# Geotechnical Characterization of Soils in the Eastern and Western Areas of Tehran

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*Abstract*—**Tehran is placed in a high seismic risk zone with specific natural hazards. The resources to deal effectively with a possible crisis are limited, so proper preparation is a necessity. Therefore, the identification of geotechnical design building features based on local and environmental conditions plays a fundamental role in improving the construction quality. Thus, given the increase of population in Tehran, the concentration in certain areas and the need to better identify soil characteristic for safer construction in these areas, a zoning study is performed in this study. The results showed that soils in regions 4 and 22 belong to B Tehran formation and are coarse. Because the soil is coarse-grained in these areas, earthquake liquefaction is not expected. Given the shear wave velocity in the 4 and 22 areas, the soil mass is characterized as dense or too dense.**

***Keywords-field testing; geotechnical testing; coarse grain; shear wave velocity; young's modulus***

## I. Introduction

Quaternary as an area of human activity and expansion of urban issues, industry and agriculture is increasingly considered and the quaternary role is considered in all fields, especially in natural hazards and retrofitting civil structures and most of all in the preservation and management of land and environment. Determination of geological geotechnical characteristics of the deposits can be a suitable tool for basic information of the projects related to the Earth's surface. With increasing population growth and rapid urbanization and pollution in the environment, the importance of zoning maps and municipal engineering geology has become clear. With the rapid growth of construction in cities and considering events such as earthquakes, neglecting geological and geotechnical engineering issues has brought many problems. The geophysical methods in addition to being incapable of providing complete geotechnical data, also face numerous disturbances in urban areas and it is impractical in urban centers [1]. Aerial and satellite images also can't provide information. It seems that the best way to evaluate and interpret geotechnical properties of a place, especially in urban areas is the use of borehole data. Often boreholes are drilled in cities for various purposes and mechanical soil tests are conducted at different depths of the earth that can provide useful Information for geotechnical mapping and zoning. Geotechnical investigations and zoning can be used to retrofit buildings and engineering structures and reduce risks.

In [2], authors investigated geotechnical and seismic properties in Zanjan using geotechnical and geophysical data and usage maps drawn in GIS environments [2]. The geotechnical properties in Arak using geotechnical data was investigated in [3] and GIS maps were also drawn. In [4], authors investigated geotechnical zoning based on information obtained from boreholes in Guwahati in the northeast of India. Another study was based on information from 200 boreholes with a depth of 30 meters drilled in the city and considered the results of certain field tests such as Lofran, SPT, geophysical test results and experimental results to draw GIS geotechnical zone maps [5]. In [6], authors investigated the geotechnical properties within Pakistan's Lahore using geotechnical and geophysical data. Using information obtained from boreholes drilled in the city, they investigated geotechnical properties of different soils at various depths to be explored in the city and then using data from geotechnical boreholes zoning maps were drawn in terms of geotechnical parameters. In [7], authors examined and draw geotechnical maps for Basre using geotechnical data and GIS. Using data obtained from 105 boreholes drilled in the southern city of Basra geotechnical zoning maps were drawn.

Since Tehran is in a high risk seismic zone and due to its specific natural hazards and the limited resources to deal effectively with a possible crisis, proper preparation is a necessity. Construction rise in Tehran has caused new buildings to have more floors and basements, increasing the risk factor. Therefore, the identification of geotechnical design features for buildings based on local and environmental conditions plays a fundamental role in improving the quality of construction. Thus, given the increase in the population of Tehran in recent decades and the concentration of population in certain areas of Tehran, especially in the eastern and western regions (Zones 4 and 22) and the need for a better understanding of soil properties, for engineering and safe construction proposes, a zoning study is carried out in this paper.

## II. MATERIAL AND METHODS

### *A. Used data*

In this study, data from geotechnical boreholes drilled by different companies in the considered area were used. In Figures 1 and 2, the boreholes' locations are shown. Borehole names in Zone 4 includes BH boreholes and P Series boreholes and the T Series boreholes. Boreholes were named based on gathered data series. Boreholes are drilled between the depths of 15 to 36 meters. In this study, the depth of the boreholes is considered in a way that allowable stress under the foundation for eastern region (Zone 4) and western region (Zone 22) could be considered. In Zone 22, the names of these boreholes include CH Series boreholes and H Series and O Series boreholes are shown in the map of their location. These boreholes have been drilled between the depths of 40 to 70 meters and in the northern part of the region due to mountainous and less height construction in area, so in this section drilled boreholes were less and many drilling is focused in the center.

