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SEISMIC DAMAGE AT THE STATE OF MORELOS (MEXICO) DUE TO SEPTEMBER 19/2017 EARTHQUAKE

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Abstract

The epicenter of the earthquake that occurred in Mexico on September 19 2017 (M_W = 7.1) was near to the border between the States of Morelos and Puebla, close to the Axochiapan municipality in Morelos State. In the literature this earthquake has received the names of Axochiapan Earthquake, Puebla-Morelos Earthquake and Puebla Earthquake. The epicenter of this seismic event was around of 100 km from the southern of Mexico City, causing great damage in this big city. Nevertheless, this seismic event also caused great damage in other cities (small cities), towns and villages, which is almost unknown for the engineering community. For example, the observed damage at the epicentral zone in the State of Morelos has not been reported worldwide.

In this paper, the observed structural damage at the epicentral zone in Morelos State (Mexico) due to the September 19/2017 Earthquake is presented. The epicentral zone was covered by the author into the four weeks following the earthquake. The author is native from the State of Morelos and know the construction practice in the region. Some villages inside each municipality were visited to cover urban and rural communities.

Typical failures are graphically reported for housing, commercial buildings, schools and hospitals. Some official statistics are presented too. Conclusions and recommendations are proposed taking into account the damage distribution observed and the soil characteristics in the zones more affected.

Keywords: Mexico earthquakes; epicentral zone; seismic damage

1. Introduction

The State of Morelos (Morelos) is one of the 31 states that together with Mexico City conform the United Mexican States (Mexico). Morelos is located in the central-south region of Mexico, and is surrounding by Mexico City and the states of Mexico, Puebla and Guerrero (Fig.1). Morelos is divided into 36 municipalities and its population density is 390,000 inhabitants per square kilometer [1] (the third in Mexico after Mexico City and the State of Mexico). In Morelos there are valleys, hills, mountains and the Popocatepetl Volcano (an active volcano shared with Puebla and State of Mexico).

Fig. 1 – Location of Morelos into Mexico. Courtesy of Wikipedia.

On September 19, 2017 at 1:14:40 p.m., an important normal failure earthquake occurred in the central-south region of Mexico. Based on the official information (Fig. 2), the earthquake had a magnitude M_w = 7.1 with epicenter at 12 kilometers southeast of the municipality of Axochiapan, Morelos (Latitude: 18.4º, Longitude: -98.72º, Depth: 57 km). At first, this event was known as the Axochiapan Earthquake, after was named Puebla-Morelos Earthquake and, lately, it is known as Puebla Earthquake. The event affected the states of Morelos, Puebla, Guerrero, Tlaxcala and Mexico City, causing unfortunate deaths and injuries, as well as losses in the heritage of people, the nation and the world.

Fig. 2 – Official information about the September 19/2017 Earthquake [2]. Observe that epicenter lies near the border between the states of Morelos and Puebla

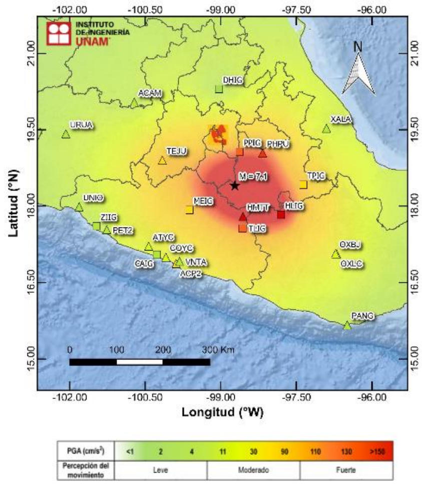


Fig. 3 – Peak ground acceleration (PGA) caused by the S/19/2017/E [3]

In Fig. 3 is depicted the peak ground acceleration (PGA) caused by the September 19/2017 Earthquake (S/19/2017/E). A PGA greater than 100 cm/s^2 is associated to a strong (*Fuerte*) perception of soil movement. The great territorial extension for PGA greater than 100 cm/s^2, (orange and red colors in Fig. 3), and the high level of damage observed there, have led to conclude that S/19/2017/E is the more destructive earthquake registered in Mexico until today [4].

