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Seismic zonation of Mexico City

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ABSTRACT: The seismic zonation of Mexico City is discussed in this work, to the light of the first earthquakes registered by the network of accelerographs installed since 1987 and of the analysis of the damage produced by the 1957, 1979 and 1985 earthquakes. As a result, a better understanding of the seismicity of the city is obtained and some recommendations to improve the present zonation are proposed.

1 INTRODUCTION

The study of the damaged buildings from the 1985 Mexico City earthquake led to a new interpretation of the seismicity of the city (Iglesias *et al.* 1987, Iglesias 1989), and to the proposal of a new seismic zonation that was partially adopted by the 1987 Mexico City Building Code (DDF 1987a, 1987b). With a similar criterion to that used for the seismic zonation, the review of the damage produced by the 1957 and 1979 earthquakes reinforced the conclusions derived from the 1985 event (Iglesias and Aguilar 1988). Recently, two earthquakes of medium magnitude have been recorded with good detail by the new network of accelerographs installed in Mexico City, one in 1988, and the other in 1989 (FICA 1988, 1989). Fundación ICA (FICA) elaborated maps of maximum horizontal acceleration resultants with the information obtained from the network, which greatly contributed to improve the understanding of the seismicity of the city.

As can be seen in Figure 1, three of the mentioned earthquakes: 79, 85 and 88, had their epicenters in the north coast of the Guerrero State, southwest of Mexico City (D.F.). The other two: 57 and 89, had their epicenters south from the city, near Acapulco.

The study of these five earthquakes allows to draw a more complete picture of the seismic response of Mexico City to subduction activity in the Mexican Pacific Coast, and to propose an improved seismic zonation, together with some recommendations to continue studying this phenomenon.

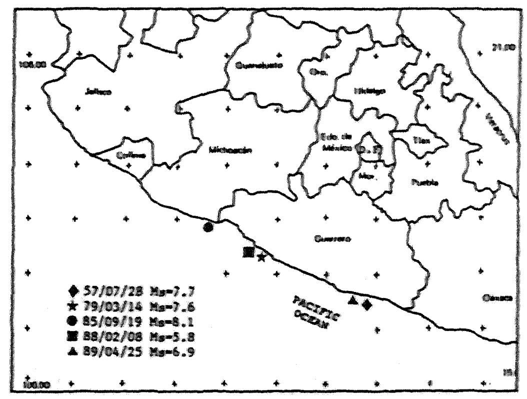

Figure 1. Magnitudes and epicenters of the studied earthquakes.

2 THE 1985 EARTHQUAKE INTENSITIES

With a simplified method for the evaluation of the seismic capacity of medium rise concrete buildings, it was possible to obtain the base shear coefficient corresponding to the failure (resistance coefficient K) for 90 severely damaged structures, and to use it as a measure of the seismic intensity to elaborate a map of intensities for the 1985 Mexico City earthquake (Iglesias 1989).

Zones I and II (Fig. 2), of low intensity ($K \leq 0.06$), coincide with the oldest districts of the city, where building had been concentrated since Aztec times until the end of the XIX century. These zones, in spite of having been considered for long time as part of the lake-bed zone, have a different stratigraphy, with historic fills more than 10 m thick and 20 to 30 m of consolidated clay below. Zone III, of medium intensity ($0.06 < K \leq 0.08$), extends over the main part of the lake-bed zone. The highest intensity zones IV, V and VI ($0.08 < K \leq 0.15$) are located between the firm soil of the old town and the Chapultepec transition zone, in the central part of the city, and between