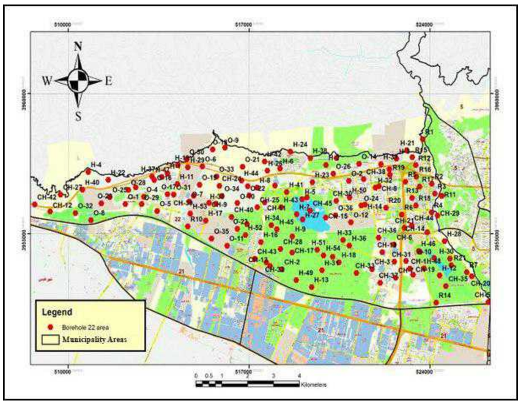


Fig. 1. Shows the position of the drill holes used in the area

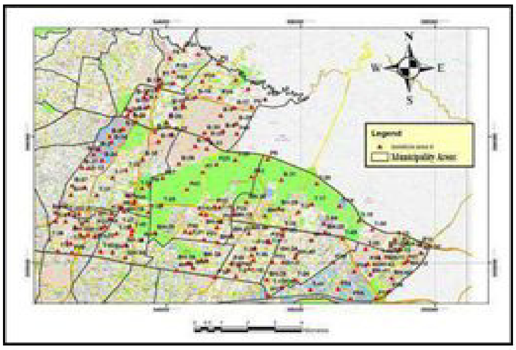


Fig. 2. Shows the position of the drill holes used in Zone 4

### *B. Data Analysis*

The considered boreholes were drilled for investigations of construction projects in the area. Data are analyzed using information from these boreholes. Data indicates that materials at area 4 include GW, GM, GC, GP, SC, SW-SC, GP-GC, GW-GM, GP-GM, SP-SC, SW-SM, SM, GW-GC, SW, SP, SP-SM and Particle-Size analysis shows that the material in Zone 4 is coarse and is a part of unit B of Tehran. Figures 3 and 4 show the percentage of each soil sample in the region, according to information obtained from boreholes. AS shown, the GW soil has the highest percentage equal to 25 percent of fourth area's soil and soils SP-SM, SP, SW with the frequency of each approximately equal to 0/43 percent, the lowest frequency. In Zone 22 the highest percentage is equal to 22/1 percent for GM soil and SW, GW-GC, SP, SP-SM with a frequency of approximately below 0/4 percent have minimum frequency.

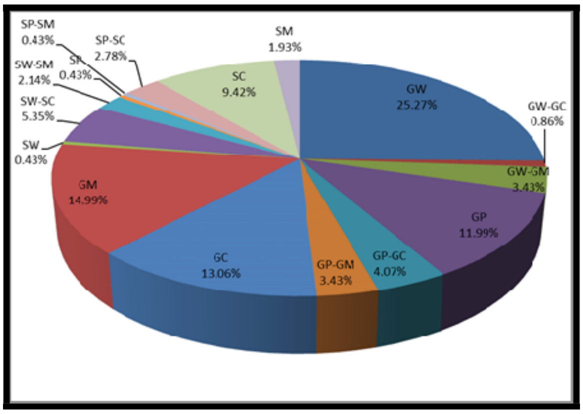


Fig. 3. Percentage of different soils in the Zone 4

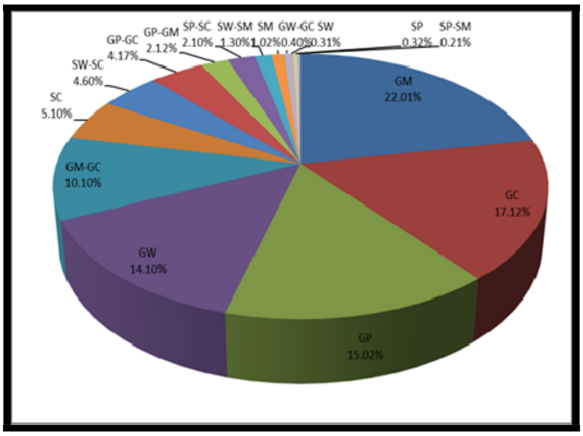


Fig. 4. Percentage of different soils in Zone 22

### *C. Exploration Drilling*

In this study exploratory boreholes drilled in Zones 4 and 22 of Tehran to identify the layers is used. exploratory bore holes drilled with a diameter of 101, aim of drilling these boreholes in addition to identifying the undersurface, was inside borehole tests such as SPT, CPT, permeability tests Lofran and Down hole geophysical study methods and obtaining undisturbed sample for laboratory tests such as Particle-Size analysis, Atterberg limits, consolidation, direct shear and triaxial test. While drilling, exploratory borehole tests, including in situ inside borehole tests such as SPT or

CPT, Lofran and geophysical down whole method are conducted.

### *D. Laboratory tests*

To complete the characterization studies and to obtain the technical and mechanical properties of subsurface materials different physical and mechanical tests were performed in the laboratory. The samples used for testing were disturbed samples of Karbali and samples from SPT sampler and Shelby samples. Tests conducted on samples were according to ASTM and AASHTO standards. The experiments included moisture content test, Particle-Size analysis, natural density and direct shear test as discussed below.

*1)* Soil moisture content determination test

This test is done based on the ASTM - D2216 standard. Soil moisture is available water in soil to the weight of its solid components.

$$W(\%) = \frac{W_w}{W_d}$$

In most soils natural moisture content is one of the important physical properties which characterizes soil behavior in comparison with Atterberg Limits [5].

