Advances in geotechnical characterization of Mexico City basin subsoil

Nouveaux développements dans la caractérisation géotechnique du sol du bassin de Mexico

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ABSTRACT

This paper presents recent advances in the geotechnical characterization of Mexico City subsoil based on a Geographic Information System for Geotechnical Borings (GIS-GB) that includes more than 7,000 soil profiles. Geostatistical techniques were used to define 2D and 3D models of the subsoil. Contours of layers thickness, as well as index and mechanical properties in the area were also obtained. The maps that have been established have been used in order to update the geotechnical zoning presented in Mexico City Building Code.

RÉSUMÉ

Cette contribution présente de nouveaux développements dans la caractérisation du sol de Mexico à partir d'un Système d'Information Géographique pour les sondages (GIS-GB) qui comprend plus de 7.000 profils de sols. On a utilisé des techniques géostatistiques pour développer des modèles 2D et 3 D du sol. Des courbes d'isovaleurs des propriétés physiques et mécaniques du sol de la zone ont également pu être obtenues. Les cartes établies ont été utilisées pour mettre à jour le zonage géotechnique publié dans le règlement de construction de la ville de Mexico.

Keywords : Geographic Information System, Geostatistics, random field, kriging.

1 INTRODUCTION

The numerous geotechnical surveys performed in the urban area of Mexico City can be used to obtain a better knowledge of the subsoil and improve the accuracy of geotechnical zoning maps for regulatory purposes of construction (GDF, 2004).

To take advantage of the new available information, it is necessary to use computational and informatics tools, such as Geographical Information Systems as well as powerful mathematical tools based on Geostatistics.

Geographic Information Systems help to organize geotechnical information for fast and easy review. On the other hand, Geostatistics, defined as the application of random functions theory to the description of the spatial distribution of properties of geological materials, provides valuable tools for estimating data such as thickness of a specific stratum, or value of a certain soil property at a given point where no information is available, taking into account the correlation structure of the medium. Additionally, uncertainty associated to these estimations can be quantified.

Fundamentals of Geostatistics applied to Geotechnics have been previously presented in detail in some publications and contributions to different conferences (Auvinet, 2002; Juárez and Auvinet, 2002). This paper illustrates the direct application of geostatistical methods to the assessment of spatial variations of index soil properties (water content) and geometric configuration of layers (depth and thickness) in the lacustrine zone of Mexico City.

2 LOCATION OF STUDY AREA

The study area is located in the south part of Mexico Basin. It includes parts of political delegations of Álvaro Obregón, Azcapotzalco, Benito Juárez, Cuauhtémoc, Gustavo A. Madero, Iztacalco, Miguel Hidalgo and Venustiano Carranza in the Federal District and municipalities of Naucalpan, Ecatepec, Nezahualcoyotl, Tlalnepantla in the State of Mexico (Figure 1).

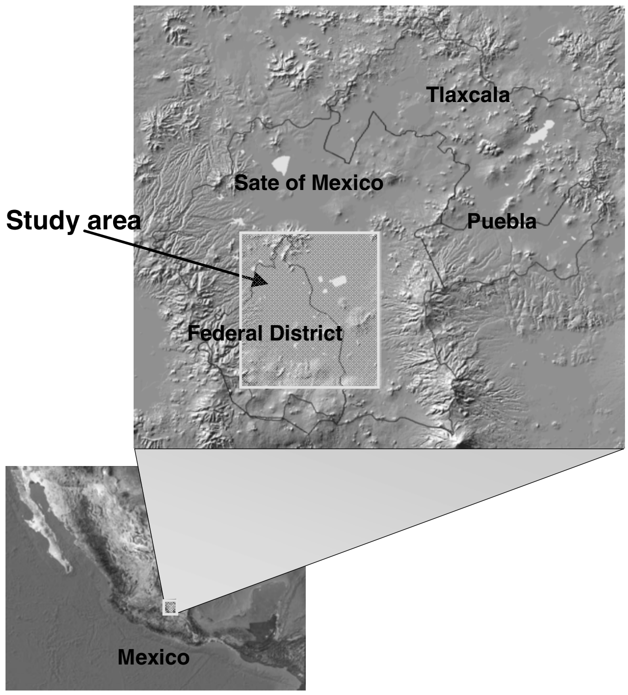


Figure 1. Location of study area.

