Soil Fracturing Induced by Land Subsidence in Mexico City

Fracturation des sols induite par la subsidence de la ville de Mexico

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ABSTRACT: Updated information concerning land subsidence and associated soil fracturing in Mexico City is presented. Subsidence was estimated from the evolution of the elevations of 2064 benchmarks and other references located in former Texcoco Lake. Geodesic and topographic surveys carried out in the middle of the XIXth century proved to constitute an excellent initial reference for subsequent measurements of land subsidence. Extensive use was made of new geocomputing tools to process these data. Results of surveys of soil fracturing associated to subsidence are also presented and discussed.

RÉSUMÉ: On présente des données récentes sur la subsidence et la fracturation des sols à Mexico. La subsidence a pu être évaluée grâce à des levés topographiques portant sur 2064 points de nivellement et d'autres repères situés dans l'ancien lac de Texcoco. Les relevés géodésiques et topographiques du milieu du XIXème siècle constituent une excellente référence initiale pour les mesures suivantes. On a utilisé de nouveaux outils informatiques pour traiter ces données. Des résultats de relevés concernant la fracturation des sols sont également présentés et commentés.

KEYWORDS: Subsidence, soil fracturing, soft clays, surveys, geocomputing.

1 INTRODUCTION.

The demographic development in Mexico City has created an accelerated demand of services, mostly of potable water. One of the cheapest ways to meet this demand has been the exploitation of the local aquifer by pumping water from deep wells. This has produced a water pressure drawdown in the subsoil that in turn is causing general subsidence of the former lacustrine area and soil fracturing. This problem has been around for almost a century but is now reaching new worrying dimensions.

Today, the subsidence phenomenon, at eighty years from Roberto Gayol's discovery (1925), and at more than sixty years from its scientific explanation by Nabor Carrillo (1947), persists with cumulative effects through time which cause differential settlements in colonial and modern structures of Mexico City. Installations as important as the subway system, the Gran Canal, and the water system network are also severely affected.

During the last decades, an increasing number of soil fractures have been detected in Mexico City valley. Such cracks are a matter of growing concern for the population and authorities since they have caused a series of accidents and serious damage to constructions and public services. It is now acknowledged that the soil fracturing problem is an important risk factor and that the best scientific tools and techniques should be mobilized to define prevention and mitigating measures.

Soil fracturing can occur as a consequence of any condition leading to large tensile stresses or extension strains in the soil. Accordingly, cracks in the soil have different origin, including contraction of compressible clays by drying, stresses induced by the weight of constructions, hydraulic fracturing of soft soils (Auvinet & Arias, 1991, Figure 1), seismic movements, etc. However, the largest and more destructive fractures are generally a direct consequence of land subsidence associated to pumping of water in the local aquifer.

Figure 1. Crack in Chalco

1 LAND SUBSIDENCE

1.1 Assessing regional subsidence

Although regional land subsidence is an old phenomenon, it has not been possible to control it. In fact, it is expected to continue in the future for many more years since, due to the high cost of other alternatives, water pumping from the local aquifer cannot be suspended. Studies and analyses are thus necessary to rethink criteria and strategies to mitigate future effects.

1.2 Local values of subsidence

Thanks to the historic information which was gathered with the support of different institutions among which stands out the Water System of Mexico City (SACM) of the Federal District Government (Pineda & Pelaez, 2009), the subsidence history in three sites of the Historic Center of Mexico City could be reconstituted (Figure 2).