*2)* Particle-Size analysis

This test is done based on the ASTM - D421 standard. Most natural soils consist of a mixture of gravel, sand, silt and clay, respectively. There are also soils which contain organic substances as well. Soils can be classified according to their different properties in a way that they have the same engineering properties. Particle-Size analysis is based on particle size and percentage of grains in the soil mass and is the simplest soil test [5, 8, 9]. Mechanical Particle-Size analysis is vibrating soil samples on a series of sieve that their size decreases respectively from top to bottom. This test is used for soils that their particle diameter is larger than 0/075 mm [5, 8, 9].

*3)* Atterberg limits

Based on the ASTM D4318 standard, other physical parameters such as soil liquid limit, plastic limit and plasticity index have important role in soil classification and behavior determination. The relationship between changes in volume due to moisture change is known as Atterberg limits. Liquid limit (LL) is minimum soil moisture that soil behaves as liquid and plastic limit (PL) is minimum soil moisture that then becomes plastic. The difference between them is the plasticity index (PI) that is one of the most important factors in classification of fine grained soils [4-7].

*4)* Direct Shear test

This test is done based on the ASTM D3080-72 standard. On all issues related to soil stability such as the design of foundations, retaining walls and embankments, having data about soil strength is essential. Soil shear strength is the internal resistance of the soil surface that can withstand rupture and slip along each internal surface. The amount of soil shear strength is important for issues such as bearing capacity of foundations slope stability, and effective horizontal pressure on the earth retaining structures (retaining walls). This test is performed on disturbed samples from boreholes. To determine the mechanical properties and shear strength parameters for soil in drained condition ($C, \varphi$) what should be noted is that the adhesion (C) and internal friction angle (ø) of soil are not fixed properties and vary with different factors [5, 8, 9].

### *E. Obtaining Data bank*

In the geotechnical data bank, created in Tehran for the regions 4 and 22 only a geotechnical perspective is considered on a conceptual level while some other perspectives, including geotechnical, geological and environmental each separately can be used as a part of or all of the bank in line with its objectives. For the geotechnical database, a relational database management system is used. Relational database management systems are based on a common language and set of rules. In this study according to the database features of geotechnical database, information is classified and then analyzed. Provided geotechnical database contains several important components. These components include:

- Borehole position (position and altitude)
- Drilling Type (manual or machine)
- Groundwater level
- Depth
- Profile classification of soils at various depths
- Atterberg Limits at different depths (including LL, PL and PI)
- Permeability at different depths
- Shear strength parameters C and φ in direct shear at different depths
- Elastic parameters at different depths in the loading page
- NSPT at different depths
- N60 and N70 at different depths
- Soil density (in normal, dry and saturated) at different depths
- Moisture content at different depths

In Table I, the properties and the number of holes in each region are shown and in Tables II to IV, the number of tests and parameters used in this study are shown.

TABLE I. INFORMATION ABOUT BOREHOLES SPECIFICATIONS.

| Depth | Zone 22 | Zone 4 |
|---|---|---|
| Lower than 15 | **30** | **55** |
| 15 to 25 meter | **40** | **35** |
| 25 to 35 meter | **36** | **40** |
| 35 to 50 mete | **24** | **50** |
| Deeper than 50 | **50** | **0** |
| Total sum | **180** | **180** |

TABLE II. FIELD INFORMATION

| Depth | Direct shear test | | Plat load test | | Lefran test | | SPT test | |
|---|---|---|---|---|---|---|---|---|
| | **Zone 22** | **Zone 4** | **Zone 22** | **Zone 4** | **Zone 22** | **Zone 4** | **Zone 422** | **Zone 4** |
| < 15 | 900 | 900 | 900 | 900 | 900 | 900 | 1260 | 1260 |
| 15-25 | 450 | 375 | 450 | 375 | 450 | 375 | 750 | 625 |
| 25-35 | 330 | 270 | 330 | 270 | 330 | 270 | 550 | 450 |
| 35-50 | 370 | 250 | 370 | 250 | 370 | 250 | 520 | 350 |
| > 50 | 350 | - | 350 | - | 350 | - | 500 | - |
| Total sum | 2400 | 1795 | 2400 | 1795 | 2400 | 1795 | 3580 | 2685 |

TABLE III. LABORATORY INFORMATION

| Depth | Aterberg limit | | Water content | | Density | | Sieve analysis | |
|---|---|---|---|---|---|---|---|---|
| | **Zone 22** | **Zone 4** | **Zone 22** | **Zone 4** | **Zone 22** | **Zone 4** | **Zone 22** | **Zone 4** |
| < 15 | 900 | 900 | 900 | 900 | 900 | 900 | 1260 | 1260 |
| 15-25 | 450 | 375 | 450 | 375 | 450 | 375 | 750 | 625 |
| 25-35 | 330 | 270 | 330 | 270 | 330 | 270 | 550 | 450 |
| 35-50 | 370 | 250 | 370 | 250 | 370 | 250 | 520 | 350 |
| > 50 | 350 | - | 350 | - | 350 | - | 500 | - |
| Total sum | 2400 | 1795 | 2400 | 1795 | 2400 | 1795 | 3580 | 2685 |

