presents the geographical distribution of the stations of Vallarta, Manzanillo, Lázaro Cárdenas and Zihuatanejo recorded at sea level.

GAUGE LOCATION	GAUGE COORDINATES LAT	LON	TIME OF MEASURE (UTC)	MAXIMUM TSUNAMI HEIGHT	WAVE PERIOD (MIN)
SANTACRUZ GALAPAGOS	0.7S	90.3W	2307	0.12M/ 0.4FT	14
BALTRA GALAPAGS EC	0.4S	90.3W	2232	0.07M/ 0.2FT	12
LAZARO CARDENAS MX	17.9N	102.2W	2147	0.32M/ 1.0FT	14
ZIHUATANEJO MX	17.6N	101.6W	2121	0.53M/ 1.7FT	16
PUERTO VALLARTA MX	20.7N	105.2W	1820	0.21M/ 0.7FT	06
MANZANILLO MX	19.1N	104.3W	1924	0.79M/ 2.6FT	32
ACAPULCO MX	16.8N	99.9W	1907	0.13M/ 0.4FT	34

Figure 2.12. Tsunami observations reported by the Pacific Tsunami Warning Center, PTWC (2022b).

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 ZCZC
WEPA40 PHEB 191809
TSUPAC

TSUNAMI MESSAGE NUMBER 1
NWS PACIFIC TSUNAMI WARNING CENTER HONOLULU HI
1809 UTC MON SEP 19 2022

...PTWC TSUNAMI THREAT MESSAGE...


**** NOTICE **** NOTICE **** NOTICE **** NOTICE **** NOTICE *****

 THIS MESSAGE IS ISSUED FOR INFORMATION ONLY IN SUPPORT OF THE
 UNESCO/IOC PACIFIC TSUNAMI WARNING AND MITIGATION SYSTEM AND IS
 MEANT FOR NATIONAL AUTHORITIES IN EACH COUNTRY OF THAT SYSTEM.

 NATIONAL AUTHORITIES WILL DETERMINE THE APPROPRIATE LEVEL OF
 ALERT FOR EACH COUNTRY AND MAY ISSUE ADDITIONAL OR MORE REFINED
 INFORMATION.

**** NOTICE **** NOTICE **** NOTICE **** NOTICE **** NOTICE *****


PRELIMINARY EARTHQUAKE PARAMETERS
---------------------------------

  * MAGNITUDE      7.5
  * ORIGIN TIME    1805 UTC SEP 19 2022
  * COORDINATES    18.2 NORTH  103.4 WEST
  * DEPTH          10 KM / 6 MILES
  * LOCATION       NEAR THE COAST OF MICHOACAN  MEXICO


EVALUATION
----------

  * AN EARTHQUAKE WITH A PRELIMINARY MAGNITUDE OF 7.5 OCCURRED
    NEAR THE COAST OF MICHOACAN, MEXICO AT 1805 UTC ON MONDAY
    SEPTEMBER 19 2022.

  * BASED ON THE PRELIMINARY EARTHQUAKE PARAMETERS... HAZARDOUS
    TSUNAMI WAVES ARE POSSIBLE FOR COASTS LOCATED WITHIN 300 KM
    OF THE EARTHQUAKE EPICENTER.


TSUNAMI THREAT FORECAST
-----------------------

  * HAZARDOUS TSUNAMI WAVES FROM THIS EARTHQUAKE ARE POSSIBLE
    WITHIN 300 KM OF THE EPICENTER ALONG THE COASTS OF

      MEXICO.


RECOMMENDED ACTIONS
-------------------

  * GOVERNMENT AGENCIES RESPONSIBLE FOR THREATENED COASTAL AREAS
    SHOULD TAKE ACTION TO INFORM AND INSTRUCT ANY COASTAL
    POPULATIONS AT RISK IN ACCORDANCE WITH THEIR OWN
    EVALUATION... PROCEDURES AND THE LEVEL OF THREAT.
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  * PERSONS LOCATED IN THREATENED COASTAL AREAS SHOULD STAY ALERT
    FOR INFORMATION AND FOLLOW INSTRUCTIONS FROM NATIONAL AND
    LOCAL AUTHORITIES.


ESTIMATED TIMES OF ARRIVAL
--------------------------

  * ESTIMATED TIMES OF ARRIVAL -ETA- OF THE INITIAL TSUNAMI WAVE
    FOR PLACES WITH A POTENTIAL TSUNAMI THREAT. ACTUAL ARRIVAL
    TIMES MAY DIFFER AND THE INITIAL WAVE MAY NOT BE THE
    LARGEST. A TSUNAMI IS A SERIES OF WAVES AND THE TIME BETWEEN
    WAVES CAN BE FIVE MINUTES TO ONE HOUR.

    LOCATION          REGION              COORDINATES    ETA(UTC)
    ------------------------------------------------------------
    LAZARO CARDENAS  MEXICO              17.9N 102.2W   1827 09/19
    MANZANILLO       MEXICO              19.1N 104.3W   1827 09/19


POTENTIAL IMPACTS
-----------------

  * A TSUNAMI IS A SERIES OF WAVES. THE TIME BETWEEN WAVE CRESTS
    CAN VARY FROM 5 MINUTES TO AN HOUR. THE HAZARD MAY PERSIST
    FOR MANY HOURS OR LONGER AFTER THE INITIAL WAVE.

  * IMPACTS CAN VARY SIGNIFICANTLY FROM ONE SECTION OF COAST TO
    THE NEXT DUE TO LOCAL BATHYMETRY AND THE SHAPE AND ELEVATION
    OF THE SHORELINE.

  * IMPACTS CAN ALSO VARY DEPENDING UPON THE STATE OF THE TIDE AT
    THE TIME OF THE MAXIMUM TSUNAMI WAVES.

  * PERSONS CAUGHT IN THE WATER OF A TSUNAMI MAY DROWN... BE
    CRUSHED BY DEBRIS IN THE WATER... OR BE SWEPT OUT TO SEA.


NEXT UPDATE AND ADDITIONAL INFORMATION
--------------------------------------

  * THE NEXT MESSAGE WILL BE ISSUED IN ONE HOUR... OR SOONER IF
    THE SITUATION WARRANTS.

  * AUTHORITATIVE INFORMATION ABOUT THE EARTHQUAKE FROM THE U.S.
    GEOLOGICAL SURVEY CAN BE FOUND ON THE INTERNET AT
    EARTHQUAKE.USGS.GOV.

  * FURTHER INFORMATION ABOUT THIS EVENT MAY BE FOUND AT
    WWW.TSUNAMI.GOV.

  * COASTAL REGIONS OF HAWAII... AMERICAN SAMOA... GUAM... AND
    CNMI SHOULD REFER TO PACIFIC TSUNAMI WARNING CENTER MESSAGES
    SPECIFICALLY FOR THOSE PLACES THAT CAN BE FOUND AT
    WWW.TSUNAMI.GOV.

  * COASTAL REGIONS OF CALIFORNIA... OREGON... WASHINGTON...
    BRITISH COLUMBIA AND ALASKA SHOULD ONLY REFER TO U.S.
    NATIONAL TSUNAMI WARNING CENTER MESSAGES THAT CAN BE FOUND
    AT WWW.TSUNAMI.GOV.
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Figure 2.13. Tsunami warning from Pacific Tsunami Warning Center (PTWC, 2022a)

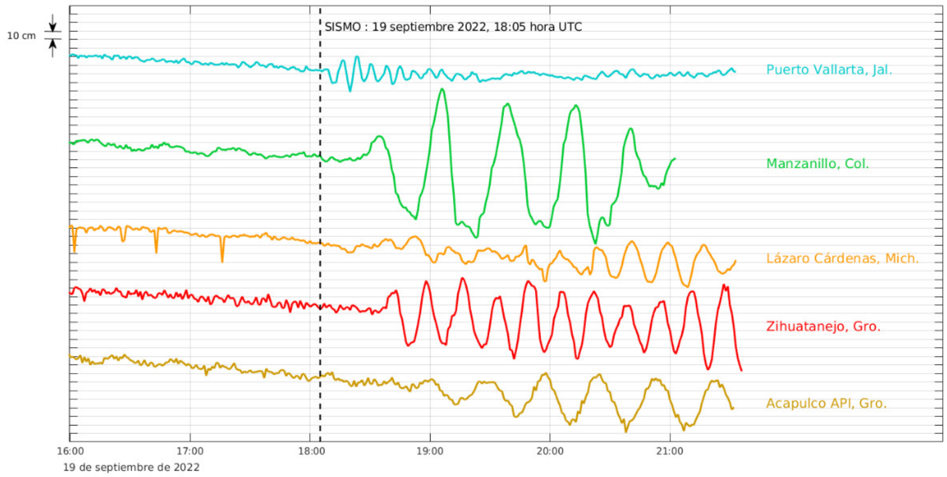
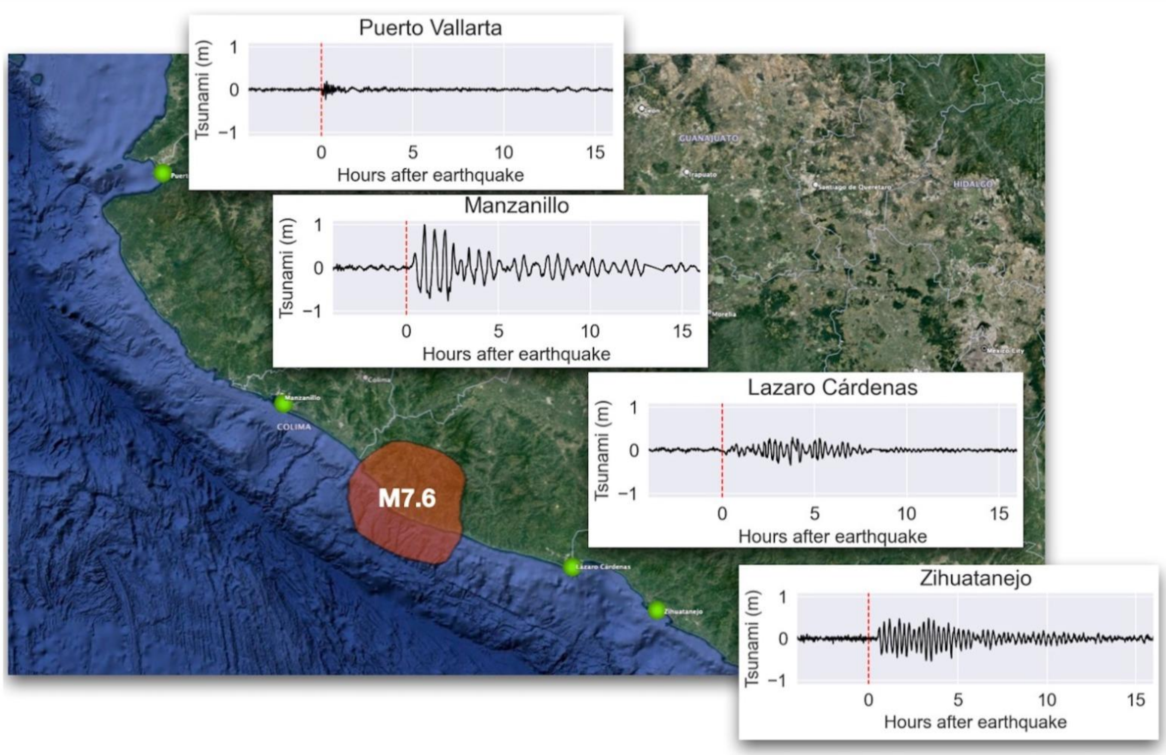


Figure 2.14. Records of the sea level in the stations of Vallarta, Manzanillo, Lázaro Cárdenas, Zihuatanejo and Acapulco. The arrival of the tsunami waves after the earthquake (indicated by a black dotted line) can be observed. (Twitter, 2022p)



Tsunami amplitudes recorded at four regional tide gauges operated by the Servicio Mareográfico Nacional.

Figure 2.15. Tsunami amplitudes at four stations (Gonzalez-Huizar et al., 2022).

Table 2.7. Maximum amplitudes with respect to the sea level in the stations of Vallarta, Manzanillo, Lázaro Cárdenas, Zihuatanejo and Acapulco, produced by the M7.6 earthquake of September 19, 2022 (Twitter, 2022q).

Station	Tsunami arrival time (central Mexico CDT)	Maximum recorded amplitude (m)	Maximum recorded amplitude time	Period (minutes)
Puerto Vallarta, Jalisco	19/09/2022 13:10	0.417	19/09/2022 13:20	10
Manzanillo, Colima	19/09/2022 13:26	1.749	19/09/2022 14:05	30
Lázaro Cárdenas, Michoacán	19/09/2022 13:15	0.425	19/09/2022 15:59	15
Zihuatanejo, Guerrero	19/09/2022 13:36	1.000	19/09/2022 14:42	15
Acapulco API, Guerrero	19/09/2022 13:48	0.635	19/09/2022 15:38	30

The first bulletin by the Tsunami Warning Center of the Mexican Secretary of the Navy was issued approximately at 1:32 pm local time. According to their bulletin, sea level variations were not expected due to the location of the epicenter (Twitter, 2022r). However, about 40 minutes later, they predicted anomalous variations of 82 centimeters in sea level in the region of earthquake generation, warning the population to stay away from the coastline, expecting strong currents at the entrance of ports (Twitter, 2022s). On the other hand, the Pacific Tsunami Warning Center, PTWC, issued their first report four minutes after the 7.6 earthquake, stating the possibility of hazardous tsunami waves for coastal areas located within 300 km of the earthquake epicenter. Further reports forecast waves reaching 1 to 3 meters above the tide level for some coasts of Mexico, and waves less than 0.3 meters above the tide level for other Pacific coasts. (PTWC, 2022a)

3 Recorded Ground Motions

In Mexico there are several seismic networks. The Institute of Geophysics and the Servicio Sismológico Nacional (SSN) of UNAM operates a national network of broadband instruments. The Instituto de Ingenieria at UNAM also operates a network of strong motion accelerographs. The M7.6 event was recorded by 20 stations of the accelerograph network of the Institute of Engineering at UNAM (RAII-UNAM). At the time of writing this report, response spectra values are available only for 13 stations, 9 of which are in Mexico City. At the time of this report, further information is being collected. Table 3.1 summarizes spectral acceleration intensities, including PGA, of three-component ground motions recorded by UIS (2022a). The geographical distribution of the geomean of the horizontal components for PGA and spectral acceleration at the 1 s period (Sa(T=1s)) are presented in Figure 3.1a and Figure 3.2a, respectively. Maximum values of PGA and Sa(T=1s) recorded during the earthquake were 0.16 and 0.18 g, respectively, recorded at the COMA station, located at a rupture distance of 55 km from the fault plane. Maximum recorded values in Mexico City were 0.043 and 0.089 g, recorded at the CMEN station at about 450 km of hypocentral distance (see Figure 3.3).

On Sept 22, 2022, an aftershock struck about 20 km to the south of the main shock. Table 3.2 summarizes spectral acceleration intensities, including PGA, of three-component ground motions provided by UIS (2022b) and recorded during the M6.8 Aftershock. The geographical distribution of the geomean of the horizontal components for PGA and spectral acceleration at the 1 s period (Sa(T=1s)) are presented in Figure 3.1b and Figure 3.2b, respectively for the M6.8 aftershock. The maximum values of PGA and Sa(T=1s) recorded during the M6.8 aftershock were 0.030 and 0.026 g, respectively, recorded at the COMA station. A comparison of the PGA values recorded for both main and aftershock is presented in Figure 3.4. It is noted that not all records were available. PGA values larger than 300 Gal were seen in ZIIG and MMIG stations.

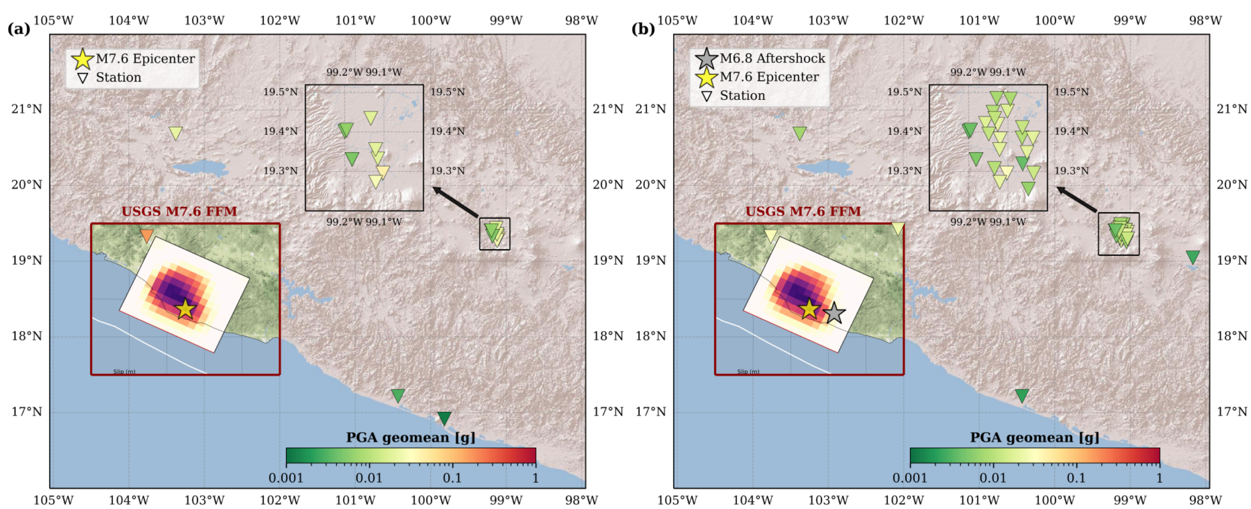


Figure 3.1. Geographical distribution of the geomean of PGA in the (a) M7.6 earthquake; (b) M6.8 aftershock.

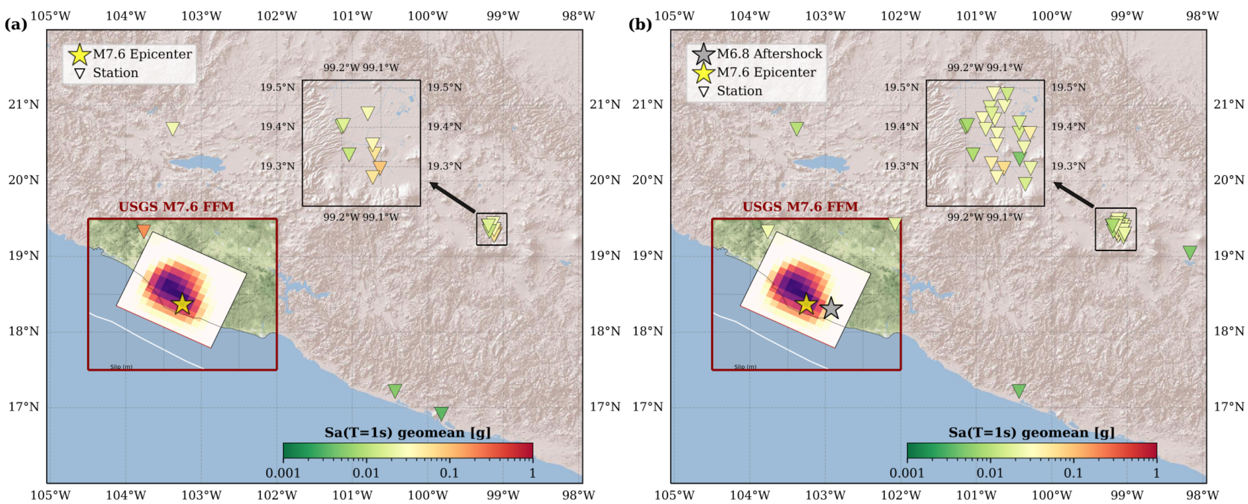


Figure 3.2. Geographical distribution of the geomean of 5%-damped 1s spectral accelerations, Sa(T=1s), in the (a) M7.6 earthquake; (b) M6.8 aftershock.

