The paper was published in the proceedings of XVI Pan-American Conference on Soil Mechanics and Geotechnical Engineering (XVI PCSMGE) and was edited by Dr. Norma Patricia López Acosta, Eduardo Martínez Hernández and Alejandra L. Espinosa Santiago. The conference was held in Cancun, Mexico, on November 17-20, 2019.

Geotechnical Engineering in the XXI Century: Lessons learned and future challenges
N.P. López-Acosta et al. (Eds.)

doi:10.3233/STAL190259

Mexico City 1985 and 2017 Earthquakes: Soil Response and Code Lessons

Guillermo DÍAZ-FAÑAS[a,1], Sissy NIKOLAOU[a], Olga-Joan KTENIDOU[b],
Evangelia GARINI[c], George GAZETAS[c] and Xin MA[a]
[a] *Geotechnical and Tunneling Technical Excellence Center, WSP USA, United States*
[b] *Institute of Geodynamics, National Observatory of Athens, Greece*
[c] *Department of Civil Engineering, Technical University of Athens, Greece*

Abstract. Mexico City is one of the world's most tectonically active regions, with a long history of destructive earthquakes and volcanic eruptions. With over 100 earthquakes of magnitude 6 or higher since 1787 and poor subsurface conditions, Mexico City is a modern metropolis with challenges for architects, urban planners, engineers, developers and stakeholders.

On September 19th, 1985, a M8.0 earthquake in Michoacán killed more than 40,000 people and caused 880 buildings to collapse in Mexico City. At the wake of its 32nd anniversary, the 2017 M_w7.1 Puebla-Morelos earthquake struck, leaving behind about 219 dead and 38 collapsed buildings in Mexico City.

This paper will present similarities and differences of the two events in aspects of: (i) geotechnical and seismological observations, (ii) building code evolution and its impact to building response, and (iii) analytical predictions of response of characteristic soil profiles at sites with actual recordings of the ground motions.

Keywords. Mexico City earthquakes, seismic design, soil amplification, historic seismicity, lake and basin effects.

1. Introduction

Exactly on the 32nd anniversary of the September 19th, 1985 M8.0 Michoacán earthquake, the 2017 M_W7.1 Puebla-Morelos earthquake struck south of Puebla in Mexico. This event was a dire reminder of the city's seismic vulnerability that generated direct losses of over 2b USD and claimed the life of 219 people [1]. Historically, Mexico City has experienced devastation from major earthquakes - including these two events - primarily due to effects generated by its unique geologic and topographic setting. This setting amplifies and modifies the seismic waves as they propagate upwards within the former great Lake Texcoco. In this paper, key unique features of Mexico City and valuable lessons learned from the two important earthquakes in 1985 and 2017 will be presented. The catalytic influence of lessons learned from these events in the state-of-the-art in engineering seismology and state-of-practice in both geotechnical and structural earthquake engineering will be discussed.

---

[1] Corresponding Author, Geotechnical & Tunneling Technical Excellence Center, WSP USA, 1 Penn Plaza, New York, NY, United States; E-mail: Guillermo.DiazFanas@wsp.com.

2. Background

Mexico City is mainly built on a basin formerly occupied by the ancient Lake Texcoco. Prior to the arrival of the Aztecs in the 13th century, the lake had already been split in four smaller water bodies due to natural desiccation. In the decades following and prior to colonization, the Aztec cities were growing with the addition of more pyramids and temples and the introduction of the “chinampas”passive-farming system for irrigation and food production [2]. The chinampas were created by transferring clay from the lakes and included canals cut into the lacustrine strata. Canals, levees and low banks were constructed to avoid infiltration of saline water and prevent frequent flooding, which made the lakes to continue to desiccate. With the arrival of the Spaniards in the 16th-18th centuries, the desiccation became worse by deforestation, agriculture, pasture lands, construction and land reclamation.

