The September 19th, 2017 Puebla, Mexico Earthquake – Preliminary report

S. Roeslin & K.J. Elwood

Department of Civil Engineering, University of Auckland, Auckland

H. Juárez-Garcia & A. Gómez-Bernal

Universidad Autónoma Metropolitana Azcapotzalco, Mexico City

R.P. Dhakal

Department of Civil Engineering, University of Canterbury, Christchurch

ABSTRACT

The magnitude 7.1 Puebla, Mexico earthquake of September 19th, 2017, centred 55 km south of the city of Puebla, led to significant and extensive damage in central Mexico, especially in Mexico City. One month after the event, a team of four researchers from New Zealand travelled to the affected area with the aim of enabling access to observational data that may be relevant to New Zealand's own disaster mitigation effort. The NZ team was guided by local teams from the Universidad Autónoma Metropolitana-Azcapotzalco (UAM), and they collaborated with the American Concrete Institute (ACI) Disaster Reconnaissance team and the Colegio de Ingenieros Civiles de Mexico (CICM) – Mexican Society of Civil Engineers. The NZ team actively took part in building assessments while conducting passive observations. Preliminary observations have revealed a concentration of building damage in the transition and soft soil zones (i.e. between hard and deep soils). Some areas within Mexico City suffered widespread and extensive damage, Coapa, Jardines de Coyoacan, Culhuacan and Narvarte neighbourhoods. In general, there were 38 collapsed and more than 3000 damaged buildings. Observations reinforce the significance of local site effects, the need of informed, targeted approach in wide-scale building assessments, and the potential role for building instrumentation. The mission provided opportunities to record the performance of various retrofit and repair techniques

through examples that were installed following the 1985 Michoacán Earthquake. The team was jointly resourced by the NZ Society for Earthquake Engineering, the University of Auckland, the University of Canterbury, and Universidad Autonoma Metropolitana-Azcapotzalco.

1 INTRODUCTION

On Tuesday, 19 September 2017, at 13:14 pm local time (18:14:38 UTC) a Mw 7.1 earthquake struck the central part of Mexico (United States Geological Survey (USGS), 2017b). The affected areas encompass the metropolitan area of Mexico City (21.2 million people), Puebla (1.6 million people) and Morelos (75,000 people). The death toll rose to 369 (Munich RE, 2018), 38 buildings collapsed (Ortega, 2017) and more than 3000 buildings suffered damage (McDonnell, Vives, & Linthicum, 2017) making the Puebla earthquake the fifth largest natural catastrophe in 2017 with 6000 million US$ of overall losses (Munich RE, 2018).

The NZSEE team was in Mexico City in late October 2017. The team spent the first days in the neighbourhoods of La Roma and La Condesa (both in the yellow polygon on Figure 1), two central neighbourhoods where buildings experienced severe damage. The reconnaissance effort was also possible in Narvarte, along La Morena street (orange polygon on Figure 1); and to the southern part of Mexico City, Coapa and Jardines de Coyoacan (red polygon Figure 1). The NZ team went to Mexico with objective to study the performance of steel braced multi-storey structures similar to those affected by the 2010-11 Canterbury Earthquake sequence and the performance of modern buildings, particularly reinforced framed buildings similar to those affected by the November 2016 Kaikoura Earthquake. The team was also motivated by the particular ground shaking effects in Mexico City similar to the basin effects observable in Wellington during the Kaikoura earthquake.