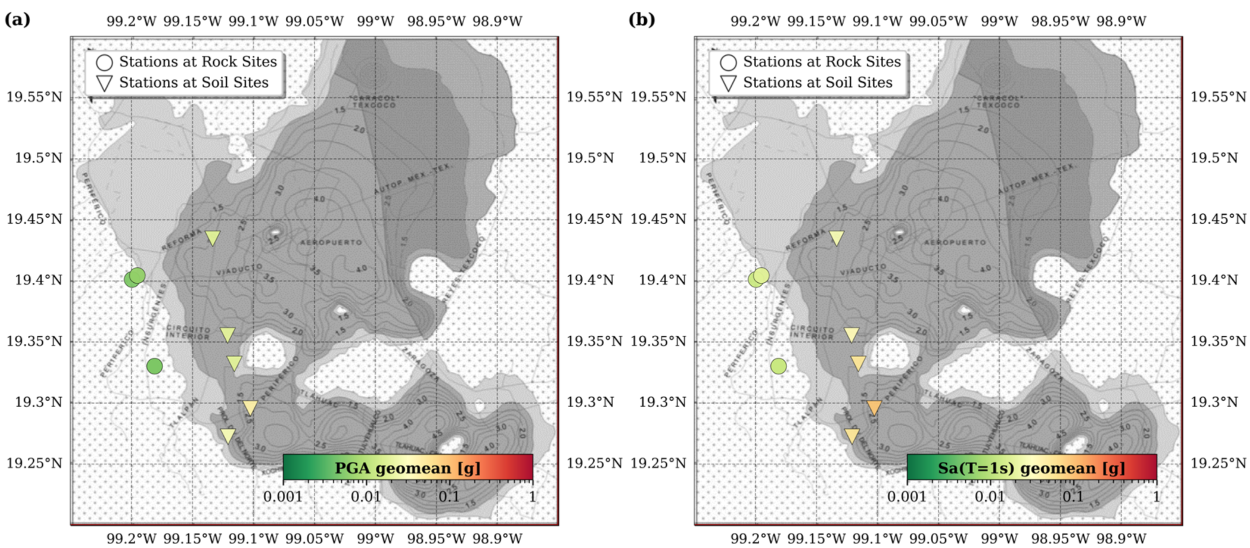


Figure 3.3. Geographical distribution of the stations within Mexico City that recorded the M7.6 earthquake (a) PGA geomean; (b) Sa(T=1s) geomean.

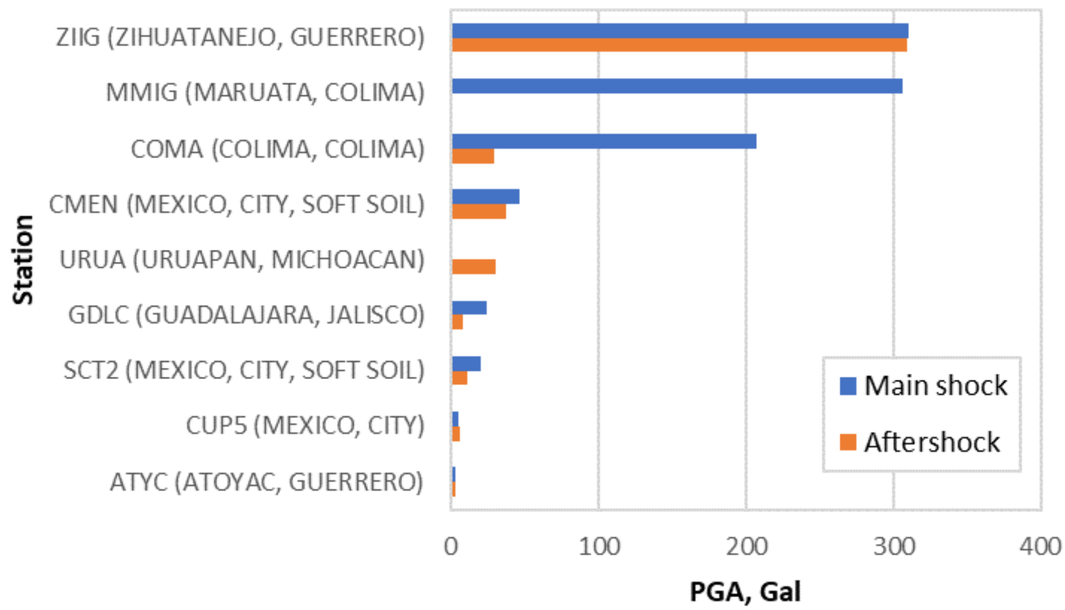


Figure 3.4. Comparison of PGAs in various stations in the main shock and in the aftershock.

Table 3.1. Recorded three-component ground motions during the M7.6 Earthquake (UIS, 2022a).

Station	Channel	PGA [g]	T=0.1s [g]	T=0.3s [g]	T=0.5 [g]	T=1s [g]	T=1.5s [g]	T=2s [g]	T=3s [g]	TA_{max} [s]	Sa_{max} [g]
COMA	ENZ	0.077	0.124	0.233	0.126	0.057	0.074	0.039	0.027	0.320	0.253
	ENN	0.119	0.290	0.430	0.216	0.221	0.085	0.081	0.041	0.400	0.491
	ENE	0.211	0.281	0.677	0.227	0.15	0.126	0.084	0.041	0.320	0.695
GDLC	ENZ	0.009	0.015	0.019	0.016	0.014	0.011	0.012	0.011	0.150	0.027
	ENN	0.018	0.020	0.035	0.057	0.026	0.016	0.013	0.012	0.660	0.066
	ENE	0.025	0.028	0.033	0.088	0.027	0.018	0.017	0.019	0.560	0.122
ATYC	ENZ	0.002	0.004	0.006	0.006	0.005	0.005	0.003	0.002	0.640	0.008
	ENN	0.003	0.005	0.007	0.008	0.005	0.004	0.004	0.001	0.540	0.009
	ENE	0.003	0.005	0.005	0.008	0.006	0.005	0.002	0.001	0.600	0.009
VNTA	HNZ	0.001	0.001	0.002	0.004	0.004	0.003	0.002	0.001	1.000	0.004
	HNN	0.001	0.002	0.003	0.003	0.004	0.003	0.002	0.001	1.200	0.004
	HNE	0.001	0.001	0.002	0.003	0.004	0.002	0.002	0.001	0.880	0.006
CUP5	ENZ	0.003	0.003	0.004	0.006	0.008	0.008	0.009	0.005	1.800	0.012
	ENN	0.006	0.006	0.010	0.012	0.011	0.018	0.018	0.009	2.400	0.022
	ENE	0.005	0.005	0.007	0.009	0.014	0.015	0.014	0.007	1.500	0.015
CMCU	HNZ	0.003	0.003	0.004	0.006	0.008	0.008	0.010	0.005	1.800	0.012
	HNN	0.006	0.006	0.010	0.012	0.012	0.017	0.018	0.008	2.400	0.022
	HNE	0.005	0.005	0.007	0.009	0.015	0.015	0.014	0.007	1.500	0.015
CMBM	HNZ	0.003	0.003	0.005	0.007	0.011	0.006	0.008	0.006	0.980	0.011
	HNN	0.005	0.005	0.008	0.011	0.013	0.016	0.012	0.007	1.500	0.016
	HNW	0.005	0.005	0.008	0.010	0.014	0.010	0.010	0.005	0.980	0.014
TACY	HNZ	0.003	0.003	0.004	0.006	0.010	0.006	0.009	0.005	2.200	0.011
	HNN	0.007	0.007	0.008	0.013	0.017	0.013	0.015	0.007	0.960	0.017
	HNE	0.006	0.006	0.008	0.011	0.021	0.011	0.009	0.006	1.000	0.021
CMP1	HNZ	0.006	0.007	0.009	0.014	0.011	0.020	0.016	0.007	0.600	0.021
	HNN	0.018	0.019	0.024	0.032	0.036	0.073	0.079	0.018	1.600	0.105
	HNE	0.043	0.043	0.046	0.047	0.081	0.184	0.124	0.025	1.600	0.222
CMMG	HNZ	0.003	0.003	0.004	0.006	0.008	0.008	0.005	0.006	0.440	0.011
	HNN	0.021	0.021	0.023	0.029	0.065	0.064	0.028	0.009	1.200	0.126
	HNE	0.017	0.018	0.020	0.022	0.043	0.085	0.026	0.013	1.400	0.107
CMRC	HNZ	0.005	0.007	0.009	0.013	0.012	0.011	0.014	0.005	1.800	0.017
	HNN	0.017	0.017	0.018	0.029	0.029	0.095	0.057	0.016	1.600	0.110
	HNE	0.023	0.023	0.023	0.024	0.044	0.101	0.072	0.019	1.600	0.119
CMEN	HNZ	0.009	0.010	0.010	0.017	0.033	0.017	0.018	0.009	1.000	0.033
	HNN	0.047	0.048	0.049	0.051	0.096	0.101	0.178	0.104	2.600	0.257
	HNE	0.04	0.041	0.042	0.046	0.083	0.083	0.131	0.081	2.400	0.255
CTCL	HNZ	0.006	0.006	0.008	0.014	0.010	0.010	0.009	0.005	0.500	0.014
	HNN	0.016	0.016	0.016	0.019	0.023	0.049	0.055	0.031	2.400	0.069
	HNE	0.022	0.022	0.024	0.026	0.032	0.057	0.099	0.029	2.000	0.099

Table 3.2. Recorded three-component ground motions during the M6.8 Aftershock (UIS, 2022b).

Station	Channel	PGA [g]	T=0.1s [g]	T=0.3s [g]	T=0.5 [g]	T=1s [g]	T=1.5s [g]	T=2s [g]	T=3s [g]	TA_{max}[s]	Sa_{max} [g]
COMA	ENZ	0.011	0.020	0.036	0.025	0.022	0.010	0.014	0.006	0.320	0.040
	ENN	0.029	0.044	0.118	0.079	0.026	0.020	0.021	0.011	0.260	0.127
	ENE	0.030	0.055	0.106	0.073	0.027	0.018	0.033	0.013	0.260	0.109
URUA	ENZ	0.010	0.015	0.028	0.025	0.024	0.014	0.005	0.003	0.940	0.029
	ENE	0.031	0.038	0.158	0.071	0.024	0.015	0.007	0.004	0.300	0.158
	ENN	0.019	0.024	0.096	0.063	0.019	0.015	0.006	0.003	0.280	0.098
GDLC	ENZ	0.004	0.005	0.010	0.006	0.005	0.004	0.006	0.006	0.220	0.010
	ENN	0.007	0.009	0.015	0.024	0.012	0.006	0.007	0.003	0.640	0.032
	ENE	0.008	0.010	0.012	0.027	0.009	0.011	0.008	0.003	0.560	0.033
ATYC	ENZ	0.003	0.003	0.007	0.009	0.004	0.006	0.003	0.001	0.480	0.011
	ENN	0.002	0.003	0.007	0.006	0.005	0.003	0.001	0.001	0.580	0.007
	ENE	0.002	0.004	0.006	0.007	0.004	0.004	0.001	0.001	0.760	0.007
CUP5	ENZ	0.003	0.003	0.003	0.004	0.007	0.006	0.006	0.008	2.800	0.008
	ENN	0.007	0.007	0.008	0.011	0.009	0.016	0.018	0.007	1.800	0.023
	ENE	0.004	0.004	0.006	0.006	0.010	0.011	0.012	0.009	1.800	0.015
CMCU	HNZ	0.003	0.003	0.003	0.004	0.007	0.006	0.006	0.008	2.800	0.008
	HNN	0.006	0.007	0.008	0.011	0.009	0.015	0.018	0.007	1.800	0.023
	HNE	0.004	0.004	0.006	0.006	0.010	0.011	0.012	0.010	1.800	0.015
TACY	HNZ	0.002	0.002	0.004	0.004	0.004	0.006	0.005	0.006	2.200	0.008
	HNE	0.004	0.005	0.007	0.006	0.006	0.006	0.007	0.010	3.000	0.010
	HNN	0.004	0.004	0.007	0.009	0.012	0.011	0.009	0.006	0.840	0.015
CMBM	HNZ	0.003	0.003	0.004	0.005	0.003	0.005	0.005	0.007	2.800	0.008
	HNN	0.004	0.004	0.005	0.008	0.010	0.014	0.008	0.006	1.500	0.014
	HNW	0.004	0.004	0.005	0.007	0.007	0.005	0.009	0.009	0.680	0.011
CMP5	HNZ	0.003	0.003	0.004	0.006	0.005	0.005	0.006	0.007	0.620	0.008
	HNE	0.012	0.012	0.014	0.022	0.040	0.023	0.022	0.026	0.880	0.055
	HNN	0.009	0.009	0.011	0.016	0.043	0.022	0.015	0.011	0.980	0.044
CMP1	HNZ	0.005	0.006	0.008	0.015	0.009	0.013	0.014	0.013	2.400	0.017
	HNN	0.017	0.019	0.021	0.025	0.026	0.053	0.070	0.033	1.800	0.092
	HNE	0.026	0.026	0.027	0.037	0.046	0.145	0.080	0.045	1.600	0.151
SCT2	HNZ	0.004	0.005	0.006	0.010	0.007	0.007	0.007	0.007	0.560	0.019
	HNN	0.012	0.012	0.013	0.016	0.027	0.044	0.039	0.015	1.800	0.056
	HNE	0.012	0.012	0.013	0.018	0.022	0.063	0.044	0.032	1.600	0.081
CMCL	HNZ	0.004	0.005	0.006	0.009	0.008	0.007	0.009	0.006	0.700	0.019
	HNE	0.021	0.021	0.021	0.023	0.032	0.064	0.056	0.036	1.600	0.077
	HNN	0.016	0.016	0.017	0.019	0.033	0.059	0.103	0.019	2.000	0.103
CMEN	HNZ	0.008	0.008	0.008	0.015	0.019	0.012	0.021	0.020	2.600	0.029
	HNN	0.029	0.029	0.031	0.030	0.057	0.045	0.097	0.087	2.600	0.122
	HNE	0.038	0.038	0.039	0.048	0.074	0.066	0.115	0.145	2.600	0.231

Station	Channel	PGA [g]	T=0.1s [g]	T=0.3s [g]	T=0.5 [g]	T=1s [g]	T=1.5s [g]	T=2s [g]	T=3s [g]	TA_{max}[s]	Sa_{max} [g]
CMRC	HNZ	0.003	0.003	0.006	0.014	0.006	0.010	0.010	0.004	0.520	0.016
	HNE	0.022	0.023	0.025	0.028	0.041	0.155	0.053	0.032	1.500	0.155
	HNN	0.017	0.017	0.018	0.030	0.029	0.101	0.039	0.016	1.600	0.108
CMRA	HNZ	0.003	0.004	0.004	0.006	0.007	0.007	0.010	0.007	2.200	0.011
	HNE	0.024	0.024	0.026	0.030	0.031	0.039	0.068	0.087	2.800	0.093
	HNN	0.021	0.021	0.021	0.027	0.028	0.045	0.056	0.057	2.600	0.123
CTCL	HNZ	0.003	0.003	0.005	0.009	0.006	0.008	0.008	0.008	0.420	0.012
	HNN	0.010	0.010	0.010	0.014	0.018	0.047	0.040	0.018	2.200	0.049
	HNE	0.014	0.014	0.016	0.018	0.019	0.036	0.038	0.048	1.800	0.053
CMP7	HNZ	0.006	0.006	0.006	0.008	0.009	0.011	0.010	0.011	0.860	0.015
	HNE	0.023	0.023	0.024	0.029	0.028	0.057	0.073	0.077	2.400	0.093
	HNN	0.019	0.020	0.021	0.026	0.027	0.070	0.061	0.034	1.500	0.070
CMCT	HNZ	0.004	0.004	0.005	0.011	0.008	0.010	0.009	0.005	2.400	0.013
	HNE	0.010	0.010	0.014	0.013	0.020	0.031	0.029	0.032	1.400	0.040
	HNN	0.010	0.010	0.011	0.013	0.022	0.033	0.029	0.015	1.600	0.037
CMP9	HNZ	0.002	0.003	0.004	0.006	0.005	0.005	0.004	0.003	0.680	0.011
	HNN	0.008	0.008	0.009	0.011	0.034	0.037	0.020	0.012	1.500	0.037
	HNE	0.008	0.009	0.009	0.012	0.026	0.023	0.020	0.009	0.920	0.029
CMSG	HNZ	0.004	0.004	0.005	0.007	0.009	0.016	0.021	0.018	2.000	0.021
	HNN	0.006	0.006	0.008	0.009	0.015	0.011	0.018	0.017	2.400	0.019
	HNE	0.007	0.007	0.009	0.011	0.017	0.015	0.019	0.024	2.800	0.025
CMJR	HNZ	0.004	0.004	0.004	0.005	0.006	0.011	0.013	0.011	2.600	0.016
	HNN	0.003	0.003	0.005	0.005	0.005	0.009	0.009	0.008	1.600	0.012
	HNE	0.005	0.005	0.006	0.006	0.005	0.009	0.015	0.014	2.000	0.015
CMJC	HNZ	0.003	0.003	0.003	0.006	0.011	0.007	0.008	0.004	1.000	0.011
	HNN	0.018	0.018	0.020	0.021	0.027	0.037	0.063	0.058	2.200	0.069
	HNE	0.017	0.018	0.018	0.021	0.028	0.040	0.054	0.059	2.200	0.074
CMTD	HNZ	0.008	0.008	0.010	0.017	0.022	0.017	0.020	0.012	2.600	0.026
	HNE	0.014	0.014	0.019	0.017	0.023	0.034	0.055	0.033	2.000	0.055
	HNN	0.013	0.013	0.014	0.017	0.024	0.035	0.045	0.028	1.800	0.048
CMP3	HNZ	0.002	0.003	0.004	0.006	0.004	0.003	0.004	0.003	0.640	0.011
	HNN	0.007	0.008	0.008	0.010	0.015	0.029	0.033	0.011	1.800	0.035
	HNE	0.009	0.009	0.010	0.014	0.014	0.025	0.037	0.014	2.400	0.039
CM55	HNZ	0.003	0.003	0.004	0.005	0.007	0.008	0.007	0.012	2.800	0.015
	HNN	0.010	0.010	0.010	0.012	0.014	0.020	0.021	0.042	4.000	0.043
	HNE	0.009	0.009	0.010	0.012	0.018	0.021	0.022	0.031	1.200	0.049
CMRM	HNZ	0.007	0.007	0.009	0.012	0.020	0.014	0.023	0.019	2.400	0.025
	HNN	0.025	0.025	0.026	0.026	0.032	0.039	0.075	0.078	2.400	0.119
	HNE	0.016	0.016	0.018	0.023	0.021	0.033	0.062	0.068	2.600	0.073
CMPR	HNZ	0.004	0.004	0.004	0.007	0.009	0.012	0.007	0.007	1.200	0.018
	HNN	0.012	0.012	0.014	0.018	0.018	0.031	0.033	0.042	2.200	0.055
	HNE	0.013	0.013	0.013	0.019	0.020	0.036	0.039	0.045	3.000	0.045

Station	Channel	PGA [g]	T=0.1s [g]	T=0.3s [g]	T=0.5 [g]	T=1s [g]	T=1.5s [g]	T=2s [g]	T=3s [g]	TA_{max}[s]	Sa_{max} [g]
CMFZ	HNZ	0.009	0.009	0.010	0.012	0.012	0.019	0.019	0.016	2.400	0.024
	HNE	0.018	0.018	0.019	0.025	0.043	0.041	0.042	0.076	3.000	0.076
	HNN	0.022	0.022	0.026	0.026	0.041	0.070	0.030	0.060	1.400	0.087
PHPU	ENZ	0.001	0.001	0.003	0.004	0.002	0.004	0.004	0.002	0.600	0.007
	ENN	0.003	0.003	0.005	0.010	0.006	0.007	0.008	0.002	0.600	0.015
	ENE	0.002	0.002	0.003	0.008	0.004	0.007	0.004	0.001	0.560	0.008
OXBJ	ENZ	0.000	0.001	0.001	0.001	0.001	0.002	0.001	0.001	1.200	0.002
	ENE	0.001	0.001	0.001	0.001	0.001	0.001	0.003	0.001	2.000	0.003
	ENN	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.002	2.200	0.002

3.1 Comparison with ground motion models

The recorded ground motion intensities were compared against the predictions of two ground motion prediction models (GMPMs) for PGA (Figure 3.5a and Figure 3.5b) and Sa(T=1s) (Figure 3.5c and Figure 3.5d).The comparisons are made with respect to a local model developed by Arroyo et al. (2010) for rock sites in Figure 3.5a and Figure 3.5c., and for the geometric mean of the KBCG (Kuehn et al., 2020) and PSHAB (Parker et al., 2021) NGA-Subduction GMPMs in Figure 3.5b and Figure 3.5d. The selected models used different definitions of the horizontal component of the pseudo-acceleration spectral ordinates (PSA), both KBCG and PSHAB GMPMS estimates RotD50 PSA while Arroyo et al. (2010) estimate the random (sometimes also referred to as arbitrary) horizontal component PSA. Hence, for each station both as-recorded horizontal components are compared against the Arroyo et al. (2010) estimates. On the other hand, the geomean of the as-recorded horizontal components is compared against the NGA-Sub models as a proxy to RotD50, because at the time of this writing the acceleration records were not available. Note that intensities at soil sites in Mexico City are significantly higher than those recorded at rock sites in Mexico City due to large site effects that occur there. All the PGAs recorded outside Mexico City fall in the 16/84th percentiles of the Arroyo et al. (2010) model whilst the model presents a slightly lower performance for T=1s. Regarding the stations located in Mexico the recorded ground motions at rock sites for T=1s, are in the 50 to 84th percentiles of the Arroyo et al (2010) estimates. The remaining recorded ground motions in Mexico City (i.e., PGA and soil sites at T=1s) are above the 84th percentiles of the Arroyo et al (2010) estimates. All the recorded PGA values at soil sites in Mexico City are higher than the 84^{th} percentile of the NGA-Sub GMPMs estimations, while for Sa(T=1s) half of those stations lies in the 50-84th percentile of the NGA-Sub GMPMs estimations for soils. Regarding the stations located at rock sites in Mexico for PGA the recorded values are in 50-84th percentile of the NGA-Sub GMPMs estimations for rocks, whilst for Sa(T=1s) there is one station above the 84th percentile of GMPMs estimates. Lastly, there is also a fairly good agreement between the recorded intensities and the NGA-Sub GMPMs estimates.