3 GEOGRAPHIC INFORMATION SYSTEM FOR GEOTECHNICAL BORINGS

The information used to assess the configuration of typical layers and spatial variation of soil properties from profiles of geotechnical borings, has been incorporated into a Geographic Information System developed by the Geocomputing Laboratory of Institute of Engineering, UNAM.

This Geographic Information System for Geotechnical Borings (GIS-GB) for the area has been built using ArcMap ver.

Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering
M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-2679

9.2 (commercial software). Nowadays, the system includes a database with information on more than 7,000 borings (type, date, address, depth, water table level, etc.) and a database of images of geotechnical profiles, which can be readily consulted, Figure 2.

Incorporating information from the borings in the system requires pre-processing: the information is critically reviewed and converted from analog to digital format of either raster (cell information) or vector (digitized information) type.

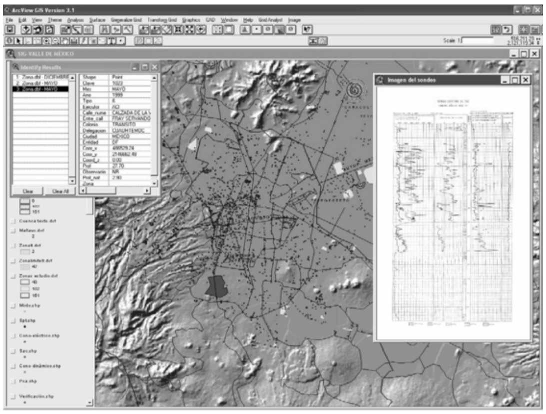


Figure 2 . Geographic Information System for Geotechnical Borings.

4 SUBSOIL MODEL

4.1 *Vertical model*

The typical soil profile sequence in the lacustrine zone of Mexico City subsoil includes a thin superficial Dry Crust (DC), a First Clay Layer (FCL) several tens of meters thick, a First Hard Layer (FHL), a Second Clay Layer (SCL) and a second hard layer called "Deep Deposits (DD)" (Marsal and Mazari, 1959).

4.2 *Horizontal model*

Article 170, Chapter VIII, of Mexico City Building Code (GDF, 2004), establishes that for regulatory purposes, Mexico City is divided into three zones with the following general characteristics:

Zone I. Hills, formed by rocks or hard soils that were generally deposited outside the lake area, but where sandy deposits in relatively loose state or soft clays can also be found. In this area, cavities in rocks, sand mines caves and tunnels as well as uncontrolled landfills are common.

Zone II. Transition, where deep firm deposits are found at a depth of 20 m or less, and consisting predominantly of sand and silt layers interbedded with lacustrine clay layers. The thickness of clay layers is variable between a few tens of centimeters and meters.

Zone III. Lake, composed of potent deposits of highly compressible clay strata separated by sand layers with varying content of silt or clay. These sandy layers are firm to hard their thickness varies from a few centimeters to several meters. The lacustrine deposits are often covered superficially by alluvial soils, dried materials and artificial fill materials, the thickness of this package can exceed 50 m.

5 GEOTECHNICAL ZONING MAP

The geotechnical zoning map is based on the model previously described. Applying geostatistical methods the depth of deep deposits (DD) is considered as a random field $V(X)$, distributed within an R^P domain, with p = 2 (area). The set of measured values within the R^P domain is a random sample of this random field. A structural analysis was performed to obtain experimental correlograms and correlation distances. Theoretical correlograms were fitted to the data set after removing a linear trend, Figure 3.

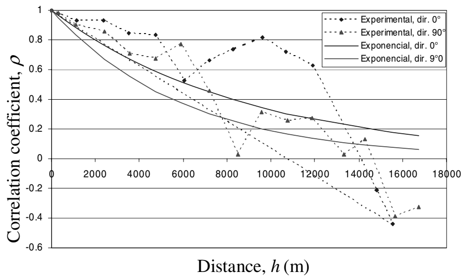


Figure 3. Directional correlograms for Deep Deposits depth.

From the data set without trend (residual field) and using the results of structural analysis, the expected value and standard deviation of the depth of the deep deposits were obtained on all nodes of a regular grid conveniently defined, using the technique of Ordinary Kriging (Journel & Deutch 1992). The final estimate of the field was obtained reinstating the trend into the results. A contours map could then be drawn, Figure 3, as well as the 3D view shown in Figure 4.

