Engineering Geology of Quaternary Deposits of Greater Tehran, Iran

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Abstract: The Greater Tehran Area, the capital of Iran is located at the foot slope area of the Alborz range which form a part of the Alps-Himalayan Orogenic belt with high earthquake potential. Urban development has been rapidly progressing in Tehran. Preparation of engineering geological maps for the city plays a vital tool for planner and decision maker to reduce subsurface investigations and serve as a basis to assess geo-environmental impacts. In this research, physical and mechanical characteristics of the quaternary deposits of Greater Tehran city are examined. For this purpose, a large amount of geotechnical information derived from 950 boreholes was collected and analyzed. The combinations of the collected geotechnical data has led to the compilation of several engineering geological maps and cross sections for the area. Practical applications of the study, include preparation of maps showing the presumed allowable bearing pressures under static loading for preliminary design purposes of shallow foundations for normal ranges of buildings and engineering structures.

Résumé: La région métropolitaine de Téhéran, le capital de l'Iran, se place au pied de la chaîne Alborz faisant partie le centre de la ceinture Alpe-Himaliane et ayant une potentille de séisme très élevée. Regardant le développement urbain et industrielle très rapide, les cartes de géologie d'ingénierie peuvent être très utiles pour fin de la planification régionale. De plus, elles diminuent les coûts d'exploration sous terrain et aussi rendrent service pour l'estimation des effets local et régional des projets industriels et logements sur l'environnement. Dans cette recherche, les caractéristiques physiques et mécaniques des dépôts quaternaires de la métropolitaine de Téhéran ont était examinées. Pour ce fin, une grosse quantité des donnés géotechniques obtenus par 950 forages a été ramassée et examinée. Les caractéristiques géologie d'ingénierie des classes principales des quaternaires de Téhéran été déterminés. La combinaison des données et les résultats obtenus a été présentée sous forme de plusieurs cartes et sections transversales géologies d'ingénierie de la région. La capacité portante de différente classes des dépôts quaternaires pour les fondations superficielles est presente dans un carte.

Key words: alluvium, engineering geology maps, laboratory tests, drilling, cohesive materials, database system

INTRODUCTION

Information about subsurface conditions is required for a wide range of construction and environmental assessment activities such as construction of linear infrastructures, sewage systems, buildings, as well as environmental impact assessment studies, urban expansion, etc. To this end, site investigations are generally carried out and many boreholes are excavated in different locations of large cities. During these investigations, numerous tests are carried out in order to determine geotechnical characteristics of subsurface layers. The results of such studies are used for the specific project due to poor data management.

Subsurface data collection is a major activity of crucial importance in urban geology (Mulder, 1997) but it is unnecessarily time-consuming when existing data are stored in unorganized paper archives. Thanks to the widespread application of computers, data management has advanced significantly. New soft wares have been developed for optimal use and improved representation of data. Burnett and Fookes (1974) were one of the first that applied personal computers to organize, save, recover and display geological data. Turner (1983) presented a review of computer applications in geological map development.

Hardware and software advancements made it possible to use GIS systems with the technology of remote sensing in geology. Many attempts were made in the last two decades to create geological and geotechnical databases and apply them to the development of geological and engineering geological maps for example Walters and Lloyd (1985), Chaplow (1986), Herbschleb (1990), Bellotti and Dershowitz (1991), Koike, Ohmi & Kaneko (1990), Ghayoumian et al (1994), Orlic (1997), Park and Yu (1998), Koike, Sakamoto & Ohmi (2001), Luna et al (2001), and Renger et al (2002). One of the most advanced geotechnical data bank belongs to the National Geological Survey of the Neatherland (NITG-TNO) which holds and manages a relational digitized databank of some 400,000 boreholes and cone penetration tests from all over the country (Mulder et al 1997).

Over the last two decades there have been large amounts of borehole data from various kinds of construction works in Greater Tehran, but there has not been a systematical and efficient management technique of such data. Construction of a geotechnical database for management of these data and its application in preparation of engineering geological maps have now been achieved.

Study Area

The study area consists of the 22 municipal districts of Greater Tehran (Fig. 1). This area is about 1100 km^2 wide and is located between 51° 15′ and 51° 33′ Eastern longitude and 35° 32′ and 35° 49′ Northern latitude. Alborz

Mountain Range is located at the north of the region. The area is bounded by the Sepayeh to the east, the River Karaj to the west, and the south by southern Tehran height. Tehran plain starts near the city center with an elevation of 1250 meters above sea level, and stretches over to the southern parts of Rey in a mild slope. The elevation declines in a mild west-east slope.