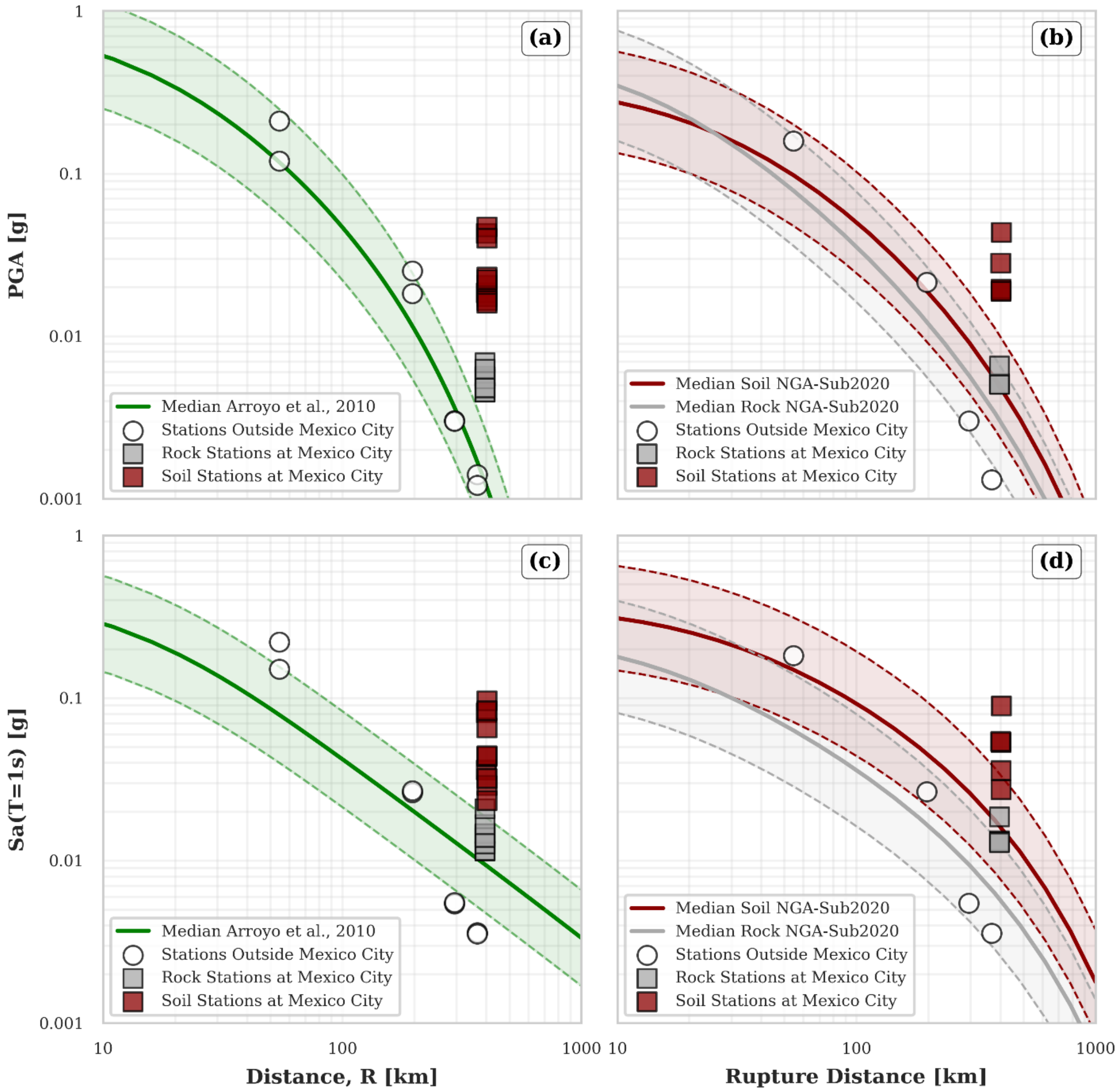


Figure 3.5. Comparison of pseudo-acceleration data computed from recorded accelerations with estimates of Arroyo et al. (2010) and NGA-Sub GMMs. Shaded regions represent the 16/84th percentiles of the GMMs.

4 "Did you feel it?" Reports

Did You Feel It? (DYFI), is a system developed by the USGS that allows people who felt the earthquake to report it. It helps describe people's experience during and after the event, which may be correlated with a distribution of intensities or damage (USGS, 2022b). The DYFI Map and related products by the USGS are created within minutes of each earthquake of magnitude 1.9 or greater. The origin information (location and time) of each earthquake is provided by the Advanced National Seismic System (ANSS) and its regional and national network partners in the U.S.

For this event, the DYFI survey available on the USGS website had over 600 responses within the first hour after the earthquake. The evolution over time of these responses is shown in Figure 4.1. It can be seen from the figure that the number of responses reached about 1000 responses after eight hours. It is worth noting that not many people know about USGS's DYFI in Mexico and most of those aware of it are typically located in the capital, Mexico City.

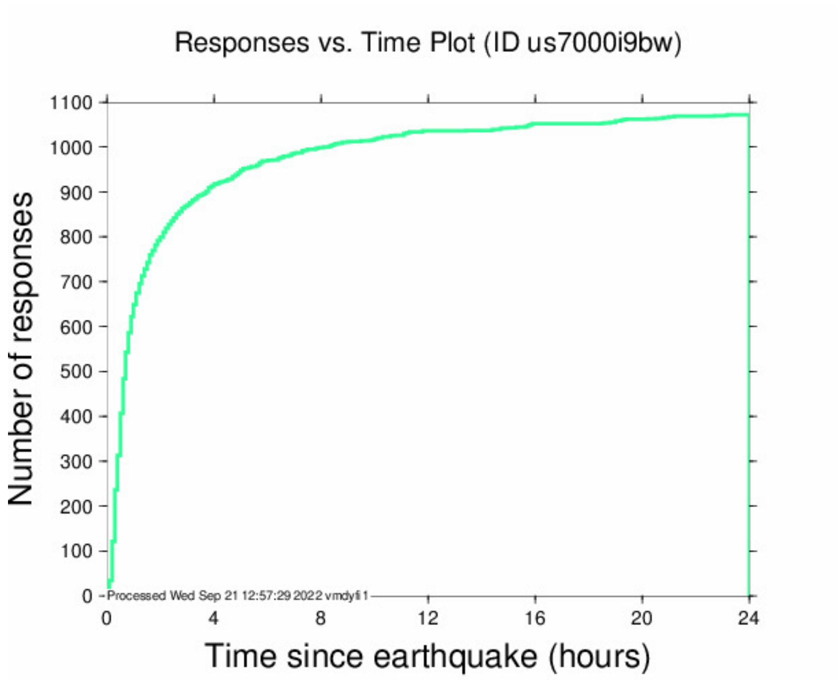
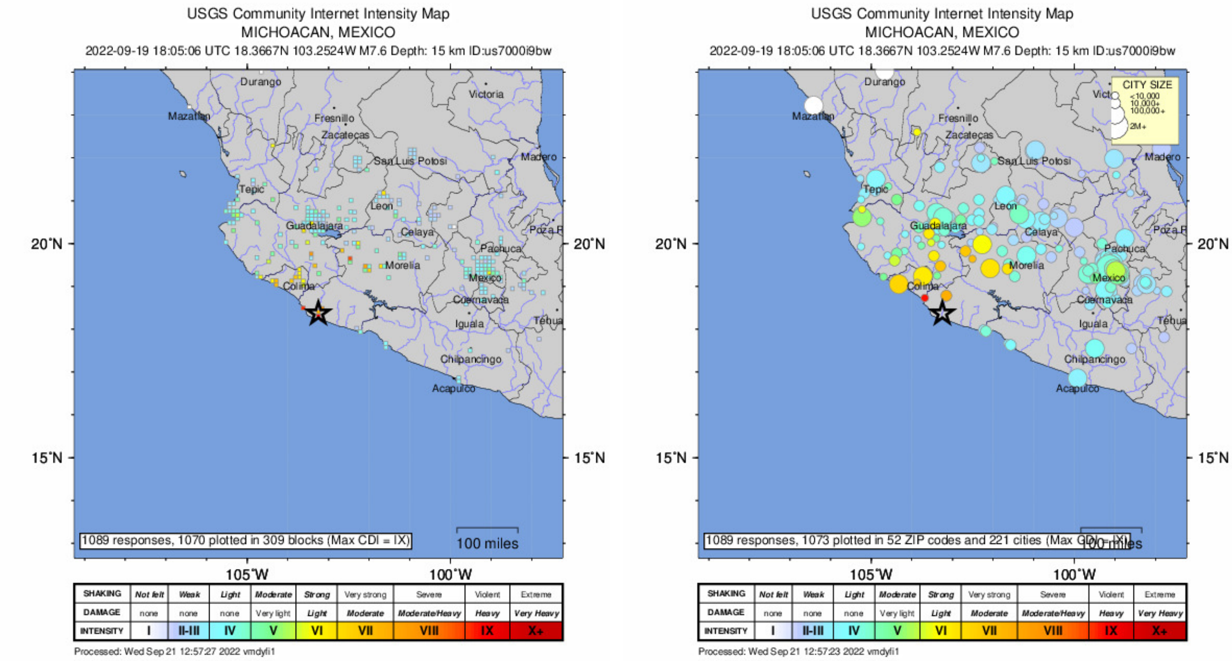


Figure 4.1. "Did you feel it?" (DYFI) responses collected by the USGS up to 9/21 (USGS, 2022b).

A map of intensities inferred from DYFI responses and the spatial variation of intensity for the Mw 7.6 earthquake is plotted in Figure 4.2. The highest intensity levels range from VIII to IX of the Modified Mercalli Intensity (MMI) scale, close to the epicenter (e.g., Colima). These large intensities are consistent with the observed damage in the epicentral zone. The attenuation of intensity with distance shows levels VII, VI, and IV close to Guadalajara.

The attenuation of intensity with increasing hypocentral distance shows large dispersion and can be found in Figure 4.3.



(a) (b)

Figure 4.2. (a) Geocoded location and (b) City map of Intensities inferred from DYFI responses (USGS, 2022b).

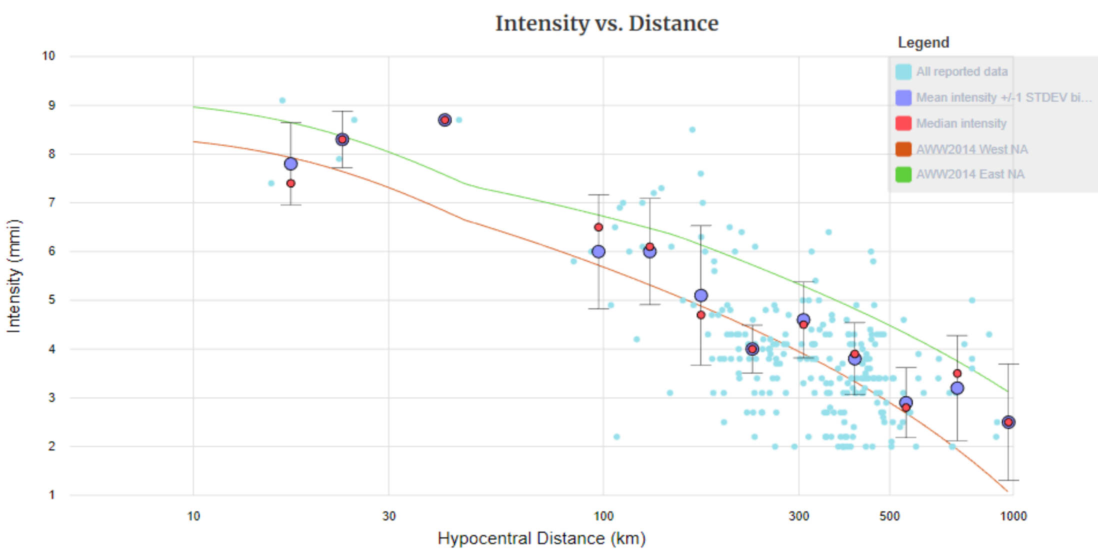


Figure 4.3. Attenuation of earthquake intensity with increasing hypocentral distance compared with empirical relationships (USGS, 2022b).

5 Local Codes and Construction Practices

Seismic design codes have existed in Mexico for more than 80 years. The first Mexican code for structural design was issued in 1920, but the first to include seismic loading was the 1942 Mexico City code. Some of the country's more recent versions of seismic provisions originated in the first seismic maps based on probabilistic hazard analyses by professors Luis Esteva and Emilio Rosenblueth in the late sixties (Esteva and Rosenblueth, 1972). However, most efforts to develop and improve the Mexican building codes have primarily been focused on Mexico City. The Mexico City Building Code has included several important innovations over the years, such as the first code with a seismic microzonation (since 1957), modal combination rules accounting for modal correlation, simplified rules for bidirectional loading, period-dependent reduction factors, use of response history analyses as an analysis method, etc. For example, many of these innovations at the time were implemented in the Mexico City code soon after the publication of the ATC 3-06 report (ATC, 1978) in the United States and before their adoption in U.S. seismic codes. Thus, the Mexico City Building Code (MCBC) for seismic design of buildings is often used as a model code for the drafting of most of the municipal codes in the country, which, by law, are of the municipal (county) competence (Ordaz and Meli, 2004). For a summary of the innovations introduced in the 1976 code, the reader is referred to Rosenblueth (1979). For excellent summaries of changes in seismic codes and practice in Mexico after the great 1985 earthquake, the reader is referred to Esteva (1987, 1988). On average, the MCBC has been updated every 13 years; modifications have typically occurred after significant events.

Some Federal government agencies have issued standards and manuals to be used within their projects. The best example is the Manual of Civil Structures, MOC, of the Federal Electrical Commission, first published in 1969, also known as MOC-CFE. The MOC-CFE is a comprehensive document that includes analysis and design provisions of several structures (buildings, bridges, dams, power stations, industrial facilities, etc.) for hazards such as earthquakes and wind. Its use is mandatory only for designing structures owned or operated by the Comisión Federal de Electricidad (Federal Electrical Commission). Still, it often serves as a model design code in Mexico (Tena-Colunga et al., 2009). For states, counties, or cities without a seismic code, two common alternatives are to use the MOC-CFE or use the seismic hazard maps included in MOC-CFE combined with the Mexico City code design criteria. The evolution of seismic codes in Mexico is also available in Ordaz et al. (2004) and Alcocer et al. (2008).

Similar to other developing countries, there is a significant amount of construction, primarily in rural areas but also within urban areas that do not comply with any code requirement and are mainly self-construction. This self-construction is commonly used in low-income one and two-story residential housing. Unreinforced masonry (URM) is frequently used for this type of construction in urban areas, but adobe construction is still used in some rural areas.

Since its first edition in 1969, the MDOF-CFE has been updated and improved in 1981, 1993, 2008, and 2015. Figure 5.1 shows the seismic zonation of Mexico in the 1993 version of this document, in which the country was divided into four seismic zones from A (low seismic hazard) to D (highest seismic hazard). The epicenter of the September 19, 2022, event falls within zone D, with the highest hazard level.

Figure 5.1. Seismic zonation of Mexico according to the 1993 edition of the Manual for Civil Works of the Federal Commission Electricity (MOC-CFE, 1993).

The 2015 edition of the MOC-CFE seismic guidelines provide design spectra for any location within Mexico and considers three soil types according to a combination of the shear wave velocities and thicknesses of soil deposits at the site. In this classification, site class I corresponds to stiffer and shallower soil, whereas site class III corresponds to deeper and softer soils. In this version of the MOC-CFE, the software tool PRODISIS, shown in **Error! Reference source not found.**, is used to obtain the seismic design spectra similarly to recent USGS tools.

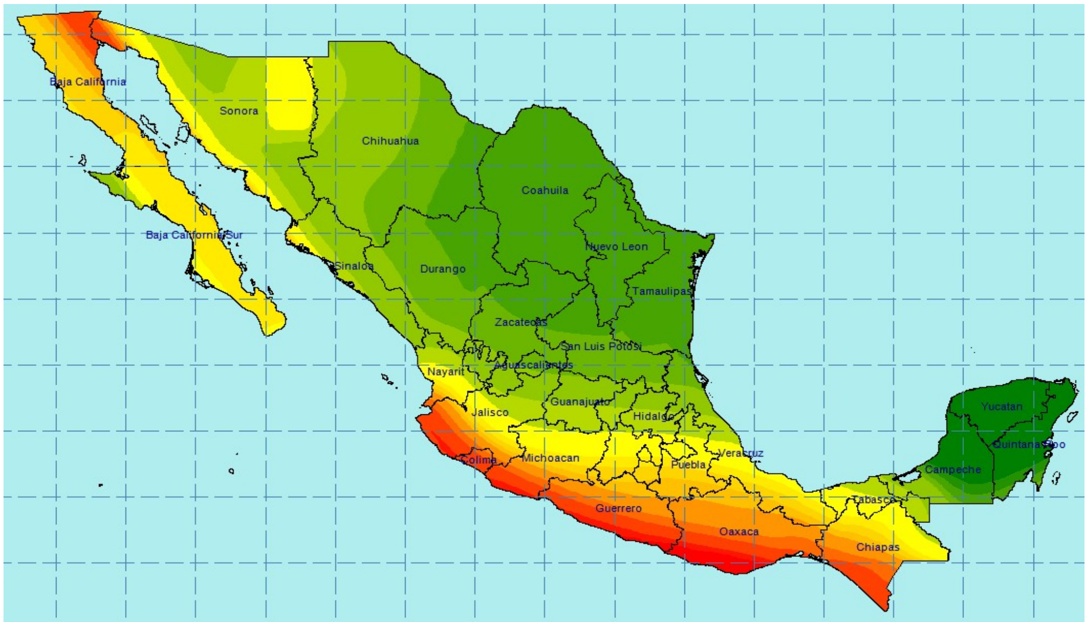


Figure 5.2. Seismic hazard map to compute the seismic design spectra according to the 2015 edition of the Manual for Civil Works of the Federal Commission Electricity (MOC-CFE) obtained from software PRODISIS V4.1.

Figure 5.3 presents the design spectra for the two soil classes (I and III) of the MOC-CFE 2015 standard in the cities of Coalcomán de Vázquez, Lázaro Cárdenas, Manzanillo, Guadalajara and Morelia, located approximately 60 km, 120 km, 140 km, 260 km, and 270 km, respectively, from the epicenter.