2. Global damage

In Fig. 4 are located the municipalities of Morelos visited by the author into the four weeks following the S/19/2017/E. The marks are over the geographic coordinates of the historic city hall of each municipality. Since the Mexican colonial age, historic city halls in Morelos are in the downtown, and around them, the urbanism developed. In a downtown are housing, commercial and school/day-care-center zones. In a typical downtown can be found structures of adobe, confined/reinforced masonry, unreinforced masonry, reinforced concrete and, to lesser extent, steel. The suburbs are, in general, housing zones developed over former farmlands (rural zones); nevertheless, it is very common that in suburbs there are public schools. The municipalities more developed are Cuernavaca (at the north), Cuautla (at the east) and Jojutla (at the south). Some municipalities are complete rural zones (located principally at south and east into Morelos).

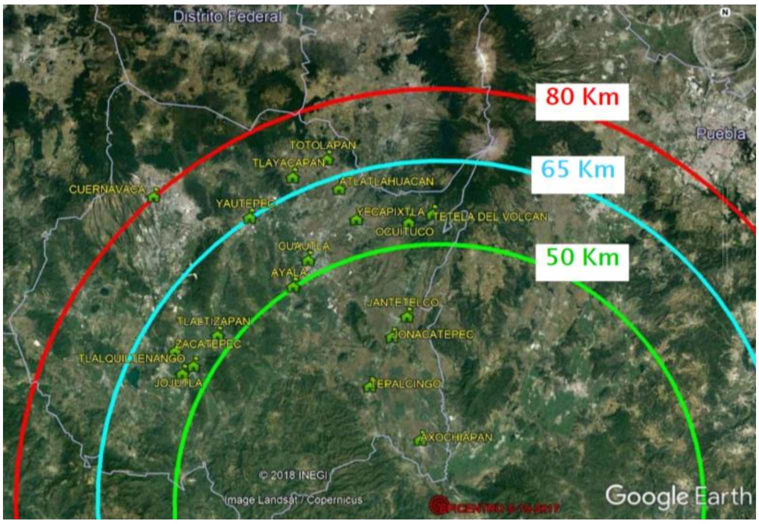


Fig. 4 – Location of the municipalities visited in Morelos after S/19/2017/E. Marks are over the location of the city hall in the down town (courtesy of Google Earth)

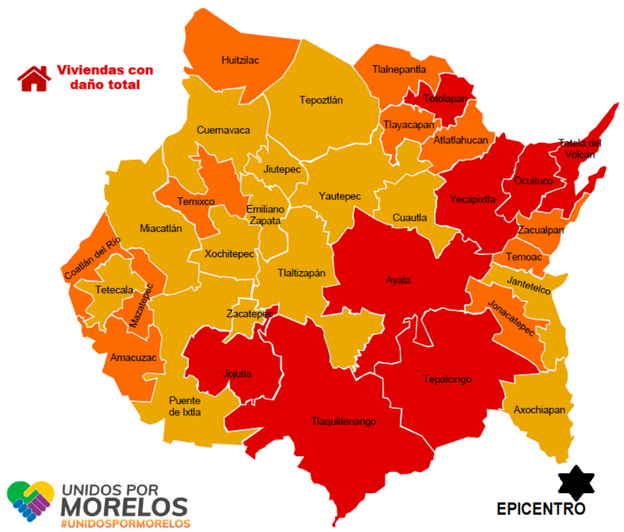
Epicentral radius for 50, 65 and 80 kilometers are depicted in Fig. 4. According to the principal Mexican manual for seismic design [5, 6], an epicentral seismic zone has a radius of 80 kilometers and, inside this zone, the vertical acceleration has to be considered for seismic design/evaluation. The epicentral radius of 80 kilometers involve practically the whole Morelos, meaning that Morelos was a complete epicentral zone due to S/19/2017/E.