To avoid damage from differential settlements and prevent earthquake-induced damage, the new settlers established the Cervantes de Salazar code in 1550, limiting construction height to two stories, introducing “probably the first rule for building earthquake-resistant structures in the Americas” [3]. The Lake Texcoco area decreased from 700 km^2 during Aztec times to 140 km^2 by the end of 18th century [4]. The drainage of the lake system, shown on Fig. 1 as ancient and current lake has caused significant soil settlements of the ancient lake bed that currently underlies the more recent sediments in Mexico City. The location of the former “chinampas” and the ancient Aztec capital “Tenochtitlán”, with respect to Mexico City are also shown on Fig. 1. Today, the lake is almost completely drained and the city rests on the lake bed’s saturated clay, experiencing subsidence due to the continuing extraction of groundwater, which has reached levels of 9 m since the beginning of the 20th century [5].

Figure 1. Evolution of the former lake system in Mexico City valley [2].

2.1. Tectonic Setting

Four large tectonic plates (North American, Cocos, Caribbean, Pacific) and microplate Rivera converge at Mexico. Most of the country lies on the North American tectonic plate, but the Pacific Ocean floor at the south rests on the Cocos plate which moves towards the North American plate at a rate of 61 mm/yr [6]. The two plates meet off the southern shore, forming a deep underwater trench that runs parallel to the shoreline. While most of Mexico's seismic activity occurs at the Pacific coast in the mid-American subduction [7, 8, 9], events also originate at the Rivera and Caribbean plates edge [10].

2.2. Geotechnical Setting

A generalized section across central Mexico City is shown on Fig. 2. The dominant layer is the Upper Clay (in purple), which contains volcanic ash and is characterized by unusually high plasticity (PI $\approx$ 200-300), natural water content ($w_n \approx$ 200-600) and low shear wave velocity ($V_s \approx$ 40-90 m/s) [11]. Below lies a compact silty sand layer that are underlain by a hard crust: a compact and very dense sand, followed by a series of preconsolidated lacustrine clays, which eventually turn in thick layers of very dense silts, sands and hard clay known as "Depósitos Profundos" (Deep Deposits, in orange and gray).

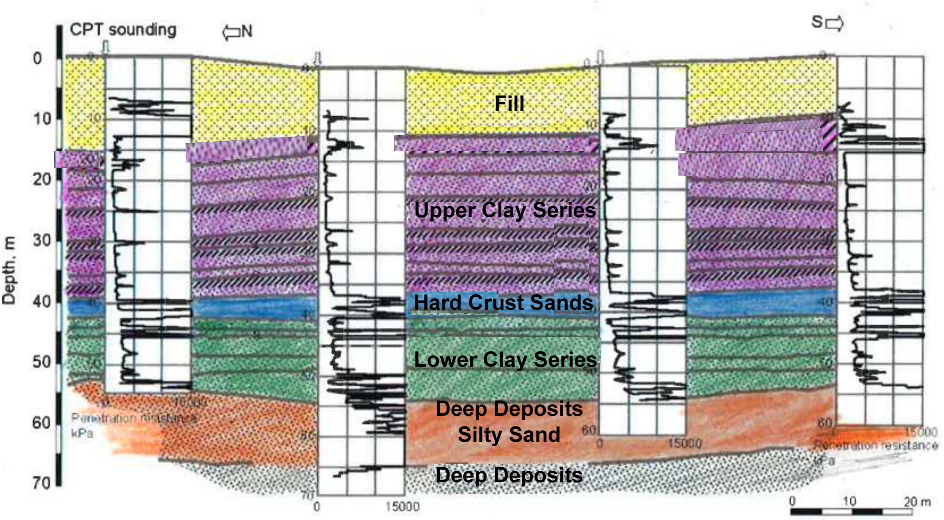

Figure 2. Generalized soil stratigraphy in central Mexico City represented by colors [3], yellow (fill), purple (upper clay), blue (hard crust sands), green (lower clay), orange (deep silty sands deposits), gray (deep clays).

Currently, regional developments are founded in soils that contain volcanic material and lacustrine clays. The urban landscape of Mexico City is supported by foundations that differ in age and type to accommodate for loads from a variety of structures, ranging from magnificent high-rises in Paseo de la Reforma, such as the iconic 55-story Torre Mayor [12], to colonial and other traditional structures.