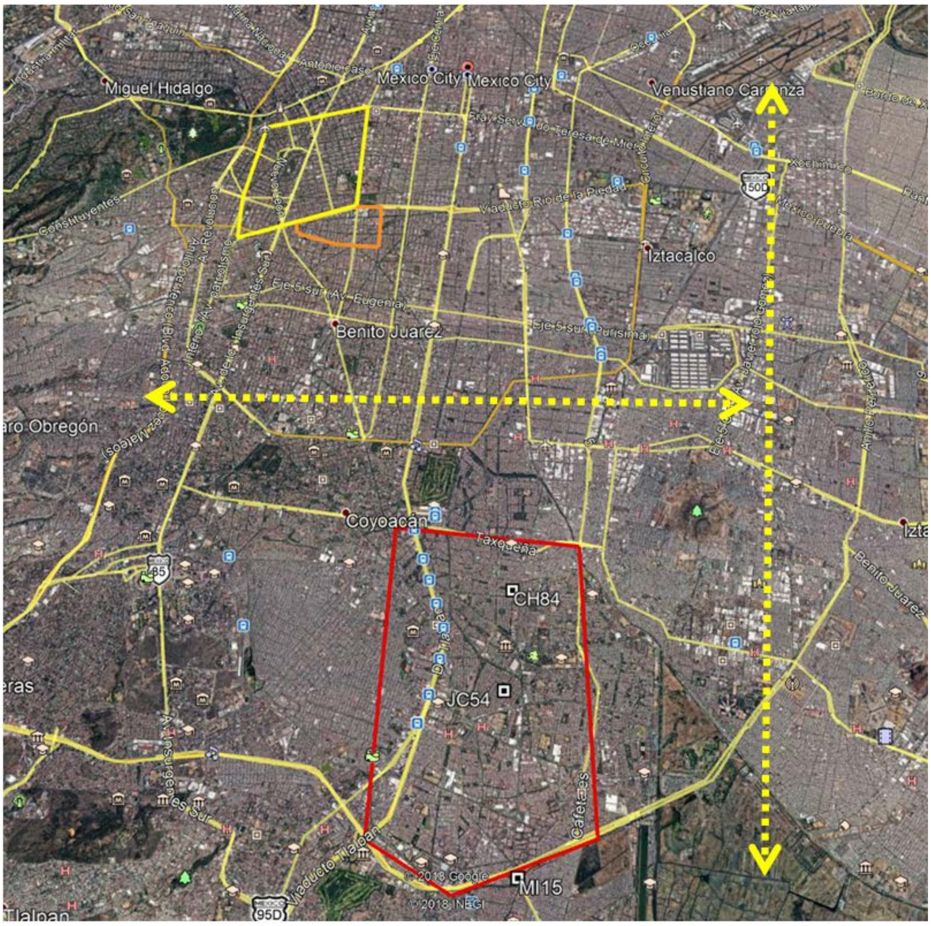

Figure 1: Overview of the central part of the urban area of Mexico City (north-south arrow 20km long, east-west arrow 15km wide). The yellow polygon encompasses the neighbourhoods of La Roma and La Condesa. The orange one surrounds the Morena street and the red one englobes the southern part with Coapa and Jardines de Coyoacan (Google Maps, 2017)

2 SEISMOLOGICAL FEATURES

The September 19th, 2017 Puebla earthquake was of Mw 7.1 (United States Geological Survey (USGS), 2017b). The earthquake source was a normal fault, considered as an intraplate earthquake, at an intermediate epicentral depth of 48.0 km. The epicentre was located 12 km to the southeast of Axichiapan between the states of Morelos and Puebla (United States Geological Survey (USGS), 2017a).

Due to the rupture in the Cocos plate and the inslab location of the epicenter, the distance with the neighbourhood of La Roma in Mexico City was only 120 km (Jaimes, 2017). This is more than three times closer compared to 400 km that separated Mexico City from the subduction zone where the Mw 8.0 Michoacán earthquake started (United States Geological Survey (USGS), 1985). While most of the earthquakes affecting Mexico start from the subduction zone, some intraplate earthquakes were also observed. Figure 2 illustrates the location of significant historical earthquakes in Mexico. Ellipses represent subduction earthquakes and stars intraplate earthquakes. The red stars represent the location of deep intraplate earthquake and the blue ones the location of shallow intraplate earthquake. As shown on the map Figure 2, most events occurred along the south-west coast of Mexico following the Middle America Trench (represented with a blue dotted line).

Cruz Atienza, Krishna Singh, & Ordaz Schroeder (2017) compared strong motions recordings of the 2017 Puebla earthquake with the 1985 Michoacán earthquake. However, the seismic features and amount of energy of the September 19th, 2017 and 1985 earthquakes are different (Cruz Atienza et al., 2017). The faulting mechanisms, duration and epicentre location produced different characteristics in terms of seismic parameters. After the 1985 earthquake, it was clear that subduction mechanisms would have a significant impact in very soft soils in Mexico City, and in taller buildings. It was also expected that intraplate earthquakes could have a significant impact on firm and transition zones of Mexico City and hence in low to medium rise buildings, as discussed by Gomez-Bernal et al (2012).

