Crucecitas, Mexico Mw 7.4 Earthquake

June 23, 2020

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NHERI DesignSafe Project ID: PRJ-2805

PRELIMINARY VIRTUAL RECONNAISSANCE REPORT (PVRR)

Structural failure of a medical unit located in Oaxaca, Mexico (Twitter, 2020l).

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PREFACE

The National Science Foundation (NSF) awarded a 2-year EAGER grant (CMMI 1841667) to a consortium of universities to form the Structural Extreme Events Reconnaissance (StEER) Network (see https://www.steer.network for more details). *StEER builds societal resilience by generating new knowledge on the performance of the built environment through impactful post-disaster reconnaissance disseminated to affected communities.* StEER achieves this vision by: (1) deepening structural engineers' **capacity** for post-event reconnaissance by promoting community-driven standards, best practices, and training, as well as their understanding of the effect of natural hazards on society; (2) **coordination** leveraging its distributed network of members and partners for early, efficient and impactful responses to disasters; and (3) **collaboration** that broadly engages communities of research, practice and policy to accelerate learning from disasters. StEER works closely with other extreme event reconnaissance organizations and the Natural Hazards Engineering Research Infrastructure (NHERI) to foster greater potentials for truly impactful interdisciplinary reconnaissance after disasters.

Under the banner of NHERI's CONVERGE node, StEER works closely with the wider Extreme Events Reconnaissance consortium including the Geotechnical Extreme Events Reconnaissance (GEER) Association and the networks for Nearshore Extreme Event Reconnaissance (NEER), Interdisciplinary Science and Engineering Extreme Events Research (ISEEER) and Social Science Extreme Events Research (SSEER), as well as the NHERI RAPID equipment facility and NHERI DesignSafe CI, long-term home to all StEER data and reports. While the StEER network currently consists of the three primary nodes located at the University of Notre Dame (Coordinating Node), University of Florida (Atlantic/Gulf Regional Node), and University of California, Berkeley (Pacific Regional Node), StEER aspires to build a network of regional nodes worldwide to enable swift and high quality responses to major disasters globally.

StEER's founding organizational structure includes a governance layer comprised of core leadership with Associate Directors for each of the primary hazards as well as cross-cutting areas of Assessment Technologies and Data Standards, led by the following individuals:

- **Tracy Kijewski-Correa (PI),** University of Notre Dame, serves as StEER Director responsible for overseeing the design and operationalization of the network and representing StEER in the NHERI Converge Leadership Corps.
- **Khalid Mosalam (co-PI),** University of California, Berkeley, serves as StEER Associate Director for Seismic Hazards, leading StEER's Pacific Regional node and serving as primary liaison to the Earthquake Engineering community.
- **David O. Prevatt (co-PI),** University of Florida, serves as StEER Associate Director for Wind Hazards, leading StEER's Atlantic/Gulf Regional node and serving as primary liaison to the Wind Engineering community.
- **Ian Robertson (co-PI),** University of Hawai'i at Manoa, serves as StEER Associate Director for Coastal Hazards, serving as a primary liaison to the coastal engineering community and ensuring a robust capacity for multi-hazard assessments.
- **David Roueche (co-PI),** Auburn University, serves as StEER Associate Director for Data Standards, ensuring StEER processes deliver reliable and standardized reconnaissance data suitable for re-use by the community.

ATTRIBUTION GUIDANCE

Reference to PVRR Analyses, Discussions or Recommendations

Reference to the analyses, discussions or recommendations within this report should be cited using the full citation information and DOI from DesignSafe (these are available at https://www.steer.network/products).

Citing Images from this PVRR

Images in this report are taken from public sources. Each figure caption specifies the source; re-use of the image should cite that source directly. Note that public sources might still have copyright issues and depending on the use case, the user may need to secure additional permissions/rights from the original copyright owner.

ACKNOWLEDGMENTS

This material is based upon work supported by the National Science Foundation under Grant No. CMMI 1841667. Any opinions, findings, and conclusions or recommendations expressed in this material are those of StEER and do not necessarily reflect the views of the National Science Foundation. All authors and editors listed on the cover page participate as volunteer professionals. Thus, any opinions, findings, and conclusions or recommendations expressed herein are those of the individual contributors and do not necessarily reflect the views of their employer or other institutions and organizations with which they affiliate.

Special thanks also go to Prof. Miguel Angel Jaimes, Prof. Gustavo Ayala, Prof. Eduardo Reinoso, Prof. Leonardo Ramírez of the Institute of Engineering and Prof. Xyoli Perez-Campos of the Institute of Geophysics who provided valuable information about the earthquake which was very valuable during the preparation of this preliminary Virtual Reconnaissance Report (PVRR). Both Research Institutes are at the National Autonomous University of Mexico, UNAM.

The sharing of information via Slack by the entire NHERI community was tremendously helpful and much appreciated. StEER recognizes the efforts of the DesignSafe CI team who continuously supported and responded to StEER's emerging needs.

For a full listing of all StEER products (briefings, reports and datasets) please visit the StEER website: https://www.steer.network/products

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EXECUTIVE SUMMARY

On June 23rd, 2020, at 10:29 am local time, a moment magnitude 7.4 earthquake struck near the towns of La Crucecita and Huatulco in the state of Oaxaca in Mexico. The State of Oaxaca is one of the poorest states in Mexico where approximately two-thirds of the population are below the poverty rate. The largest recorded peak ground acceleration was 0.44g recorded near Huatulco by one of the broadband stations of the Institute of Geophysics of the National Autonomous University of Mexico. Since 1991 Mexico operates an Early Warning System which for this event provided warning ranging from 30 seconds for the capital of Oaxaca located at approximately 170 km from the epicenter to almost 2 minutes for Mexico City located approximately 530 away from the epicenter.

The earthquake produced 9 deaths, hundreds of injuries, damage to more than 2,000 residential buildings, damage to many commercial structures and damage to infrastructure including highways, bridges, hospitals, oil refineries.

The purpose of this Preliminary Virtual Reconnaissance Report is to provide a summary of the characteristics of this event, the seismicity of the regions and to provide a brief description of the main effects of the earthquake collected from publicly available information.

The earthquake highlighted the important vulnerability of adobe structures that were responsible for many of the collapses in the state of Oaxaca.

1.0 Introduction

On June 23rd, 2020, at approximately 10:29 am local time, a moment magnitude 7.4 earthquake struck 12 km south-southwest of Santa Maria Zapotitlán, Mexico. The epicentral coordinates reported by the U.S. Geological Survey (USGS, 2020a) and the Servicio Sismológico Nacional de México (SSN, 2020a) were 16.029°N, 95.901°W and 15.582°N, 96.079°W, respectively. Servicio Sismológico Nacional reported a slightly larger magnitude for the event at Mw 7.5 (SSN, 2020a). The USGS reported a hypocenter depth of 26.3 km, whereas the SSN reported a depth of 20 km. At the time of writing of this report, over 2060 aftershocks (Gobierno de Mexico, 2020) have occurred with magnitudes as large as Mw 5.5. This earthquake caused extensive damage to structures in the region near to the epicenter, and with damage reported as far as Mexico City, located at over 530 km from the epicenter.

The initial product of the StEER response to the 2020 Oaxaca Mexico Earthquake is this **Preliminary Virtual Reconnaissance Report (PVRR)**, which is intended to:

1. Provide an overview of the main characteristics of the event;

2. Summarize the seismicity of this region of Mexico;

3. Provide a brief overview of seismic codes and construction practices in Mexico;

4. Summarize preliminary reports of damage to wide-range of structures and infrastructure; and

5. Provide some preliminary recommendations.

2.0 Hazard Characteristics

2.1 Tectonic Summary

Mexico is located in a very active seismic region. The seismicity in Mexico is the result of the relative motion between five tectonic plates: North American, Pacific, Rivera, Cocos and Caribbean, which are shown in Figure 2.1 (Pérez-Campos et al., 2018). Since 1900 it has experienced 211 earthquakes with magnitudes equal to or larger than 6.5 (Servicio Sismológico Nacional, 2020b). This is an average of approximately one per year. To put this seismicity into perspective, during the same period of time the contiguous 48 United States have only experienced 54 earthquakes with magnitudes equal to or larger than 6.5, for an average of one every 2.2 years. Of the 211 earthquakes in Mexico, 81 have had magnitudes between 7 and 8 and four with magnitudes larger 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 subduction events that occur in the interface between the Cocos and the North American Plates, which converge at a rate of approximately 64 mm/year in the Oaxaca region (Singh et al., 2000). 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 in 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. An example of subduction event between the Rivera and North American plates is the 1932 Mw 8.1 Jalisco earthquake (Singh et al 1985).

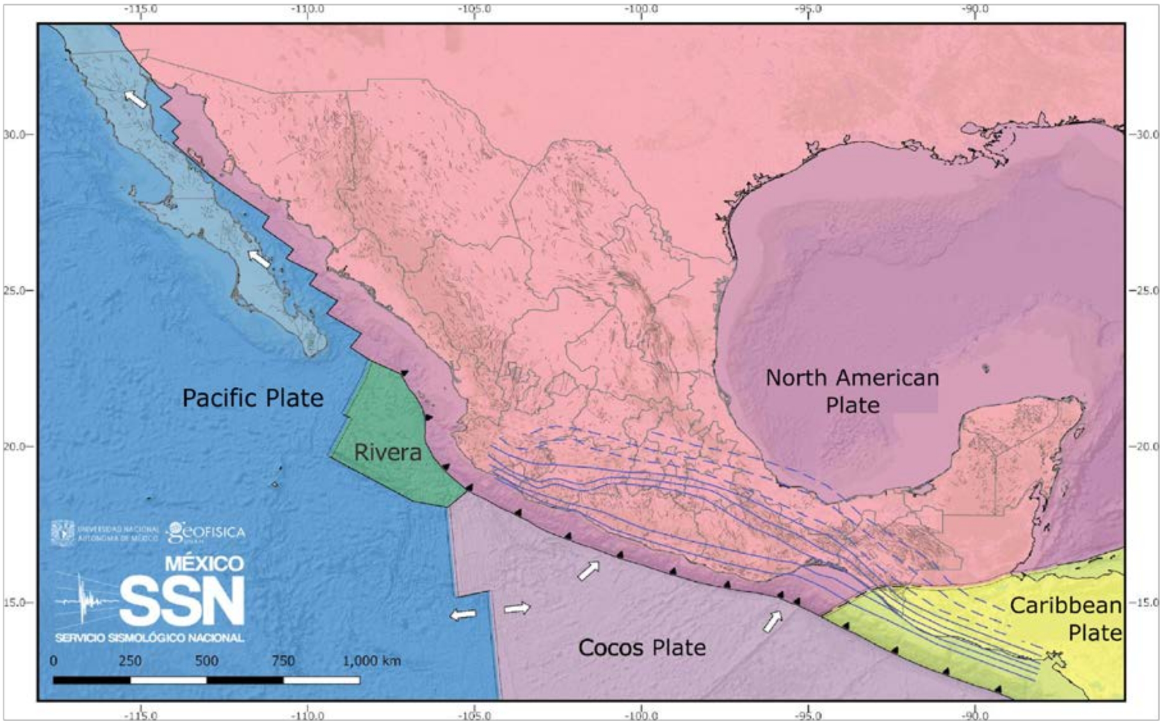


Figure 2.1. Tectonic plates that determine the seismicity in Mexico (Adapted from SSN, 2020a).

In the northwest of Mexico 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. Moreover, 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).

As mentioned previously, Mexico is a highly active seismic country. In May 2020 alone the SSN reported approximately 2,000 earthquakes with epicenters within Mexico with magnitudes ranging from 1.8 to 6.1 (SSN, 2020c). Figure 2.2 shows the epicenter location of these earthquakes. This figure illustrates that most earthquakes in Mexico are associated with the subduction trench along the pacific coast.

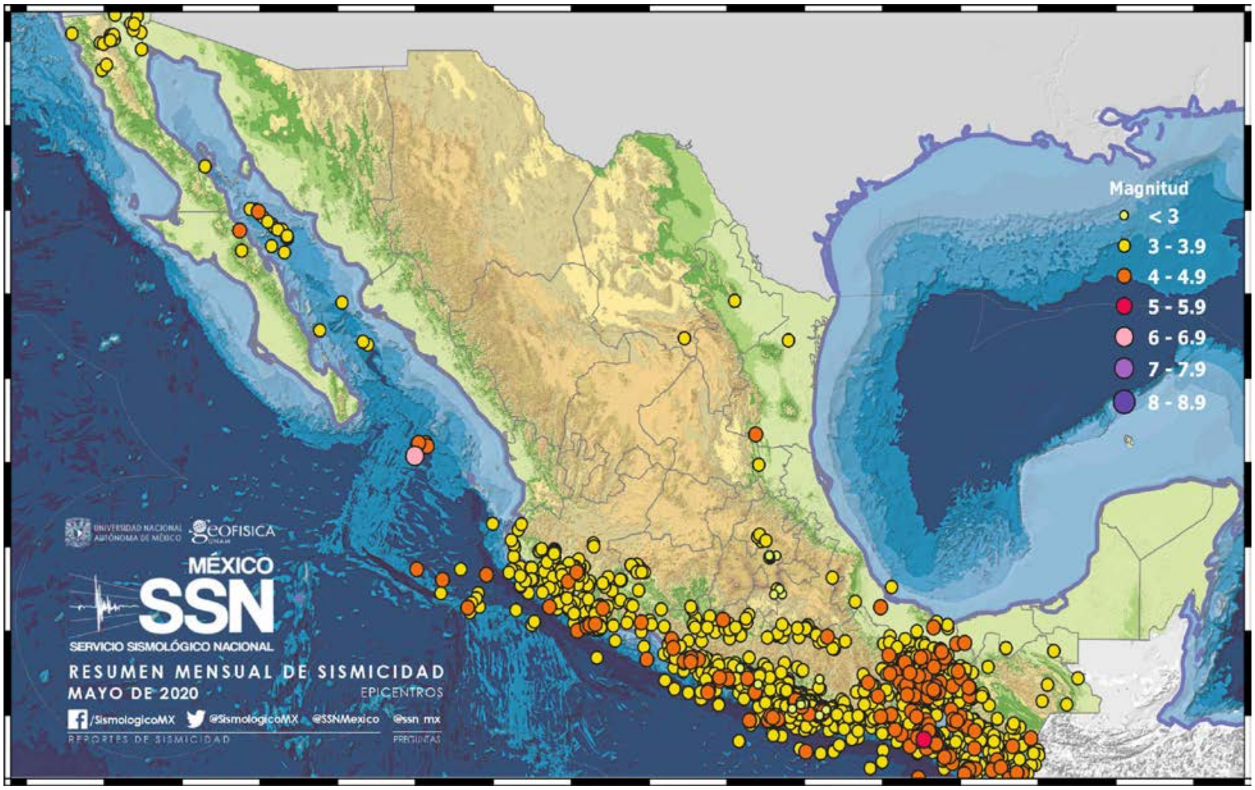


Figure 2.2. Epicenter location and magnitude of seismic events in Mexico for the month of May, 2020 (SSN, 2020c).