The observed damage in Morelos due to S/19/2017/E was very important in practically the whole Morelos (epicentral zone, Fig. 4). According to official sources [7] the deaths counted were 74, houses with total damage were around 7,400 and other 16,500 presented some kind of structural damage. Around of 1,300 schools (84% from the total) were damaged (36 collapsed), and 7,000 economic units were affected (factories, markets, stores, particular service offices, etc.). Some hospitals, ordinary electrical substations, hydraulic infrastructure and bridges also presented seismic damages that left them totally or partially inoperative. For example, the major public regional hospital in Cuautla, the second city in importance in Morelos (own population of 200,000 inhabitants but 400,000 inhabitants as metropolitan area), was closed two years because of slight to moderate structural damage and moderate to severe nonstructural damage in components and equipment (Fig. 5). In the same way, Cuautla was left without electric energy around 12 hours after of S/19/2017/E because of the shutdown of the electrical substation located at the downtown [8]. Finally, a bridge located on the shortcut between Tlaltizapan and Tlaquiltenango (at the southwest) was closed three weeks due to slight structural and nonstructural damage in the road pavement and abutments (Fig. 6).

Fig. 5 – Typical structural and nonstructural damage due to S/19/2017/E in the IMSS Zonal General Hospital No. 7 at Cuautla, Morelos

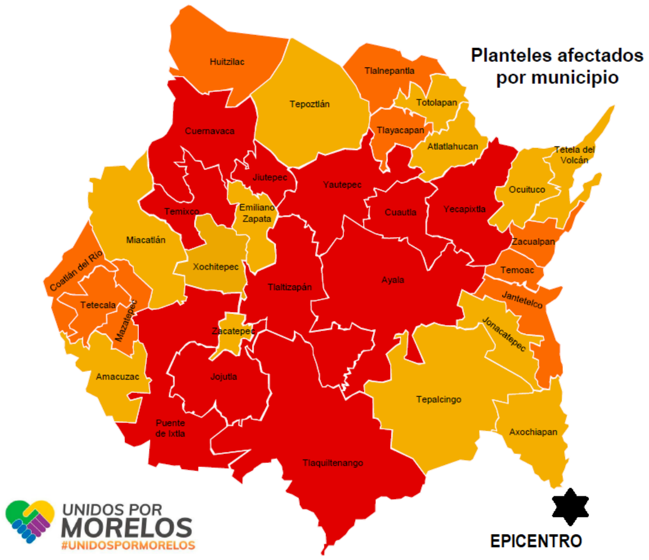
Fig. 6 – Typical structural and nonstructural damage due to S/19/2017/E in a bridge on the shortcut between Tlaltizapan and Tlaquiltenango, Morelos

The damage distribution in Morelos caused by S/19/2017/E is presented in Fig. 7 and Fig 8 for housing and schools, respectively. As can be seen in Fig. 7, the major seismic damage in housing was concentrated at the south and east regions (red color in Fig. 7). This can be explained by the fact that both regions are close to the epicenter and they are predominant rural zones in which self-construction with masonry and reinforced concrete are very poor quality in materials and manpower, especially in suburbs (Fig. 9). In Morelos, 84% from the total schools were damaged [7]. The damage distribution in schools (Fig. 8) agrees with the level of urbanism and population. In the municipalities with the major urbanism and population there are the major quantity of schools and therefore more quantity of schools with damage (red color in Fig. 8). It is worth noting that, from decades, in Mexico the schools have to be designed with special seismic considerations. It is evident that something wrong has been happening with the seismic design of schools in Morelos (Fig. 10).



Municipio	Daño total
Tetela del Volcán	831
Jojutla	652
Ocuituco	529
Tepalcingo	486
Tlaquiltenango	396
Totolapan	334
Ayala	333
Yecapixtla	324
Puente de Ixtla	293
Jantetelco	281
Tlaltizapán	258
Axochiapan	243
Yautepec	242
Miacatlán	232
Cuautla	209
Tepoztlan	203
Zacatepec	190
Jiutepec	158
Cuernavaca	152
Emiliano Zapata	142
Tetecala	111
Xochitepec	109
Tlayacapan	95
Temoac	90
Jonacatepec	82
Temixco	82
Tlalnepantla	65
Amacuzac	64
Zacualpan	55
Atlatlahucan	49
Coatlan del Río	47
Huitzilac	45
Mazatepec	28
TOTAL	7,410