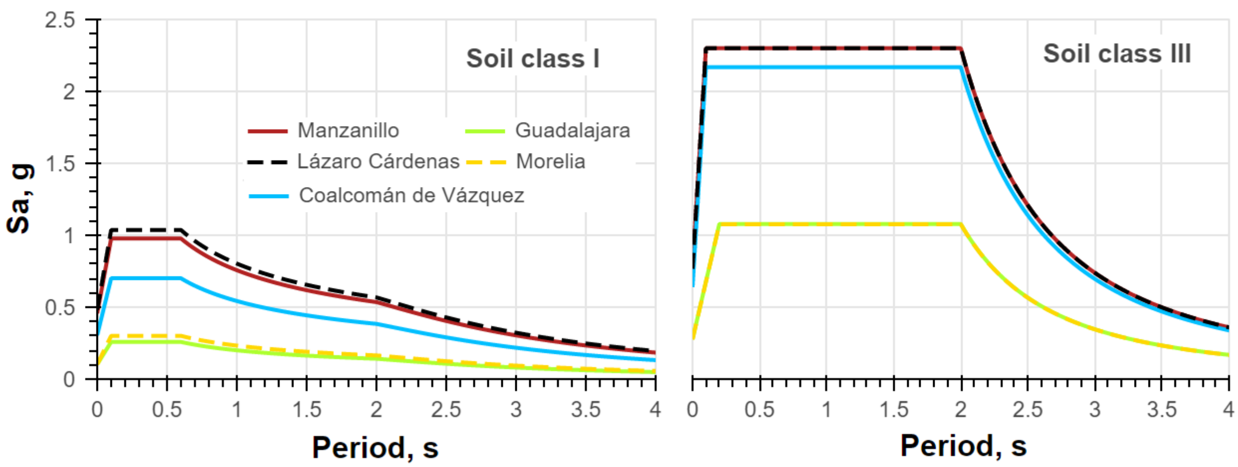


Figure 5.3. Elastic design spectrum for soil classes I and III for the cities of Manzanillo, Guadalajara, Coalcomán de Vázquez, Lázaro Cárdenas, and Morelia according to MDC CFE 2015.

Figure 5.4 compares the design spectra for soil class I, with the response spectra of both horizontal components recorded at COMA station in the city of Comala, located 132 km from the epicenter of the 09/19/22 earthquake (UIS, 2022a). Particular values of the response spectra for both 09/19/22 and 09/22/22 events were reported by the *Unidad de Instrumentación Sísmica* reports (UIS, 2022b), which include spectral accelerations at periods of 0.1 s, 0.3 s, 0.5 s, 1.0 s, 1.5 s, 2.0 s and 3.0 s and maximum values of Sa (see Table 3.1 and Table 3.2). In Figure 5.4, ENE and ENN correspond to the west-east and north-south components of the records. Figure 5.4 shows that the ENE component of the 09/19/22 event slightly overpassed the design spectra. Table 5.1 summarizes the recorded PGAs at the COMA station for both events.

Table 5.1. PGAs recorded in COMA station for both events (UIS, 2022a and 2022b).

Event	Magnitude	Epicentral distance, km	PGA, g
09/19/22	7.7	132	0.211
09/22/22	6.9	157	0.030

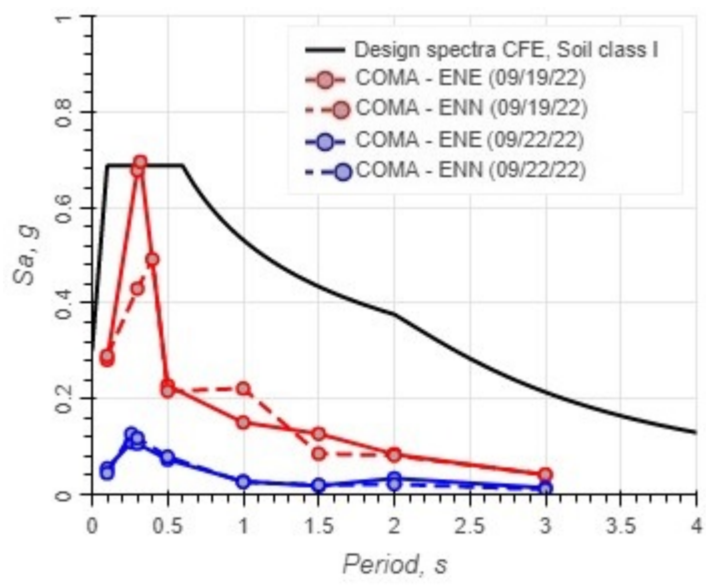


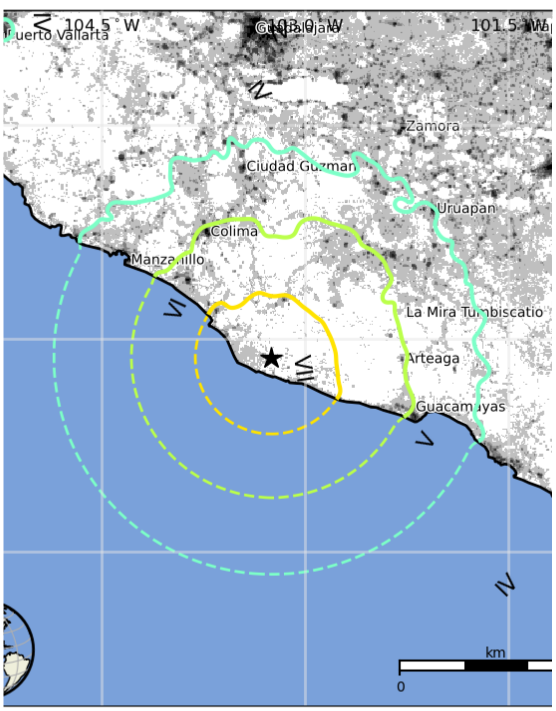
Figure 5.4. Comparison of response spectra computed from recorded horizontal accelerations at COMA station in the City of Comala to the elastic design spectra for soil class I according to MDOC CFE 2015.

6 Impacts

6.1 Estimated Population Exposed

PAGER (Prompt Assessment of Global Earthquakes for Response) is a product of the USGS that produces automatic reports on estimates of the possible impacts of large earthquakes by combining information from the spatial distribution of population and isoseismals of Modified Mercalli intensity (MMI) estimated by ShakeMap. This section discusses the population exposure.

Figure 6.1 shows the isoseismals estimated for the Mw 7.6 earthquake, and Figure 6.2 shows the number of people exposed to each shaking intensity in selected cities. These figures illustrate that 13.6 million people (83% of the total population exposed) were subjected to an MMI lower or equal to IV. Of this population, 1.64M were in Guadalajara and nearly 1M in Zapopan. Two million people experienced a moderate intensity (V), highlighting Ciudad Guzmán among the cities exposed to this MMI. Colima is the city with the highest population exposed to a strong (VI) shaking in the MMI, with over 127000 people exposed, with three killed people and several hundred injured recorded at the time of writing this report.



MMI	Shaking	Population
I	Not Felt	0 k*
II-III	Weak	112 k*
IV	Light	13,566 k*
V	Moderate	1,996 k
VI	Strong	755 k
VII	Very Strong	66 k
VIII	Severe	0 k
IX	Violent	0 k
X	Extreme	0 k

*Estimated exposure only includes population within map area (k = x1,000)

Modified Mercalli Intensity (MMI) scale

Figure 6.1. Isoseismals (curves of equal MMI) estimated for the Mw 7.6 earthquake (USGS, 2022a).

MMI	City	Population
VII	Coalcoman de Vazquez Pallares	11 k
VII	Aguililla	9 k
VII	Coahuayana Viejo	7 k
VI	Ixtlahuacan	0 k
VI	Los Tepames	2 k
VI	Bonifacio Moreno (El Aguaje)	2 k
VI	Colima	127 k
IV	Zapopan	988 k
IV	Guadalajara	1,641 k
IV	Morelia	593 k
IV	Tlaquepaque	494 k

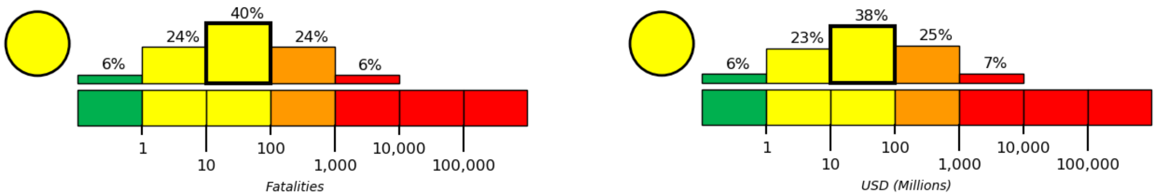
From GeoNames Database of Cities with 1,000 or more residents (k = x1,000)

Figure 6.2. The number of people exposed to different ground shaking intensities (MMI) in selected cities resulted from the earthquake (USGS, 2022a).

6.2 Estimated Loss of Life and Injures

PAGER produces rough estimates of the probability density functions of the number of fatalities and economic losses in U.S. dollars. More specifically, these approximate probability density functions provide estimates of the order of magnitude of the number of fatalities and economic losses by providing probabilities within specific ranges, each varying an order of magnitude from the previous one.

The number of shaking-related fatalities in this event was projected to be low to intermediate, according to the USGS, compared to previous earthquakes with similar magnitudes. Past events with an equivalent level of projected fatalities require a local or regional response. In particular, as shown in Figure 6.3, the USGS PAGER tool estimated fatalities to be 0, 1 to 10, 10 to 100, 100 to 1000, and over 1000 with probabilities of 6%, 24%, 40%, and 6% for the Mw 7.6 event. Furthermore, at the time of the writing of this report, three fatalities have been reported from the main event and two from the aftershock (Diario de Colima, 2022a; El Universal, 2022b). Also, PAGER estimated economic losses due to damage to be between \$1 million and \$10 million, between \$10 million and \$100 million, between \$100 million and \$1,000 million, and between \$1,000 million and \$10,000 million with probabilities of 6%, 23%, 38%, 25%, and 7%, respectively (USGS, 2022).



(a) (b)

Figure 6.3. PAGER Estimated probability of (a) fatalities and (b) economic losses for the September 19, 2022, Michoacán Earthquake (USGS, 2022a).

7 Damage (Michoacán, Colima and Surrounding States)

Most of the damage was concentrated in the states of Michoacán and Colima. On September 20, National Coordination of Civil Protection reported the following fatalities and structural damage in several states (Twitter, 2022a):

- Two people died and nine were injured in Manzanillo (western state of Colima).
- Seven medical centers suffered structural and non-structural damage in the state of Colima and twenty-one medical centers experienced damage in the state of Michoacán.
- Two churches suffered some structural damage.
- More than 150 houses and other buildings suffered damage in the state of Colima.
- Eight state highways, and five bridges suffered damage in the state of Colima, but their functionality has been restored.
- Thirty schools suffered damage in the state of Michoacán.
- Government buildings suffered damage in the state of Michoacán.
- Slight damage was reported in Jalisco, Aguascalientes, Nayarit, the State of Mexico and Mexico City.

In a press conference given by the governor of Colima the morning of September 20th, the following structural damage was reported (Facebook, 2022a):

- Major structural damage at the ISSSTE Miguel Trejo Ochoa medical center, Colima.
- Major structural damage at the General Hospital at Ixtlahaucán.
- Major structural damage at the General Hospital at Tecomán after the explosion of an oxygen tank. This explosion left four people injured.
- Structural damage at the Torre Médica from Plaza Sendera building.
- Minor structural damage (pending evaluation) at the blood bank building, the No. 1 sanitary jurisdiction building, the COEPRIS (State Commission for the Protection against Sanitary Risks) building, the State Cancer Institute building, and the Infant-Maternal hospital. All these buildings are in Colima city.
- Landslides in the roads to Minatitlan and La Becerrera.
- Wall cracks of the Coquimatlán church.
- Minor structural damage at Zentralia Shopping Center
- Minor damage at the Licenco and Armeria bridges.

The States of Michoacán and Colima experienced several partial and full collapses of non-engineered structures, especially unreinforced masonry construction. Cracking, dislodging and crushing damage of masonry walls were evident in many buildings as seen from the photos in this section. Structural and non-structural damage was observed in commercial buildings, including glass shattering, and furniture and contents damage. Several hospitals experienced structural and non-structural damage. According to National Coordination of Civil Protection (Twitter, 2022a), 153 households and nine medical centers had some damage. Additionally, nine collapses/landslides were reported in highways (this includes damage in the states of Michoacán and Colima). Highway authorities reported that a landslide caused a blockage on the highway between Coalcoman and Villa Victoria on the Coalcoman-Tepalcatepec section (Quadratin, 2022a).

Damage to the electrical infrastructure in Michoacán was reported by Federal Electricity Commission (CFE by its initial in Spanish) (Twitter, 2022b): (i) Power outage affected 106,037 users in Michoacán, which was restored at 15:40 local time, approximately 2.5 hours after the earthquake, (ii) power outage affected 145,808 users in Colima, and 77% of those affected were restored at 15:40 local time. According to the Federal Electricity Commission (CFE), 1.2 million users were affected by power outages throughout several states. However, by 19:39 local time on September 19th, around 6.5 hours after the earthquake, power had been restored to 95% of those that were affected (Twitter, 2022b).

In Guadalajara, Jalisco, authorities reported damage to several historic buildings, as well as campuses of the University of Guadalajara (UdeG) and government offices (Proceso, 2022a). Masonry pieces fell from the temples of La Merced and San Agustín.

According to El Consejero (2022) a local newspaper in Puerto Vallarta, Jalisco, the Civil Protection and Fire Department released a preliminary report after the earthquake reporting damage in some buildings and hotels in this city and no casualties. The government buildings of the county (municipio in Spanish) were evacuated without incident, but some nonstructural damaged occurred. In the UNIRSE building, there were fallen light fixtures, but without causing injuries to the occupants. The building housing the Office of the State Prosecutor was evacuated without incident, as was the Secondary School No. 29. The traffic lights on Francisco Medina Ascencio Avenue were reported temporarily out of service.

7.1 Single-Family Residential Buildings

Most of the damage was concentrated in single-family residential buildings that were mainly non-engineered construction. Several single-family residential buildings experienced various levels of damage ranging from minor wall cracking to complete collapse.

According to Nelson Bautista Gómez, director of Roads and Highways (“Caminos y Carreteras”), the damage to single-family residential buildings per district was as follows (AM, 2022):

- Coahuayana 1,143 damaged units - 398 collapsed
- Aquila 1,133 damaged units - 400 collapsed
- Chinicuila 24 damaged units - no collapses
- Coalcomán 63 damaged units - no collapses

The images of collapsed residential buildings (Figure 7.1 - Figure 7.3) show vulnerable unreinforced masonry (URM) structures, which are known to have low in-plane and out-of-plane displacement capacity. There were also cases of severe URM damage in the form of shear failure of short piers due to the low in-plane masonry strength (Figure 7.4), collapsed roofs (Figure 7.5), and cracked walls (Figure 7.6). Reinforced concrete building collapses also occurred possibly due to system irregularities and non-ductile concrete characteristics (Figure 7.7 and Figure 7.8). Intact columns are observed in Figure 7.7, indicating potential failure of beam-column joints, leading to collapse.

Figure 7.1. Collapsed building in Coahuayana, Michoacán (El Sol de Morelia, 2022a).

Figure 7.2. URM single-family house completely collapsed in Coalcoman, Colima (PBS, 2022).

Figure 7.3. Collapsed URM wall in single-family buildings in Morelia, Michoacán (Quadratin, 2022b).

Figure 7.4. Collapsed URM wall in single-family house in Tecomán, Colima (Twitter, 2022f).

Figure 7.5. Single-family building in Armería, Colima with collapsed wooden roof. The state governor visited affected regions. Many single-family buildings are made of unreinforced masonry, which are highly vulnerable to ground motions. This type of damage is typical in the affected regions (Facebook, 2022c)

Figure 7.6. Cracking wall in a unreinforced masonry house in Tolimán, Colima (Imagen Noticias, 2022)

Figure 7.7. Total collapse of a reinforced concrete single-family building with masonry infill walls in San Vicente, Michoacán (Twitter, 2022c).

Figure 7.8. Total collapse of a reinforced concrete single-family building with masonry infill walls in San Isidro, Tecomán, Colima (Facebook 2022d)

7.2 Multi-Family Residential Buildings

Multi-family residential buildings are not common in small municipalities like those close to the epicentral region. They are more common in large cities like Puerto Vallarta, Colima or Manzanillo. Some media reports indicate that damage in this type of construction was mostly non-structural (Figure 7.9 and Figure 7.10).

Figure 7.9. Portofino Condominium, Puerto Vallarta, Jalisco. No structural damage was observed. Only minor damage to ceilings, partition walls and ornaments was reported (Contralinea, 2022)

Figure 7.10. Tres Mares Condominium in Puerto Vallarta, Jalisco. Only nonstructural damage was observed and mainly occurred in facades, tiles and ceilings (Informador.Mx, 2022).

7.3 Commercial Buildings

Many commercial buildings experienced damage. The collapsed roof at Plaza Punto Bahia is one of the most relevant as it caused the death of one occupant. According to the pictures in Figure 7.11 to Figure 7.13, the steel structure seems to have failed when the beams detached from the concrete structure during the earthquake (Figure 7.11). The other case which also resulted in a fatality was the out-of-plane partial collapse of the facade of the Valle de Garzas store as shown in Figure 7.14 to Figure 7.16. It is likely that the heavy masonry sections that fell were not effectively anchored to the main structure.

Figure 7.11. Collapsed roof in Plaza Punto Bahía in Manzanillo, Colima (Twitter, 2022d).

Figure 7.12. Collapsed roof in Plaza Punto Bahía in Manzanillo, Colima (Twitter, 2022e)

Figure 7.13. Collapsed roof in Plaza Punto Bahía in Manzanillo, Colima (Diario de Colima, 2022a)

Figure 7.14. Out-of-plane wall failure in the Coppel store at Valle de las Garzas in Manzanillo, Colima (Diario de Colima, 2022b)

Figure 7.15. Out-of-plane wall failure in the Coppel store at Valle de las Garzas in Manzanillo, Colima which resulted in one fatality (Twitter, 2022e).

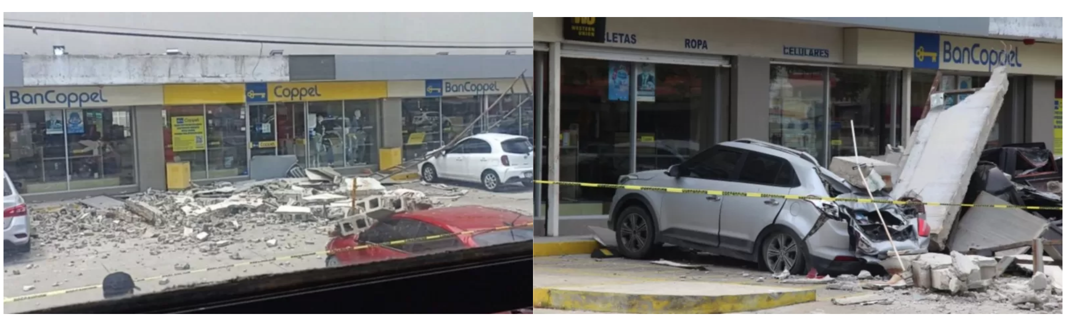


Figure 7.16. Out-of-plane wall failure in the Coppel store at Valle de las Garzas in Manzanillo, Colima (BBC, 2022).

Figure 7.17. Sheraton Buganvilias hotel, Puerto Vallarta, Jalisco. Damage in facades and interior walls. (El Financiero, 2022a).

Minor to moderate facade / interior wall damage was also observed in the Sheraton Buganvilias in Puerto Vallarta (Figure 7.17) and in the Telmex building in Colima (Figure 7.18). On the other hand, the Grand Pacífico Hotel in Colima experienced severe damage in the walls at the lower stories (Figure 7.19) and severe cracking was observed on the facade of Plaza Country in Colima (Figure 7.20).

Figure 7.18. Damage on Telmex building in Colima, Colima: left (Credits: Rafael Cruz, Facebook 2022f) right (Credits: Rafael Cruz, Facebook 2022e); .

Figure 7.19. Severe wall damage in Gran Pacífico Hotel in Manzanillo, Colima (Colima Noticias, 2022).

Figure 7.20. Severe cracking on the facade of Plaza Country in Colima, Colima (Facebook, 2022g).

7.4 Healthcare/Medical Facilities

At least 28 hospitals and medical facilities in the Mexican States of Michoacán and Colima were reported as having sustained some type of structural damage. Temporary or mobile medical units were deployed to provide healthcare services. The Maruata hospital in Michoacán (Figure 7.21 and **Error! Reference source not found.**), located in the region of highest intensity, suffered severe damage, in particular due to the extensive collapse of the masonry facade. Significant steel corrosion is observed in **Error! Reference source not found.** with clear traces of ferrous oxide. The health center at Aquila, in the epicentral region also experienced extensive damage and was closed for further inspection. Figure 7.23 shows wide shear cracks in a facade spandrel.