TABLE IV. NUMBER OF THE BOREHOLE SEISMIC INFORMATION

| Depth | Zone 22 | Zone 4 |
|---|---|---|
| < 15 | 900 | 900 |
| 15-25 | 450 | 375 |
| 25-35 | 330 | 270 |
| 35-50 | 370 | 250 |
| > 50 | 350 | - |
| Total sum | 2400 | 1795 |

### *F. Geotechnical zoning using Arc GIS software*

Digital data prepared for city map, geology and topography of Tehran provided by a mapping agency was used. For this study, a digital map of Tehran is prepared and after the correction and the scaling, basic GIS mapping is provided by collecting information from geotechnical boreholes at Zones 4 and 22 and entering this data in ARC GIS software [1]. Another positive feature of this research, is the ability to be updated in subsequent complementary studies and research. With the addition of geotechnical data in future the geotechnical parameters estimation can be presented even more accurately.

### *G. Analysis using SPSS software*

Now it is necessary to specify the parameters of each soil in the area. Thus, an analysis was carried out in SPSS for each parameter. The number of samples used in statistical tables (N), the difference between the maximum and minimum data (Rang), the maximum data (Max), minimum data (Min), average data (Mean), standard deviation (Variance), the tilt disruption (Skewness) and the elongation (kurtosis) were considered.

## III. ANALYSIS

### *A. Atterberg zoning maps*

According to the information obtained from boreholes at different depths of Zones 4 and 22, maps are drawn which include Atterberg changes maps, plasticity limits changes and plasticity index to a depth of 10 meters. In the depths of 10 meters in Zone 4 Atterberg limits vary between 0 to 34% and the largest coverage area is about Atterberg limits between 20 and 30 percent. Also in Zone 22 in depth of 10 meters deep the Atterberg limit vary between 0 to 36% and the largest coverage area is about Atterberg limits from 20 to 36 percent (Figure 5 and Figure 6). In Figures 7 and 8, plasticity limits zoning maps are shown. In the depths of 10 meters in Zone 4 the plasticity limit ranges between 0 to 25%. The largest portion of the area has a plasticity limit less than 10%. In Zone 22, plasticity limits range between 0 to 24 % and the largest portion of the area has approximately zero plasticity, as well as 10 to 20 percent plasticity. In Figures 9 and 10, plasticity index zoning maps are shown. In the depths of 10 meters in Zone 4 plasticity index ranges between 0 to 13% and the largest coverage area has the plasticity index between 4 and 7%. In Zone 22 plasticity index ranges between 0 to 13% and the largest coverage area is with the plasticity index of zero as well as 4 to 7 percent.

### *B. Density maps*

In Figure 11 and Figure 12 dry density zoning maps are shown. In the depths of 10 meters in the Zone 4 dry density varies between 1.87 to 2.02 grams per cubic centimeter and maximum dry density in area varies between 1.90 to 1.98 grams per cubic centimeter is. In Zone 22 dry density varies between 1.9 to 2.05 grams per cubic centimeter and maximum dry density in area varies between 1.95 to 2.0 grams per cubic centimeter.