Fig. 7 – Damage distribution of housing (total damage) due to S/19/17/E [6]



Municipio	Planteles Dañados
Cuernavaca	164
Cuautla	111
Ayala	89
Jiutepec	72
Yautepec	72
Tlaquiltenango	68
Temixco	58
Jojutla	57
Puente de Ixtla	53
Yecapixtla	52
Tlaltizapán	50
Xochitepec	38
Axochiapan	37
Emiliano Zapata	36
Miacatlán	33
Tepoztlán	31
Tepalcingo	31
Atlatlahucan	29
Tetela del Volcán	29
Zacatepec	29
Ocuituco	26
Jonacatepec	23
Totolapan	22
Amacuzac	20
Coatlan del Río	19
Tlayacapan	19
Jantetelco	18
Temoac	16
Tetecala	16
Zacualpan	14
Huitzilac	13
Mazatepec	11
Tlalnepantla	10
TOTAL	1,366

Fig. 8 – Damage distribution of schools (any level of damage) due to S/19/17/E [6]

a)

b)

c)

Fig. 9 – Typical failures in housing with poor quality: a) adobe (Jonacatepec, east region), b) adobe in first level and concrete/masonry in second level (Jantetelco, east region) and, c) unreinforced masonry (Jojutla, south region)

a)

b)

Fig. 10 – Collapsed public schools: a) elementary school (Jojutla, south region) and, b) kindergarten (Tepalcingo, south region)

3. Damage in urban regions

The most affected urban areas in Morelos were Jojutla and Cuautla (in this order). These both cities: i) are equidistant (50 kilometers) to the epicenter (Fig. 11), ii) were founded over alluvium soil deposits that surely caused important seismic site effects (Fig. 12), iii) have almost the same level of urbanism and, iv) have a similar construction industry. These coincidences would suggest that the seismic damage would be similar in both cities; nevertheless, the downtown and suburbs of Jojutla were the most damaged areas in whole Morelos. In Cuautla, the seismic damaged was important but definitely it was not comparable with the observed damage in Jojutla.

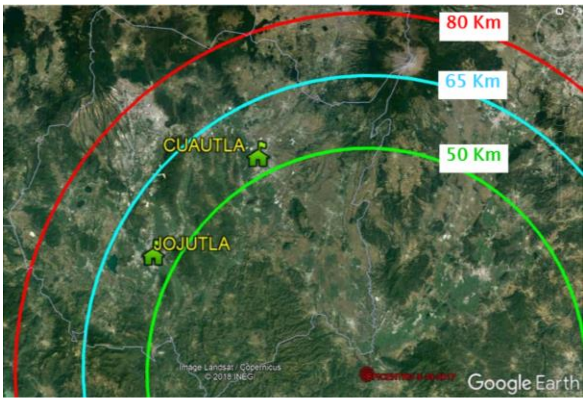
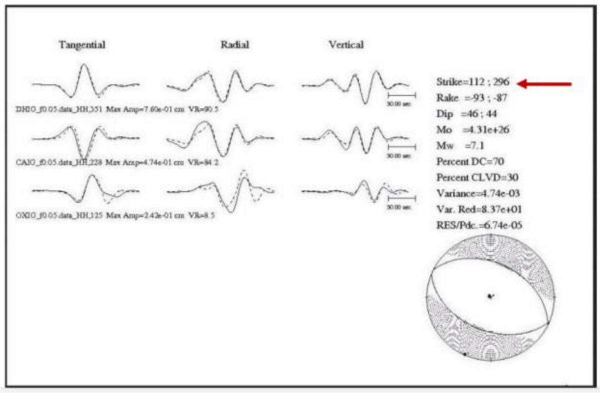


Fig. 11 – Location of the city hall in the downtown in Jojutla and Cuautla (Morelos). Courtesy of Google Earth