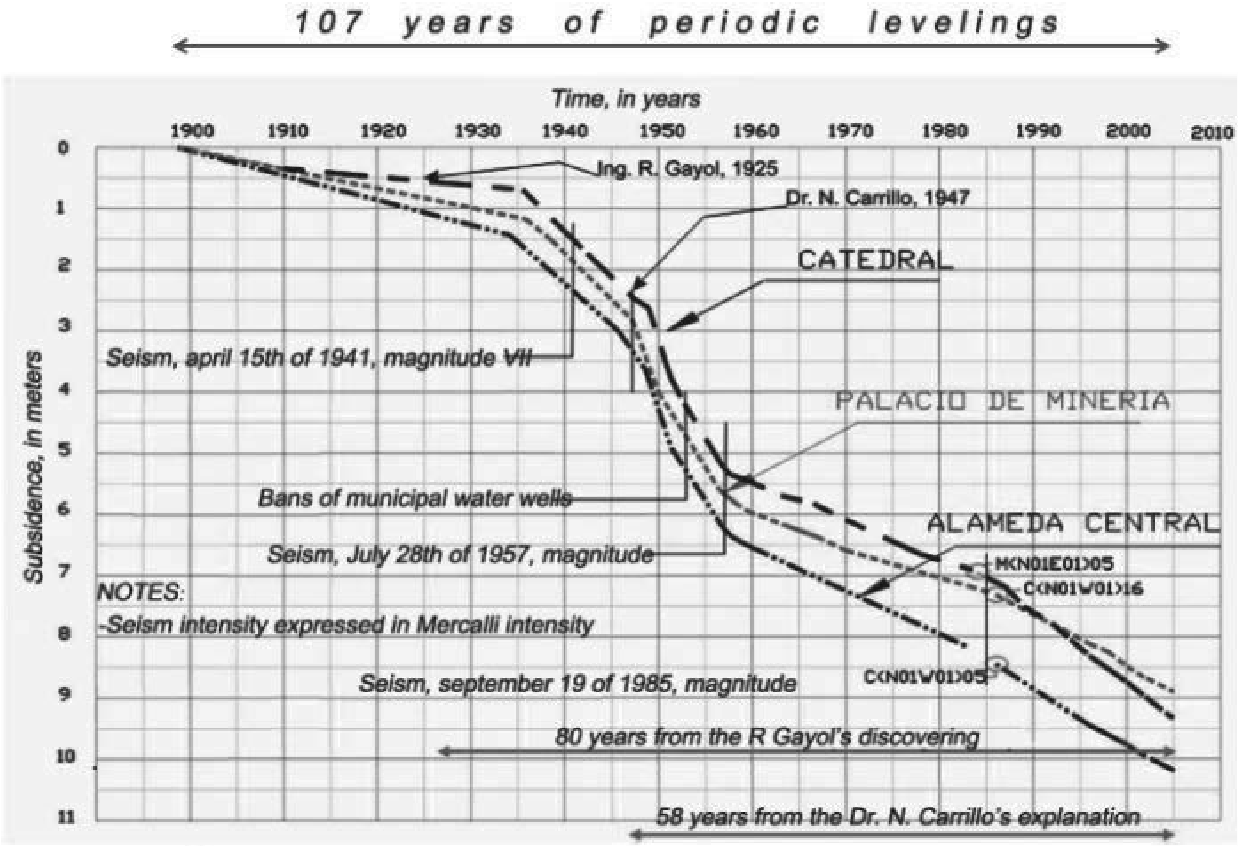

Figure 2. Local evolution of subsidence for the 1898-2005 period.

In the figure 2, it is observed that the subsidence rate reached a 29cm/year peak during the 1947-1957 period, and is still of the order 10cm/year for these three sites.

The accumulated settlement since the end of the XIXth century is of the order of 10m for these sites but, in other points of the valley, accumulated subsidence values as high as 13.5m have been observed (Pérez, 2009).

Some physical evidences of the general subsidence such as former well casings protruding from the subsiding surrounding soil can be observed in the city (Figure 3). The authorities have been asked to protect such evidences.

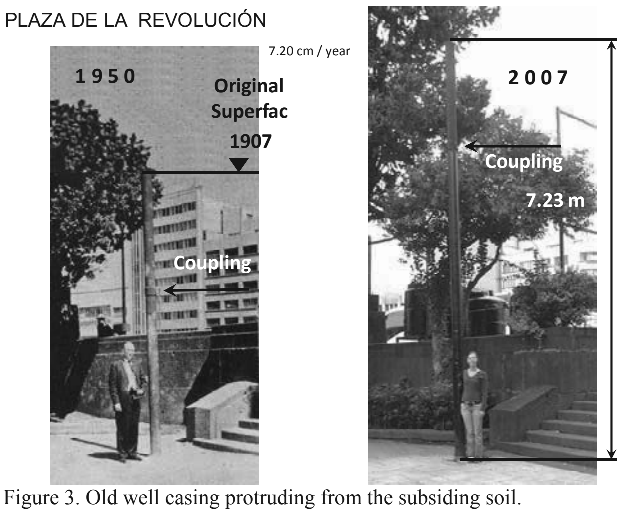

Figure 3. Old well casing protruding from the subsiding soil.

1.3 Spatial distribution of the subsidence phenomenon

In order to assess the spatial distribution of the subsidence in the former lacustrine area, it was necessary to build a Geographic Information System (SIG-BN) to process the data obtained from surveys of the existing benchmarks. Geodesic and topographic surveys carried out in the middle of the XIXth century were reviewed and proved to constitute an excellent initial reference for subsequent measurements. From the contour map obtained by geostatistical methods it was possible to develop a model of the present configuration of the surface relief of the bottom of the former lakes of Mexico valley (Figure 4).