Historically, many significant interplate and intraplate earthquakes have happened in Mexico, causing widespread damage in the country. Some examples are:

- **<u>1932</u>**: A Mw 8.4 thrust earthquake occurred in the region of Jalisco, several hundred kilometers to the northwest of the 2020 Oaxaca earthquake.
- **<u>1980:</u>** On October 24, 1980, a Ms7.0 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.
- **<u>1985</u>**: The deadliest earthquake in Mexico happened on September 19, in the Michoacan region, approximately 700 km to the northwest of the 2020 Oaxaca event. This Mw 8.0 earthquake resulted in at least 9,500 fatalities, injured about 30,000 people, and left 100,000 people homeless.
- **<u>1995</u>**: 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.
- **<u>2003</u>**: 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.
- **<u>2012</u>**: A Mw 7.4 earthquake that occurred 250 km to the northwest of the 2020 Oaxaca earthquake killed two people and injured 11 in the Oaxaca region.

- **2017**: On September 8th, a Mw 8.2 earthquake occurred offshore Chiapas, 240 km southeast of the 2020 Oaxaca earthquake. 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, 390 km northwest of the 2020 Oaxaca earthquake, resulting in over 300 fatalities and significant damage in Mexico City and the surrounding region.
- **2018**: In February, a Mw 7.2 struck 225 km to the northwest of the 2020 Oaxaca earthquake that injured four people and damaged 1,000 homes in Oaxaca.

Approximately, one fourth of the earthquakes in Mexico have epicenters within the state of Oaxaca (SSN, 2020c). Table 2.1 lists some of the most important seismic events in Oaxaca:

Table 2.1. Historic earthquakes with epicenter in the state of Oaxaca.

Date	Latitude, °N	Longitude, °W	Depth [km]	Magnitude
October 3,1864	18.70	97.40	-	7.3*
May 17, 1879	18.60	98.00	-	7.0*
February 10, 1928	18.26	97.99	84	Ms 6.5
January 15, 1931	16.40	96.87	40	Ms 7.8
July 26,1937	18.48	96.08	85	Ms 7.3
October 11, 1945	18.32	97.65	95	Ms 6.5
May 24, 1959	17.72	97.72	80	Ms 6.8
August 28, 1973	18.30	96.53	82	Mw 7.0
October 24 1980	18.03	98.27	65	Mw 7.0
June 15, 1999	18.20	97.47	60	Mw 7.0
September 7, 2017	14.76	94.10	58	Mw 8.2

*The type of magnitude scale is not known.

2.2 Earthquake Details

On June 23, 2020, at approximately 10:29 am local time, an earthquake occurred 12 km SSW of Santa Maria Zapotitlan, Mexico. Figure 2.3 shows the epicenter of the earthquake. The moment magnitude of the event was 7.4 according to the USGS (2020), and 7.5 according to the SSN (2020). The USGS located the hypocenter at 16.029°N, 95.901°W (±7 km), with a depth of 26.3 km (±3.6 km) (USGS, 2020a), whereas the SSN located it at 15.582°N, 96.079°W, with a depth of 20km (SSN, 2020). The earthquake was followed by more than 2000 aftershocks as indicated by the Mexico Civil Protection Force (Gobierno de Mexico, 2020).

Figure 2.3. Epicenter of the Oaxaca, Mexico earthquake (USGS, 2020a).

The earthquake mechanism 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 thrust fault striking towards the West or on a steeply dipping reverse fault striking towards the ESE. Although earthquakes of this magnitude have rupture areas of about 70 x 35 km (length x width), the USGS computed a rupture plane of about 30 x 20 km (USGS, 2020a). The rupture plane found by USGS also had a strike of 263.5° and a dip angle of 23.0°, with a maximum slip of 8.2 m (USGS, 2020a). Figure 2.4 shows the dimensions of the fault plane and the slip distribution, as well as its surface projection. Given the small area over which slip occurred, the estimations of rupture distance R_{rup} in Section 3 are set equal to the hypocentral distance R_{hyp}.

USGS Shakemap (Fig. 2.5) estimates an intensity of VIII and a Peak Ground Acceleration (PGA) of approximately 0.4g near the epicenter. This high level of shaking is consistent with the observed damage including the collapsed buildings (USGS, 2020a). Similarly, Figure 2.6 shows the preliminary map of the geometric mean of the two horizontal components of the peak ground acceleration (PGA) estimated by the Instituto de Ingeniería (Institute of Engineering) at UNAM.

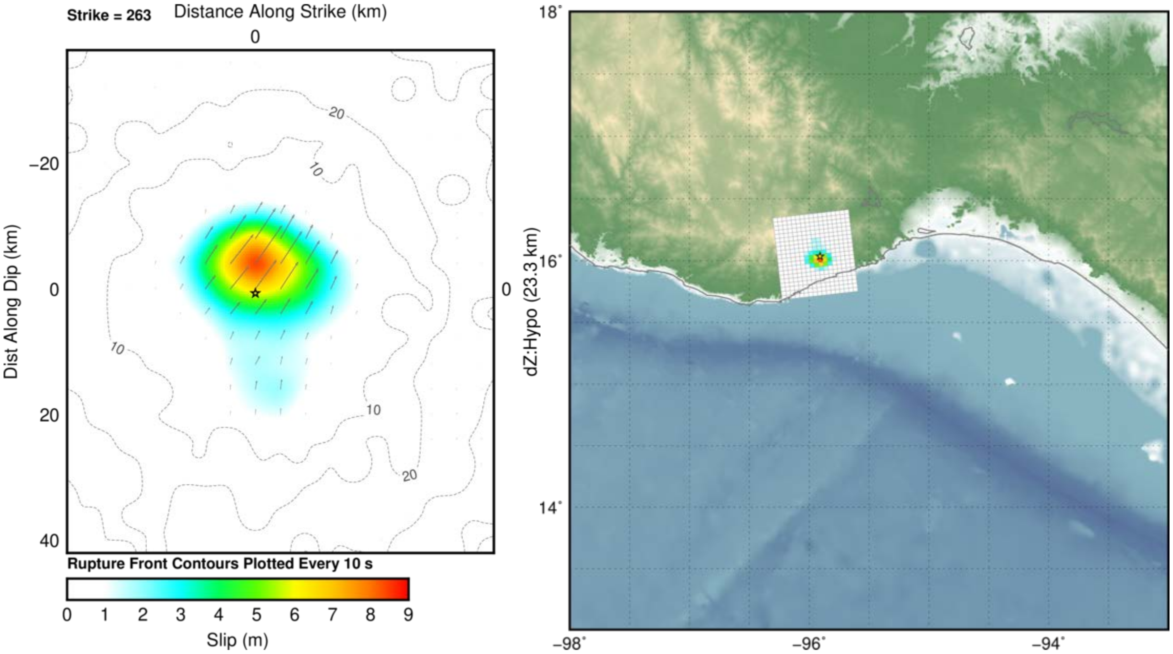
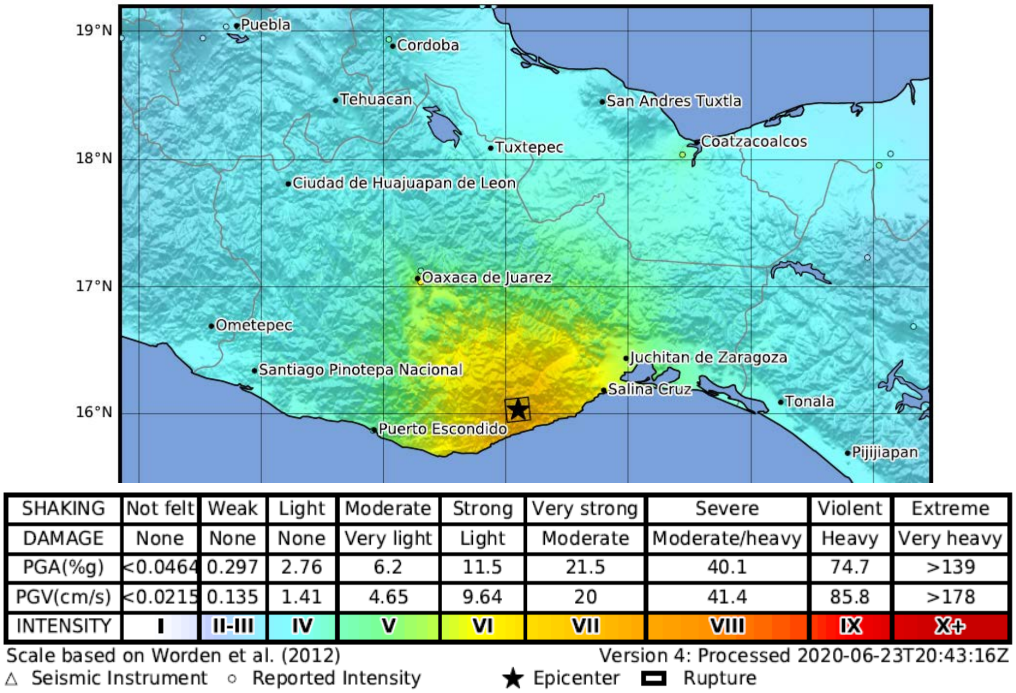


Figure 2.4. Cross-section and surface projection of slip distribution (USGS, 2020a).



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 4: Processed 2020-06-23T20:43:16Z
△ Seismic Instrument ○ Reported Intensity ★ Epicenter ▭ Rupture

Figure 2.5. Intensities estimated from ShakeMap (USGS, 2020a).

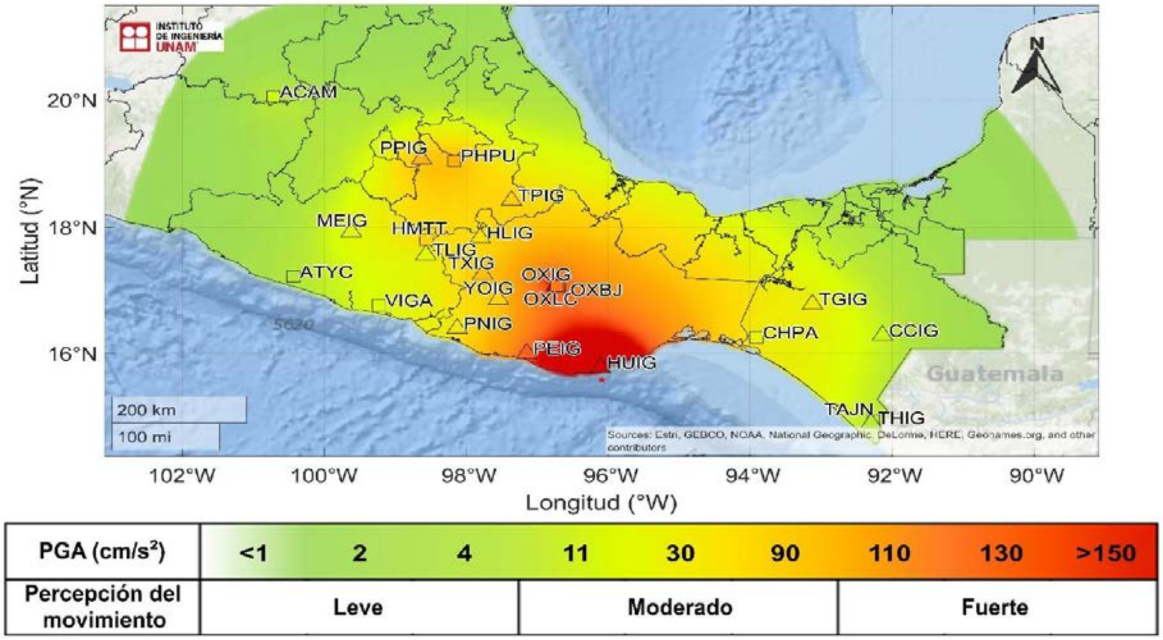


Figure 2.6. Intensity map estimated from recorded PGAs in stations of the Institute of Engineering at UNAM (Adapted from SSN, 2020a).

2.3 Tsunami and Tsunami Warning

The earthquake triggered a relatively small tsunami that affected coastal waters along the Oaxaca coastline. The effects of the tsunami were observed in the form of drawdown at beaches and marinas, and outflow currents in river estuaries. At the time of writing this report there were no reports of inundation or damage caused by the tsunami waves.