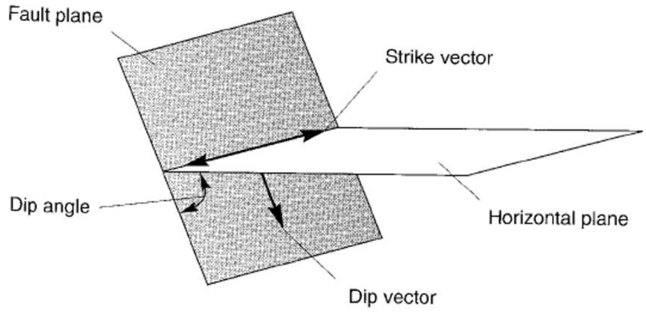
a) b)

Fig. 12 – a) Location of Jojutla and Cuautla over alluvial soil deposits (*aluvión*) [9], and b) Geological cross section of Cuautla indicating alluvial soil deposits underneath [10]

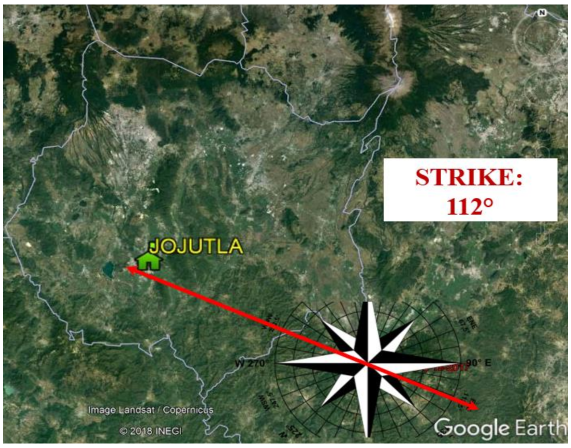
A possible explanation for the different level of seismic damaged observed in Jojutla, against the observed in Cuautla, could be the strike vector direction of the fault plane of the S/19/2017/E. As depicted in Fig. 13 Jojutla lies over the strike vector direction (112° approximately). Of course, this is a very rough analysis that could explain just some differences, if any, in the accelerations at bedrock between Jojutla and Cuautla.



a)



b)



c)

Fig. 13 – a) Focal mechanism of S/19/2017/E [11], b) Geometric notation for description of fault plane orientation [12] and, c) Location of Jojutla respect to the strike vector of the fault due to S/19/2017/E

In Fig. 14 is presented the typical seismic damage in Jojutla due to S/19/2017/E. Massive damage was observed at downtown in commercial buildings of one to four levels. It is worth noting that, as a rule, in this failures an absent or deficient seismic detailed was observed in columns, beams and structural walls. In the same way very deficient building materials was detected (concrete and masonry). Some blocks of downtown in the commercial zone was demolded due to the extensive damage. In the other hand, it was observed that some houses with architectural project collapsed (in the majority of the registered cases an architect was on charge of the structural project). Finally, self-construction housing of unconfined/unreinforced masonry was massively damaged, so much that a big block was complete demolded (to 400 meter of downtown).

In Fig. 15 is presented the typical seismic damaged observed in Cuautla. In general, the damage has the same typology observed in Jojutla, but not so concentrated, neither so strong. As particular case, in Cuautla was observed a big unit housing (80 buildings of three or four levels) with moderate damaged (but six buildings already demolded due to severe damaged). This unit housing had to be designed to resist strong seismic motions; nevertheless, preliminary analyses suggest that the area of walls in one direction was insufficient to resist the S/19/2017/E and the seismic forces recommended in the year of its design/construction (about 1995) [13].