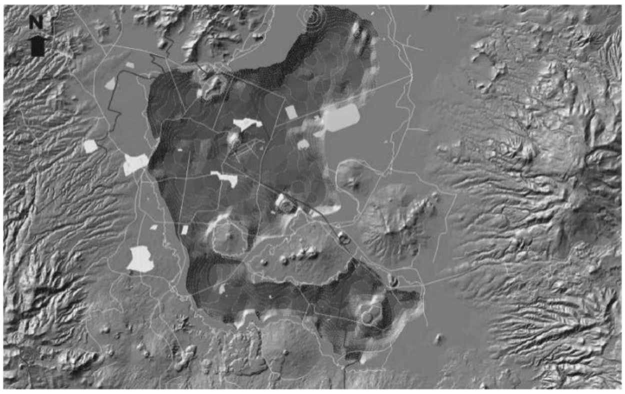

Figure 4. Relief of the former lakes of Mexico Valley.

1.4 Spatial distribution of the subsidence rate

Figure 5 shows the spatial distribution of the subsidence rate for the 1998-2002 period. The sites with the highest rate (40 cm/year) are located east of Tlahuac, in the Chalco Lake, and in Nezahualcoyotl City, in front of the Marquez hill.

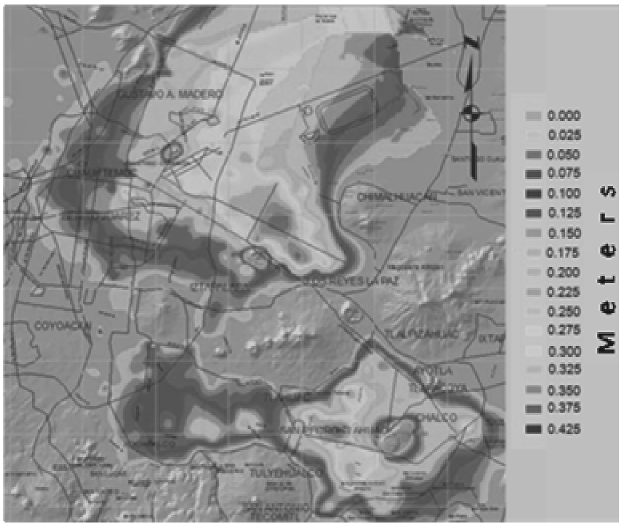

Figure 5. Subsidence rate in m/year during the 1998-2002 period.

2 SOIL FRACTURING

The Geocomputing Laboratory group of the Engineering Institute, UNAM, has undertaken a systematic study of the fracturing phenomenon, including both descriptive aspects and theoretical interpretation. For that purpose, a Geographic Information System was developed, using as a support a similar system developed by the authors to describe geotechnical characteristics of Mexico Basin subsoil (Auvinet *et al*., 1995).

Field work consisting of direct surveys of fractures in situ was carried out. Use was made of Geodesic control techniques recurring to differential Global Positioning Systems (GPS) equipped with double frequency antennas. At this moment, 868 fracturing sites have been documented. About 45 sites where cracks had been reported were discarded when, during the field visits, it became evident that no fracturing could be detected and that defects in the soil surface could be attributed to other factors (mainly scour).

The amount of information stored in the data base regarding the exact location as well as the description of the geometric characteristics and special features of each fracture has increased steadily. This database has been called: SIG-G. Figure 6 shows the spatial distribution of the 868 sites included until now in SIG-G.

The most important and destructive cracking mechanism is a direct result of subsidence. It is observed in abrupt transition zones between firm and soft soils. Cracks of this type are characterized by a step toward the compressible zone where larger settlements are observed (Figure 7). The Iztapalapa precinct, with 30 kilometers of abrupt transition, is the most affected by this phenomenon.

Using an extensive photographic file of cracks, a digital album is being elaborated in order to facilitate the analysis of evolution of each fracture through the years. This album is integrated by a set of files; each file contains from two to six photos of the same crack taken during one of the 1996, 1999, 2001, 2002, 2005, 2006, and 2007 campaigns. A complementary file includes photos of the damage caused by the fracture in adjacent buildings or negative effects in the vital lines of the city.

