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GEOTECHNICAL STUDY OF BAGHDAD SOIL

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ABSTRACT
This paper comprises the study and analysis of Baghdad soil for 23 geotechnical properties which were extracted from field tests of 630 boreholes with depth taken to 30m and representing 200 sites. Soil investigation reports are collected from different laboratory tests. The soil layers were divided into each 2m, which means 15 studied layers and the soil properties values were adopted and submitted in tables and digital maps to represent the variation of soil properties values with depth and relationships between the properties values. Different softwares and tools were implemented for digital maps preparation. The results clarify that Baghdad upper soil layer is mainly fill with poor strength. The stratum is erratic and non-homogenous with water levels near the natural ground surface. Baghdad soil is generally alkaline with high concentration of sulphates in the upper layers.

INTRODUCTION
It is well known that all the civilization projects are always constructed and built on or into the ground at suitable depths. So, the nature and behavior of the soil under these civilization features are so important and the soil must be investigated very well to be sure of safety as well as time and cost saving which should be taken into engineering considerations (Smith and Smith, 2006). Prior to start any civil construction project, the site features and characteristics should be understood completely. This complete understanding of natural conditions for the site and the site surroundings of proposed construction is constitutive to evaluate the general suitability of the site and to prepare an adequate and economic safe design for the proposed project.

In geotechnical engineering, soil formation, physical, chemical and engineering properties of soil layers must be known down to a required depth. In order to get the information about the site soil properties in possible minimum time, there is a need arises to employ modern means which reduce the time, cost, efforts and staff. Site investigations or subsurface explorations are done to determine the in situ (field) and laboratory geotechnical properties of the soil underlying the site (Clayton et al., 1995).

Many different soil investigation methods are used to determine the suitability of site locations and then to subject sufficient, safe and economic design for the projects depending upon suitable subsoil investigations. Primarily, the direct laboratory investigations for boreholes samples are the mainly used method to investigate and determine the physical, engineering and chemical soil properties. These properties are sometimes entirely different from site to site and even from depth to another in the same site location boreholes.

The use of indirect geophysical methods such as electrical conductivity or resistivity test, Ground Probing Radar (GPR), magnetic and seismic refraction or reflection methods are also important in some cases of investigations (Hunt, 2007). With the development of technology, the Geographic Information System (GIS) and other sensing tools enable the geotechnical engineer to make use of these tools for non-data areas prediction in addition to gain reliable and accurate interpret to any complex data areas (Rajesh et al., 2003).

The study of the sedimentation, especially in alluvial deposits, is of great importance to simulate field conditions. The deposition of sand and fine content (silt and clay) in a succession, depth of groundwater and mass of the soil particle would have an effect only if very short periods for sedimentation were considered. If sufficient time is allowed for sedimentation, mostly all soil particles are settled before the next layer is deposited. Moreover, in certain situations, soils below groundwater table are not usually assumed fully saturated. The condition of partial saturation may be caused by, for example fluctuating water tables that are associated with natural or manmade processes.

The soil properties specify the behavior of the soil under static and dynamic types of loading. The water table is affected by the water fluctuation from season to another, that fluctuation changes the soil properties and the soil behavior under loading. It is necessary in civil engineering field to assess the geotechnical properties which are obtained through site investigations. These properties are generally required for every engineering project which serves as a basis for the establishment of that project and for many other practical applications. Karim et al. (2010) evaluated some geotechnical properties and liquefaction potential from seismic parameters for 14 sites in Iraq. Later, Karim and Wadaa (2017) evaluated Baghdad soil liquefaction potential under earthquakes effect by analyzing data for 630 boreholes representing 200 site location points spread all over the city of Baghdad.

Due to the development in construction projects in Baghdad Governorate as it is the capital of Iraq, it has become necessary to prepare studies and researches gathered as a database to study the distribution and homogeneity of sediments and groundwater fluctuation of Baghdad city and their influences on geotechnical properties, such studies will be as reference guide to civil engineers in design and analysis of different structures. As well as, it will give a preliminary idea about the soil properties for the selected sites which reduce the cost and saving time.