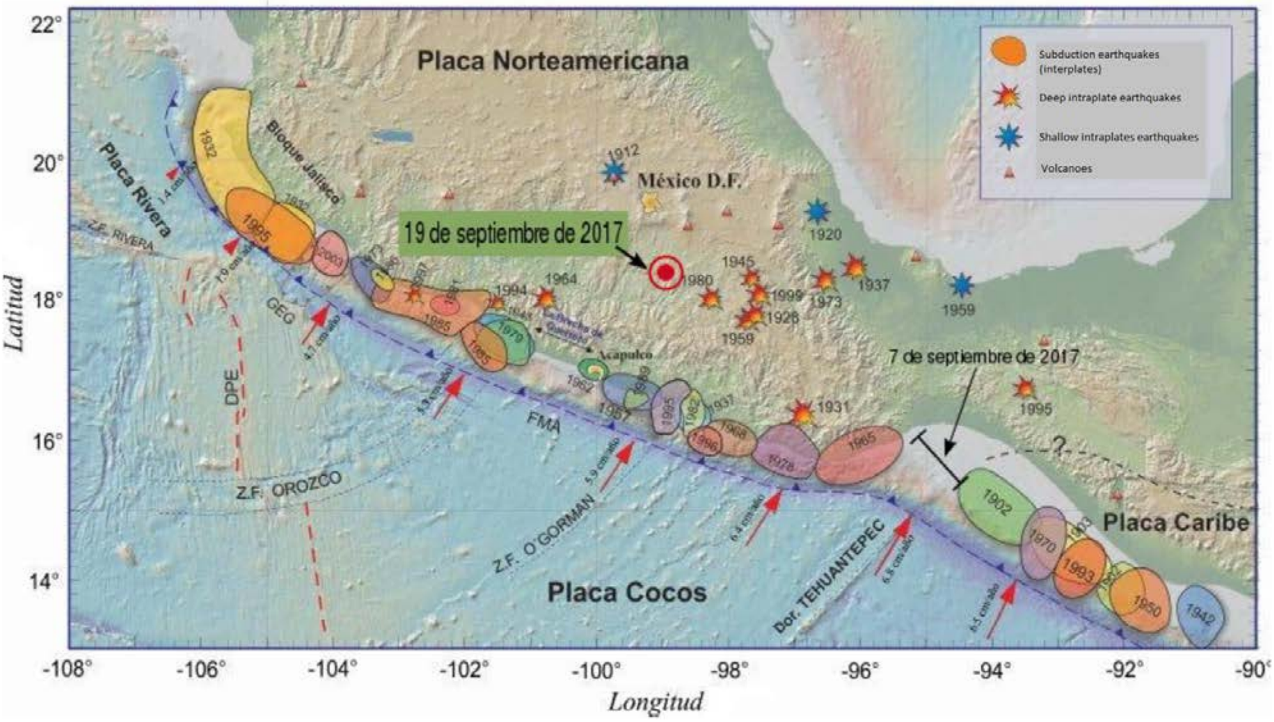

Figure 2: Map of the rupture areas of the most significant past earthquakes that occurred in Mexico (Servicio Sismológico Nacional, 2017)

3 MEXICAN CODES AND SEISMICITY IN MEXICO CITY

3.1 Mexican standards

Mexico has a unique system of managing the seismic codes at a state and municipality level. A common national code does not exist (although there is a seismic guideline by the Federal Commission of Electricity at a national scale, which has to do with power supply facilities). In 2008, Mexico had 104 building codes (32 at state level and 72 at municipal level). However, over the years, the Mexico City Building Code (MCBC) acquired greater relevance in Mexico, due to the size and importance of Mexico City. The first Mexican standard was published in 1920. This first buildings code was based on an allowable stress design approach. It then evolved to include performance-based requirements during the update in 1976. The Mexican seismic code evolution shows that after each significant earthquake (1957, 1985) emergency regulations took into account the lessons learned from them. The 2004 version is a revision of the 1987 code (Alcocer & Castaño, 2008). A new design standard was released in December 2017, authorities included guidelines for assessing existing buildings, and they reviewed the design spectra after the 2017 earthquake.

The emergency regulations of 1957 introduced the need to account for the effect of the soil type profiles (firm, transition and soft soil) and the seismic shear coefficient, Cy. The 1966 Mexico City building code included the three soil types, but only one Cy value for all of them. In 1976, the three soil categories were defined based on the soil depth: firm soil for $d \leq 3$ m , transition soil for $3\text{ m} < d \leq 20$ m and soft soil for $d > 20$ m. In the 1987 code update, the soil zonation was reviewed. The 2004 code had six different zones: I, II, III_a, III_b, III_c, III_d (Órgano del Gobierno del Distrito Federal, 2004). Zone I corresponds to the firm soil, Zone II to the transition and Zone III to the soft soil zone. Zone III is divided in four sub-categories, from a to d, each of the sub-categories having a different design spectrum. Maps showing the seismic zones along with the soil periods are available in the design code (Órgano del Gobierno del Distrito Federal, 2004). The 2017 code kept the same soil zones (Órgano de Difusión del Gobierno de la Ciudad de México, 2017).