3. The 1985 and 2017 Earthquakes

3.1. 1985 M8.0 Michoacán Earthquake

On September 19th, 1985, the Mexican state of Michoacán was struck by one of the most severe earthquakes in the history of the country, a M8.0 occurring in the subduction zone off the western coast. This event is unique because the severe damage was localized damage in Mexico City, about 400 km away from the epicenter. The effect on the capital was catastrophic, with life loss reaching 40,000. Structures of 6-20 stories were severely affected [13, 14, 15] due to resonance; i.e., their natural period coinciding with the predominant period of the ground motion. It also became clear that the basin's soft clay was a main contributor to the disaster [14, 15, 16, 17], amplifying the incoming motion predominantly at around 2 s [15], within the 1.5-3.0 s range [11, 17, 18], which coincided with the natural period of the collapsed buildings. This "double resonance" resulted in pancake and soft story collapses (Fig. 3) throughout the city [13, 19]. A smaller number of buildings outside the 6-20-story range (with less than 5 or more than 15 stories) also sustained significant damage.

Figure 3. Collapse of residential multistory building in the 1985 Michoacán earthquake [13, 19].

3.2. 2017 M_w7.1Puebla-Morelos Earthquake

On 19 September 2017, a M_W7.1 earthquake struck Puebla-Morelos [20]. This seismic event also caused severe localized damage in Mexico City, which was located approximately 120 km away from its epicenter [21]. Numerous schools sustained significant damage, and one collapsed showing once again a pancake effect collapse (Figure 4), causing the death of dozens of students. In terms of geotechnical failures, settlement of buildings, slope failures, and ground movements were the most conspicuous. The availability of social media was a factor that set this seismic event apart from the one in 1985: the emergency preparedness, retrofit and recuperation were reported in detail this time. Moreover, the residents were notified almost a minute before the strong shaking arrived, thanks to the early warning system that had been introduced.

Most buildings exhibiting severe damage or collapse had been constructed before 1985, as they were designed to a version of the code with accelerations values up to 40% lower than what post-1985 codes prescribe. Generally, newer buildings had only cosmetic damage. Nonstructural unreinforced concrete masonry partition walls suffered damage, and in many cases, may have contributed significantly to the lateral strength of the structure and prevented further damage and collapse. The resonance phenomenon was also evident in this earthquake. Comparing rock or hard soil response spectra from records in 2017 and in 1985 shows that the incoming motion was rich in periods around 2 s [11]. Response spectra recorded in soft soil sites indicate that the most significant site amplification effects were within the 0.5 to 1.8 s range [11, 20, 22]. These coincided with the periods of damaged buildings throughout the city, particularly at locations where the soil column's period was similar and thus amplified ground motion further.

Figure 4. Collapse of school in the 2017 Puebla-Morelos earthquake (Photo by Carlos Cisneros/AP).

4. Assessment and Comparison of the Seismic Events

The accelerograms recorded during the Puebla-Morelos 2017 event at stations CU (rock outcrop) and SCT (soft soil), outside and inside the lake basin, respectively, provide an indication of the intensity of ground shaking. The recorded Peak Ground Acceleration (PGA) at CU was 0.05 g and 0.1 g at SCT. Figure 5 compares recorded acceleration time series and corresponding elastic response Spectral Accelerations (SA) at the two from the 1985 and 2017 earthquakes. The comparison shows that the rock motion was similar for both events in terms of PGA; however, the largest peak in 2017 occurred at 0.2 s, while the 1985 showed additional peaks between periods of 1.0 to 3.0 s. The records had more striking differences at the SCT soft soil site with overburden thickness of about 40 m [11]. The 2017 event produced lower that the 1985 SAs for most structural periods.

The properties of the Mexico City clay deposits have been the topic of research for many years following the 1985 earthquake. In 1991, Vucetic and Dobry concluded, through advanced soil testing and observations, that the remarkably high Plasticity Index (PI) of the upper clay results in an almost purely elastic response to earthquake shaking, with almost absent strength degradation, even under strong excitation [23]. Using this unique characteristic allows practitioners to reproduce typical seismic site response using simplified, equivalent linear methods with software like Shake [24] and DeepSoil [25] or even by using analytical engineering approximations [10, 26, 27].