The tide gauge record from Salina Cruz, Oaxaca shows tsunami waves starting at low tide and ending before high tide (Figure 2.7). The maximum positive wave amplitudes were about 2.3 feet (Figure 2.8). These peaks match, but do not exceed, the daily high tide, while the negative amplitudes resulted in about 1.5 feet more drawdown than the anticipated tidal drawdown on June 23 (Figure 2.7). The leading negative wave arrived approximately 11:28 AM local time, about one hour after the earthquake. The Pacific Tsunami Warning Center (PTWC) broadcast tsunami warnings starting at 11:39 AM local time (Figure 2.8).

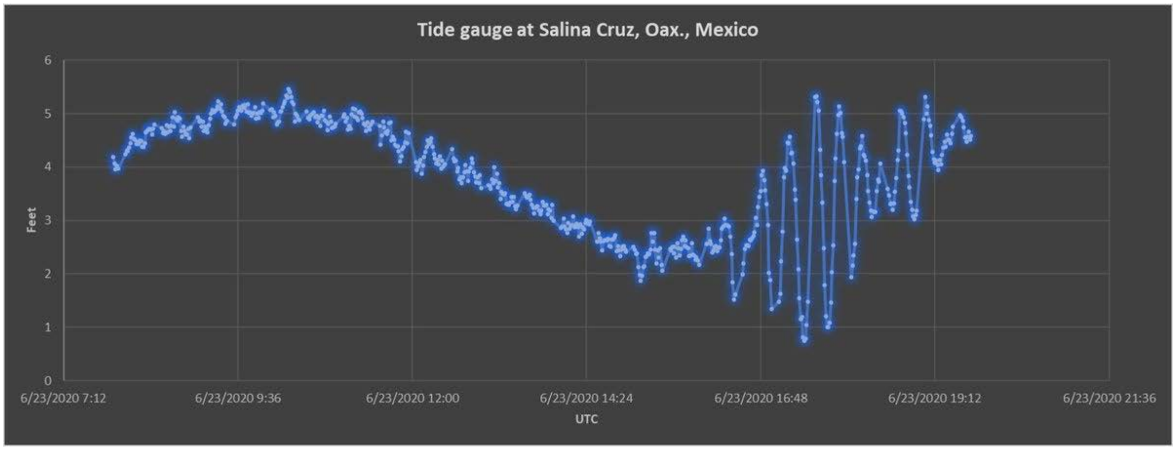
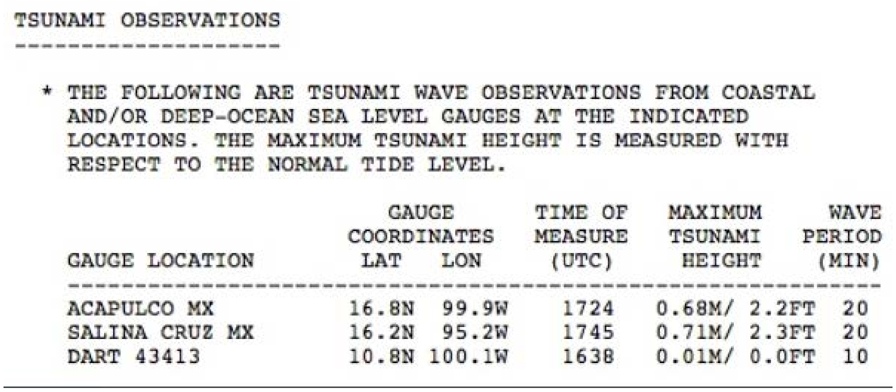


Figure 2.7. Tide gauge record from Salina Cruz, Oaxaca, for June 23, 2020. Tide gauge located at 16.1684°N, 95.1968°W.
(https://twitter.com/nickgraehl/status/1275522014027997185?s=20)



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TSUNAMI OBSERVATIONS
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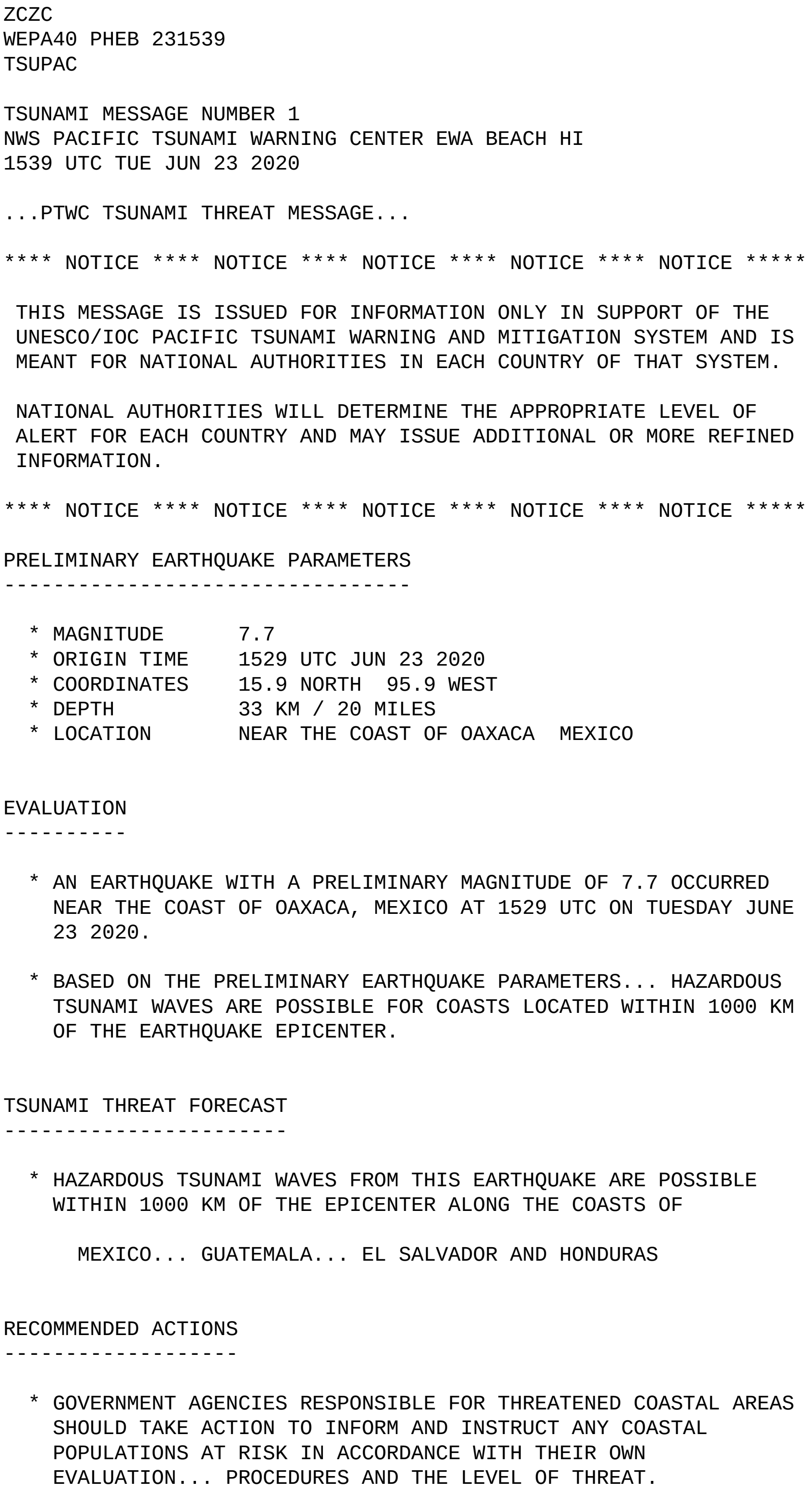
  * THE FOLLOWING ARE TSUNAMI WAVE OBSERVATIONS FROM COASTAL
    AND/OR DEEP-OCEAN SEA LEVEL GAUGES AT THE INDICATED
    LOCATIONS. THE MAXIMUM TSUNAMI HEIGHT IS MEASURED WITH
    RESPECT TO THE NORMAL TIDE LEVEL.

                          GAUGE       TIME OF   MAXIMUM      WAVE
                       COORDINATES    MEASURE   TSUNAMI     PERIOD
    GAUGE LOCATION       LAT   LON     (UTC)     HEIGHT     (MIN)
    -----------------------------------------------------------------
    ACAPULCO MX        16.8N  99.9W    1724    0.68M/ 2.2FT   20
    SALINA CRUZ MX     16.2N  95.2W    1745    0.71M/ 2.3FT   20
    DART 43413         10.8N 100.1W    1638    0.01M/ 0.0FT   10
```

Figure 2.8. Tsunami observations reported by Pacific Tsunami Warning Center, PTWC.
(https://tsunami.gov/events/PHEB/2020/06/23/20175001/5/WEPA40/WEPA40.txt)



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ZCZC
WEPA40 PHEB 231539
TSUPAC

TSUNAMI MESSAGE NUMBER 1
NWS PACIFIC TSUNAMI WARNING CENTER EWA BEACH HI
1539 UTC TUE JUN 23 2020

...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      7.7
  * ORIGIN TIME    1529 UTC JUN 23 2020
  * COORDINATES    15.9 NORTH  95.9 WEST
  * DEPTH          33 KM / 20 MILES
  * LOCATION       NEAR THE COAST OF OAXACA  MEXICO


EVALUATION
----------

  * AN EARTHQUAKE WITH A PRELIMINARY MAGNITUDE OF 7.7 OCCURRED
    NEAR THE COAST OF OAXACA, MEXICO AT 1529 UTC ON TUESDAY JUNE
    23 2020.

  * BASED ON THE PRELIMINARY EARTHQUAKE PARAMETERS... HAZARDOUS
    TSUNAMI WAVES ARE POSSIBLE FOR COASTS LOCATED WITHIN 1000 KM
    OF THE EARTHQUAKE EPICENTER.


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

  * HAZARDOUS TSUNAMI WAVES FROM THIS EARTHQUAKE ARE POSSIBLE
    WITHIN 1000 KM OF THE EPICENTER ALONG THE COASTS OF

      MEXICO... GUATEMALA... EL SALVADOR AND HONDURAS


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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Figure 2.9. Tsunami warning from Pacific Tsunami Warning Center, PTWC.

https://www.tsunami.gov/events/PHEB/2020/06/23/20175001/1/WEPA40/WEPA40.txt

```
  * PERSONS LOCATED IN THREATENED COASTAL AREAS SHOULD STAY ALERT
    FOR INFORMATION AND FOLLOW INSTRUCTIONS FROM NATIONAL AND
    LOCAL AUTHORITIES.

ESTIMATED TIMES OF ARRIVAL
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  * 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)
    ------------------------------------------------------------
    ACAPULCO         MEXICO            16.9N  99.9W   1616 06/23
    SALINA CRUZ      MEXICO            16.5N  95.2W   1623 06/23
    PUERTO MADERO    MEXICO            14.8N  92.5W   1641 06/23
    LAZARO CARDENAS  MEXICO            17.9N 102.2W   1643 06/23
    SIPICATE         GUATEMALA         13.9N  91.2W   1657 06/23
    ACAJUTLA         EL SALVADOR       13.6N  89.8W   1703 06/23
    MANZANILLO       MEXICO            19.1N 104.3W   1706 06/23
    AMAPALA          HONDURAS          13.2N  87.6W   1800 06/23