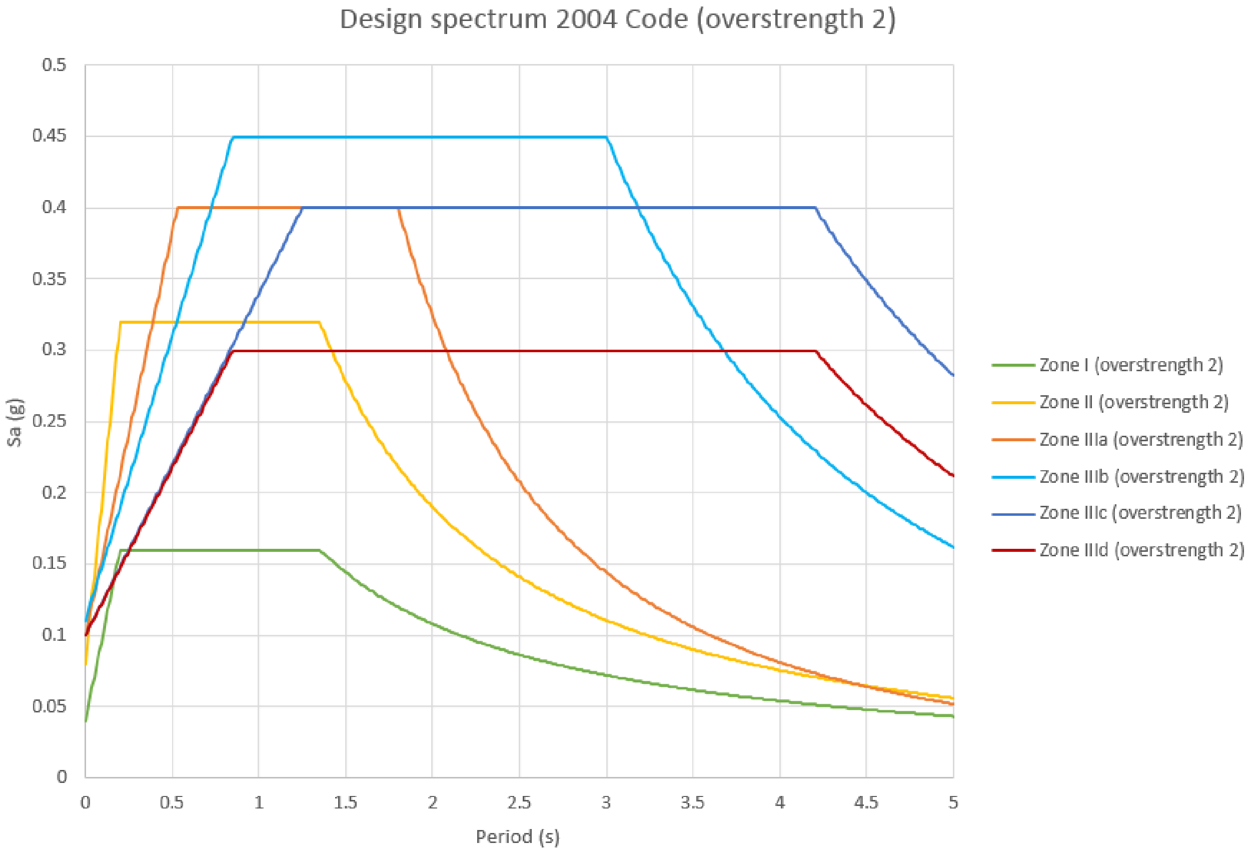

Figure 3: Design spectra for the six seismic zones according to the 2004 code for Mexico City (Órgano del Gobierno del Distrito Federal, 2004)

3.2 1985 Michoacán earthquake

Figure 4 shows the building roof acceleration at the seismic station CU and SCT for the 2017 Puebla earthquake and for the 1985 Michoacán earthquake. There were only eleven recording stations in Mexico City in 1985 as shown on Figure 5: four in firm soil zone (I) (three close to CU01 and TCY); one in transition zone (II) (SXVI); and six in lakebed zone (III) (TLHB, TLHD, CDAO, CDAF, TXSO and SCT1) (Gómez-Bernal & Saragoni, 2002). SCT1 was the one with the highest spectral response values. According to related research after 1985, Colonia Roma was supposed to be one of the zones with the largest intensity values due to the number of damaged buildings.