Figure 7.21. Maruata Hospital, Maruata, Michoacán: Frontal facade before the earthquake shown with a photo taken in 2019 (Gobierno de Michoacán, 2019).

Figure 7.22. Exterior of the Maruata Hospital, Maruata, Michoacán after the earthquake: Masonry facade collapse, exposing significant steel corrosion in columns (Twitter, 2022g)

Figure 7.23. Health center at Aquila, Michoacán. The building was evacuated due to structural damage. (El Sol de Morelia, 2022b)

There was structural and nonstructural damage in various hospital buildings in locations as far as 100 km from the epicenter. One example is the Puerta de Hierro Hospital, in Colima shown in Figure 7.24 where extensive cracking of masonry, mainly around the perimeter of infill masonry walls, in the interface with the structural concrete frame was observed. It is possible that these walls were isolated from the frame or they got separated from the frame due to interstory drift demands. Severe shear diagonal cracking was observed in some of the walls. Cracking and spalling observed in a few other facilities are shown in Figure 7.25 - Figure 7.27.

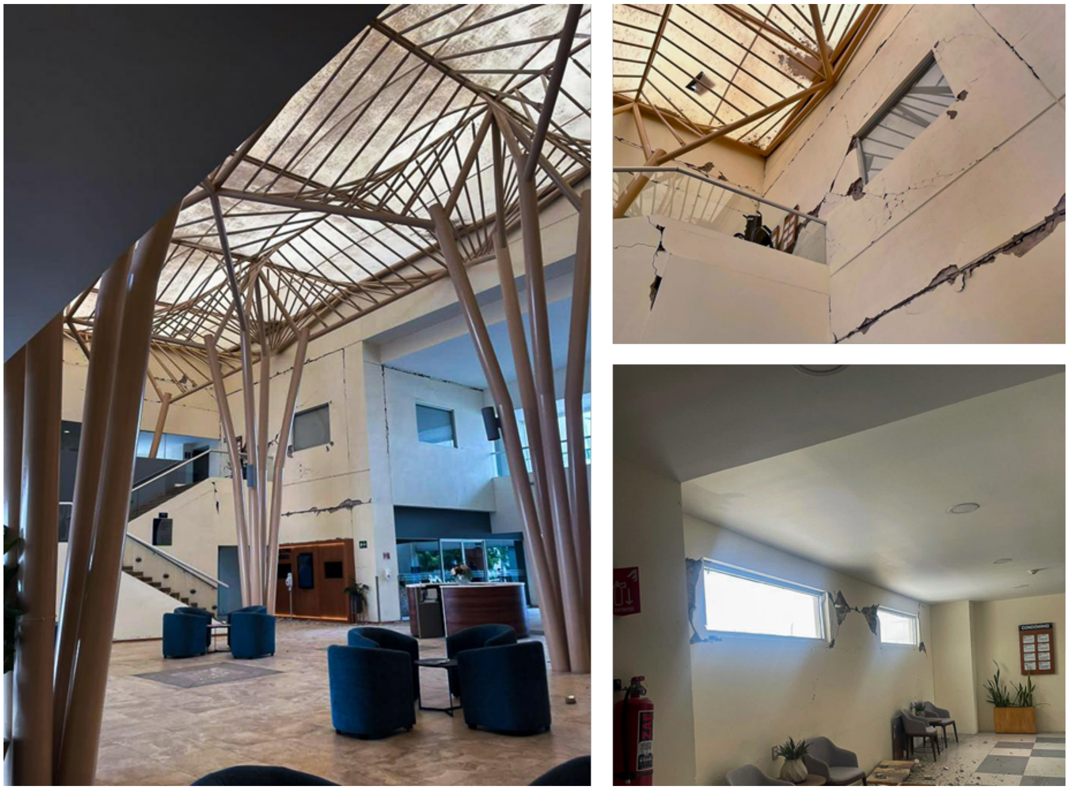


Figure 7.24. Damage to walls of the Hospital Puerta de Hierro in Colima, Colima (Twitter, 2022k).

Figure 7.25. Cracked walls of the Institute of Security and Social Services for State Workers, which is a major government health services provider in Mexico for government employees and their families (ISSSTE) in Apatzingán, Michoacán (Twitter, 2022j).

Figure 7.26. Minor cracking in Tecomán General Hospital in Colima (Twitter, 2022h).

Figure 7.27. Damage in ISSSTE Hospital "Dr. Miguel Trejo Ochoa" in Colima, Colima: left (Facebook, 2022h); center (Facebook, 2022i); right (Facebook, 2022j).

7.5 Damage to Religious and Historical Buildings

According to National Coordination of Civil Protection in the state of Colima, two churches suffered severe damage (Twitter, 2022a). Some examples of religious buildings that suffered damage are presented in this section. It is noted that old churches were typically built with unreinforced masonry (Figures 7.28 -7.36).

Figure 7.28. Damage to roof and walls in historical buildings in Coalcomán, Michoacán (Twitter, 2022w)

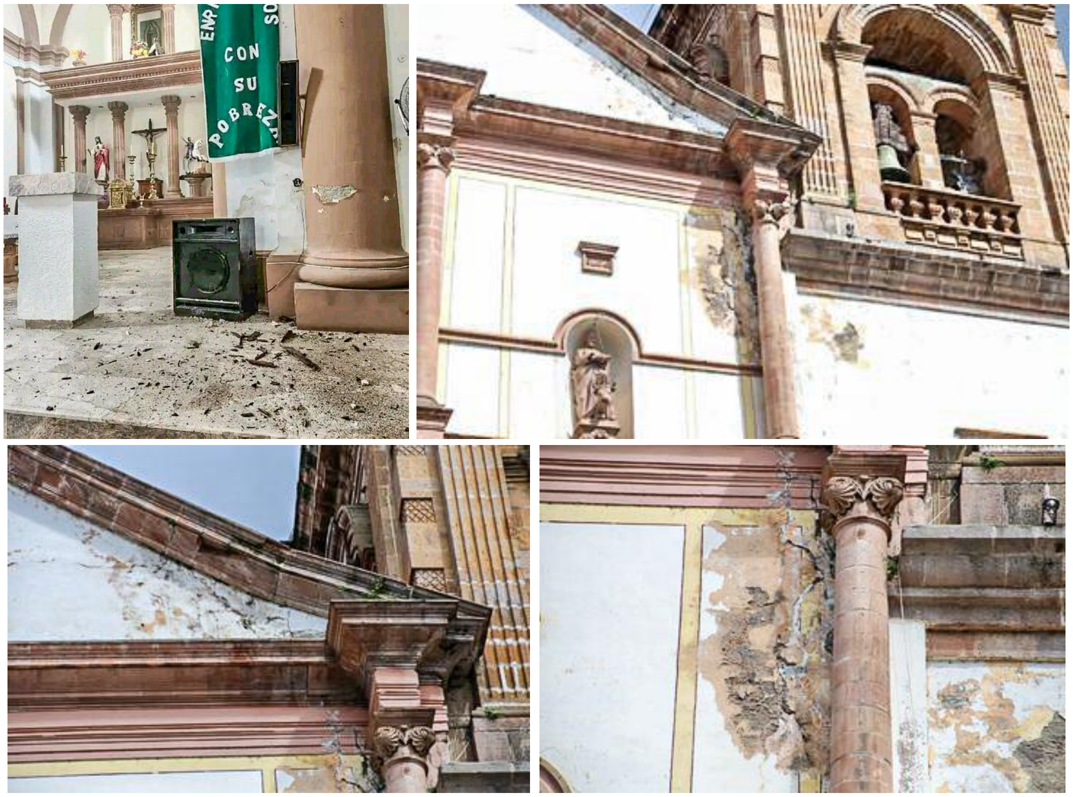


Figure 7.29. Cracks in the Basilica de Nuestra Señora de la Salud in Patzcuaro, Michoacán (Twitter, 2022i).

Figure 7.30. Damage caused by the earthquake is observed in the church of San Miguel Arcángel in Tacatzcuaro, Michoacán (Facebook, 2022b)

In the downtown area of Guadalajara two churches were damaged. First, in La Merced Church (Av. Miguel Hidalgo y Costilla 412, Zona Centro, 44100 Guadalajara, Jal.), where some stone masonry was detached from the ornamentation (Figure 7.31). Currently, the authorities are collecting and storing some of these pieces because of their historical value. Secondly, in San Agustin Temple (C. Morelos 202, Zona Centro, 44100 Guadalajara, Jal.), a piece of quarry detached from the dome and fell over a car (Figure 7.32).

Figure 7.31. Detachment of an ornamentation in the La Merced Church in downtown Guadalajara, Jalisco (Reforma, 2022)

Figure 7.32. Detachment of an ornamentation in San Agustín Church in downtown Guadalajara, Jalisco (El Occidental, 2022)

In the downtown area of Tepic, in the state of Nayarit, The Asunción Maria Cathedral (Av. México Nte. 246, Centro, 63000 Tepic, Nayarit) was damaged (Figure 7.33). The damage consisted of failure of concrete in the columns at the top of the bell tower.

Figure 7.33. Damage at the upper portion of the bell tower in the Asunción Maria Cathedral in Tepic, Nayarit (Meridiano.mx, 2022)

Figure 7.34. Damage on the bell tower of the Minor Basilica Cathedral of Colima, Colima (AFmedios, 2022a).

Figure 7.35. Parroquia de Santiago Apóstol in Tecomán, Colima (24 Horas, 2022).

Figure 7.36. Damage on the bell tower of the Nogueras Church in Colima, Colima (Facebook, 2022).

7.6 Government Buildings

According to El Sol de Morelia a local newspaper in the state of Michoacán (2022c), the municipality government building of Patzcuaro experienced several cracks; however, no photos or images have been found. There were varying levels of damage experienced in the walls and nonstructural components of several other government buildings (Figures 7.37-7.40).

Figure 7.37. Cracks and damaged walls of the "Presidencia municipal de Tecoman" in Michoacán (Diario de Colima, 2022c)

Figure 7.38. Minor cracks in walls of the government building in Villa Alvarez, Colima (Archivo Digital, 2022)

Figure 7.39. Damage in construction joints and ceilings in the Administrative Complex of the Government of the State of Colima: left (Facebook, 2022m); center (Facebook, 2022n); right (Facebook, 2022o)

Figure 7.40. Damage to ceilings and severe cracking on walls in the Culturas del Occidente Museum in Colima, Colima (Facebook, 2022p)

7.7 School Buildings

Until the 1940s, the Mexican school infrastructure had been built following state and local design and construction practices. In many cases, schools were merely adapted from old houses without any pedagogical criteria. In 1944, the Federal Government of Mexico established CAPFCE, as a national (federal) agency in charge of developing and building archetypical school projects throughout the country. Over the past 78 years, joint teams of architects, engineers and educators have developed distinctly different prototypes, built with masonry, concrete and steel for rural and urban communities. Buildings included all levels of schooling, including higher education institutions. In rural communities, one-story load-bearing masonry wall structures are prevalent. In the cities, one-to-four story structures can be found, although most common schools have one and two stories. The largest proportion of schools were built in the 1970s to address the problem of a deficit of school buildings in several parts of the country.

In 1985, in the aftermath of the Mexico City earthquake, designs were modified. Larger column and beam sizes, greater amounts of longitudinal and transverse steel and, in some cases, addition of walls or braces were implemented. Existing school buildings, whether damaged or undamaged, were rehabilitated in Mexico City. In 2008, CAPFCE was transformed into INIFED (National Institute for School Infrastructure) as a coordination agency aimed at establishing mandatory requirements and criteria for the design and construction of school buildings, but no longer in charge of their construction. Unfortunately, at present, INIFED is being dissolved by the government, thus losing the expertise and best practices learned and implemented over many years in Mexico.

Mexico has experienced vast damage in school buildings in previous earthquakes. As a consequence of the January 21, 2003 earthquake (EERI & SMIS, 2006), damage concentrated in masonry infill walls in the form of diagonal cracking and/or localized crushing next to the concrete or steel frame structure. In some cases, out-of-plane failures of unreinforced masonry parapets were observed. Shear failures in columns due to the short-column effect were also commonly observed. Other forms of nonstructural damage included broken glass windows with little or no damage to contents and equipment. The percentage of damaged school buildings from that earthquake was 12.4, 9.3 and 4.3% of the total in the states of Colima, Jalisco and Michoacán, respectively (EERI & SMIS, 2006).

In 2017 the September 7th and 19th events caused widespread damage to school buildings in which 19,194 school campuses were damaged: 12,014 were reported with minor damages (for example, only broken glass windows), 6,970 with moderate and moderate/severe damage, and 210 with very severe damage that prompted their reconstruction (Alcocer et al., 2020). No casualties were recorded in school facilities. All prototype school buildings withstood the temblors without collapse. Only four collapses were recorded of buildings that were either built informally (following self-construction procedures) and that were used as accessory buildings, not for classrooms (Ramírez et al., 2018).

With support from the Institute of Engineering at UNAM, INIFED has developed a very comprehensive post-earthquake assessment methodology and a comprehensive technical guide for seismic retrofit (information is available at INIFED, 2021a, b, c, d; which are also available at http://www.resilienciasismica.unam.mx/normas_guias.html).

Table 7.1 summarizes the total number of public school campuses reported with some level of damage during the September 19th earthquake (INIFED, 2022). Data includes damage reported up to September 22 at 18 h, local time. A typical public school campus consists of three to four buildings. It is quite common to find school campus buildings constructed from different vintage, and even built with distinct structural systems and construction materials due to the need for growth of the school.

The total number of schools damaged from this earthquake is 515 which is significantly smaller than the almost 20,000 schools damaged in the September 19th 2017 earthquake. However, one must keep in mind that the September 19, 2017 event occurred much closer to Mexico City and its surrounding cities which concentrate a large portion of school buildings in the country.

Most damaged school buildings in this earthquake are elementary schools. This is not a surprise as the largest number of schools are in this category. It will be of interest to further assess damage in schools in Nayarit, which were located several kilometers north of the epicenter.

In general, damage consisted of wall cracking (in many cases only in the mortar or stucco cover), cracking of reinforced concrete columns and beams, cracks in floor/roof slabs, and cracking and tilting of wall fences. Wall fences have shown to be vulnerable to seismically-induced forces in previous earthquakes (Alcocer et al., 2020). Wall fences are often built next to ornament gardens that lead to corrosion of vertical wall reinforcement. Corrosion often facilitates the occurrence of out-of-plane failures. A more detailed analysis of wall fence behavior is warranted for this event.

Table 7.1. Total number of damaged school campuses in the states of Colima, Jalisco, Michoacán and Nayarit (September 22, 2022; 1800 h local time) (INIFED, 2022)

	Total number of school campuses damaged				
Level	COLIMA	JALISCO	MICHOACÁN	NAYARIT	TOTAL
Elementary	131	57	54	145	387
Elementary (Rural)	20	7	10	0	37
High school	18	12	38	0	68
Higher education	0	1	16	0	17
Other (offices)	1	4	1	0	6
Total	170	81	119	145	515

After damaging earthquakes, the Mexican Government has typically implemented a Recovery Plan for School Buildings, coordinated by INIFED. At the time of this writing, there is no information about such a plan or the origin of the financial resources for the recovery (rehabilitation and reconstruction).

Classes were canceled in the states of Colima, Jalisco and Michoacán while schools are being inspected.

Figure 7.41. Cracked walls in the school of Jiquilpan, Michoacán (Cambio de Michoacán, 2022).

Damage experienced in school buildings mainly concentrated on the walls (Figures 7.41-7.45). School buildings in Figure 7.42 and Figure 7.43 show typical characteristics of facades with large openings and stiff short walls that restrain the lateral in-plane deformation of the lower section of the columns. Note the significant damage of the walls in spite of the fact that these are single story buildings. There are shear cracks in the walls due to the in-plane deformations and the damage was more extensive in the sections above the short walls than at the bottom section. The two cases in the figures do not seem to have had any out of plane damage to the walls. Damage shown in these images is very similar to the damage observed in other school buildings in previous earthquakes.

Figure 7.42. Cracked walls of a school in Coalcoman, Michoacán (MiMorelia, 2022).

Figure 7.43. Cracked walls of a school in Coalcoman, Michoacán (Notivideo, 2022).

Figure 7.44. Cracked walls of Macario G. Barbosa school in Tecoman, Colima (Twitter, 2022l)

The case of the kindergarten Josefina Beas in Figure 7.45 shows the importance of carefully evaluating not only school buildings but also their neighboring structures. This kindergarten building was severely damaged by the partial collapse of the parapets and wall of an old structure, apparently made out of a combination of unreinforced masonry and adobe.

Figure 7.45. Collapsed walls of neighboring structure next to the kindergarten Joseffina Beas in Coquimatlan Colima (Twitter, 2022m)

According to state officials in the state of Michoacán, 334 schools were damaged in that state (Noventagrados, 2022). At the time of the writing of this report, damage levels in those buildings is unknown.

7.8 Non-structural Components

Damage to non-structural components was reported by several newspapers, news agencies and in social networks. Dislodging of ceiling tiles, as shown in Figure 7.46 and Figure 7.47, and damage to partition walls were the most common damages reported. Collapse of windows and glass facades, as the one in Figure 7.48, were also widely reported. At the public square Jardin Alvaro Obegón extensive damage to the decorative pavement was noted apparently due to the absence of a movement joint between the shore and the wharf structure (see Figure 7.49).

Figure 7.46. Non-structural damage in the Institute of Security and Social Services for State Workers (ISSSTE) in Apatzingan, Michoacán (Twitter, 2022j).

Figure 7.47. Non-structural damage in Condusef Morelos office in Cuernavaca, Morelos (Twitter, 2022n).

Figure 7.48. Non-structural damage of the mall in Colima, Colima (Publimetro, 2022).

Figure 7.49. Public square Jardín Álvaro Obregón in Manzanillo, Colima (Facebook, 2022q).

7.9 Geotechnical Observations

The earthquake triggered dozens of landslides and falling of large rock blocks along the entire epicentral area (Figure 7.50 and Figure 7.51). A massive landslide, shown in Figure 7.52) was reported near Colima, around 50 km from the epicenter. The Central Control, Communications, Computers, Cybersecurity and Intelligence Command (C5i) monitored several points along the roads and reported landslides as far as 70 km from the epicenter (See Figure 7.53). The USGS reports PGA values around 0.15g in this region. There were also multiple landslides along the Tecoman-Colima Federal Highway (Figure 7.54 and Figure 7.55) which is approximately 80 km from the epicenter and had PGA values around 0.1g according to the USGS.

Figure 7.50. Landslide in Coalcoman-Aquila road in Michoacán (La Jornada, 2022).

Figure 7.51. Landslide in Coalcomán-Villa Victoria road in Michoacán (El Sol de Morelia, 2022a).

Figure 7.52. Landslide in Colima (La Jornada, 2022).

Figure 7.53. Landslides on the highway in Michoacán (Revolución 3.0, 2022).

Figure 7.54. Landslide on the Tecomán-Colima Federal Highway (Uno TV, 2022)

Figure 7.55. Landslide on the Tecomán-Colima Federal Highway in La Salada, Colima: left (Sentido Común, 2022); right (right (Facebook, 2022r)

Figure 7.56. Landslide on Villa de Álvarez-Minatitlán road in Villa de Álvarez, Colima (Facebook, 2022s)

7.10 Industrial Facilities

The earthquake caused some water supply problems in the city of Colima . Gov. Indira Vizcaíno suggested rationing water for the following days. According to the Head of the Potable Water Commission, the earthquake did not cause structural damage to infrastructure, but caused uplift of sediments. Consequently, it was not possible to pump water.

San Pedrito Port, in Manzanillo, an important port for Mexican trade and communications, which suffered extensive damage in the 1995 Mw8 *Manzanillo Earthquake* (as described in Rodríguez et al. 1997), temporarily ceased to function after the September 19, 2022 earthquake. According to Noticias Manzanillo (2022), after a reconnaissance of facilities, port activities were restarted that same afternoon, and as of the morning of September 21, it was fully operational.

7.11 Infrastructure

The following roads and bridges were reported with damage, along with the causes and/or form of damage:

- Autopista Siglo 21 : Rocks/Landslide
- Carretera Costera : Cracking in several places
- Coahuayana Bridge : Superstructure Damage
- Ticuiz Bridge : Superstructure Damage

The Coahuayana bridge had suffered damage in previous earthquakes (EERI & SMIS, 2006).