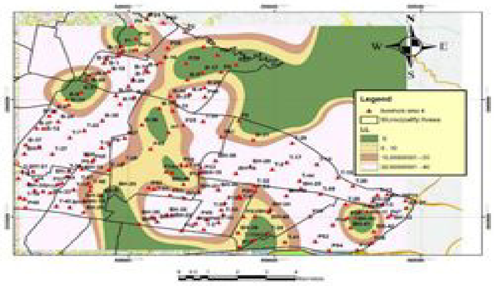

Fig. 5. The Atterberg limits zoning map at a depth of 10 meters of Zone 4

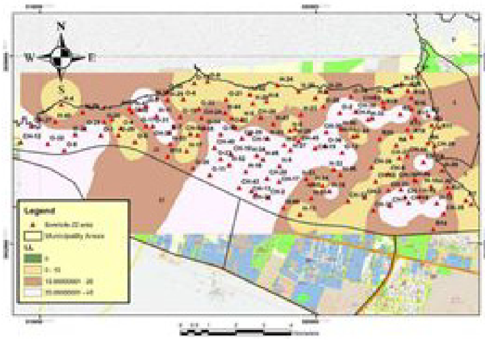

Fig. 6. Atterberg limits zoning map at a depth of 10 meters of Zone 22

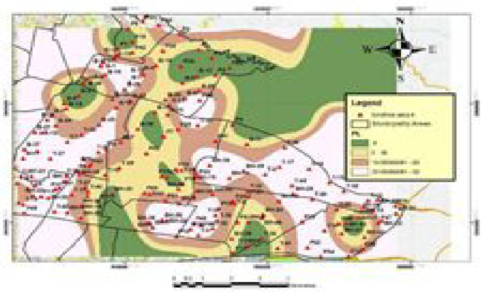

Fig. 7. Zoning map of plasticity limit at a depth of 10 meters of Zone 4

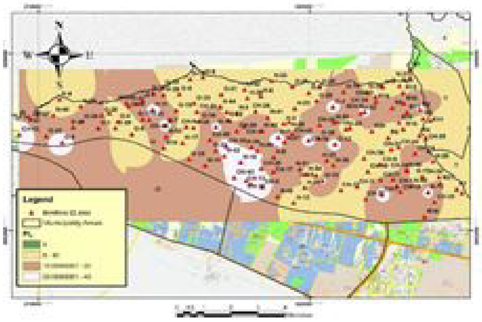

Fig. 8. Zoning Map of the plasticity limit at a depth of 10 meters in Zone 22

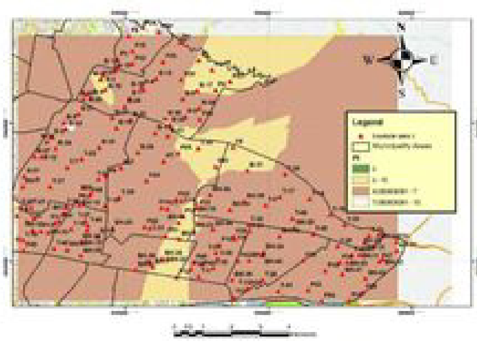

Fig. 9. Plasticity index zoning map at a depth of 10 meters in Zone 4

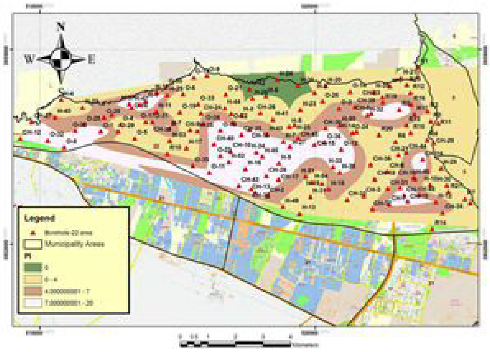

Fig. 10. Plasticity index zoning map at a depth of 10 meters in Zone 22

Fig. 11. The dry density zoning map at a depth of 10 m of Zone 4

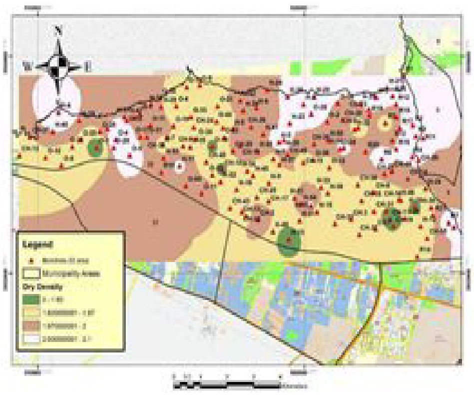

Fig. 12. The dry density zoning map at a depth of 10 meters from Zone 22

Wet density zoning maps is shown in Figures 13 and 14. In the depths of 10 meters in Zone 4, wet density varies between 1.96 to 2.13 grams per cubic centimeter and the largest coverage area has density between 0.2 to 1.2 grams per cubic centimeter. In Zone 22 wet density ranges between 1.96 to 2.12 grams per cubic centimeter and the largest coverage area has wet density of 0.2 to 1.2 grams per cubic centimeter.

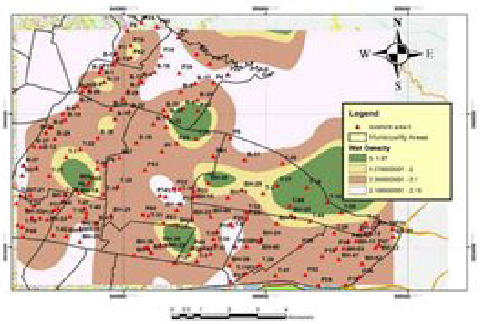

Fig. 13. Wet density zoning map at a depth of 10 m of Zone 4

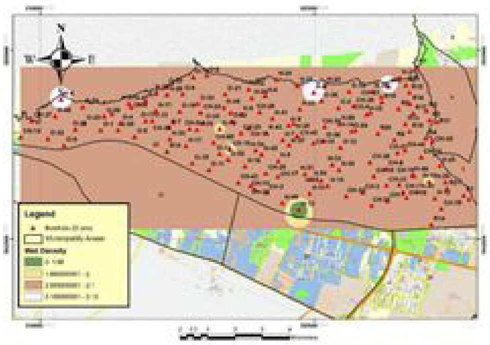

Fig. 14. Wet density zoning map at a depth of 10 meters of Zone 22

### *C. Zoning map of the shear parameters*

Figures 15 and 16 show the cohesion zoning maps. In the depths of 10 m of Zone 4 cohesion varies between 0 and 0.06 MPa and maximum coverage area is between 0.01 to 0.03 MPa. In Zone 22 cohesion varies between 0 to 0.07 MPa and the largest coverage area is between 0 to 0.03 MPa. In Figures 17 and 18, the zoning maps of internal friction angle are shown. In the depths of 10 meters in Zone 4 internal friction angle ranges between 30 and 35.8 degrees and maximum coverage area between 33 to 34 degrees. In Zone 22 internal friction angle ranges between 31 to 35.5 degrees and large portion of area has friction angle from 33 to 35 degrees.

