19th September: a date marked by earthquakes in Mexico City

Hortencia Flores Estrella[1] and Alma Villaseñor Franco[2]

[1] Applied Geophysics, TU Berlin

[2] Facultad de Ingeniería, Universidad Autónoma de Guerrero

Abstract

In Mexico City, September 19th is a remembrance date of what the combination of large magnitude earthquakes with extreme soft sediments and bad constructions can cause. On the 19th September 1985, an interplate event (Mw 8,0; depth = 20 km; epicentral distance near 350 km) caused more than 10,000 casualties and about 190 buildings suffered partial or total collapse. Exactly 30 years later the 19th September 2017, and short after a macroearthquake drill, a Mw 7,1 intraslab earthquake hit Mexico City at 13:40 hours (local time). The seismological records of the 2017 event (depth = 57 km; epicentral distance near 114 km from the city) showed that the ground motion in frequencies between 0.4 and 1 Hz was anomalously large, and it was reported as the second most destructive earthquake in Mexico City, just after the 1985 event, with 369 casualties.

After the 1985 earthquake, the knowledge about the soil conditions in Mexico City resulted in a zonation that divides the subsoil in three zones: the lakebed zone: formed by of 30-80 m deposit of highly compressible, high-water content clay; the hill zone, characterized by a surface layer of lava flows and volcanic tuffs; and the transition zone, composed of alluvial sandy and silty layers with occasional intervals of clay layers. Shear-wave velocities in the upper 30 m of the three zones are 50-100, 750, and 250 m/s, respectively. This zonation is also included on the construction regulations for Mexico City. Unfortunately, because of a lack of information, corruption and sometimes poverty, constructions are sometimes built following no regulation at all.

In this work we show the damage distribution in the south part of Mexico City, due to the 19.09.2017 event, where most of the extreme damage happened. This distribution had not been seen after interplate earthquakes, which can be explained by the closeness, the back azimuth the frequency content and the magnitude of this event, but also because of the city growth to areas that ~60 years ago were still part of a lake with the characteristic soft clay layers from Mexico Basin.

Mexico City: history and implications

Fig. 1. The lake system in Mexico Basin. Tenochtitlan Mexico indicates the island where Mexico City was founded in 1321. Different tribes had settled down around Texcoco Lake. The Aztecs settled on in island in the middle of the lake and built an empire and created a lake-centered culture. They built various dikes to separate brackish water of Texcoco Lake from the fresh water coming down from Xochimilco and developed a building system called *chinampas*.