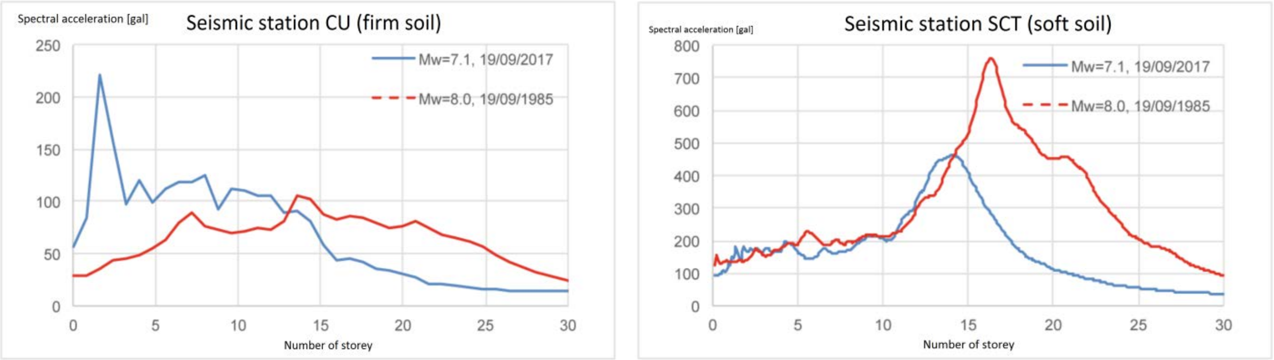

Figure 4: Building roof acceleration for firm soil, station CU (left) and station SCT (right) (Cruz Atienza et al., 2017)

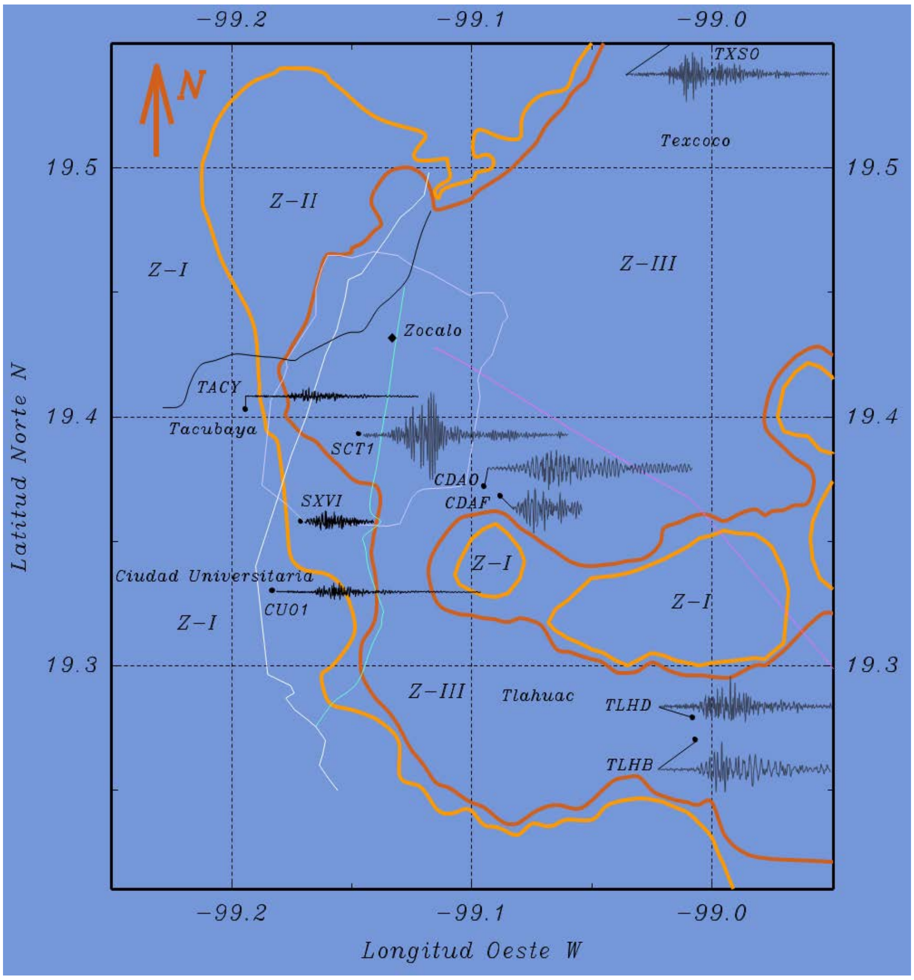

Figure 5: Map showing the location of the nine recording station available in 1985 (Gómez-Bernal & Saragoni, 2002)