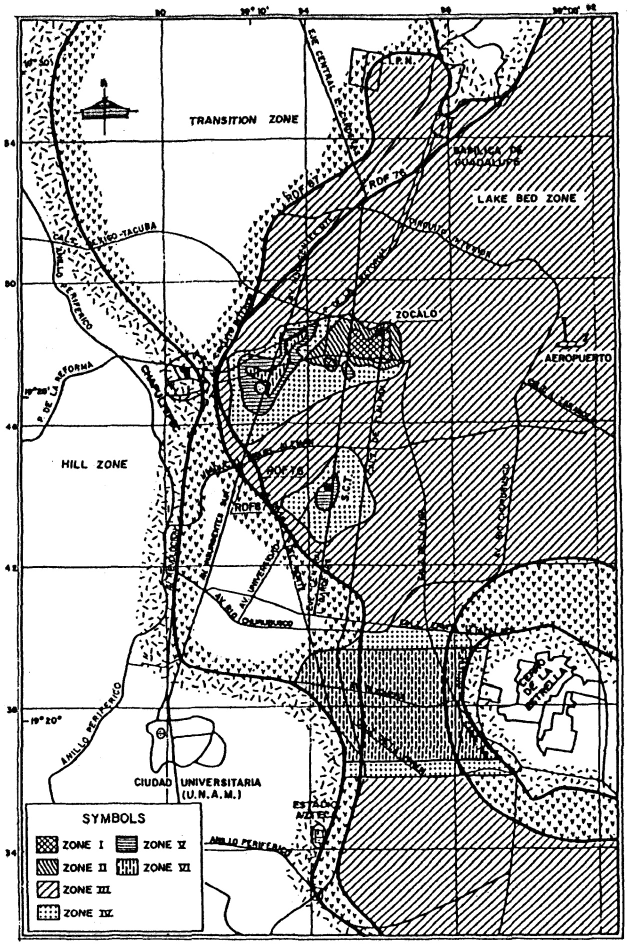

Figure 2. Map of intensities for the 1985 earthquake.

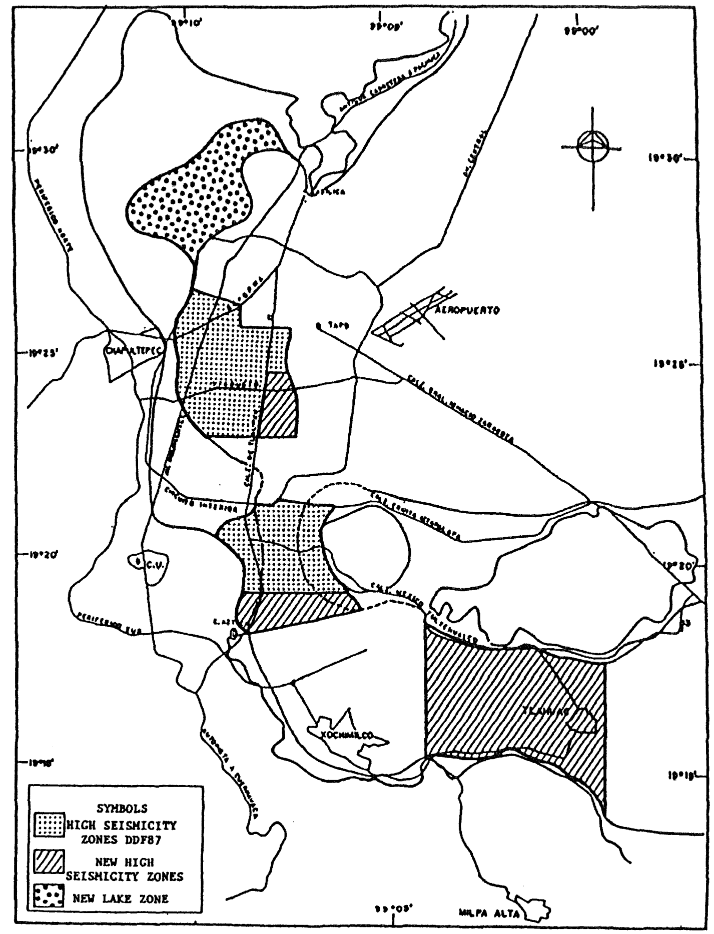

Figure 3. Seismic zonation of Mexico City.