Tehran is located on relatively recent alluvial deposits extending toward the south from the foothills of Alborz Mountains range. These deposits are the result of river activity and seasonal inundations. Tehran alluvium is comprised of four groups (Table 1). The region is characterized by high variations in soil texture and resistance characteristics.

THE GREATER TEHRAN GEOTECHNICAL BOREHOLE DATABASE

The Tehran Geotechnical Data Base (TGDB) program was written in Fox-pro language. The system consists of a data base of subsurface data, and several modules for production of thematic maps. A related geographic information system is under construction. This program is able to import, edit, recover and classify borehole data in X-base database. One can also search for geotechnical boreholes based on keywords, print and link data to graphical themes and extend the database to consider unpredicted requirements. Statistical macros can be recalled in the program or results can be demonstrated as interface files for popular statistical and spreadsheet software. The program is compatible with graphic vector soft wares, so it is also possible to export/import borehole locations into/from graphic vector media such as AutoCAD, Arc info, CARIS, MapInfo and the profile of borehole specifications can be illustrated.

Data Sources

TGDB includes data of Tehran boreholes, collected from research centres, governmental and private Consulting Engineering Companies. Data older than 25 years, handwritten and informal data, illegible, and misprinted data are removed from the collected data. Data from 950 boreholes are qualified for the database. The exact locations of 181 boreholes are unknown. The data of these boreholes are also imported into the database to determine the relationship between different soil parameters, in which the borehole location is not required. A data form was developed for borehole characteristics and all collected data were recorded in the forms. The main characteristics of each borehole include borehole location, groundwater levels, and physical and mechanical properties of soil in different depths. A sample form is shown in Figure 2. The data is imported into the database, after the forms are completed and finalized. The locations of the collected boreholes are shown in Figure 3.

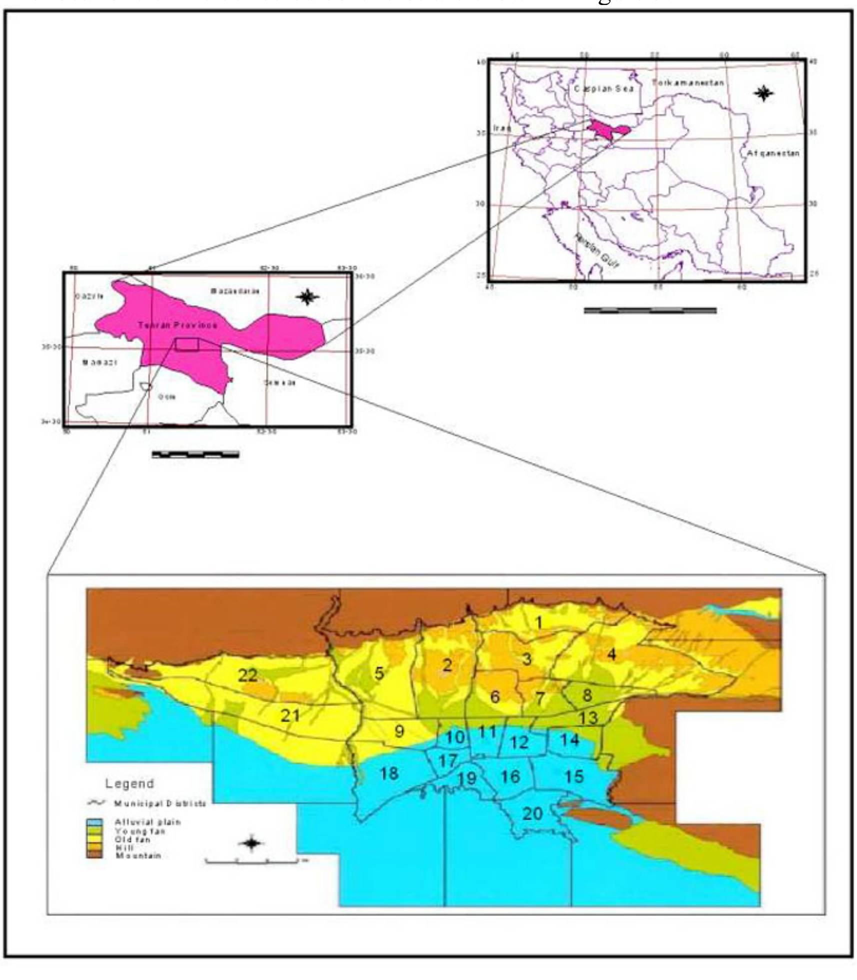

Fig. 1. Study area in Iran

Table 1. Alluvium groups in Tehran

Bed	Geological name	Thickness (m)
D	Recent Alluvium	Up to 20
C	Tehran Formation	Up to 100
B	Heterogenous Formation (Kahrizak F.)	Up to 300
A	Hezardarreh Formation	Up to 500