3.3 Seismic demands during the 2017 Puebla earthquake

The acceleration demand on firm soil was higher in the 2017 than in the 1985 earthquake. The maximum PGA in CU station was 57 cm/s^2 in 2017 and 30 cm/s^2 in 1985. On soft soil, however, seismic demands during the 2017 earthquake were in general lower than in 1985. At SCT station, the PGA was 91 cm/s^2 in 2017 and 160 cm/s^2 in 1985 (Cruz Atienza et al., 2017). Figure 4 shows the spectral acceleration for SCT station (soft soil) vs buildings with different storey levels. Buildings around a period T = 2 sec experienced the maximum acceleration of 760 cm/s^2 during the Michoacán earthquake. The response spectra in 1985 has the larger values across all the period ranges, (Cruz Atienza et al., 2017).

Seismic recordings from the 2017 Puebla Earthquake are available from the Mexican Instrumentation and Seismic Record Center (Centro de Instrumentación y Registro Sísmico (CIRES), 2017). The raw data were processed with the software Seismosignal (Seismosoft, 2016) and the filtered outputs were exported in Excel. The seismic records were grouped in relevant bins representative of each seismic zone. Figure 6 shows the seismic record for the soft-soil Zone III a in the East-West direction. The red line represents the design spectrum for the soft soil Zone III a from the values according to the 2004 design code for Mexico City (Órgano del Gobierno del Distrito Federal, 2004). The black bold line stands for the median for the same seismic zone. The design spectrum with an overstrength 2 is exceeded between the period range of T =1.0 s and T = 1.5 s. This indicates that the Puebla earthquake had high energy in the lower period range.

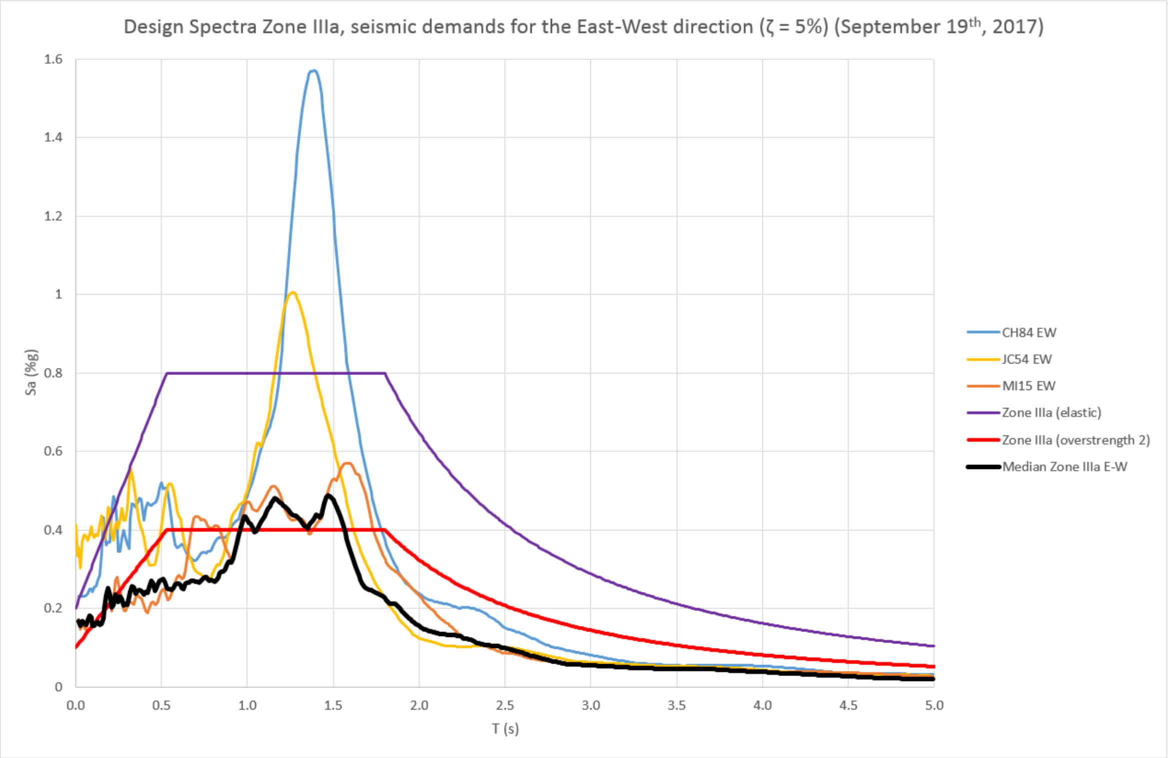

Figure 6: Peak records for the soft-soil Zone III a in the East-West direction

4 STRUCTURAL DAMAGE

4.1 Generalities

The actual urban area of Mexico City covers 1485 km^2. The city was founded on the deposit of an ancient lake, which leads to particular soft soil conditions. The soft soil has the characteristic to amplify the ground motion, as observed in 1985 earthquake. Following the Puebla earthquake 38 buildings collapsed (Ortega, 2017). It, therefore, may indicate a correlation between the amplification of motion and building damage.