Cerro de la Estrella hill and the hill zone, in the south, showing the strong interaction between neighboring zones of firm soil or rock that emit and reflect the seismic waves through the soft soil between them, amplifying the seismic intensity 100% from zone III to VI within the lake-bed zone. Finally, the central spot of zones IV and V around Secretaría de Comunicaciones y Transportes (SCT) is surrounded by three former islands inhabited since aztecs times, which again suggest the influence of the lateral interaction of zones of firm soil on the amplification of the ground motion.

Based on these results, a new seismic zonation of Mexico City was proposed for the Chapter of the 1987 Mexico City Building Code. As shown in Figure 3, besides the traditional hill, transition and lake-bed zones, it included two new zones of high seismicity, mainly with lake-bed stratigraphy, that cover the zones IV, V and VI of the map of intensities in a conservative way. The recommended resistance coefficient for design in these zones was $K = 0.15$, which is equivalent to a seismic coefficient $c = 0.60$ reduced by a ductility factor of $Q = 4$, for the static analysis; or to the design spectra of Figure 4 with a maximum ordinate of 0.80 g, for the dynamic analysis, considering typical design results. The new code was finally approved adopting the proposed zonation, but maintaining the same seismic coefficient $c = 0.40$ for the high seismicity zones and the rest of the lake-bed zone.

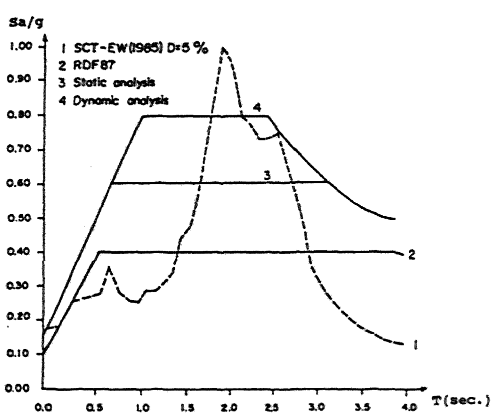

Figure 4. Response and design spectra.

3 THE 1957 AND 1979 EARTHQUAKES DAMAGE

With a damage classification criterion similar to that used for the seismic zonation, the review of the damage produced by the 1957 and 1979 earthquakes in Mexico City (Iglesias and Aguilar 1988) allowed to elaborate a map of severe damage zones as shown in Figure 5, which also includes the severe damage zone and high intensity zones V and VI of the 1985 earthquake.

Comparing the severe damage zones for 57, 79 and 85, in the central part of the city, it can be seen that they are almost concentric, from bigger to lesser magnitudes, with the high intensity zones as an inner core. In the north, there is some coincidence between 57 and 85 severe damage zones; but the 1979 earthquake did not produce severe damage there, perhaps due to its moderate magnitude. In the south, the severe damage zone for 79, including the only collapsed building during that earthquake, is inside the 85 damage zone; but in 1957 there was no reported damage there because of the lack of constructions at that time.

4 THE 1988 AND 1989 EARTHQUAKES ACCELEROGRAMS

In 1987, a new network of accelerographs was installed in Mexico City, with 74 stations, 30 controlled by Fundación ICA (FICA), and 44 by Fundación Javier Barros Sierra (FJBS). Two earthquakes of moderate magnitude have been registered with good detail to date: February 8th, 1988 (48 stations); and April 25th, 1989 (58 stations). With the obtained information, FICA elaborated maps of maximum horizontal acceleration resultants "MHAR" (FICA 1988, 1989).

Figure 6 shows the equal MHAR curves for the 1988 earthquake, in gals, which greatly coincides with the map of intensities of 1985. First, a low intensity zone Downtown can be seen, similar to low intensity zones I and II of Figure 2. Two zones of high intensity appear again; one between Downtown and the Chapultepec transition zone; and the other between Cerro de la Estrella and the hill zone, a little bit south from the correspondent in Figure 2. The high intensity zone near SCT also appears, somewhat to the east from the similar zone in 1985. Finally, it can be observed that lake-bed MHAR curves extend northwest over what is now considered transition zone. It is worth mentioning that the 1985 and 1988 earthquakes had near epicenters (Fig. 1), which helps to explain this coincidence.