A generalized and simplified soil profile of Mexico City can be a one-dimensional (1D) column of soft clay with Vs = 80 m/s and PI = 200 overlying an assumed interface between stiff soil and bedrock at a depth H from the ground surface. The fundamental soil elastic period of this column is approximately equal to $T_s \approx 4H/V_S$. Contours of T_s [28] are available from maps in the local building code which reflect the stiffness of the subsurface soils on or before 1992. The regional consolidation of the clay of the Mexico Valley, due to intensive pumping and construction growth has modified the site conditions, causing the fundamental elastic soil periods to decrease with time, as suggested in [29].

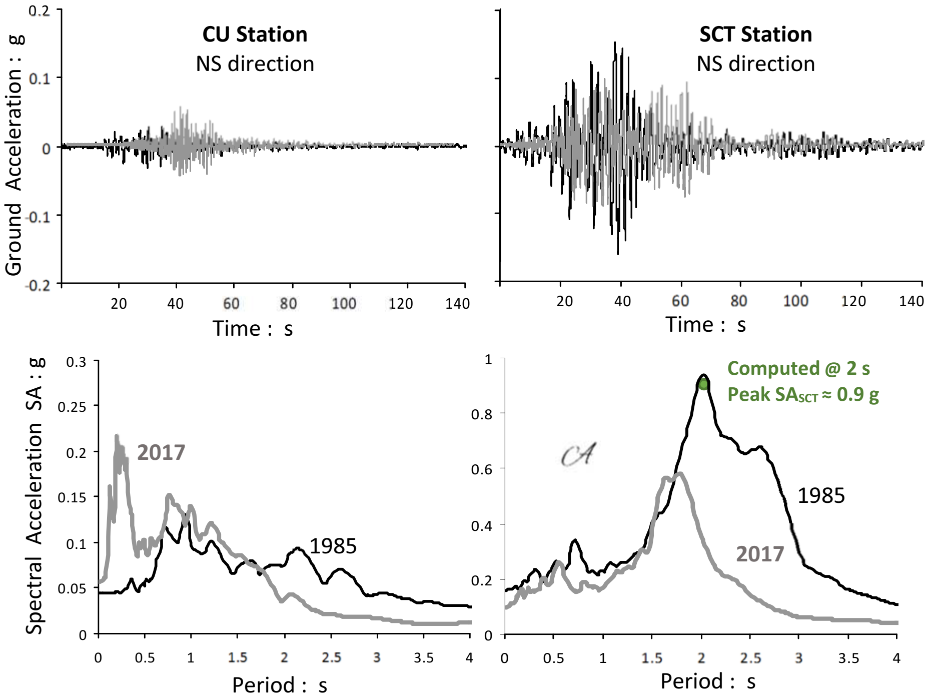

Figure 5. NS acceleration time histories at stations CU (left) and SCT (right) in the 1985 (black) and 2017 (grey) earthquakes (top). Response spectra with computed peak SA at T_s= 2 s in 1985 (bottom).

Using the simplified soil column model with H = 40 m to represent the conditions at SCT, where severe damage occurred in 1985, analyses can compare the site effects in 2017. In 1985, the site had an estimated T_s of $4 \times 40/80 = 2$ s [28] with corresponding theoretical amplification at resonance of ≈ 11 (assuming material damping of 4%). Therefore, the prediction of SA at SCT at soil resonance may be computed by amplifying the recorded SA at rock (CU) by a factor of 11, or about 0.9 g, which is close to peak SA recorded at SCT in 1985 (Fig. 5). The agreement between the 1985 observations and the simplified analysis is excellent and confirms that it is the soil resonance at $T_s \approx 2$ s subjected to a high-period rock motion that generated the high SAs between 1.5 and 3 s [11, 15, 17, 18].

5. Mexican Codes Evolution – Modifications due to 1985 and 2017 Events

Mexico does not have a national building code [30], and applying international guidelines is common in local structural design. Mexico City has a local Construction Code (MCCC), which is used as a reference in the entire country [31]. The first MCCC traces back to 1921 [31a], but it is not until 1942 when seismic loading was mandated [31b]. Emergency regulations were issued mainly due to lessons from damaging earthquakes in 1957, 1985 [32], and 2017 [33] and were incorporated in the code revisions of 1966, 1976, 1987, 2004, [32] and 2017 [34a]. Since the 1976 version, Mexico City is divided in 3 Zones (I: hill; II: transition; III: lake) depending on the site conditions and location with respect to the lake basin [34b].