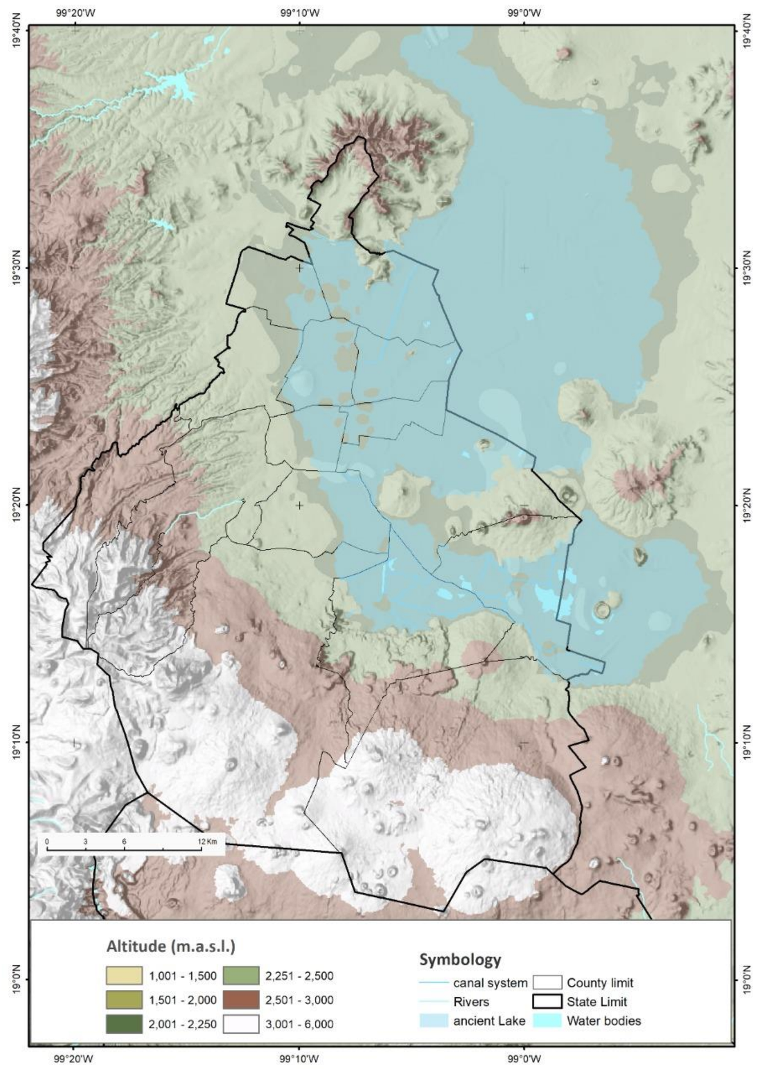


Fig. 2. In light blue the area of the ancient Lake system (see Fig. 1). In darker blue the small lakes that still exist.