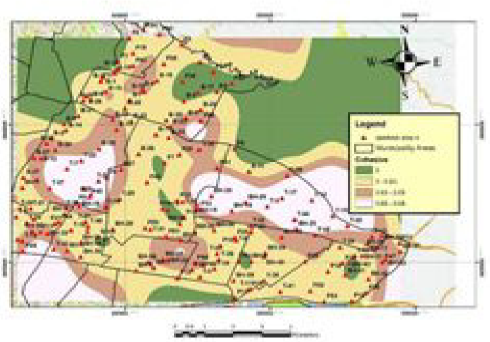

Fig. 15. Cohesion zoning map at a depth of 10 meters in Zone 4

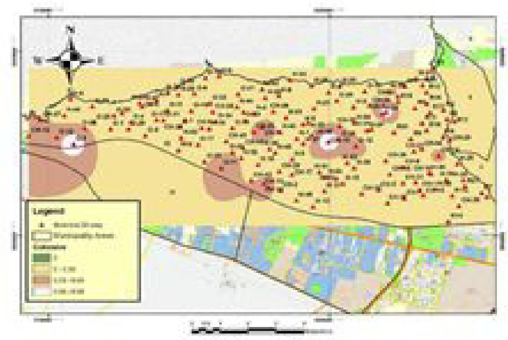

Fig. 16. Cohesion zoning map at a depth of 10 meters in Zone 22

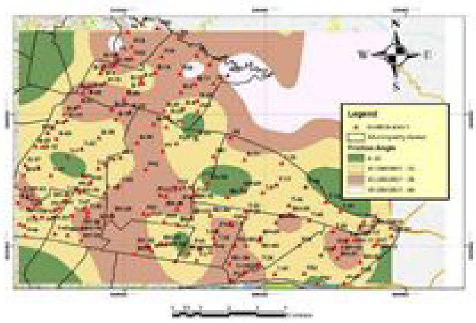

Fig. 17. Internal friction angle zoning map at a depth of 10 m in Zone 4

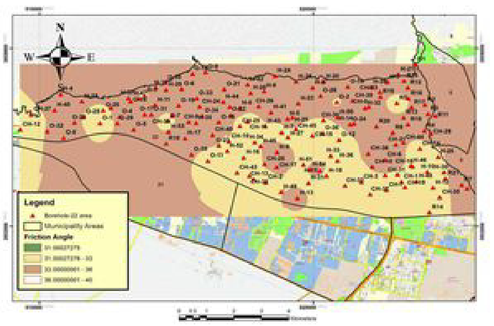

Fig. 18. Internal friction angle zoning map at a depth of 10 meters in Zone 22

### *D. Elasticity modulus zoning map*

These results have been obtained on the basis of information from plate load test, Figures 19 and 20 show elasticity modulus zoning maps. In the depths of 10 meters in Zone 4 elasticity modulus ranges between 250 and 650 MPa and the largest coverage area elasticity modulus is between 300 to 350 MPa. In Zone 22 elasticity modulus ranges between 250 to 650 kilograms per square centimeter and the largest coverage area has elasticity modulus between 300 to 350 kilograms per square centimeter.

Fig. 19. Elasticity modulus zoning map at a depth of 10 m of Zone 4

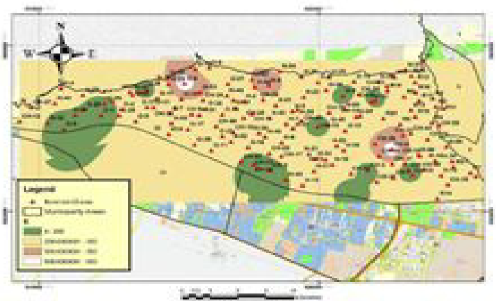

Fig. 20. Elasticity modulus zoning map at a depth of 10 m of Zone 22

Poisson ratio zoning maps are shown in Figure 21 and Figure 22. Poisson ratio varies between 0.3 and 0.35 at the depths of 10 meters in Zone 4. Poisson ratio varies between 0.3 and 0.35 in Zone 22 and the largest covering area has a poisson ratio between 0.32 and 0.34.