Following the devastation of the 1985 earthquake, emergency seismic design and construction document was issued for the reconstruction and recovery shortly after the event. This document was incorporated in the 1987 MCC, with modifications in: (i) increasing values of PGA and design shear coefficient at the plateau range of structural period for buildings in Zones II and III; (ii) modifying ductility “Q” values for certain systems; (iii) bringing stricter restrictions for steel transverse rebar and design of columns; (iv) restricting the use of simplified analysis method to walls up to 8.5 m, with parallel increase of the design shear coefficients [34c].

In 2004, a new seismic design code was introduced [34d] that further modified the zoning of the city. Specifically, Zone III was subdivided into four subzones to refine the fundamental soil periods and expected design accelerations. This version allows for two design approaches: a conventional procedure in line with the previous versions, and a more advanced approach seen as a first step towards a performance-based design code [32], despite not incorporating explicitly performance objectives for different seismic hazard levels. The latter provides uniform hazard rock accelerations for an event with a return period of 125 years, with amplification factors for different site conditions based on seismic zoning and ductility and overstrength reductions through empirical formulae and tabulated values. When a dynamic nonlinear analysis is being performed, at least four acceleration time histories - actually-recorded or simulated - consistent with the hazard code level are applied to the structural model [32d].

In 2017, emergency regulations were issued for the recovery of concrete buildings affected by the Puebla-Morelos earthquake [33] shortly after the event, followed by a code revision two weeks later [34a]. This version brings many changes, most notably: (i) the seismic hazard level is increased to a return period of 250 years; (ii) in a dynamic nonlinear analysis at least eight orthogonal pairs of representative acceleration time histories are used for buildings with structural period less than 2.0 s or twelve for buildings that exceed this period; (iii) the rock spectrum is defined as the envelope of a deterministic scenario of a subduction event and an intermediate depth event; (iv) allows use of the computer tool SASID (Sistema de Acciones Sísmicas de Diseño, or “Design System of Seismic Actions”) [35] to derive the design acceleration spectrum.

The 2017 standards define performance objectives for different seismic hazard levels, in a similar way as contemporary United States building codes; considering functionality and immediate occupancy for frequent events of low to moderate intensity that may occur more than once during the structural design life [12].

As the local city code evolves, a clear path towards Performance Based Design (PBD) would be desirable, especially for the very tall and typically irregular buildings with very deep basements of 5 or more levels. Rather than using a deterministic hazard approach that is currently prescribed for a relatively frequent, design-level, the PBD it is the state-of-practice for tall buildings to use a probabilistic seismic hazard analysis to estimate the accelerations for varying earthquake levels and corresponding performance expectations [36]. The current code is defining the design event through deterministic scenarios, but naming it an event with return period of 250 years, which is relating it probabilistically to a single-level hazard event. The deterministic scenarios may have a return period that is higher than the one defined in the code; i.e., maybe rare.

In the PBD approach, the rare events are incorporated in typically higher return periods, accompanied by expectations of some damage or downtime, without the loss of life. In addition, in a dynamic analysis approach, the Soil-Structure Interaction (SSI) effects can be incorporated by allowing modeling of the substructure, rather than imposing the motion at the ground surface that is currently in the local codes. With modern high-rise buildings having basements that reach 20-30 m below the ground surface [12], the site effects and ground motions can be drastically different at the base of the structure compared to a rigid-base motion at the surface.

International guidelines such as the Tall Buildings Initiative (TBI), address incorporation of SSI effects within a PBD approach [36], and can be used as models for next revisions of the Mexico City code, especially for very tall structures. Similarly, unique regional challenges in design and construction should also be addressed, including: (i) differential and total settlements and lateral deformations; (ii) depth at which the input ground motions will be derived for application to the structural model, (iii) drainage or corrosive soils issues that may affect the foundation materials,; and (iv) interaction with existing adjacent structures, underground structures or utilities.

6. Conclusions

The lessons learned from earthquakes in Mexico City in the past three decades have shaped the state-of-the-art in engineering seismology and the state-of-practice in geotechnical and structural engineering.