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
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  * 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.
```

Figure 2.9 (cont.) Tsunami warning from Pacific Tsunami Warning Center, PTWC.

https://www.tsunami.gov/events/PHEB/2020/06/23/20175001/1/WEPA40/WEPA40.txt

The leading negative wave was observed at a number of locations along the Oaxaca coastline including Huatulco, as shown in Figure 2.10. The locations of the Salina Cruz tide gauge and Huatulco relative to the earthquake epicenter are shown in Figure 2.11.

Figure 2.10. Ocean drawdown observed in Huatulco, Oaxaca.
(https://twitter.com/DesdePeninsula/status/1275466273783046146)

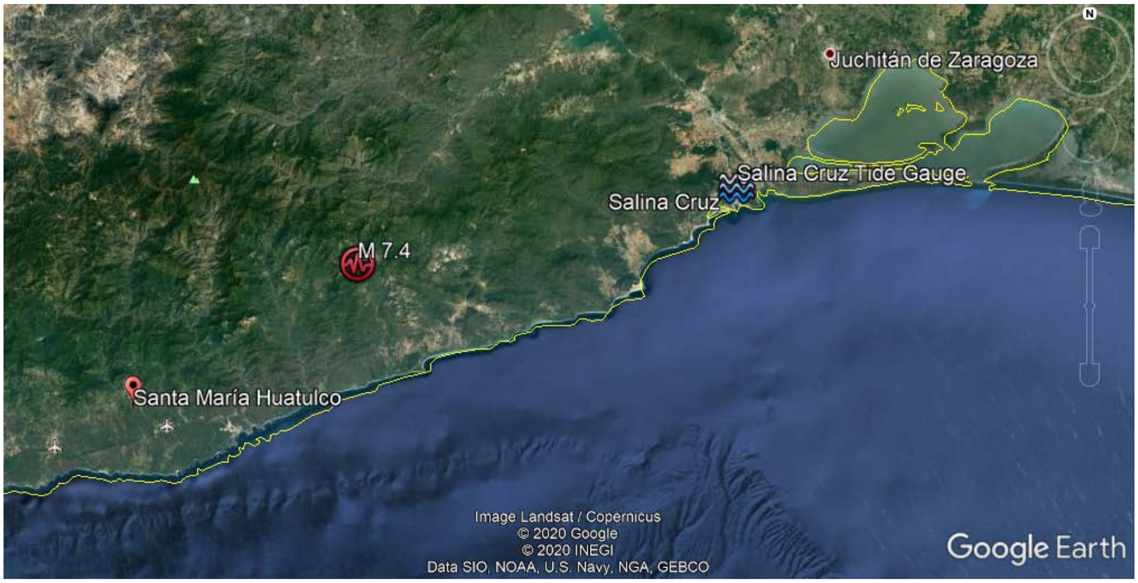


Figure 2.11. Google Earth image showing location of Salina Cruz and Huatulco relative to the earthquake epicenter.

3.0 Recorded Ground Motions

In Mexico there are several seismic networks. The Institute of Geophysics and the Servicio Sismologico Nacional (SSN) of UNAM operate a national network of broadband instruments. The locations of some of their stations, most of which recorded this event, are shown in Figure 3.1. Station HUIG, located near Huatulco to the west of Salina Cruz, recorded a PGA of 0.44g.

The Instituto de Ingenieria at UNAM also operates a network of strong motion accelerographs. Figure 3.2 shows the location of most of these stations.

Figure 3.1. Location of broadband stations operated by the Institute of Geophysics and SSN of UNAM.

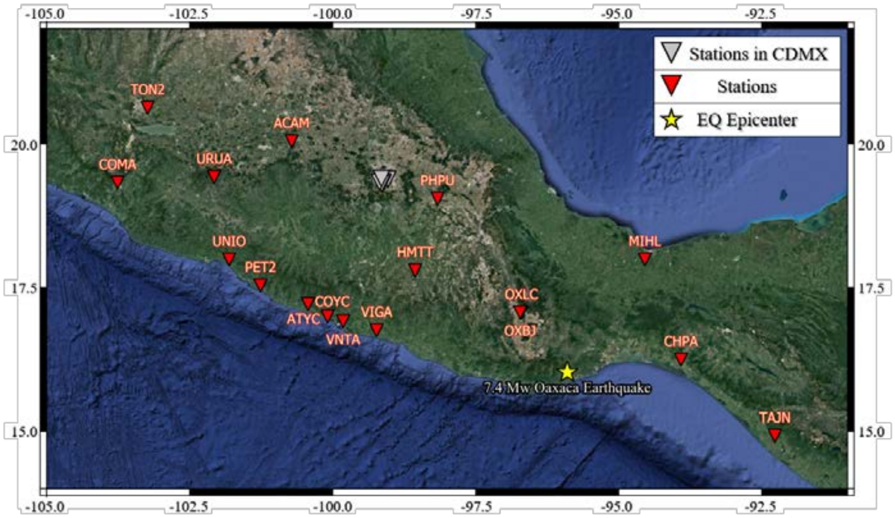


Figure 3.2. Earthquake epicenter and location of Instituto de Ingenieria recording stations.

Maximum horizontal peak ground accelerations (PGAs) computed from recorded ground motions reported by the Instituto de Ingenieria of UNAM (UIS, 2020) are shown in Table 3.1. These values and spectral acceleration ordinates computed from recorded ground motions are contrasted next against estimated values from global and local ground motion prediction models. Figure 3.2 shows the locations of the stations listed in Table 3.1. Of the five stations within Mexico City, CUP5 is located on rock on the campus of UNAM while the others are on very soft soil clay deposits. Figure 3.3 shows a map of Mexico City with curves of equal fundamental periods of the soil deposits.

Table 3.1. Peak ground accelerations reported by UIS (2020). Presented values correspond to the maximum between the two recorded horizontal components.

Station Code	Latitude	Longitude	Epicentral distance (km)	PGA (cm/s^2)
OXLC	17.0650	-96.7032	177	82.88
OXBJ	17.0673	-96.7238	179	70.91
CHPA	16.2474	-93.9126	244	6.67
MIHL	17.9888	-94.5439	314	40.56
HMTT	17.7983	-98.5597	360	13.99
VIGA	16.7587	-99.2333	360	4.24
TAJN	14.9227	-92.2710	416	2.64
VNTA	16.9143	-99.8189	425	1.58
PHPU	19.0442	-98.1685	443	26.67
COYC	16.9978	-100.0900	455	1.84
ATYC	17.2134	-100.4323	498	2.01
CMFZ	19.3841	-99.0363	525	44.68
CMMG	19.3320	-99.1157	525	28.73
CMP5	19.3071	-99.1444	525	27.14
CUP5	19.3302	-99.1811	530	8.06
SCT2	19.3947	-99.1487	533	22.81
PET2	17.5354	-101.2626	593	1.02
UNIO	17.9876	-101.8106	665	1.29
ACAM	20.0432	-100.7168	696	3.46
URUA	19.4218	-102.0741	765	1.80
COMA	19.3253	-103.7608	914	1.69
TON2	20.6246	-103.2357	940	0.96

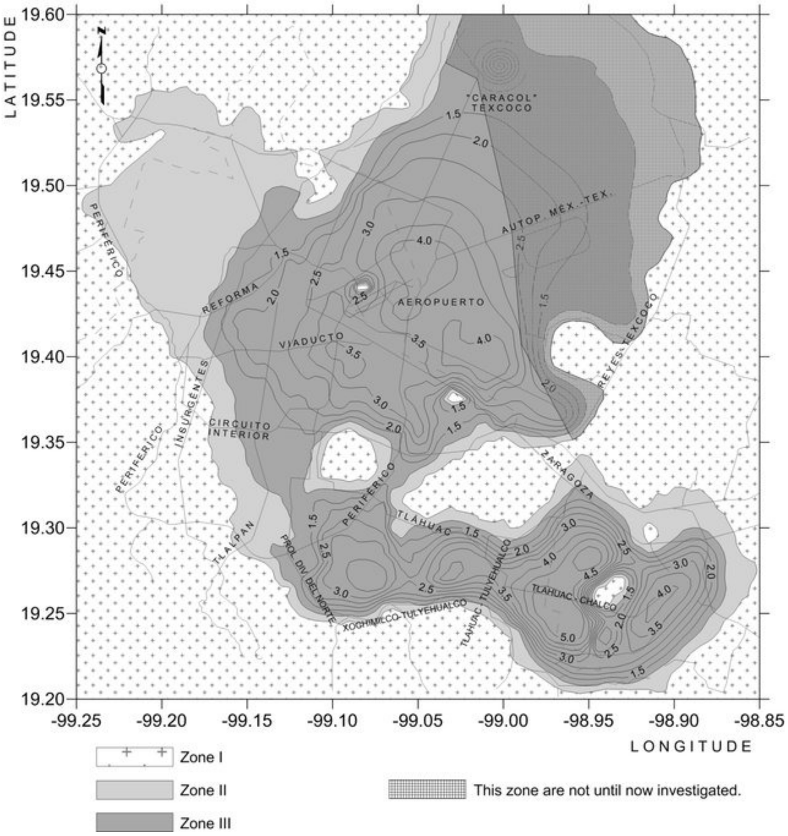


Figure 3.3. Map of Mexico City with fundamental soil isoperiod contours (Martinez et al. 2015).

Here, recorded ground motion intensities were compared with two ground motion prediction models (GMPMs), the interplate model developed by Arroyo et al. (2010) for rock sites, and the geometric mean of both NGA-Sub models (NHR3, 2020). These models differ in their distance metric and the definition of the horizontal component of the pseudo-acceleration spectral ordinates (PSA). In particular, Arroyo et al. (2010) use epicentral distance, R_{epi}, whereas NGA-Sub employs rupture distance R_{rup}. On the horizontal component, Arroyo et al. (2010) estimate the random (sometimes also referred to as arbitrary) horizontal component PSA, while the NGA-Sub model estimates the RotD50 PSA. Therefore, for each station both as-recorded horizontal components are compared against the Arroyo et al. (2010) model, whereas the geomean of the as-recorded horizontal components is compared against the NGA-Sub model as a proxy to RotD50 as we did not have access to the records themselves, just peak recorded intensities. Figure 3.4 shows data for PGA and PSA for periods of 0.5, 1.0, and 2.0 s. Note that intensities present a large variability within different stations located at similar source-to-site distance, where in some cases the ratio between the maximum to the minimum recorded intensities reach differences of almost one order of magnitude.

In Figure 3.4, stations located in Mexico City recorded PSA values greater than the median values estimated by the ground motion models for any period, with the differences larger for T =

1 s and T = 2 s, and for the estimations of the Arroyo et al. (2010) model. For the stations located outside Mexico City, most of the stations recorded PGA values greater than the 84th percentile estimates of the Arroyo et al. (2010) model and within the 16th and the 84th percentile estimates of the NGA-Sub model.

For T = 0.5 s, intensities at most of the stations outside Mexico City are within the 16th and the 84th percentile estimates for rock- and soil-site of the NGA-Sub model. Recorded PSA values at stations outside Mexico City match the estimated intensities by Arroyo et al. (2010) in the distance range 200-600 km. In stations located within Mexico City, for both T = 1 s and T = 2 s the underprediction of the ground motion models is apparent and explained by the well-known site amplification induced by the very soft soil clay deposits underlying the city.

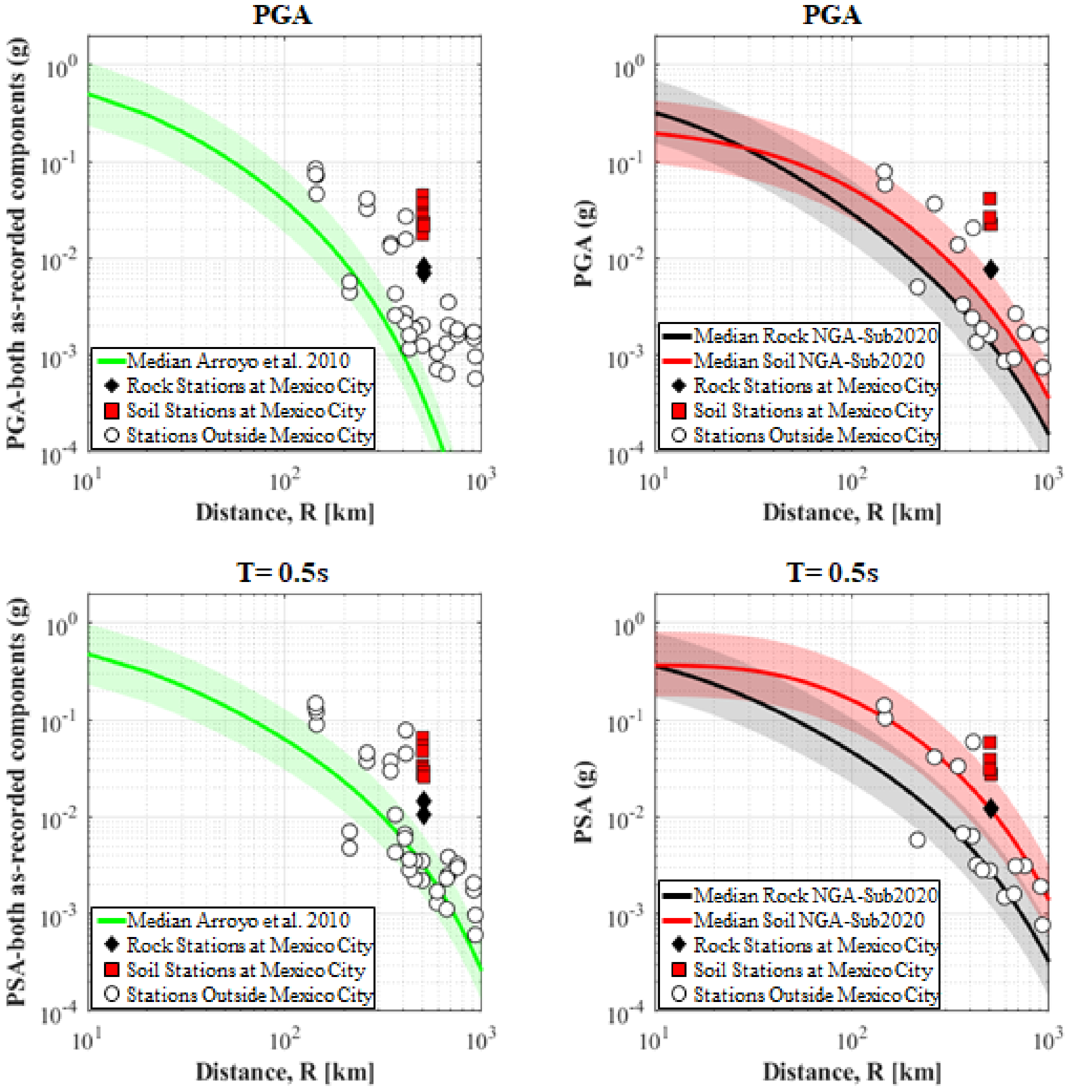


Figure 3.4. Comparison of pseudo-acceleration data computed from recorded accelerations with estimates of Arroyo et al. (2010) and NGA-Sub GMPMs predictions. Shaded regions represent the 16/84th percentiles of the GMMs.

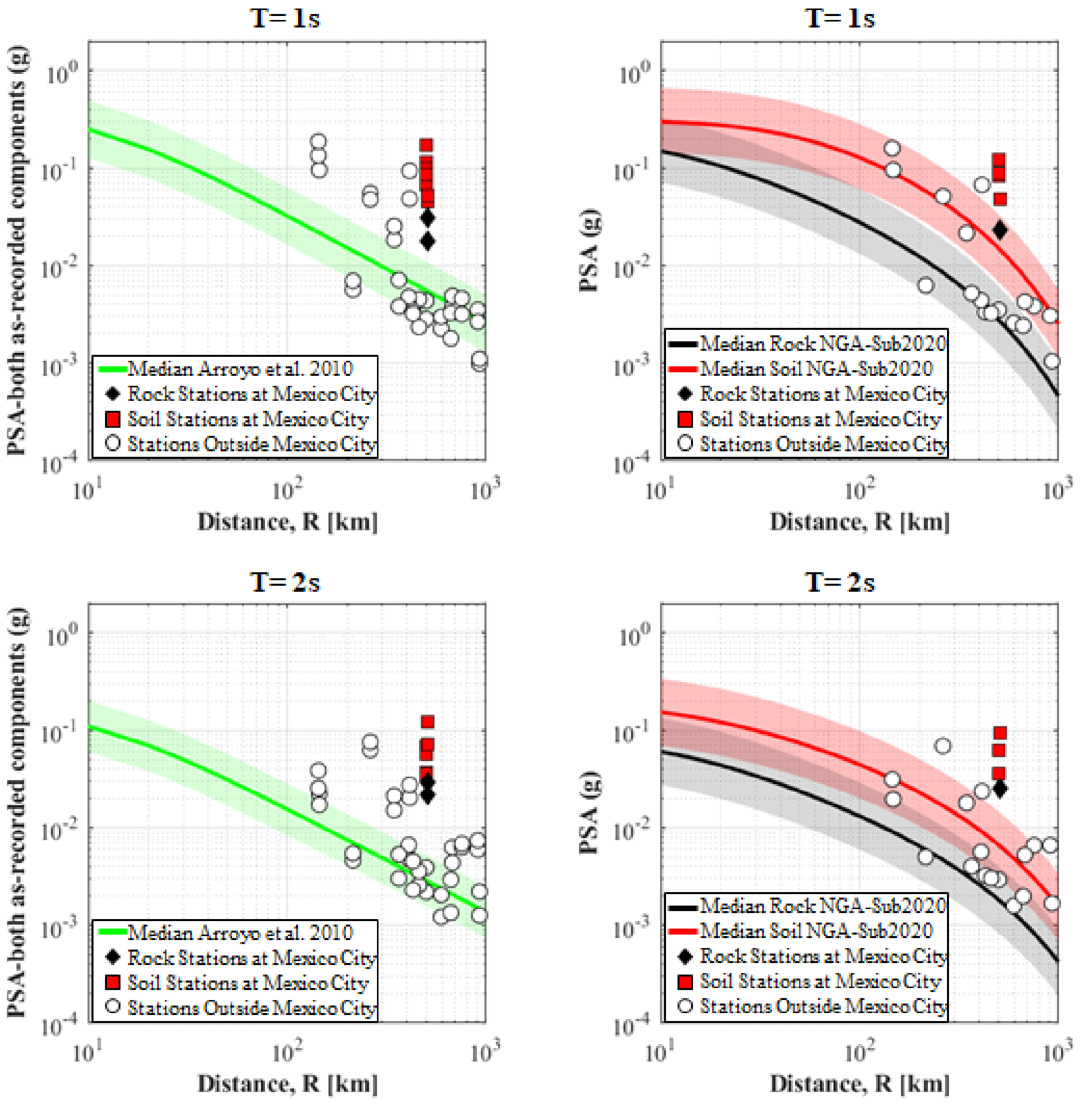


Figure 3.4 (continued). Comparison of pseudo-acceleration data computed from recorded accelerations with estimates of Arroyo et al. (2010) and NGA-Sub GMPMs estimates. Shaded regions represent the 16/84th percentiles of the GMPMs.

4.0 “Did you feel it?” Reports

Did You Feel It? (DYFI) is a system developed by the USGS to make use of reports provided by people who felt the earthquake. By taking advantage of the vast number of Internet users, it is possible to get a more complete description of what people experienced during the earthquake, the effects of an earthquake, and an empirical estimate of the spatial distribution of intensities (USGS, 2020b).

The DYFI Map and related products produced 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 at the USGS website had over 600 responses within the first 4 hours after the earthquake. The evolution over time of these responses is shown in Figure 4.1. It is worth noting that not a lot of people know about USGS’s DYFI in Mexico and most of those who are aware of it are typically located in Mexico City.

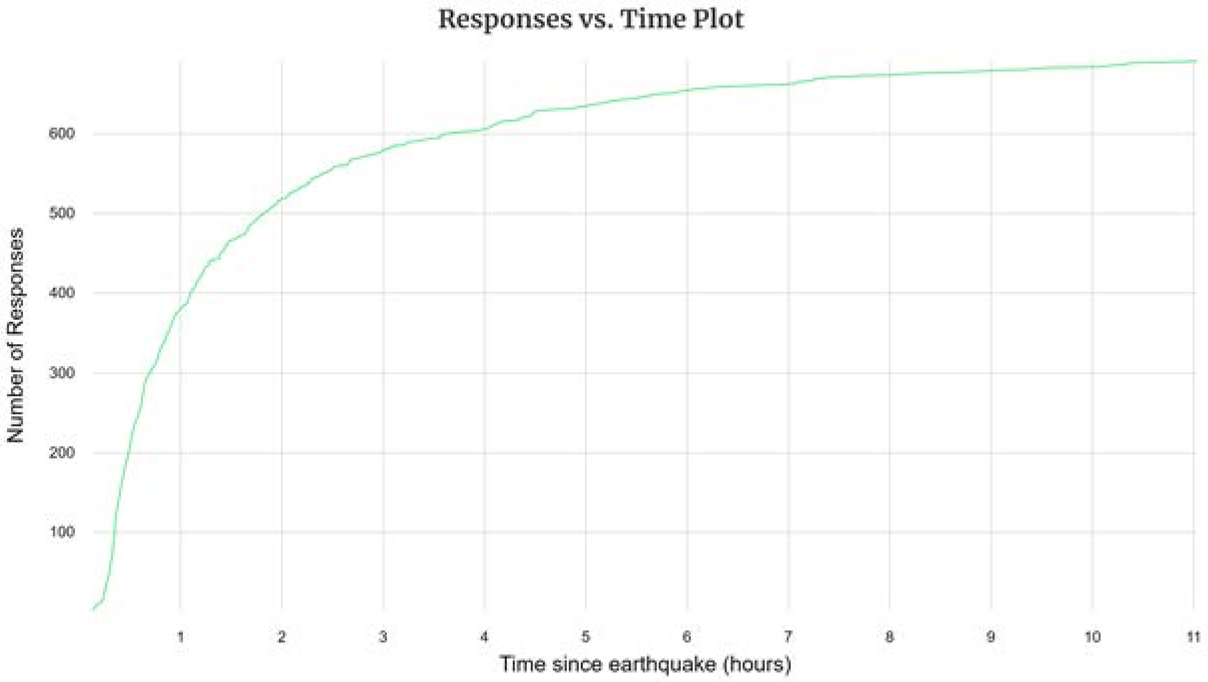


Figure 4.1. “Did you feel it?” (DYFI) responses collected by the USGS (USGS, 2020a).

A map of intensities inferred from DYFI responses and the spatial variation of intensity for the Mw 7.4 earthquake are plotted in Figure 4.2. It is observed that there are intensity levels up to

VIII registered close to the epicenter. This large intensity is also consistent with the observed damage in the epicentral region.

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

Figure 4.2. Map of Intensities inferred from DYFI responses (USGS, 2020a).

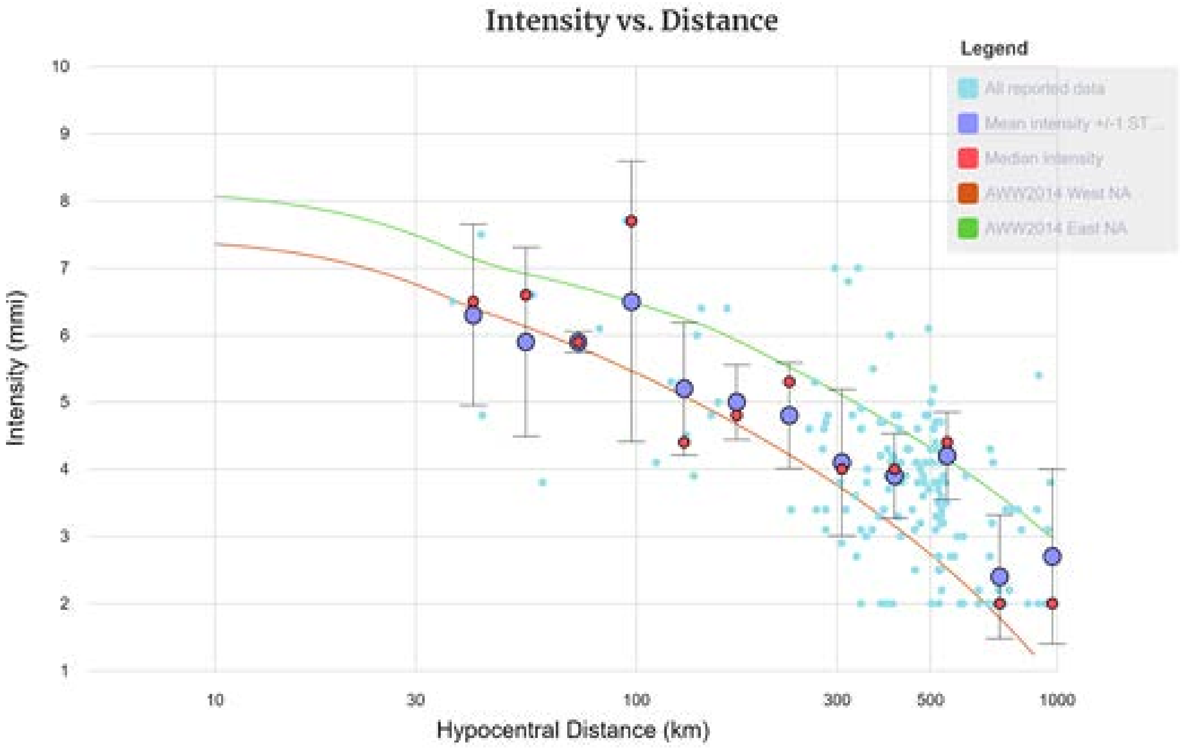


Figure 4.3. Attenuation of earthquake intensity with increasing hypocentral distance compared with empirical relationships (USGS, 2020a).

5.0 Local Codes and Construction Practices