### *E. Wave velocity zoning map*

Longitudinal wave velocity zoning maps are shown in Figure 23 and Figure 24. In the depths of 10 meters in Zone 4 longitudinal wave velocity varies between 700 to 1520 meters per second and the largest covering area has wave length of 900 to 1000 meters per second. In Zone 22, longitudinal wave velocity varies between 330 to 1300 meters per second and the largest covering area has longitudinal wave velocity of 600 to 850 meters per second.

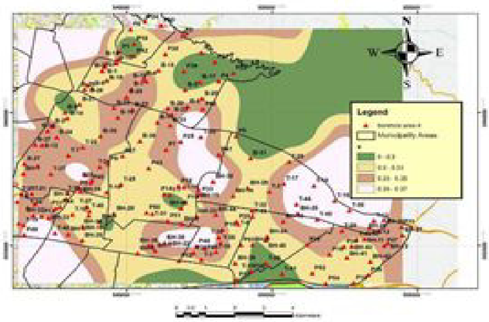

Fig. 21. Poisson's ratio zoning map of a 10 meters depth in Zone 4

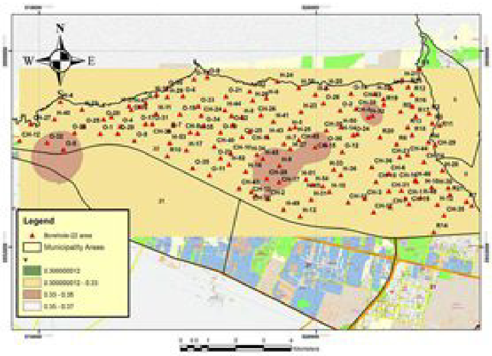

Fig. 22. Poisson's ratio zoning map of a 10 meters depth in Zone 22

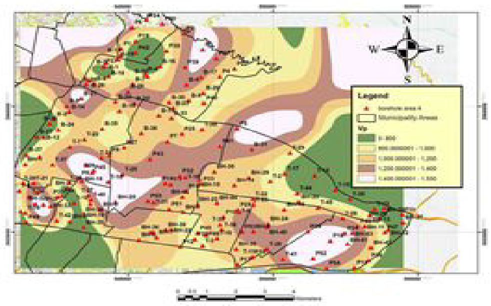

Fig. 23. Longitudinal wave velocity zoning map of a 10 meters depth in Zone 4

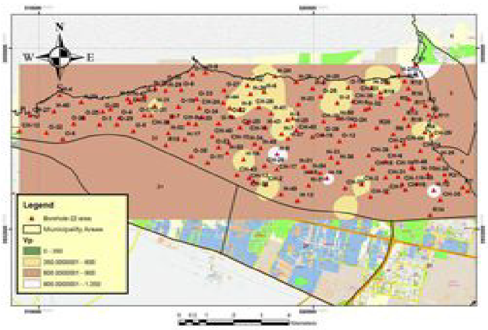

Fig. 24. Longitudinal wave velocity zoning map of a 10 meters depth in Zone 22

Shear wave velocity zoning maps is shown in Figure 25 and Figure 26. In the depths of 10 meters in Zone 4 shear wave velocity ranges between 300 to 990 meters per second and maximum coverage area varies between 600 to 700 meters per second. In Zone 22, shear wave velocity ranges between 230 and 800 meters per second and maximum coverage area is between 400 to 550 meters per second.

### *F. SPT zoning map*

One of the quickest and cheapest tests to determine the relative density of granular soils, especially sandy is using Standard Penetration Test or simply be SPT. With regard to the materials in this area and gravelly coarse aggregate all the results obtained in this area has shown NSPT more than 50 hits and in many cases NSPT value of 100 is reached. SPT and NSPT zoning maps are shown in Figure 27 and Figure 28. As shown, SPT is more than 45 in this area and can be seen in most depths more than 50. Based on SPT results soil is dense to very dense and another reason for high SPT is coarse grain of area.