Figure 7.57. Damage in Ortega-Callejones road (K2+000 to K3+300) in Colima. (Twitter, 2022o).

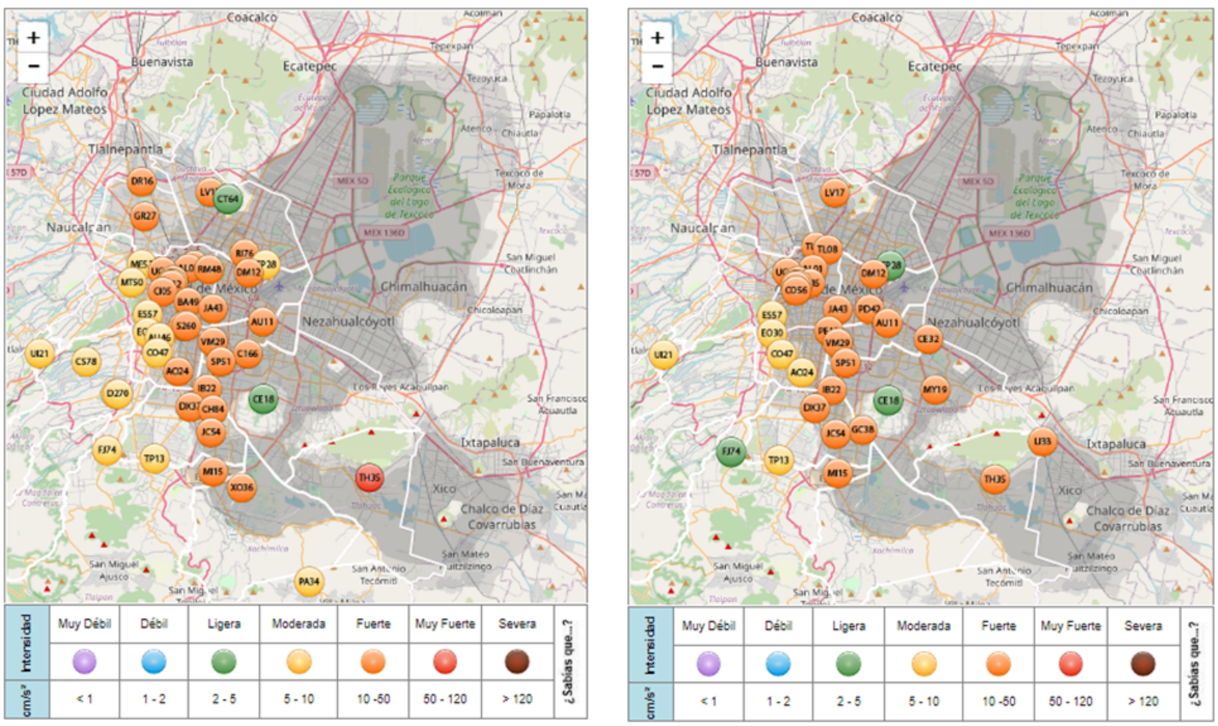
Figure 7.58. Damage in bridge “Puente Cortés” in Colima, Colima (El Comentario, 2022).

Figure 7.59. Damage at a joint in the Armería bridge located on the federal highway Colima-Manzanillo en Tecomán, Colima (Facebook, 2022k).

Figure 7.60. Damage on the Campos-Punta Grande federal highway in Manzanillo, Colima (Afmedios, 2022b).

8 Damage (Mexico City and State of Mexico)

Peak-ground accelerations recorded in Mexico City for the main event of September 19, and the aftershock of September 22 are shown in Figure 8.1a and Figure 8.1b, respectively. In the main event, one of the stations recorded accelerations classified as Very Strong ("Muy Fuerte" in Spanish) ranging from 50 to 120 gal (cm/seg2). In the September 22 aftershock several stations recorded peak-grounds accelerations classified as Strong ("Fuerte" in Spanish), ranging from 10 to 50 gal.



a) b)

Figure 8.1. Report of peak-ground accelerations in Mexico City: a) 19/09/2022, main event, and b) 22/09/2022 aftershock (cires, 2022).

8.1 Buildings

According to the information provided by the Mexico City Government, only twenty one buildings were damaged by the earthquake and none of them was severely damaged. The following buildings were reported damaged by local authorities: (Gobierno CDMX, 2022):

Minor structural damage:

- Pino Suárez No. 81, Cuauhtémoc
- Palma No. 34, Centro, Cuauhtémoc
- Uruguay No. 73, Centro, Cuauhtémoc
- Uruguay No. 75, Centro, Cuauhtémoc
- Isabel La Católica No. 85, Centro, Cuauhtémoc
- República de Brasil No. 8, Centro, Cuauhtémoc
- Eje Central No. 11, Centro, Cuauhtémoc
- Paseo de la Reforma No. 389, Centro, Cuauhtémoc
- Insurgentes No. 423, San Simón Tolnahuac, Cuauhtémoc
- Zaragoza No. 31, Buena Vista, Cuauhtémoc
- Dr. Liceaga No. 115, Doctores, Cuauhtémoc
- Dr. Río de la Loza, No. 156, Doctores, Cuauhtémoc
- San Antonio Abad No. 32, Centro, Cuauhtémoc
- Edificio del PRI, Av. Aquiles Serdán y Pdte. Madero, Azcapotzalco
- Edificio de la Lotería Nacional, Av. Paseo de la Reforma No. 1, Tabacalera, Cuauhtémoc
- Atenas y Vesalles, Juárez, Cuauhtémoc
- Antonio Caso No. 130, San Rafael, Cuauhtémoc

Moderate structural damage:

- Edif. Virreinal, Plaza de la Constitución No. 2, Centro,Cuauhtémoc
- Argentina No. 8, Centro, Cuauhtémoc
- Dr. Navarro No. 182, Doctores, Cuauhtémoc
- Filipinas No. 178, Portales, Benito Juárez

People reported falling debris during the earthquake at the building located in Palma 34 in Mexico City Downtown (Figure 8.2). It is worth mentioning that the crack shown in the picture was observed before the seismic event. However, users commented in different twitter posts that its size increased during the earthquake.

Figure 8.2. Building located at Palma 34, in Downtown Mexico City (Twitter, 2022x).

The buildings shown in Figure 8.3 to Figure 8.7 were damaged during the Sep 19, 2017 earthquake, and they have not yet been repaired. In this earthquake (Sep 19, 2022), these buildings reported new damage, including cracking on structural and non-structural walls, broken windows and detached facades.

Figure 8.3. Building located at Doctor Navarro # 182, Alcaldía Cuauhtémoc, Mexico City (Ciudadanos en red, 2022).

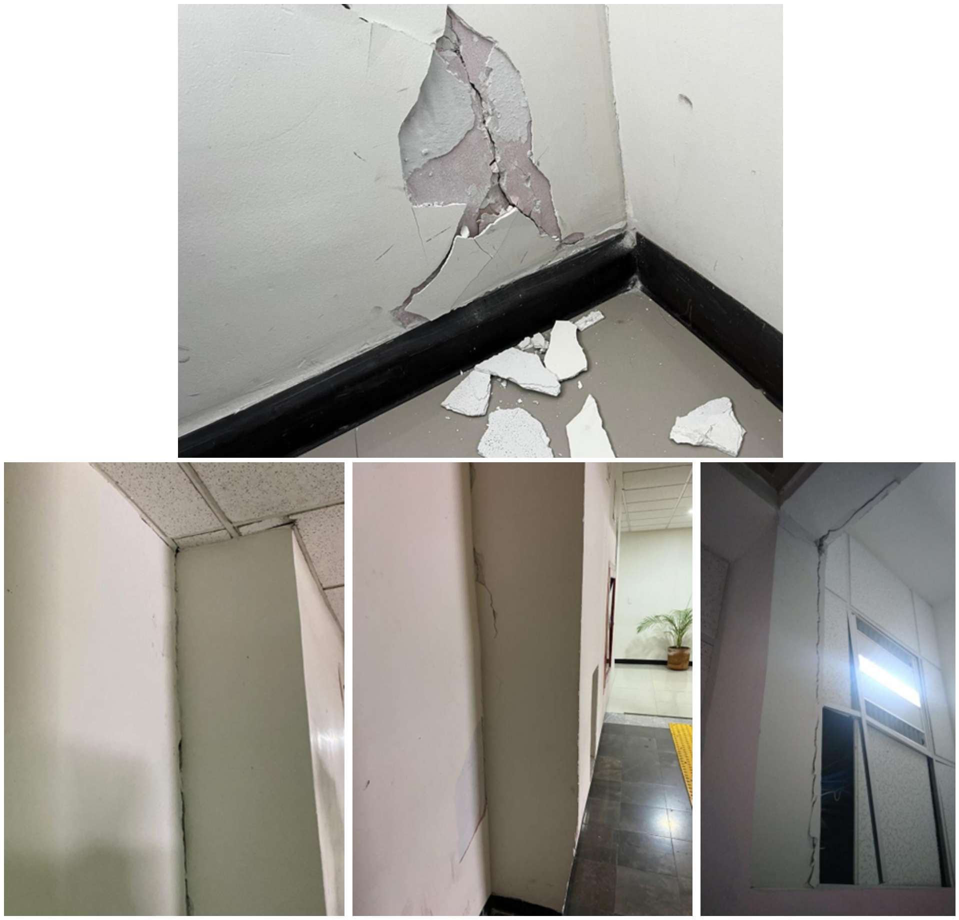


Figure 8.4. Building located at Calz. San Antonio Abad 32, Obrera, Cuauhtémoc, Mexico City (Twitter, 2022y).

Figure 8.5. Building of the Lotería Nacional (National Lotery). Avenida Paseo de la Reforma, México City (Twitter 2022z and Wradio 2022).

Figure 8.6. Building in República de Uruguay 73, Cuauhtémoc, Mexico City (Wradio 2022).

Figure 8.7. Building located at Filipinas 178, Portales Nte, Benito Juárez, Mexico City (Twitter, 2022aa).

Figure 8.8 and Figure 8.9 show two buildings where cracks were observed in the facades after the earthquake. It is unclear whether the observed cracks correspond to structural elements.

Figure 8.8. Building in the Juarez neighborhood between Atenas and Versalles Streets (Milenio 2022a and Twitter 2022t).

Figure 8.9. Building # 23, housing unit Lindavista Vallejo, Sección 2, Gustavo A. Madero, Mexico City (Twitter, 2022u).

During the seismic event, in Ecatepec, State of Mexico, it was reported that some facade elements had partially collapsed (Figure 8.10). Local firefighters assessed the damage and demolition tasks were carried out on the rest of the elements that presented structural failures.

Figure 8.10. Marketplace “5 de mayo”, in Col. La Michoacána, Ecatepec, State of Mexico (Milenio, 2022b).

Figure 8.11 to Figure 8.14 show several damaged buildings.

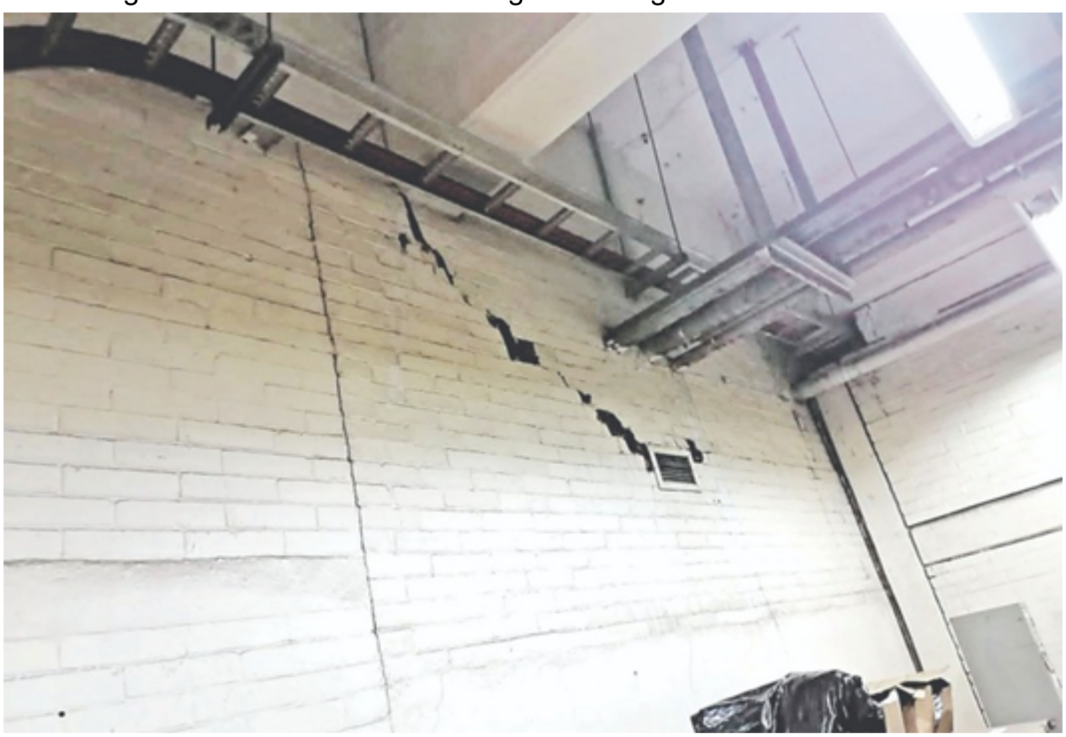


Figure 8.11. Building in Calle Gral. Gabriel Hernández # 56, Col. Doctores, Cuauhtémoc, Mexico City (Excelsior, 2022b).

Figure 8.12. Building located at José María Marroquín # 10, Downtown, Mexico City (Excelsior, 2022c).

Figure 8.13. Building located at Canal de Churubusco # 351 with some cracks and damage in the facade (Twitter, 2022v).

Figure 8.14. Building located at Calzada San Antonio Abad # 66, Alc. Cuauhtémoc, Mexico City (Newtral, 2022).

8.2 Healthcare / Medical Facilities

No damage was reported in the Hospitals of Mexico City and the State of Mexico. However, in the hospital "Siglo XXI" there were failures in the electricity supply, which caused delays to provide medical services. Figure 8.15 shows a photo of an electrical energy supply failure during a baby's surgery, according to information presented by El Heraldo de México (2020a).

Figure 8.15. Hospital Siglo XXI, Mexico City (El Heraldo de México, 2022a).

8.3 Religious and Historical Buildings

The Metropolitan Cathedral of Mexico City (Figure 8.16) did not present visible structural damage. However, people reported material spalling. As a consequence, the facilities were temporarily closed. According to Guatemala Times (2022), the General Directorate of Cultural Heritage Sites and Monuments indicated that current rehabilitation works were suspended in order to carry out a structural review. Reactivation of old cracks in the Metropolitan Sagrario was confirmed.

Figure 8.16. Cathedral of Mexico City (El Financiero, 2022b).

8.4 Non-structural Components

Only a small amount of non-structural damage was reported in Mexico City or the State of Mexico.

8.5 Infrastructure

No damage to infrastructure was reported in Mexico City or the State of Mexico. A bridge in Huixquilucan (Figure 8.17) was closed to traffic after the earthquake. After a preliminary assessment, severe structural damage was not detected (?)discarded; however, the bridge has not yet been opened to traffic. (El Universal, 2022a).

After the M6.8 aftershock, electricity supply failures were reported in Mexico City, but power was restored within a few hours.

Figure 8.17. Bridge at Palma Criolla, Huixquilucan, State of Mexico, closed to traffic after the earthquake. (La Razón, 2022a).

8.6 School buildings

After the earthquake, the “Autoridad Educativa Federal en la Ciudad de México (AEFCM)” visited all the 6849 schools in the city and found that at least 76 of them were affected during the event but were not seriously compromised (Once Noticias, 2022). Additionally, the Secretaría de Obras y Servicios de la Ciudad de México (Sobse) reported that 70 schools suffered minor damage, 5 schools presented moderate damage and only 1 school was severely damaged. (El Universal, 2022c). The schools in the most critical damage categories are:

Moderate damage in:
- Secundaria José María Velasco, en Iztapalapa.
- Primaria Mártires de Reforma, en Iztapalapa.
- Primaria, Doctor Jaime Torres Bodet, en Tláhuac.
- Primaria Luis González obregón, en Benito Juárez.
- Primaria Adriana García corral, en Cuauhtémoc.

Severe damage in:
- Primaria Albino García, en Iztapalapa

Figure 8.18. Diagonal cracking in masonry infill wall in a school. (La Razón, 2022b)

Two days after the main shock, according to local government officials, damaged schools increased to 120. Seven schools suffered medium damage, while the remainder 113 exhibited light damage. There are 56 other public schools pending to be revised (Excelsior, 2022a). Only one school ("Albino García", in Iztapalapa County) interrupted activities because of the nonstructural damage in window framing and doors (Proceso, 2022b) (Figure 8.19).

Figure 8.19. Albino García school in Mexico City with nonstructural damage in window framing (Proceso, 2022b)

9 Videos Documenting Live Earthquake Shaking and Damage

State of Colima

Collapsed gym in Blvd. Miguel de la Madrid, 1555, Manzanillo, Colima:
https://twitter.com/DDMexico/status/1571966521618092032?s=20

https://twitter.com/Spainiranpress/status/1572193584027402242

Waves in Manzanillo, Colima:
https://twitter.com/AlertaCambio/status/1571970285825576960

Pátzcuaro-Lázaro Cárdenas Highway, km 228:
https://twitter.com/Pepetonozam/status/1571948606449647617

State of Michoacán

News summary Michoacán:
https://www.youtube.com/watch?v=ZjRzFeVzaMc

https://www.youtube.com/watch?v=J1f4R_7M5A0

https://twitter.com/i/status/1572427910186946561

Single-family building, Coacolman, Michoacán:
https://twitter.com/AztecaNoticias/status/1571943777845284869?s=20

Shaking in building, Uruapan, Michoacán:
https://twitter.com/i/status/1571956699623211016

Movement of a fence in Apatzingan. Michoacán:
https://twitter.com/TerraGeaNews/status/1571940110299729920

Church in Michoacán:
https://twitter.com/i/status/1571969658051338240

Hardware Store:
https://twitter.com/AztecaNoticias/status/1571945983982063616?s=20

State of Jalisco

IMSS Hospital General Regional No. 46:
https://twitter.com/montse_rgz29/status/1571957106198319104

Centro Universitario del Sur:

https://twitter.com/adrianalunacruz/status/1571949841236000769

Buildings, Puerto Vallarta:
https://twitter.com/RochexRB27/status/1572009389845893121?s=20

Hotels, Puerto Vallarta:
https://twitter.com/itspapajon/status/1571932400648880128?s=20

https://twitter.com/intxrnetclips/status/1571961182298472448?s=20 (The Westin, Resort & Spa, Puerto Vallarta)

https://twitter.com/i/status/1572246989894742018 (Blvd Francisco Medina Ascencio, 999, Puerto Vallarta, Jalisco).

Monument “A Pio Noveno” movement in Jamay, Jalisco :
https://twitter.com/i/status/1571946983186735105 (Francisco I. Madero 57A, Centro, 47900 Jamay, Jal.)

Mexico City

Shaking of multistory buildings, Mexico City:
https://twitter.com/edsoncentricus/status/1571927092518080512?s=48&t=zk1Qir-FYgc9Dv3R291TKA

(Hotel Holiday Inn Express Mexico, Paseo de la Reforma, Mexico City)

https://twitter.com/paolagalletta/status/1571938610076864512?s=48&t=zk1Qir-FYgc9Dv3R291TKA (Roma Norte, Mexico City).

https://twitter.com/alexvilasss/status/1572048938059841536?s=48&t=zk1Qir-FYgc9Dv3R291TKA (Reforma, Mexico City)

https://twitter.com/azucenau/status/1571985098907553792?s=48&t=zk1Qir-FYgc9Dv3R291TKA (Dr. Lucio, 123, Cuauhtemoc, Mexico City).