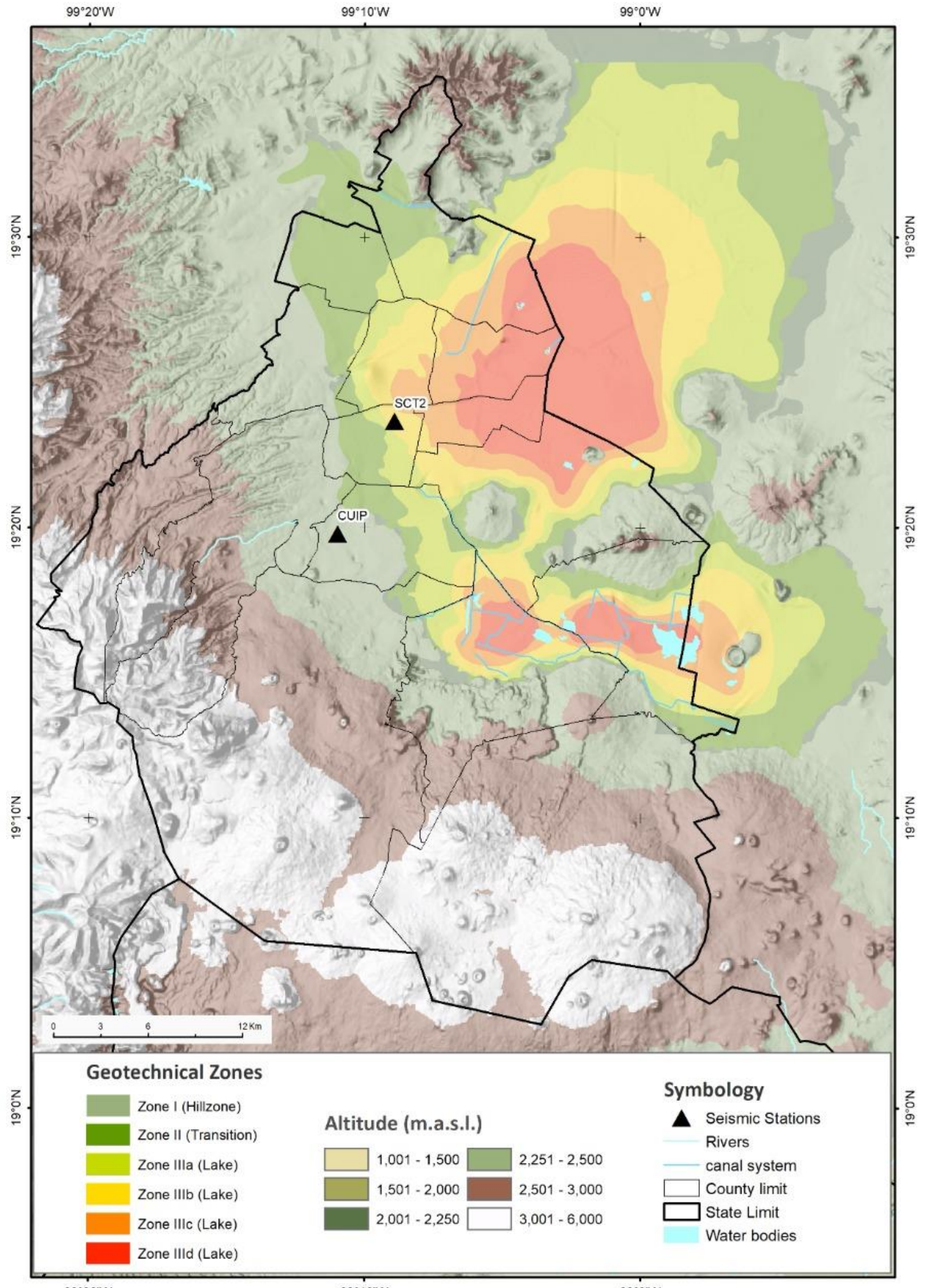


Fig. 3. Geotechnical zonation for Mexico City. Main zones: lake, transition and hill zone. The thickness of soft lake sediments can be up to 80 m in the lake zone.

Mexico City is located on a volcanic high plateau at about 2240 m above sea level, bounded by volcanic sierras, alluvial fans and plains.

The city was founded in 1321 on a small island in the middle of Texcoco Lake.

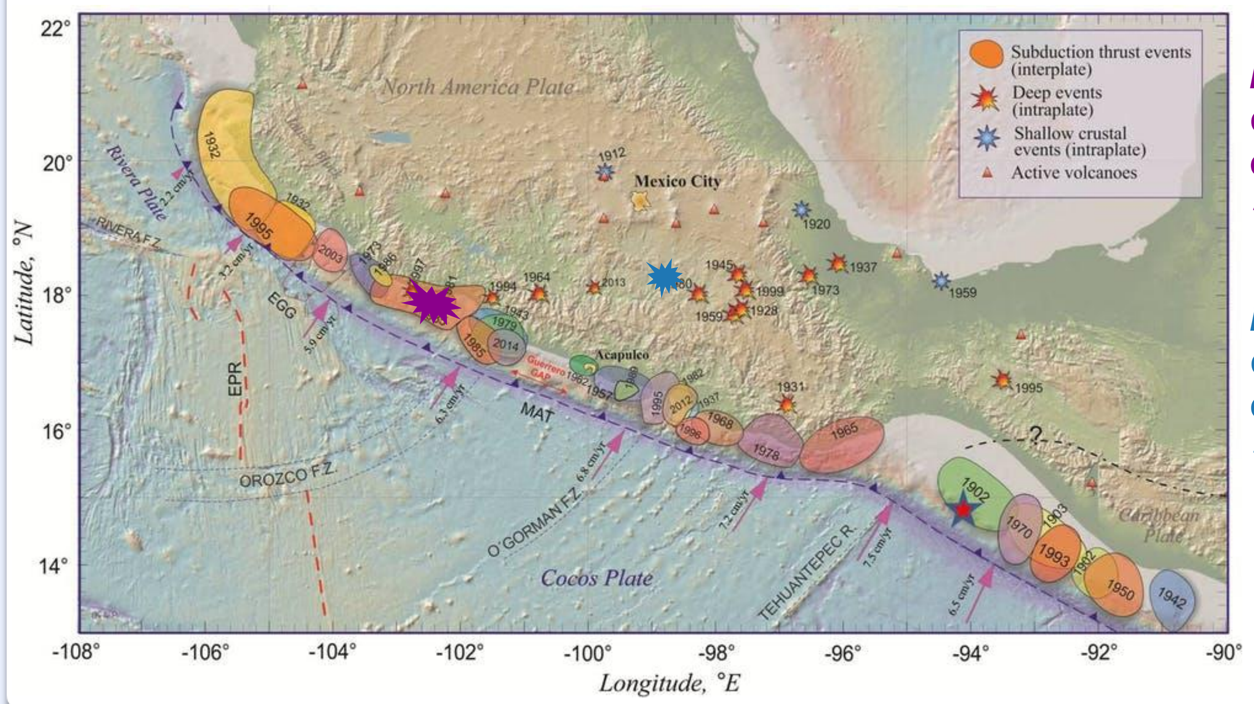
After the Spanish conquest, in 1521, floods and epidemics suggested a need to drain the lakes, which began near **1524**.