Bore hole Code	Depth (m)	Soil Description	Soil Classification	Particle Size Distribution (%)				Atterberg Limit			Density (gr/cm3)			Moisture (%)	Porosity (%)	Void Ratio	Uniaxial Strength (Kg/cm2)	Strength test result			Shear Strength		N (SPT)	N (CPT)
				Clay	Silt	Sand	Gravel	LL	PL	PI	Gs	γ_d	γ_t					ϕ	C (Kg/cm2)	Test Method	ϕ	C (Kg/Cm2)		

Fig. 2. A sample geotechnical data form for recording borehole data

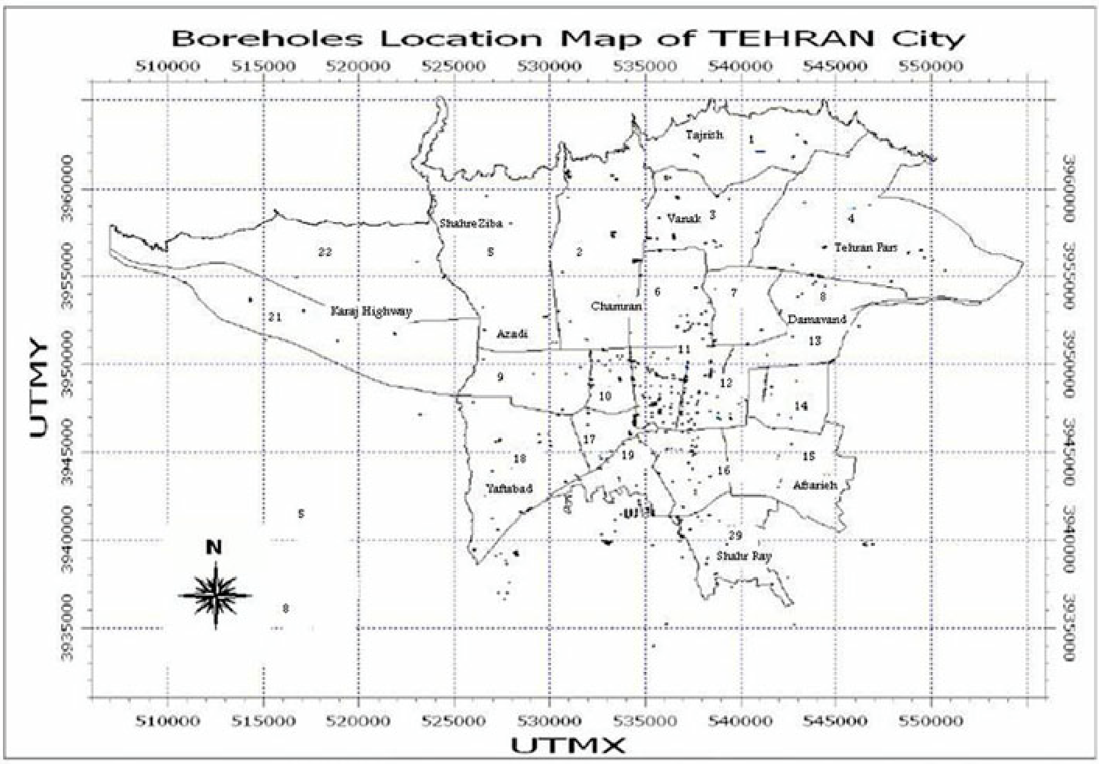

Fig. 3. Location of collected boreholes in Greater Tehran

Data Search in the Tehran Geotechnical Data Base

The most significant property of a database is its capability to search for certain data. Specific data required for a certain purpose, is easily accessed. Logic and mathematical relations are utilized to make the search easier. The capability of filtering data is as useful in a search. A filter can separate a special type of data set to be studied individually by developing relations between data of different forms. It is possible to display the requested borehole characteristics by importing them into other specialized application software, such as Arcview or Rockworks. This is useful in finding the nearest borehole to a considered location and presenting its geotechnical specifications.