The high soil amplification of ground motions in the lake zone and the "double resonance" phenomena observed in both the 1985 Michoacán and 2017 Puebla-Morelos events resulted in significant destruction throughout the City, and in the need for updating local codes to better protect the city and its residents in future events. The more recent, 2017 event, caused less damage and loss of life than the 1985 one that can be partially attributed to the facts of: (i) smaller magnitude; (ii) lower rock accelerations recorded at higher periods; and (iii) stricter building and construction requirements with an increase in the code-specified spectral accelerations (from 0.25g to 0.4g - 0.45g between the 1.0 through 3.0 s range in Zone III).

In addition to generally higher accelerations, the current code has made an attempt to incorporate some performance objectives which is consistent with contemporary United States building codes, such as functionality and immediate occupancy for frequent events of low to moderate intensity. However, the current code does not consider probabilistically rare events in the design. With the clear trend of higher buildings with deeper basements that Mexico City has been implementing, there is a need to add criteria to address associated design and construction challenges, including prediction and analysis for rare and extreme events through a probabilistic seismic hazard with corresponding performance objectives, in line with international developments and practices for dense urban environments.

References

[1] USAID, Mexico Earthquake Fact Sheet #5, US Agency for International Development, 2017.

[2] Nikolaou, S., Diaz-Fanas, G., Garini, E., McElvain, B., Gazetas, G., Dried Lakes Do Tell Tales Seismic Soil Amplification in Mexico City, *GeoStrata Magazine,* March/April (2019), in print.

[3] Ovando-Shelley, E., Ossa, A., Romo, The Sinking of Mexico City: Its effects on soil properties and seismic response, *Soil Dynamics & Earthquake Engineering*, 27(2007), 333-343

[4] Alcocer, J., & Williams, W.D., Historical and Recent Changes in Lake Texcoco, a Saline Lake in Mexico, *International Journal of Salt Lake Research,* 5(1996), 45-61

[5] Bojorquez-Tapia, L.A., et al. The Basin of Mexico: A History of Watershed Mismanagement, *USDA Forest Service Proceedings*, RMRS-P-13 (2000), 129-137

[6] USGS, Seismotectonics of Mexico, US Geologic Survey, 2017.

[7] Singh, S.K., Suarez, G., Dominguez, T., "The Oaxaca, Mexico, Earthquake of 1931: Lithospheric Normal Faulting in the Subducted Cocos Plate, *Nature*, 315 (1985), 56-58.

[8] Gardi, A., Cocco, M., Negredo, A.M., Sabadini, R. Singh, S.K., Dynamic Modelling of the Subduction Zone of Central Mexico, *Geophysical Journal International*, 143 (2000), 809-820.

[9] Payero, J.S., et al., Nonvolcanic Tremor observed in the Mexican Subduction Zone, *Geophysical Research Letters*, 35 (2008), 7

[10] Pardo, M. & Suarez, G., Shape of Subducted Rivera & Coco Plates in Southern Mexico: Seismic & Tectonic Implications, *J. Geophysical Research Atmospheres*, 100-B7 (1995), 12357-12374

[11] Nikolaou, S., Gazetas, G., Garini, E., G. Diaz-Fanas, G., Ktenidou, O-J, Geoseismic Design Challenges in Mexico City: A 32-year Déjà-vu, *Structure Magazine,* Dec. (2018), 10-13.

[12] Rahimian, A., Valles, R., Anzola, E., Shleykov, I., Nikolaou, S., Diaz-Fanas, G., Structural Design Challenges for Tall Buildings in Mexico City: A 20-year Perspective, *Struct. Mag.,* Feb. (2019), 18-21.

[13] Esteva, L., The Mexico Earthquake of September 19, 1985 - Consequences, Lessons, and Impact on Research and Practice, *Earthquake Spectra*, 4-3 (1988), 413-426.

[14] Seed, H.B., Romo, M.P., Sun, J., Jaime, A., Lysmer, J., Mexico Earthquake of 1985 - Relationships between Soil Conditions & Earthquake Ground Motions, *Earthquake Spectra*, 4-4 (1988), 687-729.

[15] Beck, J.L. and Hall, J.F., Factors Contributing to the Catastrophe in Mexico City during the Earthquake of September 19, 1985, *Geophysical Research Letters*, 13-6 (1986), 593-596.