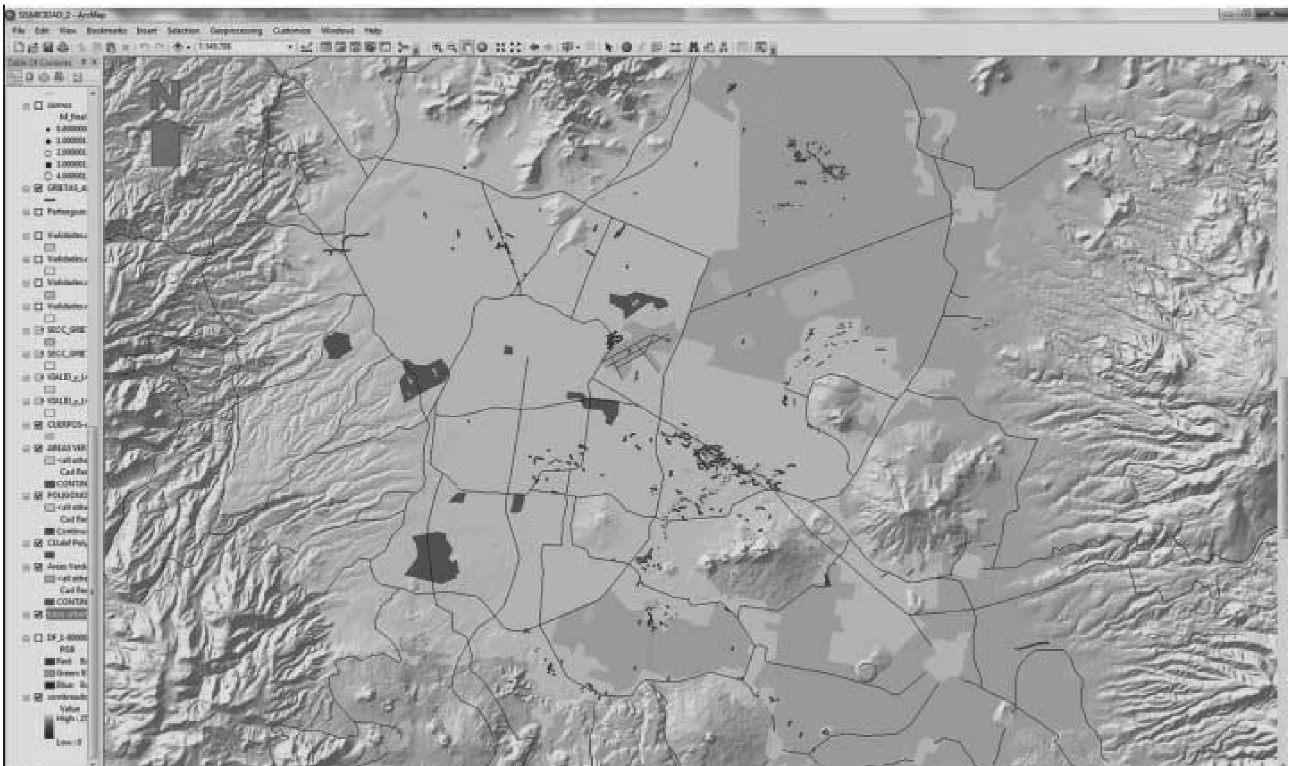

Figure 6. Spatial distribution of 868 cracks stored until now in SIG-G.

Figure 7. Crack in an abrupt transition area.

Initially, fracturing was only observed in the sediments of former Texcoco lake but, in the last years, the phenomenon has been widely reported in five areas of Mexico Valley: a) South zone: Xochimilco, Tláhuac and Chalco; b) East zone: Iztacalco, Iztapalapa, Nezahualcoyotl, Chimalhuacan and Los Reyes; c) Center area: Peñon de los Baños and Venustiano Carranza; d) North-West zone: Naucalpan, Azacapotzalco and G. A. Madero and e) North-East zone: former Texcoco lake.

3 CONCLUSIONS

Land subsidence is an ongoing process that affects the former lacustrine zone of Mexico City. Soil fracturing associated to land subsidence causes serious problems to the citizenship and the infrastructure of the metropolitan area of Mexico valley. Until now, actions in this regard have been isolated, and only short term solutions have been implemented without really trying to understand the problem in greater depth and to evaluate the true efficiency of these solutions.

Efforts by different groups, in particular by the Geocomputing Laboratory of II UNAM to achieve a better monitoring of the subsidence phenomenon of the lacustrine zone of Mexico City, as well as of others aspects of the geotechnical problematic, like soil fracturing, have allowed to obtain useful results but they just constitute the first stage of a huge monitoring work which should be followed on in a systematic way in the future. Institutional will to give continuity to these studies and availability of the required resources for its realization are essential to obtain satisfactory and up to date results.

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