DEVELOPMENT OF ENGINEERING GEOLOGICAL MAPS AND CROSS SECTIONS

Different kinds of engineering geological maps and cross sections can be developed based on the physical and mechanical characteristics of soil layers at different depths using the data of TGDB. For example, maps of density variations, SPT (Standard Penetration Test) values or any other geotechnical parameters can be produced for a specific depth. Moreover, combination of parameters, empirical equations, and statistical methods can be used to create engineering geological maps. On the other hand, engineering geological profile for a single borehole or a number of boreholes in any desired line can be produced.

Preparation of maps based on raw data

Physical and mechanical characteristics of subsurface layers can be used to prepare thematic maps for any desired depth. Figure 4 shows spatial distribution of SPT values for the surface layer (less than 3 m depth) in Tehran. According to this figure, sediments of the surface layer in most of the northern areas of Tehran have high SPT values (45 to 50). Coarse grained materials cover this part of the city. In some areas however, SPT values vary between 23 and 38, notably at Zargandeh, Southern Gheytarieh, Zaferanieh, Northern Saadatabad, Mollasadra, Modarres and Hesarak. Soil materials of these areas consist of: sand, silty clay, and silty-sandy clay.

SPT values are low in the area between Enghelab and Azadi Avenues and Rey, varying from 5 to 30 in this area. The least values of SPT correspond to the surface layer alluvial sediments located around Ghaem Park in Yaftabad, Serahe Azari, Abrisham Intersection, Aliabad, Khaniabad, Molavi and Abouzar-e-mahalati Avenue.

Another set of developed maps are the classification of Tehran sediments in two groups of cohesive and non-cohesive material. Cohesive material consists of fine grained materials represented by group symbols CL, ML, OL, OH, CH, MH, and FL (Fill Materials). Non-cohesive material however, consist of all classes of gravel and sand including GP, GW, GM, GC, SW, SP, SM and SC. Figure 5 shows the areas of cohesive and non-cohesive soils in the surface layer (<3 m deep) in Tehran. According to this figure, the majority of soil in this depth consists of non-cohesive material in the north and cohesive material in the southern part of Tehran. Cohesive material is however observed in some northern areas.