Shaking inside buildings, Mexico City:
https://twitter.com/cmjimenezxto/status/1571950902692515840?s=48&t=zk1Qir-FYgc9Dv3R291TKA (Centro Historico, Mexico City).

https://twitter.com/sergio_carreno/status/1571926230949298176?s=48&t=zk1Qir-FYgc9Dv3R291TKA (Paseo de la Reforma, 373, Cuauhtémoc, Mexico City).

https://twitter.com/mr_civico/status/1572280525934723072?s=48&t=zk1Qir-FYgc9Dv3R291TKA

(Reforma, Mexico City).

https://twitter.com/melaniesouza18/status/1572001825334915072?s=48&t=zk1Qir-FYgc9Dv3R291TKA (Lago Zurich, 245, Miguel Hidalgo, Mexico City).

https://twitter.com/i_alaniis/status/1572021094621810691?s=48&t=zk1Qir-FYgc9Dv3R291TKA (Tlapan, Mexico City).

https://twitter.com/lacostillarota_/status/1571933603180990464?s=48&t=zk1Qir-FYgc9Dv3R291TKA (Paseo de la Reforma, Cuauhtémoc, Mexico City).

https://twitter.com/aldofuego/status/1571941474635218945 (Centro Historico, Mexico City).

https://twitter.com/Sof_Cervon/status/1571967874096574465 (Santa Fe, Álvaro Obregón, Mexico City).

https://twitter.com/interludiohaq/status/1572250788885307392?s=48&t=zk1Qir-FYgc9Dv3R291TKA (Paseo de la Reforma, 26, Cuauhtémoc, Mexico City).

Shaking in public places, Mexico City:

https://twitter.com/cuauhtemoc_1521/status/1572052400499818498?s=48&t=zk1Qir-FYgc9Dv3R291TKA (Lake in Xochimilco).

https://twitter.com/quepocamadremex/status/1572324523298689024?s=48&t=zk1Qir-FYgc9Dv3R291TKA (Filming from cableway).

https://twitter.com/diariodemorelos/status/1571931140449046528?s=48&t=zk1Qir-FYgc9Dv3R291TKA (Subway station).

https://twitter.com/lalohuant/status/1571935321679450113?s=48&t=zk1Qir-FYgc9Dv3R291TKA (Valle Norte, Benito Juárez, Mexico City)

https://twitter.com/radio_formula/status/1571939424812036096?s=48&t=zk1Qir-FYgc9Dv3R291TKA, República de Uruguay, 73, Cuauhtémoc, Mexico City)

https://twitter.com/AztecaNoticias/status/1571970272412192769?s=20 (Mexico City International Airport, Capitán Carlos León, s/n, Venustiano Carranza, Mexico City).

Damage in buildings

https://twitter.com/sarahiuribeg/status/1571941006081392641?s=48&t=zk1Qir-FYgc9Dv3R291TKA (Calle de la Palma, 39, Cuauhtemoc, Mexico City).

Damage in Non-structural components

https://twitter.com/ElMundoSV/status/1571951894112751618?s=20 (Shopping Center, Colima)

Shaking in hospitals and clinics

https://www.tiktok.com/@chorizomx/video/7145170253285166341?is_from_webapp=v1&item_id=7145170253285166341 (Michoacán)

Damage to infrastructure

https://twitter.com/lopezdoriga/status/1571943436843982849 (Bridge connecting Bosque Real from Magnocentro at Palma Criolla, Interlomas, Mexico City)

Sloshing of water bodies

https://twitter.com/Jalisco_Rojo/status/1571931641903304705?s=20 (Diag. San Jorge, 93, Guadalajara, Jalisco)

https://twitter.com/i/status/1571972347690721280 (Paseo de la Reforma, 27, Cuauhtémoc, Mexico City).

https://twitter.com/ChrisFLTornado/status/1571954525413707776?s=20 (Michoacán)

https://twitter.com/soteloyafte/status/1571990092297736195?s=48&t=zk1Qir-FYgc9Dv3R291TKA (Mexico City).

https://twitter.com/i/status/1571973850795053058 (Liverpool, Cuauhtémoc, Mexico City).

https://twitter.com/i/status/1571944050433077248 (Teacapán, Escuinapa, Sinaloa)

Compilations (several locations)

A fairly complete and narrated compilation is available at
https://youtu.be/Opl5WaX3btI

Other compilations
https://twitter.com/adn40/status/1572045278441529344?s=48&t=zk1Qir-FYgc9Dv3R291TKA

https://twitter.com/temboralerta/status/1571961707953790976?s=48&t=zk1Qir-FYgc9Dv3R291TKA

M6.9 Aftershock (September 22, 2022)

https://twitter.com/i/status/1572920388534796289 (Uruapan, Michoacán)

https://twitter.com/i/status/1572836593538301952 (Coalcomán,Michoacán).

https://twitter.com/i/status/1572839477588131841 (Apatzingán,Michoacán)

https://twitter.com/i/status/1572854625916825600 (Hospital Regional Universitario, Blvrd Camino Real, Colima, Colima)

https://twitter.com/i/status/1572856894636822530 (Carretera Tecoman - Tecuanillo, Colima)

https://twitter.com/i/status/1572847282436902912 (Villa de Alvarez, Colima)

https://youtu.be/XEeeTdOz2Sw (Asunción Maria Cathedral, Tepic, Nayarit)

10 Recommended Response Strategy

Based on the information gathered in this Preliminary Virtual Reconnaissance Report (PVRR), EERI's LFE and StEER offer the following recommendations for future study.

Study of recorded ground motions: The earthquake produced a valuable set of records obtained in the different seismic networks: the broadband network operated by the Institute of Geophysics at UNAM, the strong motion accelerograph network operated by the Institute of Engineering at UNAM and the Mexico City Accelerograph Network operated by the Center of Seismic Instrumentation and Seismic Recording (CIRES). These sets of earthquake records offer the possibility to further improve our understanding of attenuation of seismic waves during subduction earthquakes as well as the response of soft soil basins.

Study of the operation and response to the Early Warning System: Mexico has operated an Early Warning System for Mexico City since 1990. The warning system provided a 58s warning to Morelia the capital of the state of Michacán and 98s warning in Mexico City. This event provides an opportunity to continue to learn about technical aspects of the operation of the early warning system as well as to learn more about the public response to the warnings. While the system was initially developed to provide warning to Mexico City, it now provides warning to 8 major cities providing an opportunity to learn about differences in response in these various cities.

Study of the Seismic Performance of Hospital Facilities: Similar to the U.S. and other countries, hospitals in Mexico are designed to higher levels of seismic forces compared to buildings of regular importance (typically forces are 50% larger). However, this does not appear to have prevented damage in many hospitals in the states of Michoacán and Colima and several of them had to be evacuated. In particular, damage in many of these hospitals was related to masonry infills which are known to be vulnerable to damage at very low levels of interstory drift such as 0.002 (Chiozzi and Miranda, 2019). This type of infill is commonly used both in the facade and as interior partitions throughout Latin America, countries around the Mediterranean Sea, and many Asian countries.

Despite the large magnitude of this event, the damage to the built environment produced by this event was limited and therefore it is not recommended at this point that EERI LFE or StEER send teams to conduct field reconnaissance. However, it is recommended to coordinate with organizations in Mexico responding to this event.

References

24 Horas (2022) “Sismo pega a inmuebles de Colima, Jalisco y Michoacán” Url: https://www.24-horas.mx/2022/09/20/sismo-pega-a-inmuebles-de-colima-jalisco-y-Michoacán/ (Last Accessed September 21, 2022)

AFmedios (2022a) “La Diócesis de Colima lamenta pérdidas de vida por sismo”. Url: https://www.afmedios.com/la-diocesis-de-colima-lamenta-perdidas-de-vida-por-sismo-senala-que-al-momento-no-hay-templos-con-danos-en-estructura/?fbclid=IwAR2l2gzS8_-dRJvb9i1rleyRyFK_cXpxkOdqQUwx4d3uJNMlvzxha9I2Y3M (Last Accessed September 21, 2022)

AFmedios (2022b) “Libramiento Campos a El Rocío, en Manzanillo, con visibles afectaciones tras sismo 19-S” Url: https://www.afmedios.com/libramiento-campos-a-el-rocio-en-manzanillo-con-visibles-afectaciones-tras-sismo-19-s/?fbclid=IwAR2PkXGCijEYLCMxaCxnW4RYQ46Qu_aessdK8BIHlKHeDyepknFYssW1mUE (Last Accessed September 21, 2022)

Alcocer, S. M., & Castaño, V. M. (2008). Evolution of codes for structural design in Mexico. Structural Survey.

Alcocer, S.M., Murià-Vila, D., Fernández-Sola, L.R., Ordaz, M., and Arce, J.C., (2020). “Observed damage in public school buildings during the 2017 Mexico earthquakes,” Earthquake Spectra del Earthquake Engineering Research Institute, ISSN 8755-2930, July, 20 pp. doi: 10.1177/8755293020926183

Allen, R. M., Gasparini, P., Kamigaichi, O., & Bose, M. (2009). The status of earthquake early warning around the world: An introductory overview. *Seismological research letters*, *80*(5), 682-693.

AM (2022). “Michoacán: Reportan tres mil casas con daños, 800 de ellas en ruinas, tras sismo de ayer” Url: https://www.am.com.mx/Michoacán/2022/9/20/Michoacán-reportan-tres-mil-casas-con-danos-800-de-ellas-en-ruinas-tras-sismo-de-ayer-623806.html (Last Accessed: September 21, 2022)

Applied Technology Council. (1978). Tentative Provisions for the Development of Seismic Regulations for Buildings, *Report ATC 3-06*, National Bureau of Standards, U.S. Government Printing Office, Washington, D.C.

Archivo Digital (2022). “Derrumbes en carretera a Minatitlán, bardas caídas e icendio e vivienda, principales daños en la Villa” Url: https://www.adcolima.com/2022/09/19/derrumbes-en-carretera-a-minatitlan-bardas-caidas-e-incendio-en-vivienda-principales-danos-en-la-villa/ (Last Accessed September 21, 2022)

Arroyo, D., García, D., Ordaz, M. et al. Strong ground-motion relations for Mexican interplate earthquakes. J Seismol 14, 769–785 (2010). https://doi.org/10.1007/s10950-010-9200-0

Arteta, C.A., Carrillo, J., Archbold, J., Gaspar, D., Pájaro, C., Araujo, G., Torregroza, A., Bonett, R., Blandon, C., Fernandez-Sola, L. Correal, J.F., Mosalam, K. M. (2019). Response of Mid-Rise Reinforced Concrete Frame Buildings to the 2017 Puebla Earthquake. Earthquake Spectra; 35 (4): 1763–1793. doi: https://doi.org/10.1193/061218EQS144M

BBC (2022). “Un fuerte terremoto de magnitud 7.7 sacude el centro de México en el aniversario de dos grandes sismos” Url: https://www.bbc.com/mundo/noticias-america-latina-62963416 (Last Accessed September 21, 2022)

Cambio de Michoacán (2022). “En seis municipios se concentran mayoría de daños por el sismo; supenden clases en cuatro” Url: https://cambiodeMichoacán.com.mx/2022/09/19/en-seis-municipios-se-concentran-mayoria-de-danos-por-el-sismo-suspenden-clases-en-cuatro/ (Last Accessed: sep 21, 2022)

Chiozzi, A., & Miranda, E. (2017). Fragility functions for masonry infill walls with in-plane loading. *Earthquake Engineering & Structural Dynamics*, *46*(15), 2831-2850.

CIRES (2022) "Efectos del Sismo M6.9 del 2022/09/22 a las 01:16:09 hrs., profundidad de 12.00 km y epicentro a 468 km de la Ciudad de México" Url: http://www.cires.org.mx/racm_mapainteractivo/. (Last Accessed September 21, 2022)

Ciudadanos en red (2022) "Reportan al menos 21 edificios con daños tras el sismo en CDMX" Url: https://ciudadanosenred.com.mx/cdmx/reportan-al-menos-21-edificios-con-danos-tras-el-sismo-en-cdmx/. (Last Accessed September 21, 2022)

CNN en Español (2022) "Al menos 2 muertos por sismo de magnitud 7,7 que sacudió a México. ¿Qué otros daños se registraron?". Url: https://cnnespanol.cnn.com/video/temblor-19s-victimas-afectacion-danos-perspectivas-mexico-muertos-heridos/ (Last Accessed September 22, 2022)

Colima Noticias (2022) "Con fracturas en gran parte de su estructura luce el Hotel gran Pacífico de Manzanillo" Url: https://www.colimanoticias.com/con-fracturas-en-gran-parte-de-su-estructura-luce-el-hotel-gran-pacifico-de-manzanillo-video/ (Last Accessed September 21, 2022)

Comisión Federal de Electricidad (1993) "Manual de diseño de obras civiles. Diseño por sismo", Departamento de Ingeniería Civil Instituto de Investigaciones Eléctricas, México

Comisión Federal de Electricidad (2015) "Manual de diseño de obras civiles. Diseño por sismo", Departamento de Ingeniería Civil Instituto de Investigaciones Eléctricas, México.

Contralinea (2022). "Determina perito inexistencia de daños estructurales en condominios de Porto Fino en Marina Vallarta" Url: https://contralinea.net/determina-perito-inexistencia-de-danos-estructurales-en-condominios-de-porto-fino-en-marina-vallarta/ (Last Accessed: September 21, 2022)

Diario de Colima (2022a). "Deja sismo dos muertos y daños materiales en Manzanillo" Url: https://diariodecolima.com/noticias/detalle/2022-09-19-deja-sismo-dos-muertos-y-daos-materiales-en-manzanillo (Last Accessed September 21, 2022)

Diario de Colima (2022b). "Hay un persona muerta en Manzanillo tras sismo, informa López Obrador" Url: https://diariodecolima.com/noticias/detalle/2022-09-19-hay-una-persona-muerta-en-manzanillo-tras-sismo-informa-lpez-obrador (Last Accessed September 21, 2022)

Diario de Colima (2022c). "Cerraran temporalmente la presidencia Municipal de Tecomán" Url: https://diariodecolima.com/noticias/detalle/2022-09-19-cerrarn-temporalmente-la-presidencia-municipal-de-tecomn (Last Accessed September 21, 2022)

Earthquake Engineering Research Institute and Sociedad Mexicana de Ingeniería Sísmica, (2006). "The January 21st, 2003 Tecomán earthquake," S.M. Alcocer and R.E. Klingner (editors). ISBN 1-932884-08-4, March, 288 pp.

El Comentario (2022) "Puente Cortés no presenta daño estructural; será reabierto en las próximas horas" Url: https://elcomentario.ucol.mx/sin-dano-estructural-puente-cortes-sera-reabierto-en-las-proximas-horas/ (Last Accessed September 21, 2022)

El Consejero (2022). "Daños Menores en Edificios y Hoteles en Puerto Vallarta: Protección Civil" Url: https://elconsejero.com.mx/danos-menores-en-edificios-y-hoteles-en-puerto-vallarta-proteccion-civil/ (Last Accessed: September 21, 2022)

El Financiero (2022a). "Sismo en México: Hotel en Puerto Vallarta niega acceso a Protección Civil tras registrar daños" Url: https://www.elfinanciero.com.mx/estados/2022/09/20/sismo-en-mexico-hotel-en-puerto-vallarta-niega-acceso-a-proteccion-civil-tras-registrar-danos/ (Last Accessed September 21, 2022)

El Financiero (2022b) “Sismo magnitud 7.7: Cierra Catedral de CDMX por afectaciones” Url: https://www.elfinanciero.com.mx/cdmx/2022/09/21/sismo-magnitud-77-cierra-catedral-de-cdmx-por-afectaciones/?fbclid=IwAR3GTET8T5iNFoUWo5C_EW_N7H6J4czzNfSy6QPqTmkgRQ3gHns9kWZfx9I (Last accesed September 21, 2022).

El Heraldo de México (2022a) “VIDEO | Médicos fueron sorprendidos por el sismo de 7.7 mientras operaban a un bebé” Url: https://heraldodemexico.com.mx/nacional/2022/9/20/video-medicos-fueron-sorprendidos-por-el-sismo-de-77-mientras-operaban-un-bebe-441405.html (Last Accessed September 21, 2022)

El Occidental (2022) “Dos templos afectados por caída de cantera tras sismo” Url: https://www.eloccidental.com.mx/local/dos-templos-afectados-por-caida-de-cantera-tras-sismo-8910910.html (Las Accessed September 21,2022)

El Sol de Morelia (2022a). “Sismo deja daños en hospitales, casas, iglesias y escuelas en Michoacán” Url: https://www.elsoldemorelia.com.mx/local/sismo-deja-danos-en-hospitales-casas-iglesias-y-escuelas-en-Michoacán-8913718.html (Last Accessed: September 20, 2022).

El Sol de Morelia (2022b). “Verifican daños en Centro de Salud de Aquila” Url: https://www.elsoldemorelia.com.mx/local/verifican-danos-en-centro-de-salud-de-aquila-8920354.html (Last Accessed September 21, 2022).

El Sol de Morelia (2022c). “Sismo de este lunes deja daños estructurales en Pátzcuaro”. Url: https://www.elsoldemorelia.com.mx/local/municipios/sismo-de-este-lunes-deja-danos-estructurales-en-patzcuaro-8911931.html (Last Accessed September 21, 2022).

El Universal (2022a). Puente de Interlomas sin daños, fue más bien "foto mal enfocada". Url: https://www.eluniversal.com.mx/metropoli/dano-en-puente-de-interlomas-es-por-foto-mal-enfocada-lo-mantendran-cerrado (Last Accessed September 22, 2022).

El Universal (2022b). “Confirman tercera víctima por sismo en Colima” Url: https://www.eluniversal.com.mx/estados/confirman-tercera-victima-por-sismo-en-colima (Last Accessed: September 22, 2022).

El Universal (2022c). “Sobse reporta 70 escuelas con riesgo bajo, cinco medio y una alto, tras sismo de 7.7 en CDMX” Url: https://www.eluniversal.com.mx/metropoli/sobse-reporta-70-escuelas-con-riesgo-bajo-cinco-medio-y-una-alto-tras-sismo-de-77-en-cdmx (Last Accessed September 22, 2022).

Esteva, L. (1987). Earthquake engineering research and practice in Mexico after the 1985 earthquakes. Bulletin of the New Zealand Society for Earthquake Engineering, 20(3), 159-200.

Esteva, L. (1988). The Mexico earthquake of September 19, 1985—Consequences, lessons, and impact on research and practice. Earthquake Spectra, 4(3), 413-426.

Excelsior (2022a). “Daños por sismos en escuelas de CDMX ascienden a 40 millones de pesos” Url: https://www.excelsior.com.mx/comunidad/danos-por-sismos-en-escuelas-de-cdmx-ascienden-a-40-millones-de-pesos/1541296 (Last Accessed September 22, 2022).

Excelsior (2022b) “Sismo registrado el pasado lunes deja daños en 76 escuelas de la CDMX” Url: https://www.excelsior.com.mx/comunidad/sismo-registrado-el-pasado-lunes-deja-danos-en-76-escuelas-de-la-cdmx/1540908 (Last accessed September 21, 2022).