Figure 7 shows the equal MHAR curves for the 1989 earthquake. This event, with an epicenter far from the correspondent to 1985 (Fig. 1), shows big differences with the map of intensities of 1985, contrary to the 1988 earthquake. A high intensity zone can be seen again between Downtown and the Chapultepec transition zone, which extends to SCT, and it is also possible to observe that lake-bed MHAR curves extend northwest over transition zone; nevertheless, quite notorius is the absence of the high intensity zone between Cerro de la Estrella and the hill zone, and the appearance of a new high intensity zone in Tláhuac, in the southeast.

It is important to observe the 100% MHAR amplification from lake-bed zone to high intensity zones for the two earthquakes.

The comparison of Arias intensities obtained from the 1985 and 1989 earthquakes allowed to calculate ductility spectra from 1989 scaled accelerograms, thus the possibility to elaborate maps of maximum ductility demands "MDD" for several period ranges (Gómez-Bernal *et al.* 1991). Figure 8 shows the equal MDD curves for the period range 2.0±0.1 sec, which greatly coincides with the 1989 MHAR map of Figure 7. It can be seen that MDD curves emphasize the high seismicity of the lake-bed zone in the south, near Xochimilco and Tláhuac. It is also important to notice that in spite of the lake-bed zone's MHAR curves that extend northwest over transition zone, the ductility demands there are very low, pointing out that the correlation between damage potential and peak ground acceleration in the lake-bed zone does not extend towards the transition zone. Maps for other period ranges, between 1.5 to 2.5 sec, lead to similar conclusions.

5 SEISMICITY OF MEXICO CITY

The available information from observed earthquakes in Mexico City, previously presented, permits to make an effort to reinterpretate the seismicity of the city and to improve its seismic zonation.

The coincidence in the intensity distribution of the 79, 85 and 88 earthquakes, confirms the hypothesis that relates the high intensity zones to the interaction between neighboring zones of firm soil or rock that emit and reflect the seismic waves through the soft soil between them, thus amplifying the seismic intensity a 100%. On the other hand, the intensity distributions of the 57 and 89 earthquakes, with epicenters south of the city instead of southwest, seem to show the importance of the epicentral position in the location of some of the high intensity zones, as can be seen comparing Figures 6 and 7, in which the 1988 high intensity zone between Cerro de la Estrella and the hill zone (Fig. 6) migrates toward Tláhuac in 1989 (Fig. 7), as the epicentral location moves to the south of the city.

In those cases in which quantitative information is available (85, 88 and 89), a 100% amplification is observed in the high intensity zones from the lake-bed zone, showing the need to use higher design parameters in them as those originally proposed for the actual seismic zonation (Iglesias 1988, 1989) (Fig. 4).

Finally, the MHAR curves for the 88 and 89 earthquakes show a similar behavior between the lake-bed zone and an important portion of the transition zone in the northwest, although the damage potential is lower in the last case.

6 CONCLUSIONS

As a main conclusion, it is clear that the understanding of the complex seismicity of Mexico City requires a thorough observation of earthquakes intensities, labor which is barely beginning. The superposition of the intensity distributions observed in future earthquakes will lead to more accurate seismic zonations.

In this work, the information derived from the subduction activity in the Mexican Pacific Coast is used to propose a conservative improvement of the actual seismic zonation. As it is shown in Figure 3, besides the increase of the actual high seismicity zones, it is proposed to extend the lake-bed zone toward the northwest, for seismic design purposes only, and to define a new high seismicity zone around Tláhuac, with at least height construction restrictions, while the seismic characteristics of the south lake-bed zone are better defined. The adoption of the design parameters that were originally proposed with the present zonation for the high seismicity zones is also strongly recommended (Fig. 4).

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