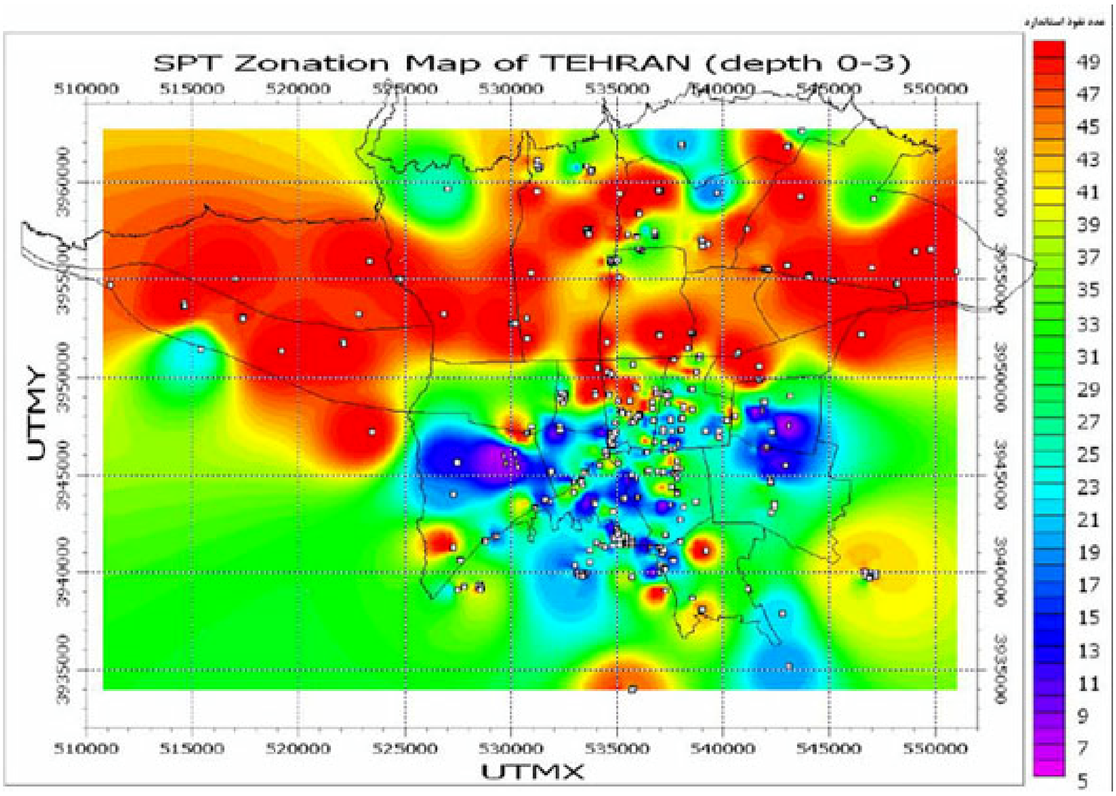

Figure 4. Spatial distribution of SPT for surface layer in Tehran

Development of geological profiles

The boreholes data in the databank can be transferred to Rockworks Software to display soil profile for each borehole of the data base. On the other hand, preparation of geological and geotechnical profiles in any desired line is possible.

The Unified Soil Classification (USC) system is used in the bank. In this study in order to simplify presentation of soil type, soil is classified as gravel, sand, silt and clay. This method has been applied by the Japan International Cooperation Agency (JICA, 2001) to classify Tehran soils. This method is used to prepare different geological profiles in Greater Tehran. A geological profile from the north to the south of Tehran is shown in Figure 6. The profile includes 16 boreholes on a line 23 km long. Most boreholes are less than 25 m deep. It can be observed that coarse sand and gravel is more common in the north of Tehran and fine silt and clay is more frequently found in the south. The developed database helps the user to draw his desired profile. On the other hand, any other geotechnical characteristics such as SPT, density, and etc. can be presented as geotechnical profile for a single borehole or a number of boreholes as cross sections in any desired line.

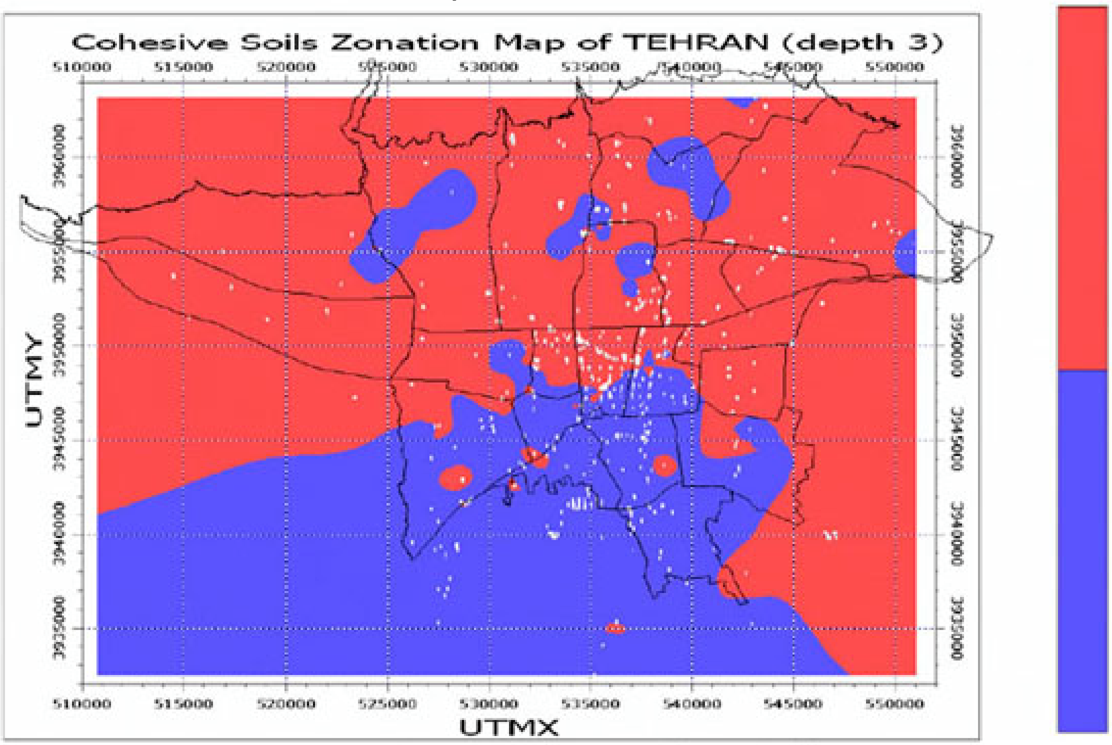

Figure 5. Spatial distribution of cohesive and non-cohesive material at surface in Tehran