The drainage was finished in **1975**. This solved the problem of recurrent floods but it also contributed to desertification, and urban growth on the ancient lakebed.

After the 1985 earthquake, the soil and subsoil of Mexico City was well characterized. The geotechnical zonation (Fig. 3) is a result of those efforts. It divided the city into three main zones according to the soil characteristics:

- Lake Zone: soft lake sediments
- Transition Zone: a combination of lake and volcanic sediments
- Hill Zone: volcanic sediments underlaid by limestones.

Mexico Tectonics



19.09.1985
Mw 8,0
depth 20 km
epicentral distance ~ 350 km

19.09.2017
Mw 7.1
depth 57 km
epicentral distance ~ 114 km

Fig. 4. Main tectonic features and main seismological sources.

Methodology

The extension of the ancient lake system, before the colonial period (Fig. 2) was created using the Continuous Elevation of the Territory (INEGI, 2020) and Ciencia UNAM (2021).

We used the elevation model from INEGI (2020) and the Risk Atlas of Mexico City to create the Geotechnical zonation map (Fig. 3). The geographical information of the two seismological stations and the seismological records were provided by Dr. L. Quintanar from the Geophysical Institute, UNAM (Fig. 3, Fig. 4 and Fig. 5).

The information for the urban growth and the damage distribution caused by the earthquakes of September 19, 1985 and September 19, 2017 (Fig. 6) was obtained from INEGI (1995, 2000, 205, 2010, 2015 and 2020).

A. Villaseñor Franco participated in the damage inventory, which was coordinated by the Commission for the Reconstruction of the government of the Mexico City. We collected extra information from the Risk Atlas of Mexico City (2020).