Seismic design codes have existed in Mexico for more than 70 years. Mexican codes are regularly updated with new ideas and methods for earthquake-resistant engineering. Most of the efforts to develop and improve the Mexican codes have been focused in Mexico City. Thus, the Mexico City Building Code for seismic design of buildings has been a model code for the drafting of most of the municipal codes, which, by law, are of the municipal competence (Ordaz and Meli, 2004). Some agencies of the Federal Government have issued standards and manuals, such as the Manual of Civil Structures, MOC, of the Federal Electrical Commission since 1969, which is also known as MOC-CFE. The MOC-CFE is a comprehensive code that specifically addresses the design of several structural systems (buildings, bridges, dams, power stations, industrial facilities, etc.) to such hazards as earthquakes and wind. Its use is mandatory only for the design of structures owned or operated by the Comisión Federal de Electricidad (Federal Electrical Commission), but it often serves as a model design code in Mexico (Tena-Colunga et al., 2009).

5.1 Building Code in Oaxaca

The epicenter of the June 23rd Mw7.4 earthquake occurred within the state of Oaxaca. Its capital, the city of Oaxaca, is located approximately 175km from the epicenter and construction there suffered both structural and nonstructural damage. For seismic design outside of Mexico City, it has been customary to use the design spectra provided by the Manual of Civil Structures of the Federal Commission Electricity (CFE), named MOC-CFE. The first edition of the MOC-CFE dates back to 1969, with updates in 1981, 1993, 2008, and 2015. As shown in Figure 5.1 the seismic zonation of Mexico in this manual includes four seismic zones from A (low seismic hazard) to D (highest seismic hazard).

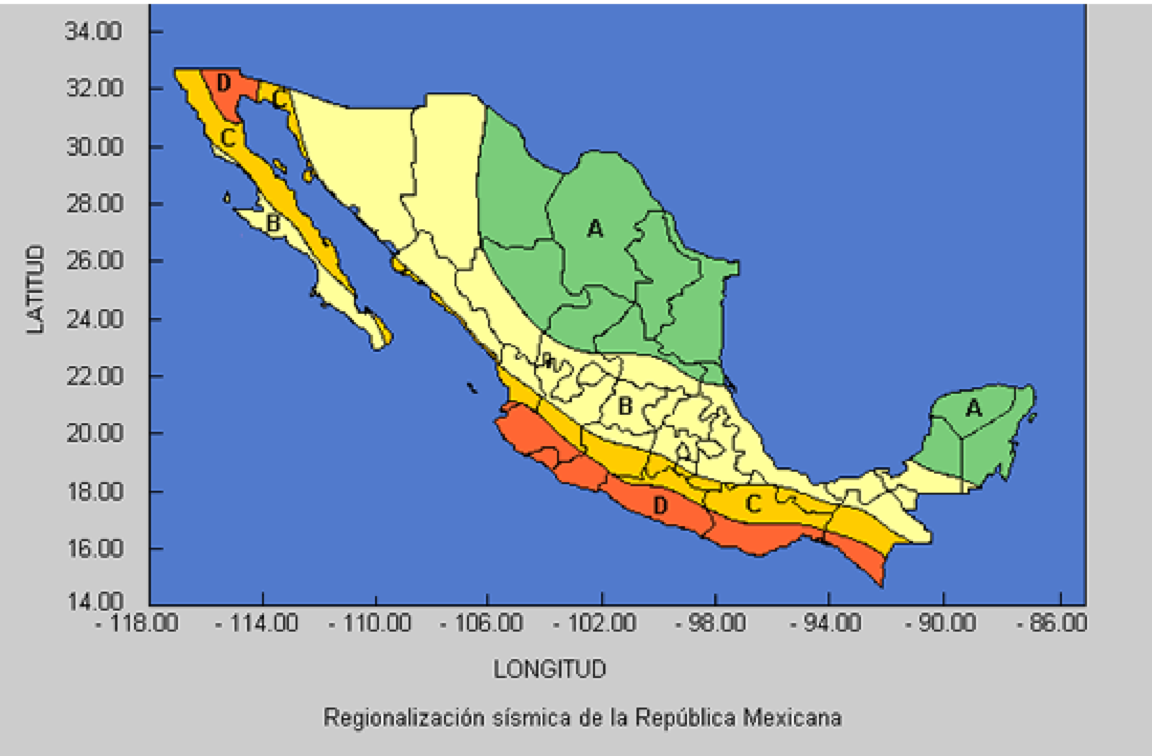


Figure 5.1. Seismic zonation of Mexico according to the 1993 edition of the Manual for Civil Works of the Federal Commission Electricity (MOC-CFE, 1993).

The current seismic design in this state is governed by the 2015 edition of the MOC-CFE seismic guidelines. This standard provides design spectra for any location within the Mexican states and divides soil types into three different classes according to a combination of their shear wave velocities and thicknesses of soil deposits. In this classification, site class I corresponds to stiffer and shallower soil whereas site class III corresponds to deeper and softer soils. The software tool PRODISIS, shown in Figure 5.2, is available to help users to obtain the seismic design spectra.

Figure 5.2. Map of iso-acceleration curves 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 platform PRODISIS.

Figure 5.3 presents a comparison of the design spectrum for site class I with the response spectra of both horizontal components recorded at two stations in the capital city of Oaxaca (UIS, 2020). As can be observed in this figure, the response pseudo-acceleration spectral ordinates of both horizontal components of the motions recorded in Oaxaca are significantly lower than the elastic design spectrum for the city of Oaxaca. Figure 5.4 presents the design spectra for the three site classes of the MOC-CFE 2015 standard in the city of Huatulco, Oaxaca, located on the Pacific coast approximately 38km northwest of the epicenter. Station HUIG, located near Huatulco to the west of Salina Cruz, in the epicentral region, recorded a PGA of 0.44g

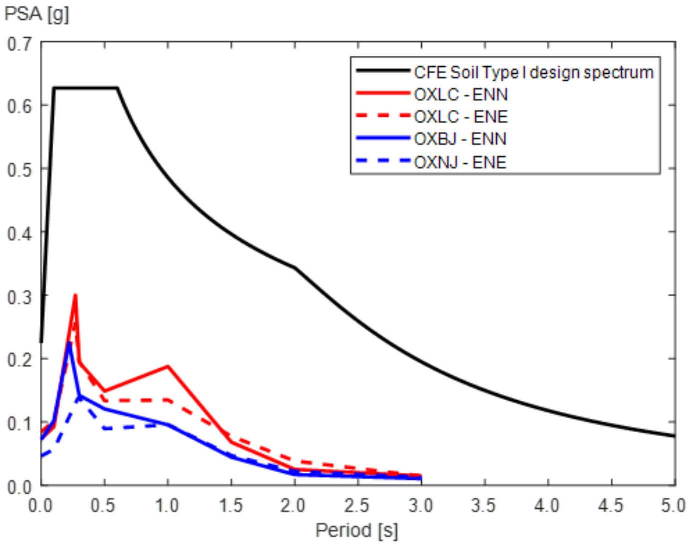


Figure 5.3. Comparison of response spectra computed from recorded horizontal accelerations at stations OXLC and OXBJ in the city of Oaxaca to the elastic design spectrum for soil class I according to MDOC CFE 2015.

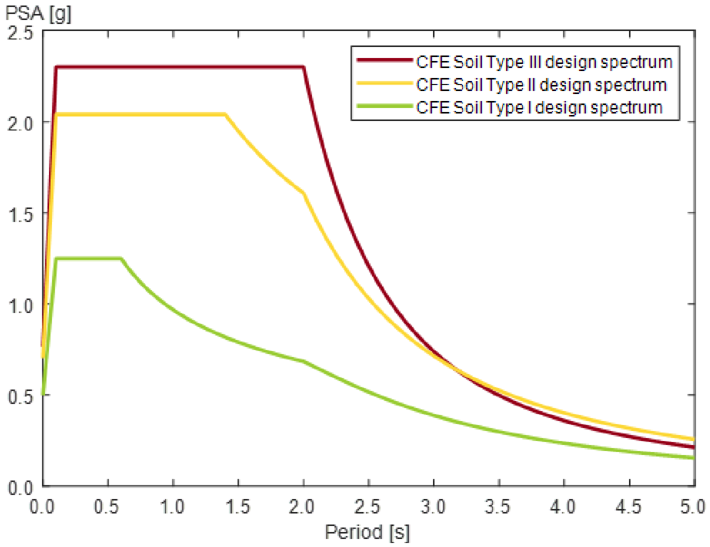


Figure 5.4. Elastic design spectrum for the three soil classes for the city of Huatulco according to MDOC CFE 2015.

5.2 Mexico City Building Code

Mexico City building code has a long history that goes back to the 1920s. It's evolution has been shaped by lessons learned from devastating seismic events and advances in research. In particular, the 1958 version of the seismic code in Mexico City was one of the first in the world to include a microzonation to mandate different seismic coefficients in different parts of the city based on local site conditions. At the time of its publication, the 1976 code introduced many recent advances in earthquake resistant design. For example, it was the first code in the world to consider period-dependent reduction factors, to include an approximate modal combination rule that considered correlation between modal responses, and to consider combination rules for seismic loading in orthogonal directions, among others. The code underwent significant modifications immediately following the September 19, 1985 earthquake with more important revisions in the 2004 and 2017 editions. Additional information regarding the evolution of seismic codes in Mexico City can be found in Galvis et al. (2017) and Arteta et al. (2019).

Figure 5.5 shows a comparison of the acceleration response spectra computed from ground motion records obtained at CUP5 station, on a rock site, on the campus of UNAM during the June 23, 2020 earthquake to the elastic design spectrum prescribed in the current 2017 edition of the Mexico City code. As shown in this figure the ground motion intensities on rock in Mexico City during this earthquake were very small compared to design spectral ordinates. It should be mentioned that strong motion records from other sites (e.g. soft soil sites) were not available at the time of writing of this report.

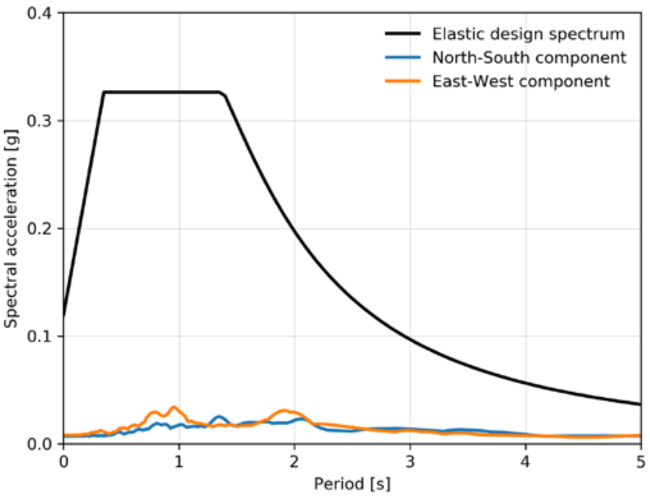


Figure 5.5. Response spectra of the two horizontal components at CUP5 station in Mexico City and the elastic design spectrum for the site.

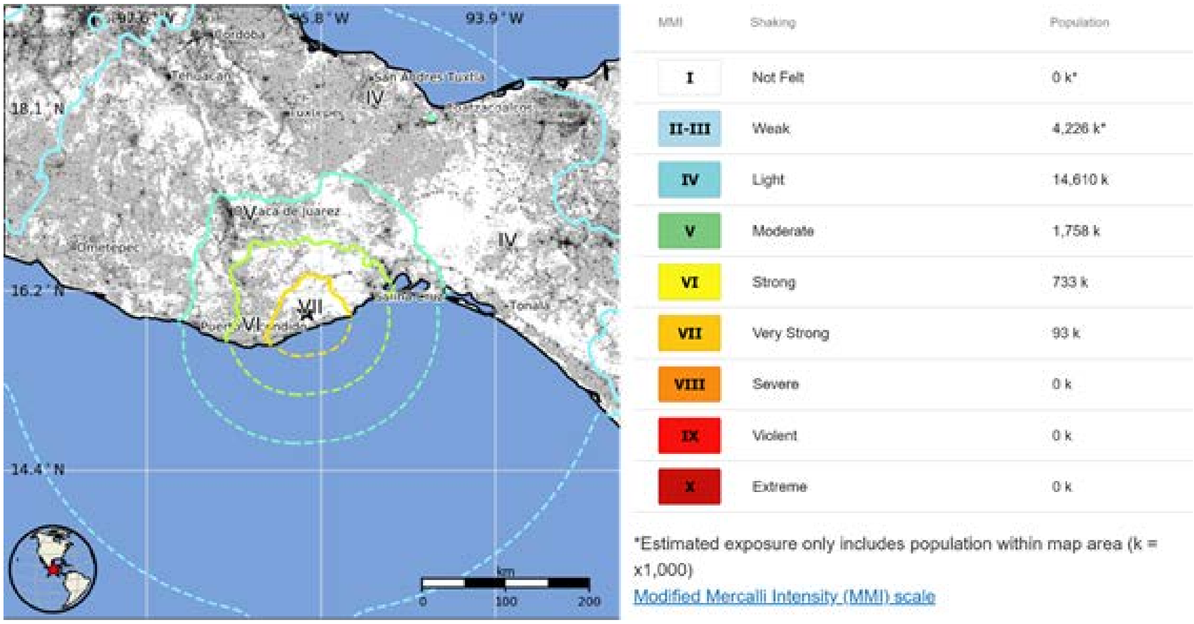
The current version of the Mexico City building code (NTC-S) includes procedures to obtain elastic design spectra at any location of the city as a function of the period of the site. Elastic spectral ordinates are then reduced by period-dependent factors to account for overstrength and due to inelastic deformation.

6.0 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). This section discusses the population exposure.

Figure 6.1 shows the isoseismals estimated for the Mw 7.4 earthquake. Figure 6.2 shows the number of people exposed to each shaking intensity in selected cities.

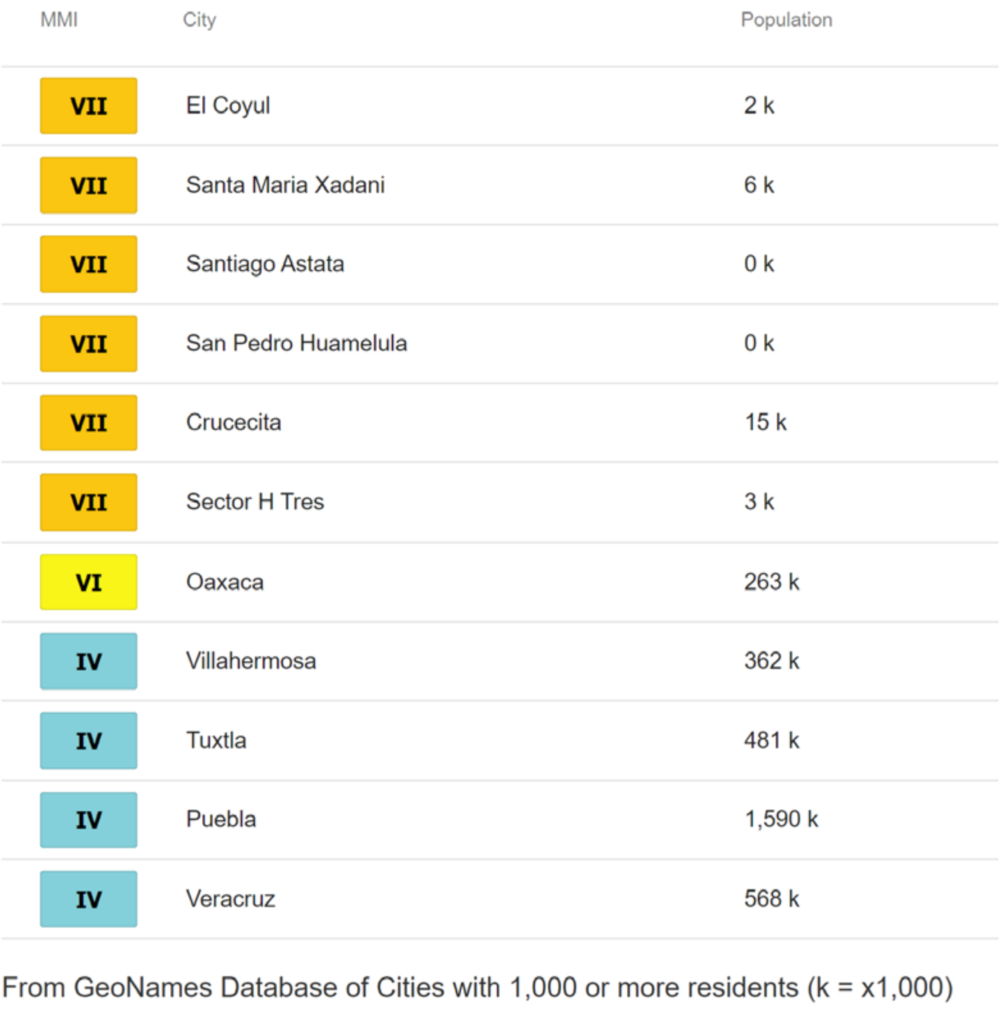


MMI	Shaking	Population
I	Not Felt	0 k*
II-III	Weak	4,226 k*
IV	Light	14,610 k
V	Moderate	1,758 k
VI	Strong	733 k
VII	Very Strong	93 k
VIII	Severe	0 k
IX	Violent	0 k
X	Extreme	0 k

*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 7.4 earthquake (USGS, 2020a).



MMI	City	Population
VII	El Coyul	2 k
VII	Santa Maria Xadani	6 k
VII	Santiago Astata	0 k
VII	San Pedro Huamelula	0 k
VII	Crucecita	15 k
VII	Sector H Tres	3 k
VI	Oaxaca	263 k
IV	Villahermosa	362 k
IV	Tuxtla	481 k
IV	Puebla	1,590 k
IV	Veracruz	568 k

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

Figure 6.2. Number of people exposed to different ground shaking intensities (MMI) in selected cities as a result of the earthquake (USGS, 2020a).

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 magnitude. 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 5%, 22%, 40%, 26% and 6% for the Mw 7.4 event. At the time of the writing of this report, 10 fatalities have been reported (Animal Politico, 2020). Also, PAGER estimated economic losses due to damage to be less than $1 million, 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 5%, 20%, 38%, 28% and 8%, respectively.

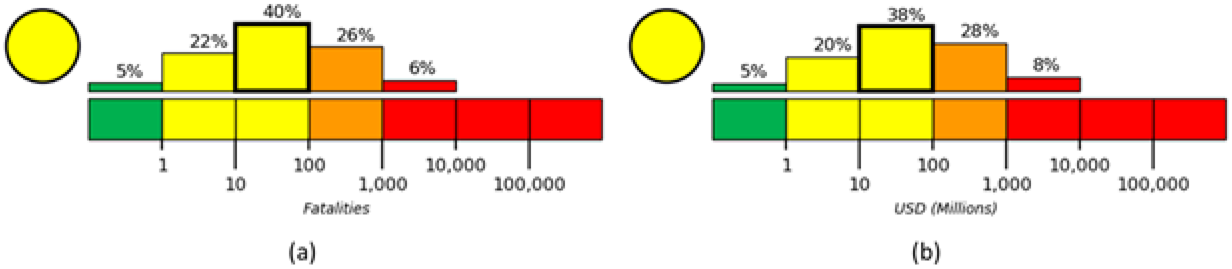


Figure 6.3. **PAGER Estimated probability of (a) fatalities and (b) economic losses for the June 23, 2020 Oaxaca Earthquake (USGS, 2020a).**

7.0 Damage (Oaxaca and surrounding states)

The state of Oaxaca suffered most of the damage. On June 24, at the Third Session of the Civil Protection and Safety Council, state authorities reported the following (Twitter, 2020a):

- More than 2,000 homes suffered damage.
- More than 55 schools suffered damage.
- Most of the state hospital system is operating normally.
- No damage has been reported in hotels or restaurants.
- All 4 airports are operating normally.
- 3 federal highways, 6 state highways, and 2 bridges suffered damage but have been functionally restored.
- The water supply and drainage systems of the Juchitán and Espinal municipalities have suffered significant damaged.