Excelsior (2022c) “Edificio en colonia Centro presenta daños tras el sismo de 7.1 grados” Url: https://www.excelsior.com.mx/comunidad/edificio-en-colonia-centro-presenta-danos-tras-el-sismo-de-71-grados/1470464 (Last accessed September 21, 2022)

Facebook (2022a). Reporte del Consejo Estatal de Protección Civil de Colima. Url: https://fb.watch/fEFvFc7MoT/ (Last Accessed: September 20, 2022)

Facebook (2022b). “Así la parroquia de San Miguel Arcángel en Tacátzcuaro, Michoacán tras el sismo de esta tarde de magnitud 7.7”. Url: https://www.facebook.com/watch/?v=788006915643255&t=3 (Last Accessed September 20, 2022)

Facebook (2022c). “Gobernadora Constitucional del Estado de Colima”. Url: https://www.facebook.com/photo/?fbid=641433730672762&set=pcb.641449244004544 (Last Accessed: September 21, 2022)

Facebook (2022d) “En segundos se viene abajo su vivienda”. Url: https://www.facebook.com/EditoraDiariodeColima/posts/pfbid0Rs8ymJ9vPdE5CSwjKF6EEYrEKwjVwfFUY9PiCPnoBULtcF4qjt4jYesUgaygGYRXl (Last Accessed September 21, 2022)

Facebook (2022e) https://www.facebook.com/guiacolimaonline/photos/pcb.5701842159860770/5701840266527626 (Last Accessed September 21, 2022)

Facebook (2022f) https://www.facebook.com/photo?fbid=425961869521695&set=pcb.425963922854823 (Last Accessed September 21, 2022)

Facebook (2022g) “Daños visibles en el exterior del edificio de Plaza Country en Colima”. Url: https://www.facebook.com/afmedios/posts/pfbid0ZvtKkZKkSPnPN7Y3zfhfGCi2wzswtsiDgLSiGgXGdxLMEQPN5HpL7Yvqn8ph4gHxl (Last Accessed September 21, 2022)

Facebook (2022h) https://www.facebook.com/photo/?fbid=520659030062932&set=pcb.520659200062915 (Last Accessed September 21, 2022)

Facebook (2022i) https://www.facebook.com/photo/?fbid=520658983396270&set=pcb.520659200062915 (Last Accessed September 21, 2022)

Facebook (2022j) https://www.facebook.com/photo?fbid=520659136729588&set=pcb.520659200062915 (Last Accessed September 21, 2022)

Facebook (2022l) https://www.facebook.com/Colimaalaire/posts/pfbid0bvKXwYSRtGx8t377MHM7egfuC2NFY1NLjquvbv7KjiRJk6J8Wk4hSwcWrTFvD3ACl (Last Accessed September 21, 2022)

Facebook (2022m) https://www.facebook.com/ColimaMovimiento/photos/pcb.5512707648806594/5512702212140471 (Last Accessed September 21, 2022)

Facebook (2022n) https://www.facebook.com/ColimaMovimiento/photos/pcb.5512707648806594/5512704705473555 (Last Accessed September 21, 2022)

Facebook (2022o) https://www.facebook.com/ColimaMovimiento/photos/pcb.5512707648806594/5512704892140203 (Last Accessed September 21, 2022)

Facebook (2022p) “Museo de las Culturas de Occidente cerrará sus puertas al sufrir daños en su estructura, principalmente pilares, muros y caída de plafones” Url: https://www.facebook.com/colimanoticias/posts/pfbid03Fxjp4okPJKCZwnt3W9QizrEatqLDxJjvPgCniNDUsTNtMKacEHDCHrUoz82Y8tgl (Last Accessed September 21, 2022)

Facebook (2022q) https://www.facebook.com/ColimaMovimiento/photos/pcb.5512707648806594/5512706438806715 (Last Accessed September 21, 2022)

Facebook (2022r) Url: https://www.facebook.com/111747786891119/photos/a.111753303557234/1012402126825676/ (Last Accessed September 21, 2022)

Facebook (2022s) Url: https://www.facebook.com/depoliticapoliticosyalgomas/posts/pfbid0dDEoyopvazm9CUysPt9hbeCYdZbxpGynb1FcmH7UAq9kLmbqQoTWygyZKVYKEYaul (Last Accessed September 21, 2022)

Galvis, F. A., Miranda, E., Heresi, P., Dávalos, H., & Ruiz-García, J. (2020). Overview of collapsed buildings in Mexico City after the 19 September 2017 (Mw7.1) earthquake. Earthquake Spectra, 36(S2), 83-109.

Geo-Mexico. (2012). "Which tectonic plates affect Mexico? | Geo-Mexico, the geography of Mexico." Url: http://geo-mexico.com/?p=6277 (Last Accessed Semptember 20, 2022)

Gobierno CDMX (2022) "REGISTRO PREELIMINAR DE INMUEBLES REPORTADOS COMO DAÑADOS POR EL SISMO DEL 19 DE SEPTIEMBRE DE 2022" Url: https://docs.google.com/spreadsheets/d/1DuG0Culq7ALrFINmhaFfrSFFkET6ISd-uxC4oEqp_wQ/edit#gid=423781846 (Last accessed September 21, 2022)

Gobierno de Michoacán (2019). "Con cirugías gratuitas y consulta de especialidad, 148 beneficiados en Maruata: SSM" Url: https://salud.Michoacán.gob.mx/con-cirugias-gratuitas-y-consulta-de-especialidad-148-beneficiados-en-maruata-ssm/ (Last Accessed September 20, 2022)

Gonzalez-Huizar, H., Pérez-Campos, X., Melgar, D., 2022, Mexico rattled by pair of earthquakes, Temblor, http://doi.org/10.32858/temblor.271

Guatemala Times (2022). "Terremoto Afecta Patrimonio Del Occidente Del País" Url: https://guatemalatimes.com/terremoto-afecta-patrimonio-del-occidente-del-pas (Last Accessed September 22, 2022)

Imagen Noticias. (2022, September 21). *Así azotó el sismo de magnitud 7.7 a Tolimán, Jalisco | Noticias con Francisco Zea* [Video]. Youtube. https://www.youtube.com/watch?v=EZemowUHzCQ&ab_channel=ImagenNoticias

Informador.Mx (2022)."Temblor hoy: Tras sismo, Puerto Vallarta reporta daños en fachadas y plafones" Url: https://www.informador.mx/jalisco/Temblor-hoy-Tras-sismo-Puerto-Vallarta-reporta-danos-en-fachadas-y-plafones-20220919-0132.html (Last Accessed September 21, 2022).

INIFED (2021a). "Evaluación postsísmica de la infraestructura física educativa de México. Volumen 1: Metodología," (in Spanish), January, 232 pp.

INIFED (2021b)."Evaluación postsísmica de la infraestructura física educativa de México. Volumen 2: Introducción al comportamiento sísmico de estructuras para fines de evaluación," (in Spanish), January, 174 pp.

INIFED (2021c)."Evaluación postsísmica de la infraestructura física educativa de México. Manual de Campo,"(in Spanish), January, 122 pp.

INIFED (2021d)."Rehabilitación sísmica de la infraestructura física educativa de México. Guía Técnica," (in Spanish), January, 288 pp.

INIFED (2022)."Acciones de seguimiento al impacto del sismo 7.7 con epicentro en Coalcoman, Michoacán, en la infraestructura física educativa nacional".

Kuehn N, Bozorgnia Y, Campbell KW and Gregor N (2020) Partially non-ergodic ground-motion model for subduction regions using NGA-Subduction database. Pacific Earthquake Engineering Research Center Rept. No. 2020/04. *University of California, Berkeley, Berkeley, California*..

La Jornada (2022).“ Daños en varios estados tras sismo de magnitud 7.7” Url: https://www.jornada.com.mx/notas/2022/09/19/galeria_imagenes/danos-en-diversos-estados-tras-sismo-de-magnitud-7.7/ (Last Accessed September 21, 2022)

La Razón (2022a) “ Cierran puente "El Yaqui" en Cuajimalpa tras sismo; fisura afecta el pavimento” Url: https://www.razon.com.mx/ciudad/cierran-puente-yaqui-cuajimalpa-sismo-fisura-afecta-pavimento-498913 (Last accessed September 21, 2022)

La Razón (2022b) https://imagenes.razon.com.mx/files/image_940_470/uploads/2020/06/02/5ed62df507b28.jpeg (Last accessed September 21, 2022)

Meridiano.mx (2022) “A punto de caer cúpula de la Catedral de Tepic tras el sismo” Url: https://meridiano.mx/2022/09/19/a-punto-de-caer-cupula-de-la-catedral-de-tepic-tras-el-sismo/ (Last accessed September 21, 2022)

MiMorelia (2022). “Suspensión de clases por sismo se extiende a 10 municipios en Michoacán” Url: https://mimorelia.com/noticias/educacion/suspensión-de-clases-se-extiende-a-10-municipios-en-michoacán (Last Accessed September 21, 2022)

Milenio (2022a) “Así quedaron los edificios tras el sismo de 19 de septiembre: grietas, inclinaciones y muebles en la calle” Url: https://www.milenio.com/politica/comunidad/quedaron-edificios-sismo-19-septiembre-2022. (Last accesed September 21, 2022).

Milenio (2022b). “Daños en Edomex por el temblor del 19 de septiembre 2022; esto sabemos” Url: https://www.milenio.com/politica/comunidad/estos-son-los-danos-que-dejo-el-temblor-en-edomex-hoy-19-de-septiembre (Last accesed September 21, 2022).

Newtral (2022) “México y el día 19 de septiembre: tres terremotos en casi 50 años marcan el calendario” Url: https://www.newtral.es/terremoto-mexico/20220920/ (Last accessed September 21, 2022)

Noticias Manzanillo (2022). “Tras el Sismo, el Puerto de Manzanillo ya Opera al 100 por Ciento este Miércoles 21 de Septiembre”. Url: https://noticiasmanzanillo.com/tras-el-sismo-el-puerto-de-manzanillo-ya-opera-al-100-por-ciento-este-miercoles-21-de-septiembre/. (Last Accessed September 21, 2022).

Notivideo (2022). https://www.notivideo.com/fotos/notas/09-2022/33710-big.jpg (Last Accessed September 21, 2022)

Noventagrados (2022). “SEE contabiliza 334 escuelas dañadas en por el sismo” Url: https://www.noventagrados.com.mx/politica/see-contabiliza-334-escuelas-danadas-en-por-el-sismo.htm (Last Accessed September 22, 2022)

Once Noticias (2022) “CDMX contabiliza afectaciones en 76 escuelas públicas tras sismo” Url: https://oncenoticias.digital/cdmx/autoridad-educativa-federal-registra-en-cdmx-afectaciones-en-76-escuelas-publicas-tras-sismo/166210/ (Last accessed September 21, 2022)

Ordaz, M., & Meli, R. (2004, August). Seismic design and codes in Mexico. In Proceedings of the Thirteenth World Conference on Earthquake Engineering (CD-ROM). Canadian Association for Earthquake Engineering, Vancouver, BC, Canada (No. 4000).

Pacific Tsunami Warning Center (PTWC) (2022a). Tsunami message number 1. Url: https://www.tsunami.gov/events/PHEB/2022/09/19/22262001/1/WEPA40/WEPA40.txt

Pacific Tsunami Warning Center (PTWC) (2022b). Tsunami message number 7. Url: https://www.tsunami.gov/events/PHEB/2022/09/19/22262001/7/WEPA40/WEPA40.txt

Parker, G. A., Stewart, J. P., Boore, D. M., Atkinson, G. M., & Hassani, B. (2022). NGA-subduction global ground motion models with regional adjustment factors. Earthquake Spectra, 38(1), 456-493.

PBS (2022) https://pbs.twimg.com/media/FdISerfXoAgmN1_?format=jpg&name=large (Last accessed September 22, 2022).

Proceso (2022a). “Jalisco reporta daños en edificios históricos y en planteles de la UdeG por sismo de 7.7” Url: https://www.proceso.com.mx/nacional/2022/9/19/jalisco-reporta-danos-en-edificios-historicos-en-planteles-de-la-udeg-por-sismo-de-77-293576.html (Last Accessed September 21, 2022)

Proceso (2022b). “Primaria de Iztapalapa afectada por sismo no tiene daño estructural” Url: https://www.proceso.com.mx/nacional/2022/9/21/primaria-de-iztapalapa-afectada-por-sismo-no-tiene-dano-estructural-293769.html (Last Accessed September 22, 2022)

Publimetro (2022). “Estos son los daños por el sismo del 19 de septiembre en Colima” Url: https://www.publimetro.com.mx/noticias/2022/09/19/asi-se-vivio-el-sismo-en-el-estado-de-colima/galeria/ (Last Accessed September 21, 2022)

Ramírez, F., Alcocer, S.M., and Murià, D. (2018). https://documents1.worldbank.org/curated/en/496651571052786670/pdf/Advisory-Services-to-Support-the-Recovery-of-School-Infrastructure-in-Mexico-Affected-by-the-September-2017-Earthquakes-Executive-Summary.pdf (Last Accessed September 21, 2022)

Reforma (2022). “Daño al patrimonio en cuatro estados por sismo 19S” Url: https://www.reforma.com/aplicacioneslibre/preacceso/articulo/default.aspx?__rval=1&urlredirect=/dano-al-patrimonio-en-cuatro-estados-por-sismo-19s/ar2472931 (Last Accessed September 24, 2022)

Revolución 3.0 (2022). “Sin pérdida de vidas humanas, saldo del sismo en Michoacán: gobiernos evaluan daños materiales” Url: https://revolucion.news/sin-perdida-de-vidas-humanas-saldo-del-sismo-en-michoacan-gobiernos-evaluan-danos-materiales/ (Last Accessed September 21, 2022)

Rodríguez, M, de la Torre, Ó, Sáenz de Miera, M, and Zamudio, R. (1997). 6 Instalaciones Portuarias. In El macrosismo de Manzanillo del 9 de octubre de 1995 (pp. 148-158). Colima, México: Sociedad Mexicana de Ingeniería Sísmica/Arturo Tena Colunga. ISBN 968-6190-83-X.

Rosenblueth, E. (1979). Seismic design requirements in a Mexican 1976 code. Earthquake Engineering & Structural Dynamics, 7(1), 49-61.

Sentido Común (2022) “Sismo de 7.7 grados en Colima deja un muerto, daños y marea elevada en Manzanillo” Url: https://sentido-comun.com.mx/2022/09/20/sismo-de-7-7-grados-en-colima-deja-un-muerto-danos-y-marea-elevada-en-manzanillo-imagenes-fuertes/ (Last Accessed September 21, 2022)

Servicio Sismológico Nacional (SSN) (2022a), Instituto de Geofísica, Universidad Nacional Autónoma de México, México. (19 de septiembre de 2022) http://www.ssn.unam.mx

Servicio Sismológico Nacional (SSN) (2022b) Reporte Especial - Sismo del 19 de Septiembre de 2022, Michoacán (M 7.7). IGEF - UNAM, México. (http://www.ssn.unam.mx/sismicidad/reportes-especiales/2022/SSNMX_rep_esp_20220919_Michoacán_M74.pdf)

Singh, S. K., Astiz, L., & Havskov, J. (1981). Seismic gaps and recurrence periods of large earthquakes along the Mexican subduction zone: A reexamination. Bulletin of the Seismological Society of America, 71(3), 827–843.

Singh, S. K., Rodríguez, M., & Espindola, J. M. (1984). A catalog of shallow earthquakes of Mexico from 1900 to 1981. Bulletin of the Seismological Society of America, 74(1), 267-279.

Suárez, G., Espinosa-Aranda, J. M., Cuéllar, A., Ibarrola, G., García, A., Zavala, M., ... & Islas, R. (2018). A dedicated seismic early warning network: The Mexican Seismic Alert System (SASMEX). Seismological Research Letters, 89(2A), 382-391.

Tena-Colunga, A., Mena-Hernández, U., Pérez-Rocha, L., Avilés, J., Ordaz, M., & Vilar, J. (2009). Updated seismic design guidelines for model building code of Mexico. Earthquake Spectra, 25(4), 869-898.

Twitter (2022a). https://twitter.com/CNPC_MX/status/1572238401633394689/photo/1 (Last Accessed September 21, 2022)

Twitter (2022b). https://twitter.com/CFEmx/status/1572318009955614720/photo/1 (Last Accessed September 21, 2022)

Twitter (2022c). https://mobile.twitter.com/Quadratin_/status/1571961756372856832 (Last Accessed September 21, 2022)

Twitter (2022d). https://twitter.com/Diario_deColima/status/1572057958137368576?s=20 (Last Accessed September 21, 2022)

Twitter (2022e). https://twitter.com/ElMundoSV/status/1571950206492774401?s=20 (Last Accessed September 21, 2022)

Twitter (2022f). https://twitter.com/indira_vizcaino/status/1572330145880608768 (Last Accessed September 21, 2022)

Twitter (2022g). https://twitter.com/Quadratin_/status/1571936767334354944 (Last Accessed September 21, 2022)

Twitter (2022h). https://twitter.com/indira_vizcaino/status/1572043725702049793/photo/1 (Last Accessed September 21, 2022)

Twitter (2022i). https://twitter.com/vozMichoacán/status/1572078359688904704?s=204 (Last Accessed September 21, 2022)

Twitter (2022j). https://twitter.com/Quadratin_/status/1571941766433214464?s=20 (Last Accessed September 21, 2022)

Twitter (2022k). https://twitter.com/erikabecerrar/status/1571977298869354500 (Last Accessed September 21, 2022)

Twitter (2022l). https://twitter.com/indira_vizcaino/status/1572298945015218176 (Last Accessed September 21, 2022)

Twitter (2022m). https://twitter.com/indira_vizcaino/status/1572274309758087170?s=20 (Last Accessed September 21, 2022)

Twitter (2022n). https://twitter.com/CarlosCuerna/status/1571980553527631873?s=20 (Last Accessed September 21, 2022)

Twitter (2022o). https://twitter.com/indira_vizcaino/status/1572387937689702400 (Last Accessed September 21, 2022)

Twitter (2022p). https://twitter.com/SMareograficoN/status/1572009493134987264/photo/1 (Last Accessed September 22, 2022)

Twitter (2022q). https://twitter.com/SMareograficoN/status/1572007475695718401/photo/1 (Last Accessed September 22, 2022)

Twitter (2022r). https://twitter.com/CNPC_MX/status/1571930172454014982 (Last Accessed September 22, 2022)

Twitter (2022s). https://twitter.com/CNPC_MX/status/1571940576123322370 (Last Accessed September 22, 2022)

Twitter (2022t) https://twitter.com/RuidoEnLaRed/status/1571951418445029377?s=20&t=BmOf5ocZTfjD6n_DfayDdg. (Last accesed September 21, 2022).

Twitter (2022u) https://twitter.com/roxarut/status/1571934753443713025?s=20&t=2R59PNWlvE4_7MCdOuXlRw. (Last accesed September 21, 2022).

Twitter (2022v) https://twitter.com/fer_marsars/status/1571932117935788032?s=48&t=zk1Qir-FYgc9Dv3R291TKA. (Last accesed September 21, 2022)

Twitter (2022w) https://mobile.twitter.com/Quadratin_/status/1571934695075487744 (Last Accessed September 21, 2022)

Twitter (2022x) https://twitter.com/SarahiUribeG/status/1571941006081392641?s=20&t=PxSRzbqWorsOKdV0sBgwZw. (Last Accessed September 21, 2022)

Twitter (2022y) https://twitter.com/keyrasaram/status/1572435624866750467?s=48&t=HRIOjMApC8TjdN4q52nZ3w. (Last accesed September 21, 2022)

Twitter (2022z) https://twitter.com/EnFocoNoticias1/status/1572021624320278528?s=20&t=jIANrZfm7we7bmaPOE0xIg. (Last accesed September 21, 2022).

Twitter (2022aa) https://twitter.com/elsolde_mexico/status/1572616773631086592?s=20&t=SftaY57qvQYEhxA0rhnRAQ. (Last accesed September 21, 2022).

Unidad de Instrumentación Sísmica (UIS) (2022a) Sismo del 19 de septiembre de 2022 Coalcomán, Mich, México (M7.4) 13:05:09 Hora Local - Reporte Preliminar, Parámetros del Movimiento del Suelo. Instituto de Ingeniería UNAM.

Unidad de Instrumentación Sísmica (UIS) (2022b) Sismo del 22 de septiembre de 2022 Coalcomán, Mich, México (M6.9) 01:16:09 Hora Local - Reporte Preliminar, Parámetros del Movimiento del Terreno. Instituto de Ingeniería UNAM.

Uno TV (2022) "Éstos son los hospitales y carreteras afectados por el sismo de 7.7 en Colima" Url: https://www.unotv.com/estados/colima/colima-sismo-dejo-dano-en-estos-hospitales-y-carreteras/ (Last Accessed September 21, 2022)

U.S. Geological Survey (USGS) (2022a) "M 7.6 - 37 km SE of Aquila, Mexico" September 19, 2022. https://earthquake.usgs.gov/earthquakes/eventpage/us7000i9bw/executive

U.S. Geological Survey (USGS) (2022b). ANSS Comprehensive Earthquake Catalog (ComCat) Documentation. Retrieved September 20, 2022, from https://earthquake.usgs.gov/data/comcat/

U.S. Geological Survey (USGS) (2022c) "M 6.8 - Michoacán, Mexico" September 22, 2022. https://earthquake.usgs.gov/earthquakes/eventpage/us7000ia36/executive

WRadio (2022) "Suman 21 inmuebles dañados a causa del sismo del 19S en CDMX" Url: https://wradio.com.mx/radio/2022/09/20/nacional/1663693126_921896.html (Last accesed September 21, 2022).

Quadratin (2022a). "Se derrumba parte del cerro sobre carretera a Villa Victoria en Michoacán". Url: https://sinaloa.quadratin.com.mx/nacionales/se-derrumba-parte-del-cerro-sobre-carretera-a-villa-victoria-en-Michoacán/ (Last Accessed: September 21, 2022)

Quadratin (2022b). "Suspenden SEE clases en 8 municipios por sismo de este lunes". Url: https://www.quadratin.com.mx/educativas/suspende-see-clases-en-8-municipios-por-sismo-de-este-lunes (Last Accessed: September 21, 2022)