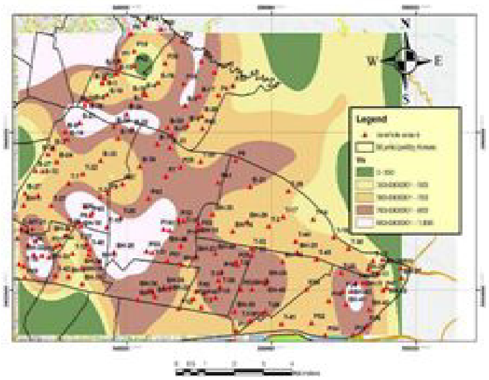

Fig. 25. Shear wave velocity zoning map of a 10 meters depth in Zone 4

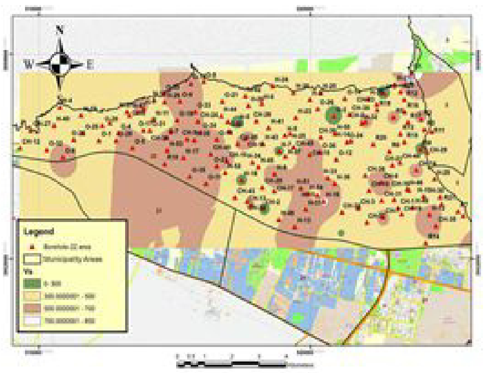

Fig. 26. Shear wave velocity zoning map of a 10 meters depth in Zone 22

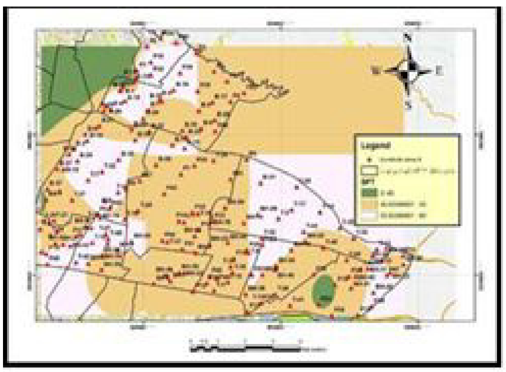

Fig. 27. NSPT zoning map of a 10 meters depth in Zone 4

*G. Permeability zoning map*

Geotechnical zoning maps is shown in Figure 29 and Figure 30. Based on existing maps the permeability in Zone 4 is between $4^{-10}$ and $2^{-10}$ cm per second. In Zone 22 permeability is between $3^{-10}$ and $5^{-10}$ centimeters per second.

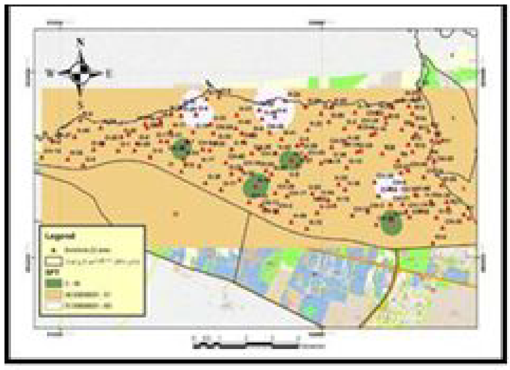

Fig. 28. NSPT zoning map of a 10 meters depth in Zone 22

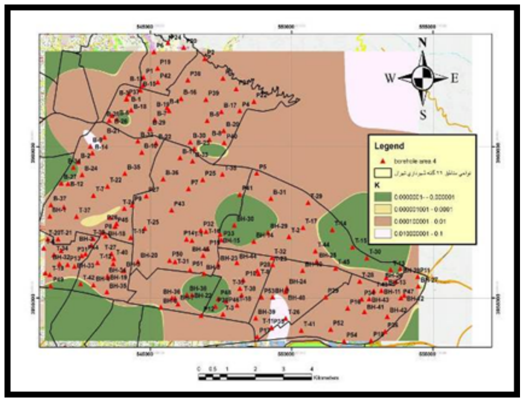

Fig. 29. Permeability zoning map at a depth of 10 meters in Zone 4

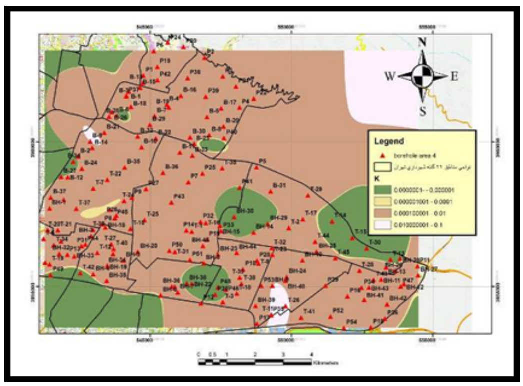

Fig. 30. Permeability zoning map at a depth of 10 meters in Zone 22

## IV. Conclusion

In this paper, Iranian geotechnical data bank, analysis of engineering geology and geotechnical properties of quaternary deposits of West and East of Tehran, statistical analysis of the data, GIS maps of different geotechnical zoning system for Zones 4 and 22 of Tehran and basic knowledge of the properties of these regions are associated to optimize costs and time. Examples of statistical results including values of minimum, maximum, mean, standard deviation, etc. are investigated in order to provide an overview of the regional characteristics of Zones 4 and 22 of Tehran. Preparation of GIS micro-zonation maps of Zones 4 and 22 provides the possibility to estimate the geotechnical parameters in any given point of these maps. This system enables the user to simultaneously display and analyze the map and tabular data and the ability to provide high services in various fields. According to the soil of Zones 4 and 22, it's seen that soil materials in the area of formation are coarse-grained type B. Materials in Zones 4 and 22 don’t have high liquid or plastic limits. According to low LL in coarse-grained soils inflation phenomena do not occur. Due to the coarse-grained soils of these areas, earthquake liquefaction will not happen and plasticity index of soils is usually in the category of non-plastic to the low plastic. Also, due to a friction angle between 30 and 37 degrees, coarse grain and relative density is considered medium to large.

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