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# INTENSIFIED ONGOING GROUND CRACKING DURING EARTHQUAKES IN MEXICO CITY

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**ABSTRACT**

This paper is based on the author's participation in the Canadian reconnaissance teams after 1985 Mw8.0 Michoacan interplate and 2017 Mw7.1 Puebla-Morelos intraplate events. While the problem of ongoing ground subsidence due to the extraction of groundwater in Mexico City is widely recognized for decades, the somewhat related problem of ongoing ground cracking and its intensification during seismic events has only recently been studied systematically since 2005 using conventional topographic methods.

Recent studies, using InSAR and GPS satellite geodetic data between November 2014 and November 2017, indicate strong horizontal gradients of subsidence occur where fractures of the ground surface are common in areas such as former Texcoco and Chalco-Xochimilco lakes and lower slopes of the Sierra de Santa Catarina.

The paper presents an overview of the intensified ongoing ground cracking during earthquakes in Mexico City. While the problem may be somewhat extreme in Mexico City, it is by no means unique. Where groundwater is extracted without an adequate recharge, similar problems would occur sooner or later.

Keywords: ground subsidence/cracking, groundwater withdrawal, InSAR satellite images, soft clay deposits, structure performance.

## 1 INTRODUCTION

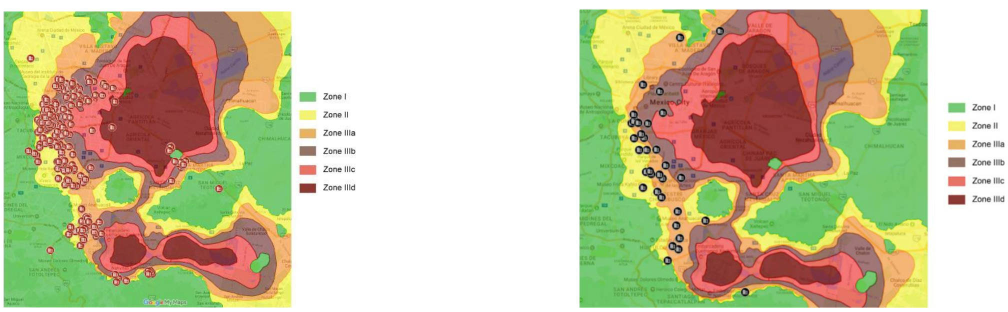
The paper first presents an overview of the physico- and seismo-tectonic setting of Mexico City. This setting together with continued groundwater extraction for the city's water supply and frequent occurrence of earthquakes has resulted in long-term areal ground subsidence. Subsidence, especially differential subsidence, poses a challenging foundation engineering problem for the design and maintenance of buildings and lifeline structures. This problem has been well-recognized for decades. A related problem of ground cracking and its intensification during earthquakes has been systematically studied rather late, ie since 2005, using conventional topographic methods. In recent years, satellite imageries have been added to the tool kits used for studying ground cracking and its acceleration during earthquakes. The evolution of Mexican's pioneering work on this new challenging problem is described below.

## 2 PHYSICO- AND SEISMO-TECTONIC SETTING OF MEXICO CITY

**2.1 Seismo-Tectonic Setting.** The bulk of Mexico is located over two large tectonic plates: North America and Cocos plates. The Cocos plate moves northeastward and subducts under the North American plate along the Middle America trench. The rate of plate convergence in the area ranges from 63 mm to 76 mm per year. The Mexican landmass is crumpled to form the Cordillera Neovolcánica mountain ranges of southern Mexico. As the Cocos plate subducts, the molten material is forced upward through fractures in the overlying North American plate. This process has caused frequent earthquakes and occasional volcanic eruptions. Seismic events affecting Mexico City include:

crustal events within the upper North American plate, intraplate events within the lower Cocos plate and interplate events at the interface between the two plates. The two most recent earthquakes that inflicted substantial damages on Mexico City occurred on the same day, 32 years apart [1]: the September 19, 1985 earthquake [2] occurred as the subducting Cocos Plate ruptured along the Michoacan Gap beneath the North American Plate (an interplate event), while the 2017 earthquake [3] occurred in the Cocos Plate (an intraplate event) as a result of normal faulting at a depth of approximately 50 km, involving a rupture plane of about 50 km long and 20 km wide.