The State of Oaxaca experienced several partial and full collapses of non-engineered structures, especially unreinforced masonry and adobe construction. Cracking, dislodging and crushing damage of masonry walls were evident in many buildings as seen from the photos in this section. Non-structural damage was evident in commercial buildings, including drop ceiling damage, glass shattering, and furniture and contents damage. Several hospitals (Mexico News Daily 2020) experienced structural and non-structural damage and a hospital that was severely damaged (Unidad Médica de Ozolotepec) in Oaxaca will be demolished. Structural damage at the Antonio Dovalí Jaime Refinery in Salina Cruz, Oaxaca triggered a post-earthquake fire. According to the Mexican Government Bulletin, there is damage in 500 households, 4 archaeological zones, and 15 medical centers as well as five collapses/landslides in highways. (This count apparently includes damage in Mexico City also).

Infrastructure damage was also reported in Oaxaca. Highway authorities reported that a landslide caused a blockage on the highway between Oaxaca City and the Isthmus of Tehuantepec on the Totolapan-El Camarón section (Mexico Daily News, 2020). The following damage to the electrical infrastructure in Oaxaca was reported by Espinosa (2020b): (i) Power outage throughout the state capital, which was restored at 12:30 p.m., (ii) electricity cut in the Ozolotepec region, and (iii) as a preventive measure, the Antonio Dovalí refinery carried out a stoppage of activities, entering a preventive release without affecting it. A fire outbreak originated. At the moment it operates normally.

According to the Federal Electricity Commission (CFE), 1,952,000 users were affected by power outages throughout several states. However, by 13:30 local time, power had been restored to 93% of those affected (Cruz Serrano, 2020b).

7.1 Single-Family Residential Buildings

Most of the damage was concentrated in the single-family housing that appears to be non-engineered. Several single-family residential buildings experienced various levels of damage ranging from minor wall cracking to complete collapse. Many of the collapses occurred in houses made of adobe. Most single-family buildings are one story high. In two-story houses, the damage was typically concentrated in their first story. The primary damage pattern was to non-engineered unreinforced masonry building wall damage, and partial or full collapse. Limited internet access in the impacted region affected the reporting of damage. Figures 7.1 through 7.9 highlight examples of this damage.

Figure 7.1. Out-of-plane collapsed walls in single family buildings. Left, Ozolotepec municipality in Oaxaca (Twitter, 2020c), and right, Santa Catarina Xanaguía, San Juan Ozolotepec, Oaxaca (Twitter, 2020d).

Figure 7.2. Top: Out-of-plane collapse of a boundary wall in an adobe residential construction, Oaxaca (Twitter, 2020e); Bottom: collapse of a confined masonry wall in a residential building, Santa Cruz Ozolotepec (Facebook, 2020a).

Figure 7.3. Out-of-plane collapse of the upper portion of a wall in an adobe residential construction, Oaxaca (Twitter, 2020f).

Figure 7.4. Severe diagonal tension cracking in a wall of an adobe house, Oaxaca (Its going down, 2020).

Figure 7.5. Out-of-plane collapse of a wall in an adobe house (Twitter, 2020g).

Figure 7.6. Examples of unreinforced masonry building collapse Top left: San Juan Ozolotepect (Zona Roja, 2020) and Top right: San Miguel del Puerto (Twitter, 2020h) Bottom: Bolivar Colonia Obrera in Cuauhtémoc (Integral Risk Management Secretariat via Twitter, 2020t).

Figure 7.7. Masonry debris after single family building collapse in Oaxaca City (Daily Mail, 2020).

Figure 7.8. Damage to masonry bearing wall in the first story of a two-story residential structure in Oaxaca (El Universal, 2020c).

Figure 7.9. Diagonal cracking in the first story of an unreinforced masonry residence (Diario Marca, 2020a).

7.2 Multi-Family Residential Buildings

At the time of writing only a few multi-family residential buildings had been reported as damaged. In general it appears that multi-family buildings near the epicentral region had a better quality of construction than single family dwellings in the same region. A very common type of damage was diagonal cracking in masonry walls.

Figure 7.10. Masonry wall facade damage in a multi-family building. Damage is heavily concentrated in the first story (Diario Marca, 2020b).

Figure 7.11. Damage inspections by Civil Protection personnel in Oaxaca (Twitter, 2020j).

7.3 Commercial Buildings

Many commercial buildings that experienced damage were single story non-engineered buildings. Damage was very common in adobe construction as well as in unreinforced masonry buildings. Larger department stores appear to be of better construction quality and they primarily experienced damage to non-structural elements such as suspended ceilings, façade, and contents. Please refer to Section 7.8 of this report for more details on non-structural damage.

Figure 7.12. Failure of adobe walls in single-story commercial building (Animal Politico, 2020).

Figure 7.13. Failure of adobe walls in single-story buildings in Oaxaca. (New York Post, 2020).

Figure 7.14. Failure of adobe walls in central Oaxaca (left), (Twitter, 2020k) and masonry wing wall damage and detachment (right) (Estado 21, 2020).

Figure 7.15. Failure of masonry walls and spalling of plaster in Oaxaca (Distinct Today, 2020).

Figure 7.16. Damage to the facade of the historical building located at the center of Oaxaca (Twitter, 2020q; Twitter, 2020i).

Figure 7.17. Damage and temporary propping of a masonry wall (Twitter, 2020r).

7.4 Healthcare/Medical Facilities

It has been reported that at least 15 hospitals and medical facilities in the Mexican States of Oaxaca, Veracruz, and Morelos suffered some type of structural damage and in particular one medical facility exhibited severe structural damage as a consequence of the earthquake. According to the Government of Oaxaca, the hospitals located at the coast region near the epicenter were among those that reported some cracking. Particularly, the medical facility located at San Juan Ozolotepec in the State of Oaxaca will need to be demolished due to the severity of the damage as shown in Figure 7.18. Similarly, the Regional Specialty Hospital of Oaxaca in San Bartolo Coyotepec showed cracking at the exterior walls as shown in Figure 7.19. Additionally, it was reported that the Subzone General Hospital of Huatulco and Family Medical Unit 41, near the epicenter, was evacuated since it requires an in-depth structural evaluation (El Universal, 2020a and El Universal, 2020b). Other medical facilities that experienced damage at the facades were reported by Espinosa (2020b) including the Oaxacan Children's Hospital in San Bartolo Coyotepec and the General Hospital in San Pedro Pochutla experienced minor cracking. Although some hospitals needed to be evacuated in Mexico City, there are no reports of structural damage there.

Figure 7.18. Failure of unreinforced masonry wall of the medical unit located at Santa Catarina Xanaguía in the San Juan Ozolotepec municipality, Oaxaca (Twitter, 2020l).

Figure 7.19. Damage to the regional Speciality hospital of Oaxaca located at San Bartolo Coyotepec, Oaxaca (Facebook, 2020b).

It should be mentioned that six hospitals in Oaxaca that needed to be evacuated after the earthquake were also employed as healthcare facilities for COVID-19 patients, which are the Hospital Regional de Espcialidades, Hospital General de Pochutla, Hospital General de Puerto Escondido, Hospital General de Pinotepa Nacional, Hospital de la NIñez, and Hospital General Subzona de Medicina Familiar 41 in Santa Cruz Huatulco, which is the only hospital closed at the time of writing this report (Hernández, 2020).

Figure 7.20. Closure of the Subzone General Hospital of Huatulco and Family Medical Unit 41 (Hernandez, 2020).

Additionally, the Civil Protection System of the State of Veracruz reported that three hospitals suffered damage, which were the Hospital de Isla, Hospital de Tlapacoya, and the Unidad Médica de Alta Especialidad in the Veracruz Port (Paredes, 2020). For instance, the Civil hospital at Tlapacoyan exhibited a long vertical cracking at its front entrance as shown in Figure 7.21.

Figure 7.21. Damage to the Civil hospital at Tlapacoyan, Veracruz (Vanguardia, 2020).