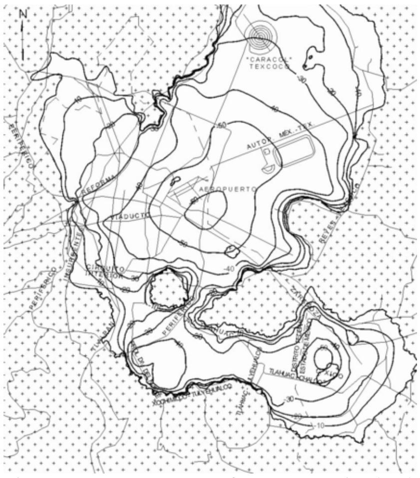


Figure 3. Contours map of Deep Deposits depth.

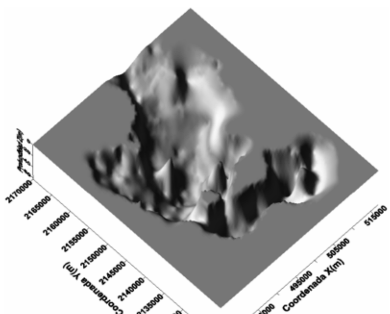


Figure 4. Estimated depth of Deep Deposits.

Taking into account the definition of transition zone previously indicated and using the map of Figure 3, it was possible to define the boundary lines between zones II and III shown in Figure 5.

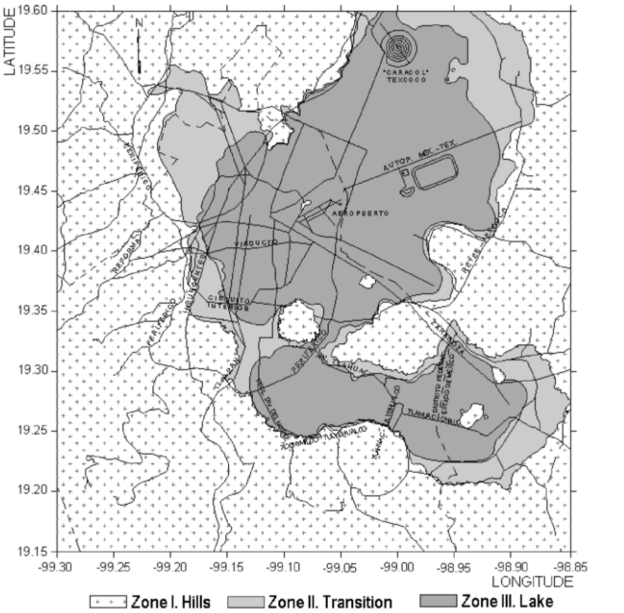


Figure 5. Geotechnical zoning map for Mexico City Building Code (GDF, 2004).

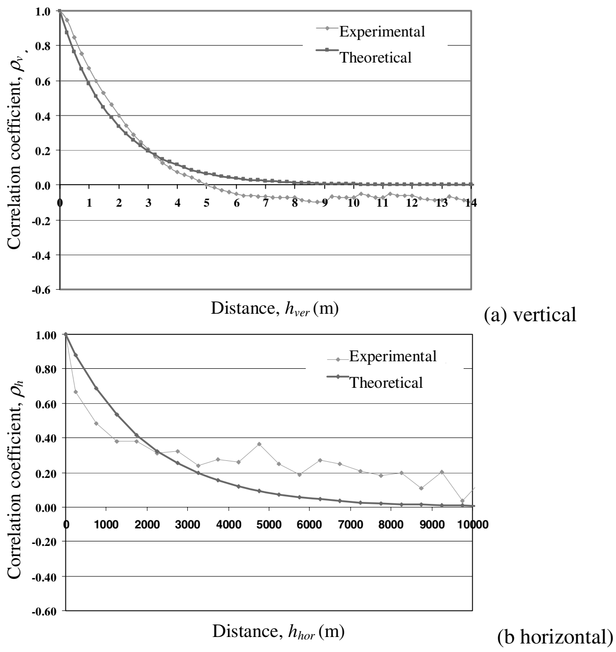


Figure 7 . Spatial correlation models for water content, w(%).

6 SPATIAL DISTRIBUTION OF WATER CONTENT

Water content is an index property that is useful for identifying the typical layers of Mexico City subsoil. High values of water content indicate the presence of soft soil with low resistance to stress shear (FLC) and (SLC) and low values are characteristic of formations with higher shear strength (DC, FHL and DD). Therefore, using the same Geostatistical method, some cross sections (virtual sections) were estimated from data set of water content, w(%), to define a continuum in each of the typical layers of subsoil. Figure 6 shows the location of cross-sections; Figure 7 shows spatial correlations models, and Figure 8 shows a 3D model of cross-sections representing water content variations in the west area of Mexico valley. This model represents the continuous spatial distribution of this property and indirectly helps defining the configuration of the typical layers in this area.