**2.2 Lacustrine Sediments in the Mexico City Basin.** The widespread presence of lacustrine deposits in the Valley of Mexico basin, including Mexico City, and local engineering practice dictate the foundation problems encountered by structures in the city [4]. These problems include: regional ground subsidence and differential settlement of buildings [5]. During seismic events, the relatively soft lacustrine deposits tend to amplify ground motions, increase site natural periods and lengthen the duration of shaking. The 1976 Mexican building code initially defined 3 seismic zones for Mexico City: the hill zone (Zone I), the transition zone (Zone II), and the lake zone (Zone III). The zones are defined based on the fundamental site period, which is essentially a function of the thickness of soft lacustrine clay. The latest version of the building code (NTCS-04 2004) further divides Zone III into 4 sub-zones [6] (IIIa, IIIb, IIIc, and IIId) as shown in Figures 1(a) and 1(b). Throughout Mexico City, the thickness of lacustrine clay varies from 0 m in the hill zone (Zone I) to about 60 m in Zone IIId with the fundamental site period varying from about 0.4 sec to 4 sec. Figure 2 illustrates remarkably the ongoing ground subsidence done to a building between 1942 and 2016. The building, being founded on reinforced concrete point-bearing piles driven to a hard stratum beneath the soft lacustrine clay, stayed put and had to grow downward, so to speak, to follow the subsiding surrounding ground.




*(a) Map showing buildings deemed unsafe for occupation* *(b) Map showing collapsed buildings*

*Figure 1 Maps showing seismic zonation for Mexico City and building damages on September 19, 2017 EQ* https://www.sismosmexico.org/mapas


*Figure 2 A building grew downward between 1942 and 2016 to adapt to the situation of ongoing settlement of surrounding ground and the building itself that is founded on piles*

## 3 GROUND CRACKING AND ITS INTENSIFICATION DURING EARTHQUAKE

### 3.1 Study by Conventional Topographic Method

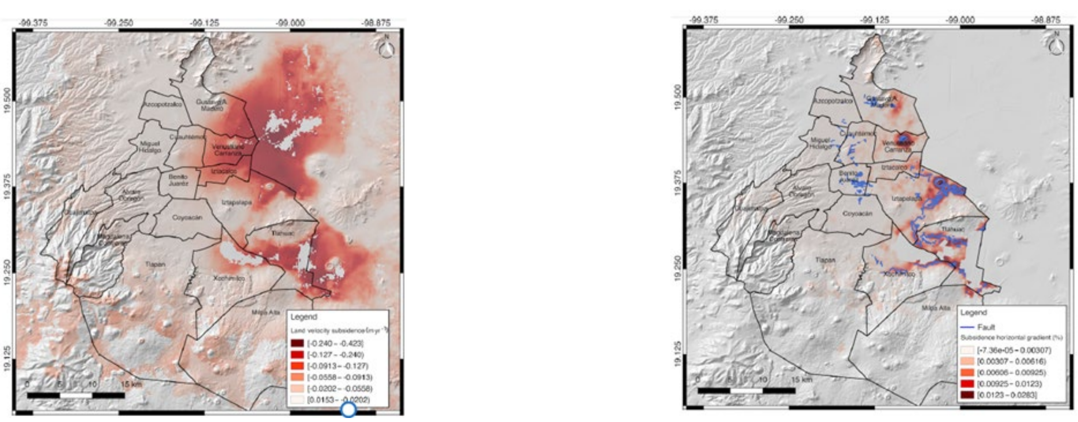
The problem of ongoing ground cracking and its intensification during seismic events, such as the September 19, 2017 event, has only recently been studied systematically since 2005 [7]. Figure 3, taken after the 2017 earthquake, shows how the buildings in the affected area were stressed, requiring shore up.  Factors contributing to this phenomenon include: (1) hydraulic fracturing in flooded areas; (2) regional subsidence in areas with abrupt transition; (3) stratigraphic anomalies; (4) evapo-transpiration; and (5) buried geologic structures.