It was reported that the Hospital “Rafael Barba Ocampo” in the City of Cuautla, in the State of Morelos, had some minor damage, such as hairline cracking, but only required closure of some nonstrategic areas (Redacción, 2020). Similarly, it was reported that the healthcare system in the State of Puebla did not suffer any damage and the hospitals continued in operation after being temporarily evacuated for safety reasons (Cuapa, 2020) (Fig. 7.22).

Figure 7.22. Temporal evacuation of a hospital in the State of Puebla (Ceballos, 2020).

7.5 Religious and Historical Buildings

According to the governor of the state of Oaxaca, 55 historical monuments (including 4 archaeological sites) suffered damage (Twitter, 2020b). Some examples of religious and historical buildings that suffered damage are presented in this section.

In the epicenter region, it was reported that the church at San Juan Ozolotepec (La Catedral de la Sierra) was severely damaged, as shown in FIgure 7.23, while the church cocoon of the San Mateo Macuilxóchitl church in the Tlacochahuaya municipality fell in front of the building as shown in Fig. 7.24 without causing injuries. Other churches reported with some degree of damage were the San Francisco Temple in San Francisco Ozolotepec, the Santa María Asunción Temple in Santa María Ozolotepec, and the San Mateo Temple in San Jeronimo Tlacochahuaya located in the Central Valley of Oaxaca state.

Figure 7.23. Damage to the La Catedral de la Sierra church at San Juan Ozolotepec, Oaxaca (Excelsior, 2020a).

Figure 7.24. Collapse of ornamentation in the San Mateo Macuilxóchitl church in the Tlacochahuaya, Oaxaca (Guerrero en Vivo, 2020).

According to the Culture and Arts Secretary of Oaxaca, the Oaxacan archaeology Ervín Frissell museum, in San Pablo Valle de Mitla, and the Oaxacan Painters museum in the City of Oaxaca experienced structural damage (Mejia, 2020). It was also reported that the Santísima Trinidad de las Huertas church, which was built at the end of the XVII century, suffered structural damage as shown in Fig. 7.25. Additionally, four catholic churches (Templo de San José, Parroquia de San Juan de Dios, Parroquia de Nuestra Señora de la Merced y Capellanía de Trinidad de las Huertas) located at Oaxaca City exhibited minor damage.

Figure 7.25. Collapse of parapet ornamentation in the church of Santísima Trinidad de las Huertas, City of Oaxaca. (Excelsior, 2020b).

7.6 Government Buildings

Espinosa (2020b) reported cracks and fissures in the Government Palace building in Santa Lucía del Camino. Figure 7.26 shows a government building in Huatulco where the unreinforced masonry parapet has collapsed.

Figure 7.26. Collapsed unreinforced masonry parapet in a government building in Huatulco, Oaxaca (Puerto Vallarta Daily News, 2020).

7.7 School Buildings

According to the Government of the State of Oaxaca, at least 59 school buildings suffered some type of damage as a consequence of the earthquake (Zavala, 2020). Similarly, The Government of the State of Puebla reported that 6 school buildings exhibited minor structural and non-structural damage (Gutierrez, 2020).

7.8 Non-structural Components

Non-structural damage occurred in multiple department and grocery stores including damage to and collapse of suspended ceiling tiles and grid failure, glass shattering, furniture and equipment toppling, content damage, HVAC duct damage and electrical wiring damage. Non-structural damage of masonry infill walls was evident on one occasion. Typical residential building non-structural damage was also present in most damaged buildings reported. Fig. 7.27 through 7.30 shows examples of non-structural damage in commercial buildings.

Figure 7.27. Collapsed acoustical ceiling in a furniture store in the city of Oaxaca (Facebook, 2020c).

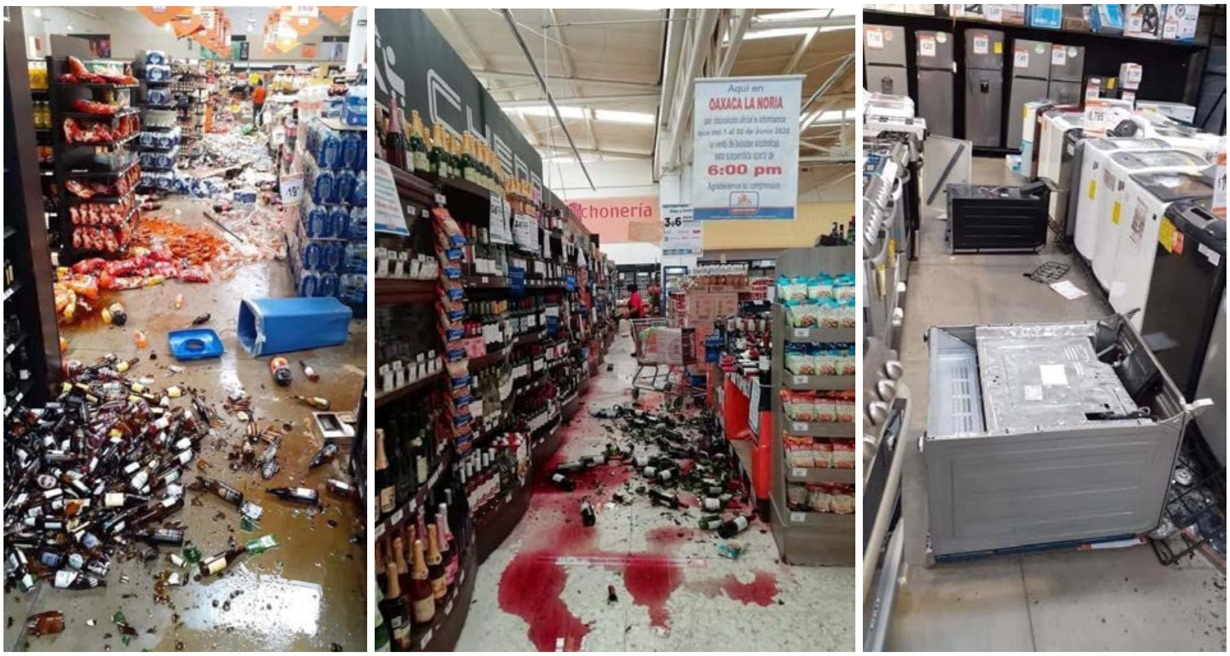


Figure 7.28. Non-structural damage in a large grocery store in the city of Huatulco in the state of Oaxaca. (Facebook 2020d, Facebook 2020e, and Facebook 2020f, for left, center and right, respectively).

Figure 7.29. Non-structural damage in a store in Oaxaca (Twitter, 2020m).

Figure 7.30. Non-structural damage in a store in Oaxaca (Twitter, 2020m).

7.9 Geotechnical Observations

Espinosa (2020b) reported the following road infrastructure damage and closures:

- Landslides on federal highway 190 at km 90
- Landslides on federal highway 190 at km 78 + 800. Total closure of the road.
- Landslides on Federal Highway 190 at km 119 + 000. Total closure of the road.
- Landslides on the Oaxaca Puerto Ángel highway, section Miahuatlán - Pochutla km 235.

Figure 7.31. Landslide in Paso Ancho, Santa María de Huatulco, Oaxaca (Facebook, 2020g).

Figure 7.32. Lateral spreading in the beach beach in Huatulco - Oaxaca (Facebook, 2020h and Facebook, 2020i, for left and right, respectively).

Figure 7.33. Landslide of Cerro La Sirena, which affected the town of Santa Catarina Xanaguia, located at the back (Twitter, 2020n).

7.10 Industrial Facilities

A fire incident was triggered and was rapidly controlled at the Antonio Dovalí Jaime oil refinery in Salina Cruz, Oaxaca, which was caused by the turbo generator and boiler, following the earthquake (Cruz Serrano, 2020a). The fire was under control, and structural damage was not detected after inspections (Figure 7.34). As a preventive measure, the Antonio Dovalí refinery carried out a stoppage of activities, entering a preventive release without affecting the plant. At the moment it operates normally.

Figure 7.34. Fire incident in the Antonio Dovalí Jaime refinery in Salina Cruz, Oaxaca (Twitter, 2020o).

8.0 Damage (Mexico City and State of Mexico)

Damage in Mexico City consisted only in minor nonstructural damage. Several buildings that suffered damage in the September 19th, 2017 earthquake had not yet been repaired and were incorrectly reported in social media to have been damaged in this event.

8.1 Buildings

The government of Mexico City reported that at least 36 buildings exhibited some type of damage, of which 32 are apartment buildings and 4 are governmental buildings (Nava, 2020). Among them, one five-story apartment building located at Unidad Habitacional Lindavista exhibited excessive tilting and extensive cracking, which might be caused by foundation differential settlement (Figures 8.1 and 8.2). Several videos capturing the actual earthquake shaking exhibited good performance of multistory concrete and steel buildings. Several adjacent buildings exhibited first mode dominated shaking without pounding into each other because of the presence of a seismic joint.

Figure 8.1. Apartment building tilted at Unidad Habitacional Lindavista-Vallejo in Mexico City (Lopez-Doriga, 2020).

Figure 8.2. Apartment building tilted at Unidad Habitacional Lindavista-Vallejo in Mexico City.

It should be noted that 4 affected buildings located at Jalapa 200, Anaxagoras 714, Pitágoras 316, and Baja California 167 streets are part of the group of 378 buildings included in the reconstruction program of the Mexico City Government (Díaz, 2020).

A building located at Tepic 40 had suffered significant damage during the September 2017 earthquake. A comparison between photographs of the building after the September 2017 earthquake and after the June 2020 earthquake shows that the damage is the same (Figure 8.3). This means that the building had been left standing in a very damaged condition for almost 3 years and that the new earthquake did not produce any additional damage to this vulnerable building.

Figure 8.3. Damage in the building located at Tepic 40 in Mexico City after the 2017 earthquake [top] (Cara, 2017) and after the 2020 earthquake [bottom] (Redacción ADN40, 2020).

It was also reported that a multi-story hotel (Hotel Miled) located at Metepec municipality in the Mexico State was slightly damaged and was tilted as a consequence of the earthquake. The building was not operating at the time of the earthquake.

Figure 8.4. Damage produced by pounding at Hotel Miled located in the Metepec municipality, Mexico State (QuieroTV, 2020).

8.2 Healthcare/Medical Facilities

The National Coordination for Civil Protection reported that the General Hospital in Chalco municipality and the Regional Hospital de Oriente in the Ecatepec municipality exhibited minor damage, mainly consisting of hairline cracking, which did not require closure operations (SanJuan, 2020). Similarly, no hospitals in Mexico City were reported with structural damage, and they continued operation after the earthquake.