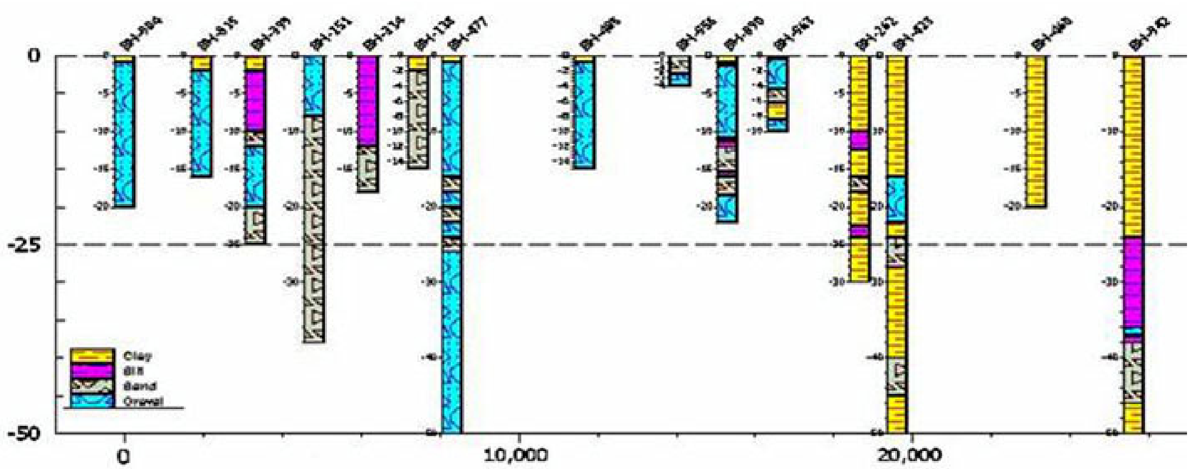

Figure 6. A geological profile from the north to the south of Tehran

Preparation of maps of empirical data

The relationship between SPT and strength of unconsolidated deposits for southern Tehran has been presented by Jafari et al (2002). Table 2 and Table 3 show these relationships for cohesive and non cohesive soils respectively. In this classification soils are classified into two main groups and 12 classes. Cohesive soils (C) and non cohesive soils (N) are classified into 7 (C1 to C7) and 5 (N1 to N5) classes respectively.

These classes were used to produce strength zonation maps at different depths for Greater Tehran. Figure 7 is the strength map for surface layer at <2 m depth. This map indicates that the northern part of Tehran is predominantly underlain by N4 (Dense) and N5 (Very dense) classes. In some areas in the north, including Vanak Square and south of Qeitariehe, C6 (Hard) and C7 (Very hard) soils are recorded. C4 to C7 soil classes predominantly underlie southern part of the city. This type of map has been produced and interpreted for different depths (Ghayoumian et al 2004).

Geological engineering maps such as soil bearing capacity zonation map for shallow foundations, and liquefaction susceptibility map are developed, considering thresholds suggested by different researchers.

Table 2. The relationship between SPT and strength of cohesive soils

Soil description	Very Soft	Soft	Soft to Firm	Firm	Very Firm	Hard	Very Hard
Symbol	C1	C2	C3	C4	C5	C6	C7
SPT	<2	2-4	4-8	8-15	15-30	30-50	>50

Table 3. The relationship between SPT and strength of non-cohesive soils

Soil description	Very Loose	Loose	Medium	Dense	Very Dense
Symbol	N1	N2	N3	N4	N5
SPT	<4	4-10	10-30	30-50	>50