In New-Zealand, the building safety evaluation follows field guides, and building assessment forms developed by the Ministry of Business Innovation and Employment (MBIE) (2017). In addition, the Guidelines The Seismic Assessment of Existing Buildings (New Zealand Society for Earthquake Engineering (NZSEE), 2017) constitute a basis for the technical assessment of existing buildings in New Zealand. In Mexico, a team at the Universidad Autónoma Metropolitana-Azcapotzalco (UAM) developed a particular form. The damage definition is based on the European Macroseismic scale EMS-98 (Grünthal, 1998) and the part assessing the building characteristics was elaborated with basis on the typologies of the buildings in Mexico City (Gomez-Bernal, 2017). Before the reconnaissance mission, the authors did an extensive review of the available assessment framework and developed a paper form based on the GEM Building Taxonomy v2.0 (Brzev et al., 2013). Details information are available in the final report of the New Zealand reconnaissance team. Typical structural failures observed are failure in columns, damage to the flat slab or in the masonry infill; failure at the joints due to improper detailing; soft story failure; damage due to pounding with adjacent buildings; torsion eccentricities because of a stiffness difference particularly in corner buildings; and corrosion issues were sometimes observed.

4.2 Performance of buildings

The Mexico City building stock is diverse. From low-rise masonry buildings in the suburbs to steel skyscrapers in the CBD and residential middle rise reinforced concrete buildings, several type of structural system are represented, and configuration are varied. Diversity is also present in the year of construction with buildings built prior to the 1985 earthquake and more recent buildings. It was possible to assess the performance of retrofitted buildings as well as non-retrofitted buildings that did not suffer damage during the 1985 earthquake and see how they performed during the 2017 Puebla earthquake. The extent of damage is diverse too. Observed damage ranged from minor cracks to total building collapse.

4.2.1 Retrofitted buildings

Mexico City suffered extensive damage due to previous earthquakes (1957 Guerrero earthquake, 1979 Guerrero earthquake, 1985 Michoacán earthquake). As the insurance penetration for geophysical events in Mexico is low (Munich RE, 2017), building's owner tended to avoid any demolition. This led to the repair and retrofit of buildings. Retrofitted measures employed were documented in the literature: (Aguilar et al., 1996), (Foutch, Hjelmstad, Calderon, Gutierrez, & Downs, 1989), (New Zealand Society for Earthquake

Engineering (NZSEE), 1988). The upgrading of critical structural elements with steel or concrete jacketing was a typical retrofit used to add strength to the building. The final report gives examples of buildings retrofitted with this technique: buildings A, E, and F (as referenced by Aguilar et al. (1996)). To protect the building in future earthquakes, a common practice was to modify the building natural period and shift the structure out of the critical period range. Steel bracing, external or in the frames, is an affordable measure that changes the natural period of the building. The full report presents illustrations of the implementation of this technique (buildings B and D (Aguilar et al., 1996), Durango building and Park España building (Foutch et al., 1989)).

In in October 2017, the NZSEE team assessed the performance of retrofitted buildings. Internal inspections were possible for the building G (Aguilar et al., 1996) and the school complex of Colegio Madrid. Figure 7 shows the assessment of a retrofitted wall and column from the building G. No apparent damage was observable. Further details for each case study are available in the full report. Overall, the retrofitted buildings performed well during the 2017 Puebla earthquake.