8.3 Religious and Historical Buildings

The Archdiocese of Mexico reported that minimal damage was recorded in six churches in the diocesan territory in Mexico City. In close collaboration with the authorities of the National Institute of History and Anthropology (INAH), the Directorate of Sites and Monuments, as well as the Ministry of Culture of Mexico City, the following damage to religious structures was reported (DLF Redacción, 2020):

- In the Minor Basilica of San José and Sagrado Corazón, the existing cracks were aggravated since the 2017 earthquake, in addition, some plaster fell and new cracks appeared on the facade.
- In the Parish of Santa Veracruz there was damage to the facade and new damage to the tower that was damaged by the earthquake of 2017.

- In the Regina Coeli Parish, the damage to the upper choir since the 2017 earthquake worsened.
- Cracks emerged inside the Parish of Our Lady of Bethlehem, but so far they have not been generated outside.
- In the Temple of the Magdalena Mixhuca, some damage was observed and is under evaluation.
- In the Catedral Metropolitana minor damage was reported, but an increase was observed in the separation between the building of the Curia and the Cathedral.

Figure 8.5. Cracks in interior walls at a religious building in Mexico City. (Espinosa, 2020a).

8.4 Non-structural Components

There were various reports of non-structural damage in buildings in Mexico City. Figure 8.6 shows a sample of interior drywall cracking.

Figure 8.6. Cracking on drywall partition in an apartment building, Mexico City (CNN en Español, 2020).

8.5 Infrastructure

The Mexican Commission for Water reported that the Cutzamala water system had to reduce the water supply due to damage detected in the Mixquic distribution branch and the well valves 9 and 10, which has affected about 75,000 inhabitants in the Nezahualcoyotl municipality of Mexico State (Flores, 2020).

8.6 Combined Response under the Earthquake and COVID-19

At the time of the earthquake, Mexico was facing an increasing trend in the number of officially reported infected people and deaths due to Coronavirus (COVID-19) disease, which was 191,410 positive accumulated cases and 23,377 accumulated deaths by June 23. Particularly, several hospitals with COVID-19 medical care in the cities affected by the earthquake were subjected to the earthquake ground shaking. Newspapers reported that hospitals in Mexico City were evacuated, or partially evacuated, after the earthquake as shown in Figures 8.7 to 8.10. The hospitals in Mexico City continue operating after an inspection that did not reveal any damage according to the government officials (El Universal, 2020b).


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Figure 8.7. Health workers in Mexico City evacuate patient from the Alvaro Obregon hospital due to the risk of aftershocks (Distinct Today, 2020).

Figure 8.8. Evacuated patients outside the Durango clinic in Mexico City after the earthquake (The Latest, 2020).

Figure 8.9. Evacuated patients outside a hospital in Mexico City, wearing masks to prevent the risk of contracting Covid-19 (Chicago Tribune, 2020 and Bloomerg, 2020, left and right, respectively).

It should be noted that the medical and technical staff in the COVID-19 area at the Hospital Júarez, one of the major public hospitals in Mexico City, followed the Safety Hospital protocol, which advised them to search for green-tagged structural walls and stay there until the earthquake ends, as shown in Figure 8.10.

Figure 8.10. Medical and technical staff of the COVID-19 area at Hospital Juárez in Mexico City following the Hospital Safety protocol (Valadez, 2020).

Such extreme event occurring amidst a pandemic has shown that society is falling short in preparedness to successfully deal with earthquake-relate crises. Furthermore, it highlights the importance of disaster research in order to implement risk managing practices to mitigate the losses and have a quicker recovery (GADRI, 2020).

9.0 Videos Documenting Live Earthquake Shaking and Damage

Examples of non-structural damage in commercial buildings,

https://twitter.com/i/status/1275462137196904448

https://twitter.com/i/status/1275493424162955264

https://twitter.com/i/status/1275574836912369664

Sloshing at a water tank and a fire at an oil refinery in Salina Cruz

https://twitter.com/i/status/1275482866718138369

Shaking and pounding at the seismic joint of a multi-story concrete hospital building in Mexico City

https://twitter.com/i/status/1275590950564311040

Shaking of adjacent buildings with different heights with and without pounding

https://twitter.com/i/status/1275477587020533760

https://twitter.com/i/status/1275464037594210305

https://twitter.com/i/status/1275480318808596487

First mode dominated shaking of a multi-story building

https://twitter.com/i/status/1275481043689062405

Shaking and roof water body sloshing in a multistory building

https://twitter.com/i/status/1275494299166220288

Shaking of a multistory concrete buildings in Mexico City

https://twitter.com/i/status/1275906955396218880

https://twitter.com/i/status/1275614753730244610

Ground movement during earthquake shaking

https://twitter.com/i/status/1275590978154496001

Shaking of a multi-story office building in Mexico City

https://twitter.com/i/status/1275591385475923970

Sloshing of water bodies

https://twitter.com/i/status/1275486141009981440

https://twitter.com/i/status/1275476870813724673

https://twitter.com/i/status/1275577377905655809

https://twitter.com/i/status/1275637101304872960

https://twitter.com/i/status/1275465457584279552

https://twitter.com/i/status/1275472436436144128

https://twitter.com/i/status/1275469390490808320

https://twitter.com/i/status/1275467124757028867 (in Tabasco, 450 km from epicenter)

Shaking of a commercial building in the City of Oaxaca

https://twitter.com/i/status/1275486026467704832

Shaking of pole-mounted electrical transformers

https://twitter.com/i/status/1275456454674112514

https://twitter.com/i/status/1275452600305848321

10.0 Recommended Response Strategy

Based on the information gathered by this Preliminary Virtual Reconnaissance Report (PVRR), StEER offers the following recommendations for future study.

Study of recorded ground motions: The earthquake produce a valuable set of records obtained in the different networks: the broadband network operated by the Institute of Geophysics at UNAM, the strong motion acclerogragh 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 1989 and for the City of Oaxaca since 1999. The warning system provided a 30s warning to the city of Oaxaca and an almost 2 min warning in Mexico City. This event provides an opportunity to learn about technical aspects of the operation of the early warning system but also of the public response to the warnings.

Study of the Response and Evacuation of COVID-19 Hospital Facilities: This earthquake occurred during an ongoing pandemic. In particular, Mexico has experienced a monotonic increase in both daily reported new cases and in the number of daily deaths. This event hence provides an opportunity to learn the effectiveness of response and evacuation of medical facilities with COVID patients. In particular, it should be of interest to study if there is a spike in the number of infections as a result of relaxation of measures to prevent spreading of the virus as a result of the earthquake.

As the damage to the built environment in this event was not significant and the recommendations above are outside of StEER's mandate, StEER does not plan to activate a Field Assessment Structural Team (FAST). As a result, this PVRR represents the extent of StEER's official response. StEER will continue to coordinate with other organizations responding to this event to encourage consideration of these recommendations and monitor their assessments. Should these ongoing efforts suggest the potential to generate new knowledge about the performance of the built environment in this event, StEER may re-evaluate its decision and deploy a FAST.

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