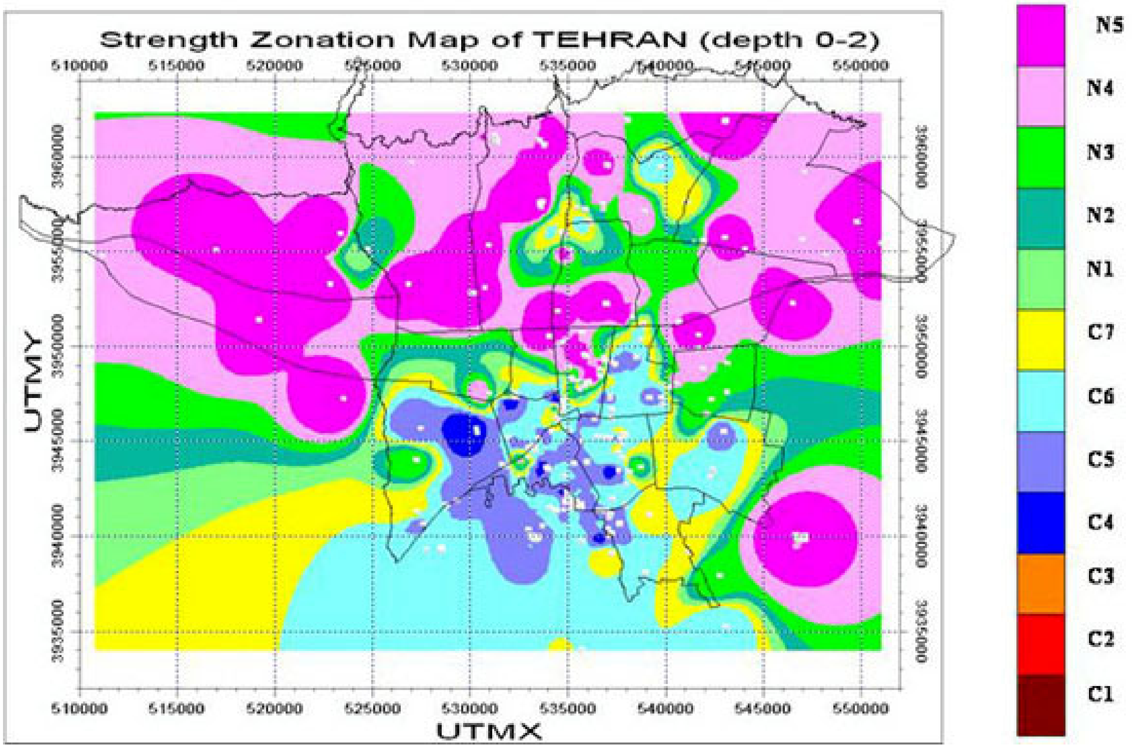

Figure 7. Strength map for surface layer in Tehran

Depth of seismic-stable bedrock map

In dynamic analysis of unconsolidated deposits, identification of seismic-stable bedrock is necessary. It is difficult to investigate the distribution of stable bedrock, which may have a shear wave velocity Vs>3000 m/sec in the intact material. Therefore the concept of engineering seismic bedrock is employed - the Technical Committee for Earthquake Geotechnical Engineering, TC4 of the ISSMFE (TC4 1993) recommended defining engineering seismic bedrock as that with a shear wave velocity of Vs ≥ 600 m/sec.

A popular method for identification of seismic characteristics of soil layers is considering empirical relations that correlate SPT N-value with Vs. There are several empirical relationships in this respect (Ohtha & Goto 1976; Imai & Tonouchi 1982). An empirical relation was proposed for southern Tehran's alluvial deposits (Jafari et al. 2002).

Vs=25.7N0.85 N≤50

Where: Vs = Shear wave velocity; N = Standard penetration test (SPT)

This empirical relationship was used to calculate Vs from SPT data in the Tehran databank. Then the layer with Vs>600 m/sec was considered as seismic bedrock, and the depth to this layer was calculated for the greater Tehran area (Fig. 8). It can be seen that seismic bedrock in the southern part of the city lies generally at depths of 15-50 m, while in the north the depth is generally <10 m. These depths to seismic-stable bedrock have been based on an empirical relationship that has been proposed for southern Tehran soils. For sound practical activities in the northern part of the city, more detailed work is necessary.