*Figure 3 Buildings damaged by intensified ground settlement and crack during September 19, 2017 Puebla-Morelos Earthquake*

*[from CAEE (2019) Reconnaissance Report on September 19, 2017 Puebla-Morelos Earthquake in Mexico]*

### 3.2 Study by InSAR Satellite Imageries Method

Solano-Rojas et al. (2020a) described the multiscale approach using multi-platform InSAR products to study ground cracking in Aguascalientes Valley and Mexico City [8]. Solano-Rojas et al. (2020b) employed InSAR and GPS satellite geodetic techniques using satellite-acquired SAR data between November 2014 and November 2017 from the Sentinel-1 satellites provided by the European Space Agency (ESA) to study the intensified ground cracking during the September 19, 2017 earthquake [9]. Figure 4(a) shows a map of the subsidence rate for Mexico City, while Figure 4(b), derived from Figure 4(a), shows a map of the horizontal gradient of subsidence for the city. Figure 4(b) indicates strong horizontal gradients of subsidence occur where fractures of the ground surface are common in areas such as former Texcoco and Chalco-Xochimilco Lakes and lower slopes of the Sierra de Santa Catarina.



*(a) Subsidence rate map* *(b) Horizontal subsidence-gradient map*

*Figure 4 Subsidence rate and horizontal subsidence-gradient maps for Mexico City (from Solano-Rojas et al. 2020b[9]).*

### 3.3 Potential Study on Lifeline-Infrastructure Performance

In the 2017 Puebla-Morelos earthquake, water and sewer lines were damaged, especially in the Colonia Del Mar area, where shallow faulting and ground surface cracking occurred [10]. Many of these damages occurred earlier in the 1985 Michoacan quake [3]. Two segments of the elevated viaduct of Metro Line 12, about 1.2 km apart, suffered structural damage in 2017: one involved a column failure near its base with spalled concrete and exposed re-bars, and the other involved failure of concrete restraint at the shear keys of steel girders. The rocking motion of the column pier appeared to be the cause at both locations (see Figure 5). The repairs were ongoing during our October 2017 visit [9]. On May 3, 2021, Metro Line 12 collapsed with a death toll of at least 25 and dozens injured [11]. The cause of this collapse has been investigated [12]. These infrastructures suffered from additional stress and strain associated with earthquake events. The phenomenon of intensified ground cracking during earthquakes most likely is at play as well. Thus, we anticipate that the new tool of InSAR Satellite Imageries can aid in the investigations of lifeline performance in certain areas of Mexico City.

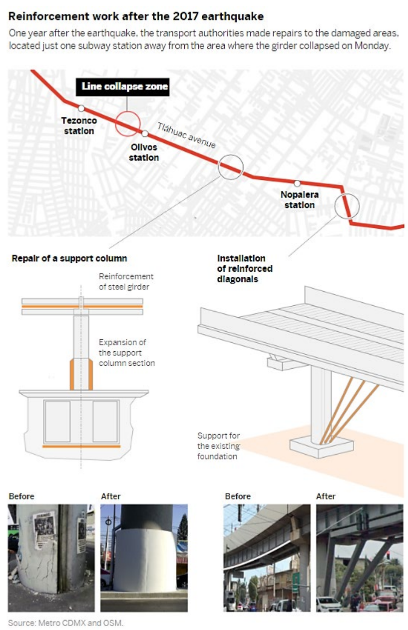



*Figure 5 Reinforcement work after the 2017 earthquake and Metro Line 12 collapse on May 3, 2021 (from El Pais 2021[11])*

## 4 SUMMARY

As Mexican experts and their international colleagues carry out their pioneering work on this new challenging problem, we expect their progress will accelerate with time by going through the learning curve of analyzing ever-increasing imageries over time. This work is important, because it would help the city to plan for future development. It is sad to observe the anguish of affected residents who were coping with the unexpected situation after the earthquakes. The more we understand the phenomena, the better we could minimize their impact on the future residents who would settle in the areas that are vulnerable to this potential problem.

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