[16] Singh, S.K., et al., Mexico Earthquake of September 19, 1985 - A Study of Amplification of Seismic Waves in the Valley of Mexico with respect to a Hill Zone Site, *Earthq. Spectra*, 4-4 (1988), 653-673.

[17] Rukos, E. A., The Mexico Earthquake of September 19, 1985—Earthquake Behavior of Soft Sites in Mexico City, *Earthquake Spectra*, 4-4 (1988), 771-786.

[18] Sanchez-Sesma, F., Chavez-Perez, S., Suarez, M., Bravo, M.A., Perez-Rocha, L.E. Mexico Earthquake of Sept. 19, 1985: On the Seismic Response of the Valley, *Earthquake Spectra*, 4-3 (1988), 569-589.

[19] El Arsenal, Gran parte de los capitalinos recuerdan terremoto del 85, 2015.

[20] Singh, S.K., et al., Deadly Intraslab Mexico Earthquake of 19 September 2017 (M_w7.1): Ground Motion and Damage Pattern in Mexico City, *Seismological Research Letters*, 89-6 (2018), 2193-2203.

[21] Galvis, F., Miranda, et al., Preliminary Statistics of Collapsed Buildings in Mexico City in the Sept. 19, 2017 Puebla-Morelos Earthquake, Blume Earthquake Engineering Center, EERI LFE, 2017.

[22] GEER, *Geotechnical Engineering Reconnaissance of the 19 September 2017 Mw 7.1 Puebla-Mexico City Earthquake: Report No. GEER-055A*, Geotechnical Extreme Events Reconnaissance Association, 2017.

[23] Vucetic M. & Dobry R., Effect of Soil Plasticity on Cyclic Response, *ASCE Geotechnical Engineering*, 117-1 (1991), 89-107.

[24] Schnabel, P.B., Lysmer, J., Seed, H.B., *SHAKE - Computer Program for Earthquake Analysis of Horizontally Layered Sites - Report 72-12*, Earthquake Eng. Research Center, UC Berkeley, 1972.

[25] Hashash, Y.M.A., Musgrove, M.I., Harmon, J.A., Groholski, D.R., Phillips, C.A., Park, D., *DEEPSOIL 6.1, User Manual*, University of Illinois, Champaign-Urbana, 2017.

[26] Gazetas, G., *Soil Dynamics*, National Technical University of Athens, 1989.

[27] Gazetas G., The role of soil in the Mexico 1985 and the Kalamata 1986 earthquakes, Proceedings of the 1st Greek Conference of Geotechnical Engineering, Athens, Greece, 1988.

[28] Ordaz & Perez-Rocha, Microzonif. de la CDMX con fines de diseño símico de estructuras, 1992,

[29] Arroyo, D., et al., M.S., Evaluation of the Change in Dominant periods in the Lake-bed Zone of Mexico City, *Soil Dynamics & Earthquake Engineering*, 44 (2013), 54-66.

[30] Alcocer, S., The September 7 and 19, 2017 Earthquakes in Mexico: Overview and First lessons, Proceedings of the 11th National Conference of Earthquake Engineering, SS088A (2018).

[31] OGDF, *Normas Técnicas Complementarias del Reglamento de Construcciones del D.F.*, Órgano del Gobierno del Distrito Federal, Mexico City, Mexico, 1921(a); 1943(b).

[32] Alcocer, S. & Castaño, V., Evolution of Codes for Structural Design in Mexico, *Structural Survey*, April, 26-1 (2008), 17-28

[33] OGDF, *Normas para la Rehabilitación Sísmica de Edificios de Concreto Dañados por el Sismo del 19 de Septiembre de 2017,* Órgano del Gobierno del Distrito Federal, Mexico City, Mexico (2017)
[34] OGDF, *Normas Técnicas Complementarias del Reglamento de Construcciones del D.F.*, Órgano del Gobierno del Distrito Federal, Mexico City, Mexico, 2017(a); 1976(b); 1987(c); 2004(d).
[35] OGDF, SASID Software," *Órgano del Gobierno del Distrito Federal*, 2017
[36] TBI, *Guidelines for Performance-Based Seismic Design of Tall Buildings - PEER Rep. 2017/06 v.2.03*, Tall Building Initiative - Pacific Earthquake Engineering Research Center, Univ. of CA, Berkeley, 2017.