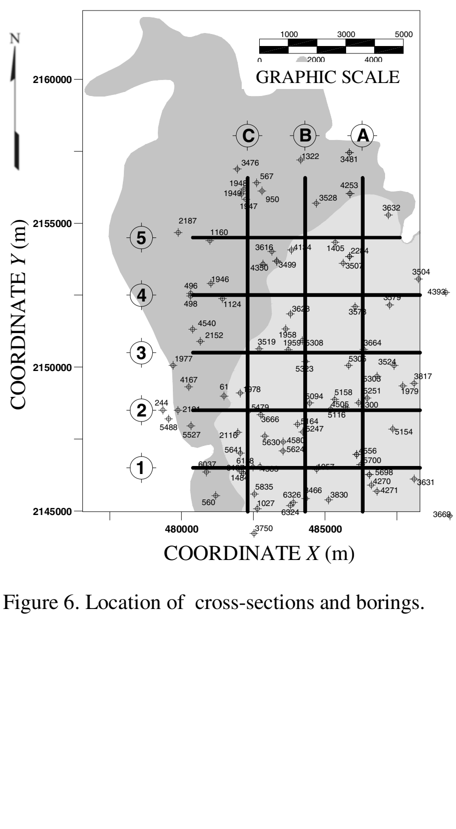


Figure 6. Location of cross-sections and borings.

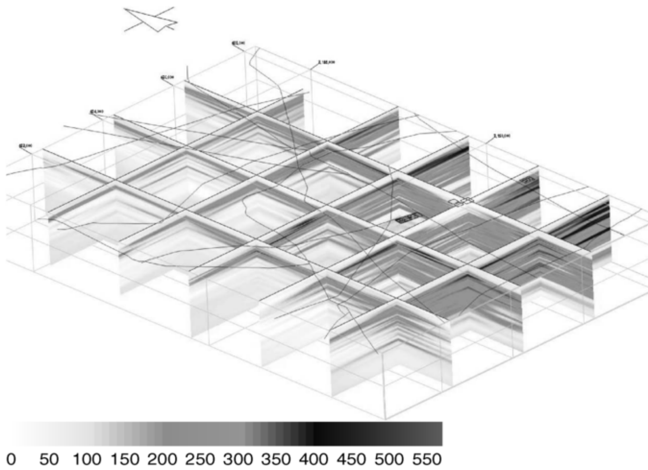


Figure 8. 3D model with cross-sections representing estimated water content variations, w(%).

7 ARCHEOLOGICAL FILL

Detailed maps of specific parts of the geotechnical zones have also been established. In the case of the historic center of Mexico City it is important to map the superficial archeological fill dating back to the pre-Columbian era. Using the same geostatistical methodology, the contours map for this archeological fill shown in Figure 9 was obtained. Figure 10 presents a 3D view of this fill. Proceeding in systematic form for other layers, it was possible to obtain configurations of other strata. The contours maps were integrated through the GIS-GB to be presented in a model of the typical layers of the subsoil for the downtown area, as shown on Figure 11. Water content cross-sections were also built to assess the continuity of typical layers, Figure 12.

The proposed geotechnical zoning map for the downtown area, is presented on Figure 13. It considers the following subzones: transition zone II and lake zone III divided in IIIa (lake) and IIIb (lake with significant superficial fill, corresponding to the sites where clay layers have been heavily consolidated under the weight of large fills and aztec and colonial buildings).

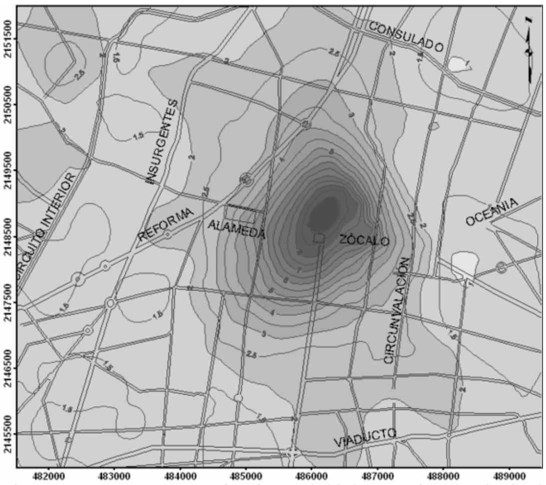


Figure 9 Contours map of estimated thickness of archeological fill.