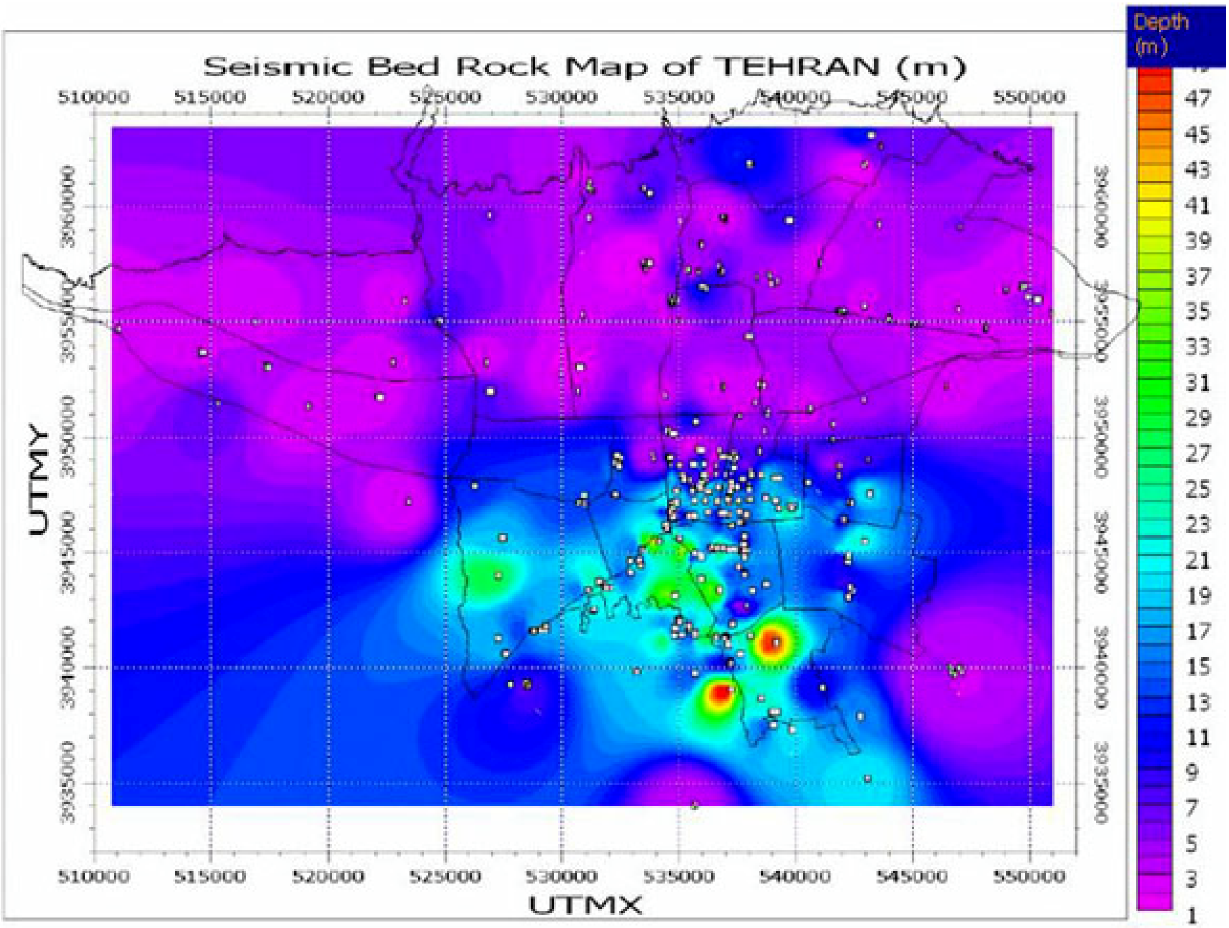

Figure 8. Depth to seismic-stable bedrock in Tehran

CONCLUDING REMARKS

The Tehran Geotechnical Database (TGDB) has been developed to import, edit, recover, classify and search geotechnical data, and to develop engineering geological maps. This system will offer financial saving and environmental benefits to the municipality and its citizens, including cheaper soil surveys and better archive management, with cost savings in geotechnical and hydrogeological contract work and environmental surveys, and further cost saving as a result of selecting optimum locations and routes.

This database facilitates determining the nearest borehole to the desired location, geology profile preparation, and development of geotechnical maps using raw or analyzed data that relate to different thresholds. The threshold may also be user-defined. Experimental relations may be developed for geotechnical parameter values in the database. The developed database may cause high reductions in costs by reducing the number of necessary boreholes or determining specific areas for borehole excavation. The database allows the user to develop a map of any geotechnical parameter in a desired depth.

The results for Greater Tehran indicate that the northern part of Tehran city is predominantly underlain by relatively coarse grained materials, while the southern party of the region is underlain by weaker soils with poor geotechnical characteristics. The Tehran Geotechnical Database needs to be completed so that all geotechnical data is uniformly considered. By completing the database, study of the paleogeography of the Tehran plain will be facilitated.

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