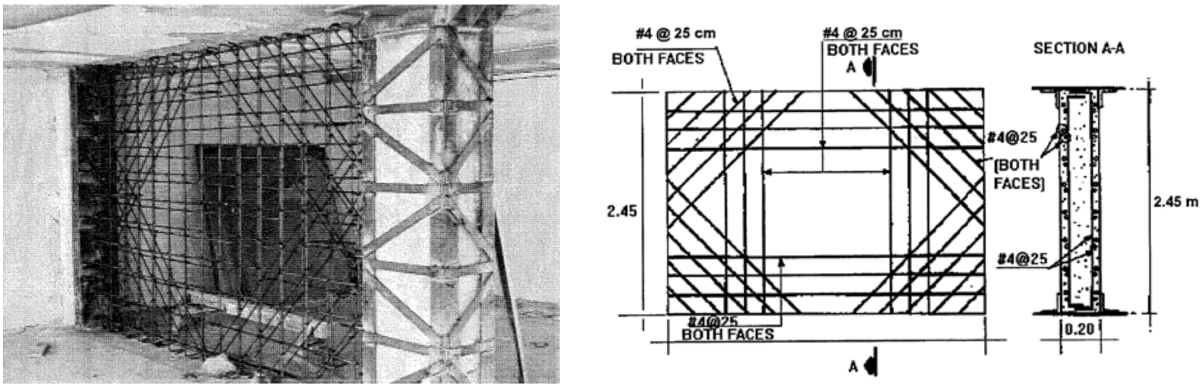

Figure 7: Wall reinforcement and column jacketing in Z251 (left), details of the retrofit (right) (Aguilar et al., 1996)

Figure 8: Retrofitted wall in 2017 (left), Steel connection (right)

4.2.2 Non retrofitted buildings

The assessment of building following the Puebla earthquake revealed a concentration of damage in the low-rise buildings (Galvis, Miranda, Heresi, Dávalos, & Silos, 2017). From the small sample of buildings that were assessed, the NZSEE team observed a concentration of damage in the non-retrofitted buildings. Each case is documented and illustrated in the final report.

5 LESSONS FOR NEW ZEALAND

5.1 Early Warning System

An Earthquake Early Warning System (EWS) alerts the population before an earthquake strikes. An EWS works with the recording of the first ground motion waves and profits from the wave travel time to send an alert of imminent damage. Following the aftermath of the M8.0 Guerrero-Michoacan earthquake, the Mexican government decided to develop an EWS to monitor the Guerrero seismic gap (Suárez & García-Acosta, 2014). Events in the past, such as the 2009 Guerrero earthquake triggered the EWS giving a prevention time for the inhabitants of Mexico City of 58 seconds. On 19 September 2017, due to the proximity of the epicentre with the urban area of Mexico City, the alarm sounded a little after the first waves reached the city. Nevertheless, it raised the awareness of the people who reacted and quickly protected themselves.

The presence of an EWS in Japan (Japan Meteorological Agency (JMA), 2007) and the current development in California (United States Geological Survey (USGS), 2018) should awake curiosity and foster interest on the benefits of an EWS for New Zealand.

5.2 Site effect

The increased acceleration in the lower period range underlined the necessity and importance to consider soil effects. Differences between the 1985 Michoacán and the 2017 Puebla earthquake show that the distance to the epicentre as well as the thickness of the soft-soil in the lake bed zone affected different types of buildings. Better knowledge about the soil under a building will provide invaluable information regarding the type of damages that can be expected in that particular building. For New Zealand, particular attention should be paid to the basin effects in Wellington. It is preponderant to understand the influence of the soil on the amplification of the seismic ground motion in each area of the city.

6 CONCLUSIONS

The 2017 Puebla (central Mexico) earthquake left a bitter feeling in the heart of the Mexican precisely on the day of the 32nd anniversary of the 1985 Michoacán earthquake. The close location of the epicentre situated in the Morelos region about 150 km away from the capital led to particular ground motion characteristics throughout the city, affecting the vulnerability of the Mexico City building stock. Collapses and structural building damage occurred mainly in the transition and shallow soft soil zones. The 2017 earthquake revealed the presence of column reinforcement deficiencies, slab issues, improper joint detailing, soft-stories and eccentricities (in plan and vertical) in several buildings. Nevertheless, the Puebla earthquake pointed the high overall performance of buildings repaired after 1985. The assessment of retrofitted building showed that reinforcement measures applied in the past performed as intended. Solutions employed for the retrofit of buildings are various yet most of the time straightforward and relatively affordable.

Each event leading to damage should be taken as an opportunity to learn and implement new steps for further improvement. History showed that each major earthquake brought a change in the Mexico City seismic design code. The 2017 Puebla earthquake should also enable progress not only for Mexico (in terms of better design of its building stock and improvement of its code) but also for foreign countries in terms of valuable learnings. Learnings from the benefits of an Early Warning System and ground motion amplification due to site effects are relevant for New Zealand. The lessons learnt from the 2017 Puebla earthquake also remind us that gaps in our understanding remain. While the 2017 Puebla earthquake highlighted the potential value of a EWS, the instrumentation of structures to collect real-time building acceleration and displacement should be encouraged. A dense network of seismic monitoring instrumentation implanted in buildings will enable a significant improvement in our understanding of the building response during an earthquake. More research is necessary to improve our knowledge.

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