Earthquakes on 19th September

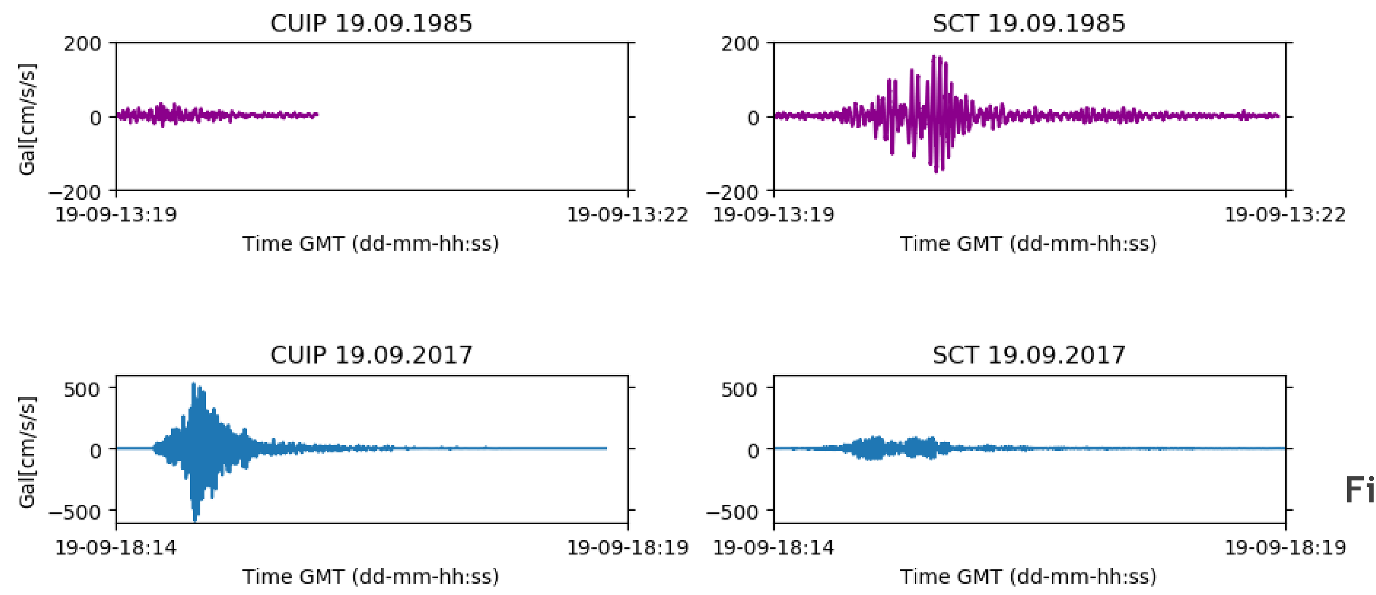


Fig. 5. Seismograms for stations CUIP and SCT for 19.09.1985 upper panels, and 19.09.2017 bottom panels.

During the 1985 earthquake (Fig 4. and upper panels Fig. 5), the ground acceleration in the ancient lakebed (station SCT2) was more than 50 time bigger as the one recorded at Hill Zone (station CUIP)

During the 2017 earthquake, non expected high ground acceleration was recorded at CUIP station.