a) commercial buildings

b) housing architectural project

c) self-construction

Fig. 14 – Typical seismic damage in Jojutla, Morelos, due to S/19/2017/E

a) commercial buildings

b) housing with architectural project

c) housing unit

Fig. 15 – Typical seismic damage in Cuautla, Morelos, due to S/19/2017/E

4. Conclusion

A personal interpretation of the author for the seismic damage observed in Morelos due to S/19/2017/E was presented. The author is native of Morelos and know very well the local environments related with the construction practice (professional, educational and government). The State of Morelos belong to an important seismic zone in Mexico; this has been recognized from decades in the manual for seismic design most used in Mexico excepting for Mexico City [5, 6, 13]. Unfortunately, this situation was not being well understood or recognized by some engineers and architects in Morelos which, in turn, it was reflected on the questionable elaboration of local buildings codes (municipality buildings codes). For example, the latest building code for Jojutla, prior to S/19/2017/E [14], specifies for seismic design coefficients c=0.16 to firm soil and c=0.32 to intermediate soil. In this code, implicitly it is supposed that a spectrum has to be considerate to perform a static or dynamic analysis, but there are not equations in the code, neither a clear reference to another document. A better recommendation to perform the seismic design of housing in Jojutla should be with a simplified method where the coefficients should had been [13]: c=0.32 and c=0.43 for confined masonry with solid units and hollow units, respectively (the soft soil effect is considerate with these coefficients). In Cuautla the situation was very similar to Jojutla. Other municipalities have lacked of regulations (for example, Axichiapan, Jantetelco, Tepalcingo and others).

Other problems well identified were: i) the absent of buildings materials with enough quality to be used as structural material (masonry and concrete), ii) absent of seismic detailed in structural elements (concrete columns/beams and masonry walls) and, iii) the absent of construction supervision. All the evidence suggests a lack of seismic design culture in Morelos.

What is important to do in Morelos? In the author opinion it is very important: i) to perform a seismic zonation of each municipality to identify the more zones where the effects of soft soils are important [15], ii) elaborate rational municipality building codes taken into account the experience of the S/19/2017/E, iii) improve the characteristics of the local masonry [16], iv) select the engineers and architects that can develop a structural project and, v) to place a seismic instrumentation network in the municipalities to record future earthquakes and calibrate the seismic regulations. Efforts are carrying out.

5. Acknowledgements

As mentioned above, in this paper is presented the personal opinion and interpretation about the seismic damage observed in Morelos due to S/19/2017/E. Nevertheless, the interaction with good and generous persons improved the understanding of this topic. The author thanks to: i) Dr. Arturo Tena-Colunga for his invaluable guide and transmission of knowledge, ii) Arq. Luis E. Arvizu-Romano, Mtro. José Juan Guerrero-Correa, Ing. Juan Gómez-Santoyo, Arq. Alberto Beltrán-Barrera, Arq. José Antonio Contreras-Quintero, Ing. Biviano González-Torres, Ing. Fernando Andrés-Mazón and Ing. Wendolyne Mata-González for sharing time and experience in the first post-seismic evaluation in Cuautla, iii) Dr. Arturo Tena-Colunga, Ing. Oscar Daniel Reyes-Pérez, Dr. Manuel Eurípides Ruiz Sandoval-Hernández, Arq. Alberto Beltrán-Barrera, Ing. Juan Gómez-Santoyo, and Ing. Biviano González-Torres for sharing time and experience in the seismic evaluation of the Unidad-Habitacional Tetelcingo, iv) Dr. Luis Eduardo Pérez-Rocha, Dr. Eber Alberto Godínez-Domínguez, Dr. Raúl Aguilar-Becerril, Dr. Ulises Mena-Hernández, Ing. Ignacio González-Espinoza, Ing. Ignacio Guerra-Gutiérrez, Ing. Gabriel Tico Nava-Oliva and Ing. Agustín Orea-González for the rich interchange of information and opinions, v) Dr. Arturo-Tena-Colunga, Dr. Alonso Gómez-Bernal and Dr. Eber Alberto Godínez-Domínguez for sharing time and experience in the earthquake reconnaissance route in Chiapas-Oaxaca two weeks before to S/19/2017/E, vi) Dr. Alonso Gómez-Bernal, Dr. Darío Rivera-Vargas and Dr. Fernando Peña-Mondragón for sharing time and experience in some earthquake reconnaissance routes in Morelos, vii) Ing. Raúl Aguilar-Montiel and Ing. Luis Guerra-Gutiérrez for helping in managing permits to enter in some restricted areas in Cuautla, viii) Arq. Aldo Gaspar-Beto and C.P. Alba Jiménez Velázquez-Jaimes for sharing statistic information of damages and, ix) C.P. Marbella Fernández-

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