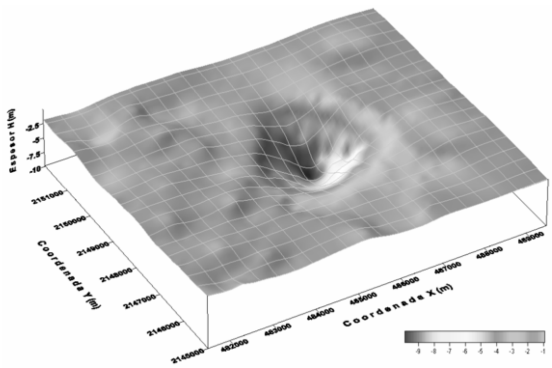


Figure 10 Estimated thickness of archeological fill

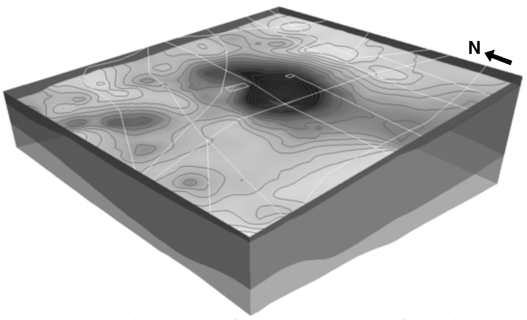
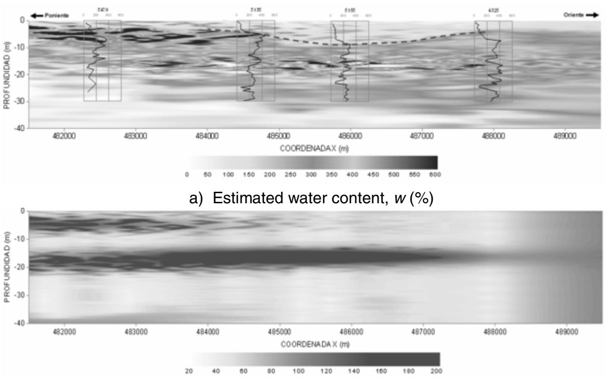


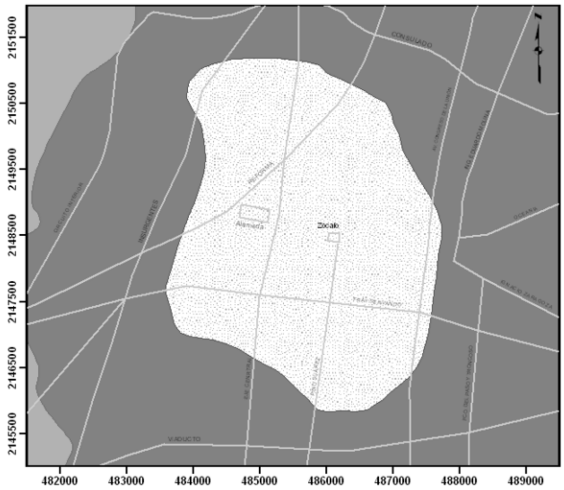
Figure 11. Digital model for typical layers of Mexico City downtown area subsoil.



a) Estimated water content, *w* (%)

b) Estimation standard deviation

Figure 12. Cross-sections showing variations of estimated water content and associated uncertainy.



Zone II - Transition Zone II - Lake
Zone IIIb – Lake with superficial fills

Figure 13 Geotechnical zoning map proposed for Mexico City downtown area.

8 CONCLUSION

Recent advances in the geotechnical characterization of Mexico City subsoil based on a Geographic Information System for Geotechnical Borings (GIS-GB) have been presented. Geostatistical techniques were used to define 2D and 3D models of the subsoil. Contours of layers thickness, as well as index and mechanical properties in the area were also obtained. The maps that have been established have been used in order to update the geotechnical zoning presented in Mexico City Building code.

The availability of increasingly accurate information about the distribution of materials and index and mechanical properties in Mexico City subsoil has immediate implications for planning of future works and is deemed to be useful for civil engineers working in this area.

ACKNOWLEDGMENTS

The authors acknowledge the valuable support of Dirección General de Apoyo al Personal Académico, UNAM, Gobierno del Distrito Federal and various private companies that provided geotechnical information for this work.

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