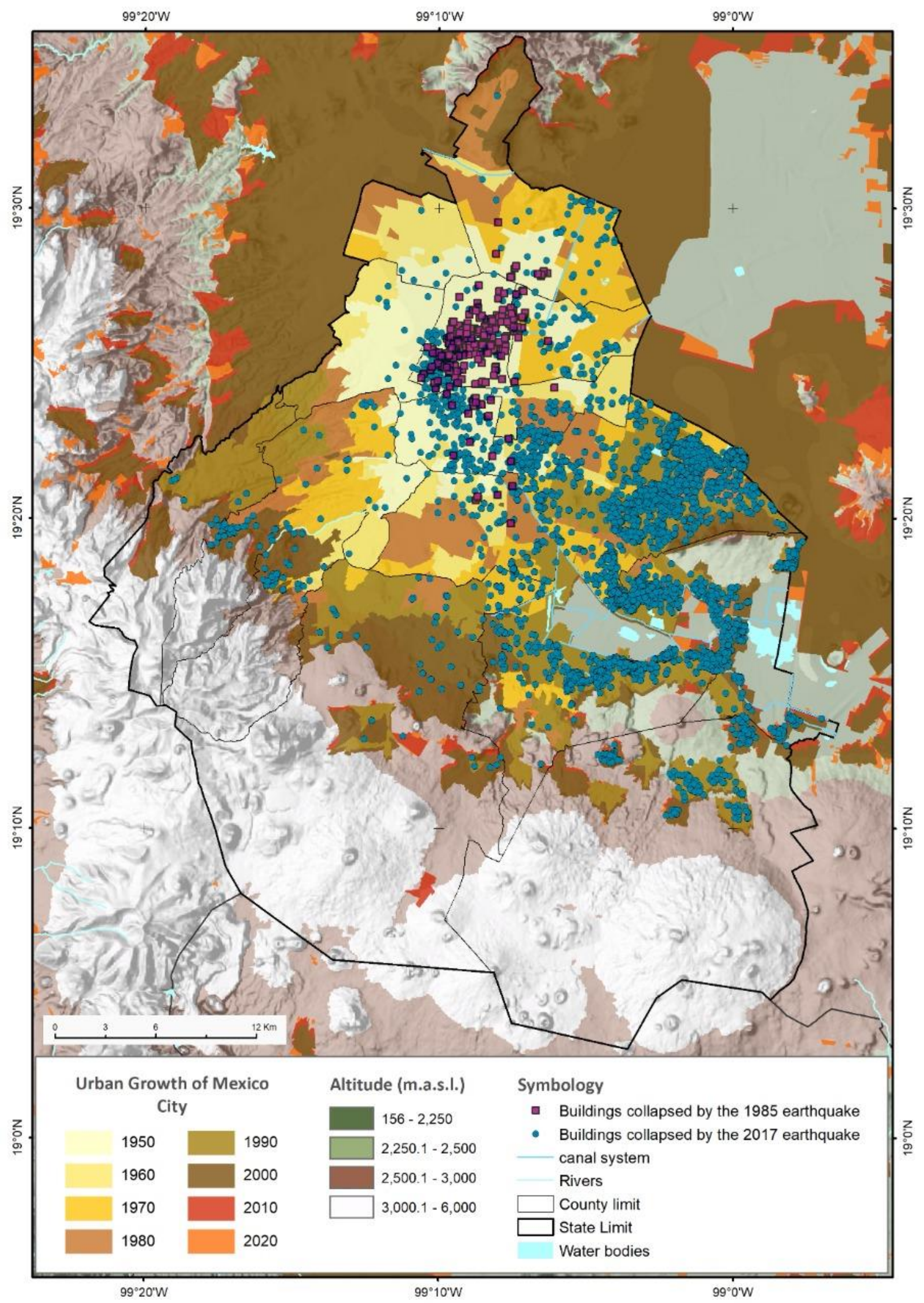


Fig. 6. Distribution of the collapsed buildings by the 19.09.1985 event in dark purple, and by the 19.09.2017 event in blue. The yellow to brown areas indicate the urban growth of Mexico City.

As a result of the geotechnical zonation (Fig.3) a building code was created and the building in the lake zone (in the center of the city) became more controlled, in terms of material, building height, structural elastic properties and seismic safety.

However, the more the lake was drained, the more the city extended on the former bed. In Fig 6, it is clear how the urban area extended to the south east part of the basin between after 1990.

Unfortunately, most of the new buildings in this area didn't follow the seismic safety rules of the building code.

In Fig. 6 it is quite clear the damage distribution in the lake zone to the center of the city (yellow area) but increased dramatically to the southeast part of the basin. We identify many reason for this:

- The earthquake characteristics (magnitude, epicentral distance, frequency content)
- Age of many churches (see Fig. 7 a)
- Buildings didn't follow the seismic safety rules of the buildings code (see Fig. 7 b)

Fig. 7. Damages after the 19.09.2017. (a) Several old churches had severe damages. (b) Damages due to bad quality in buildings materials and construction.

Outlook

The inhabitants of Mexico City have learnt to live with a high seismic hazard, they know how to act when they hear the early warning alarm, which gives aprox. 2 minutes before the motion, generated from events of the subduction zone, arrives to the city.

However, intraslab events are not considered for the early warning system, they are rare, and they occur closer to the city, which changes the ground motion characteristics. This can explain part of the damages in old structures (i.e. churches) or structures which were built before 1985. However, most of the damage in recent urbanized areas (see Fig. 6), was due to a lack of the safety norms in the structures.

Most of the constructions built with the norms from the newest building code, did not collapse. This shows that the city seismic vulnerability can be reduced if the seismic safety norms are known and followed

Contact: h.floresestrella@tu-berlin.de
alvif27@gmail.com

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Flores Estrella et al., 2007. Nat Hazards (2007) 40:357–372.
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