GEOLOGY AND SEDIMENTS OF BAGHDAD SOIL

Baghdad area is located in the middle part of Mesopotamian alluvial plain. As Baghdad located at Tigris River and the Euphrates River is about 40 km away, so its sediments are recent not exceeding Quaternary ages. Generally, the soil of Baghdad area has been derived from around areas especially Mesopotamian plain and the desert (Buringh, 1960). Most soils of Baghdad area are therefore secondary soils (residual soils) derived from the above regions, transported from place of weathering and accumulated as a result of sedimentation. Besides, Baghdad soil strata are affected by river course changes during previous decades leading to coarse silt deposits and giving different depositional stratigraphy each few meters, thus Baghdad strata are erratic, somewhat are nonhomogeneous with a water table near ground. This soil in generally is alkaline with poor permeability (NCCL, 1986; Karim and Schanz, 2006).

Baghdad area is covered by recent sediments of alluvial origin, deposited by repeated floods of Tigris River and by wind action (Ramiah and Ovanessian, 1982). Tigris river flood may be considered as a main factor in sediment accumulations. With flooding, wide areas around the river will be covered by water, these lands usually called flood plain, where coarse materials deposited near river banks and nearby lands, whereas fine materials (silt and clay) were deposited away from the river, when the river changing its course it also changing its flood plain and so on. Thus, the sedimentation sequences of rivers basin are changing from time to time forming a very erratic strata for soil of Baghdad. Accordingly, the sequence of strata is very varied from one borehole to another even a few meters apart due to the above factors.

The main stratigraphic units of Baghdad soil are: landfill layer consists of cohesive and non-cohesive materials; the upper natural sub-soil strata consists mainly clay or brown silty clay or clayey silt sometimes with sand or a little amount of gravel; while the lower layer is the natural soil strata consists of medium dense to very dense brown to grey sand mixed with gravel or lenses of clay or silty clay (NCCL, 1986; Karim and Schanz, 2006). The depositional conditions of Baghdad area during geological times, such as and human activities, affect the nature of Baghdad soil and its groundwater quality. Baghdad soil is characterized by its high salinity due to dryness, rainfall scarcity and evaporation leading to groundwater upward movement and causing fluctuation of groundwater levels in the area. Generally, Baghdad groundwater levels are shallow and their fluctuation depends upon season, soil properties and uses (NCCL, 1986).

DATA AND LOCATIONS

Baghdad City is now located between latitudes 33º10′ - 33º30′ N, and longitudes 44º10′ - 44º35′E. Tigris River splits Baghdad in half, with the eastern half being called 'Rasafa' and the western known as 'Karkh'. The Mayoralty of Baghdad consists of fourteen administrative units, eight in Rusafa and six in Karkh. Both are divided into 97 districts (Hays) or neighborhoods. The major data sources were the soil investigations reports, bore logs, and

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boreholes data carried out by different Iraqi companies and agencies. The data were adopted for 630 boreholes and are representing 200 site location points (105 in Rusafa and 95 in Karkh) for different kinds of projects (e.g., hotels, malls, schools, mosques, banks, police stations, water treatment stations, colleges, hospitals etc.), in addition to soil investigations reports for different existing construction projects. Site location points spread randomly within Baghdad City and the boreholes were with different soil layers depths ranging between 8 to 46 m in some locations. The available data representing 23 geotechnical properties for the 200 sites of Baghdad area have been analyzed in order to be used to determine the homogeneity and soil properties of Baghdad city soil. These data represent results of boring tests for physical, geotechnical and chemical soil properties (water content, SPT, unit weight, specific gravity, void ratio, etc.). Also fill layers and water levels were included.

DATA ANALYSIS

The data of the 200 site points are linked to their geographic locations through ArcGIS10. GIS techniques were used to show the spatial locations and distributions of site point's location of Baghdad City as shown in Figure (1). The fill layer depth determination is so important due to the relation between the fill layer thickness and the site stability. Thus, a digital map for fill layer has been constructed for the city in Figure (2). The site with thick fill layer is inherently unstable for construction as the land fill material behavior can be unpredictable and take years to consolidate properly risking settlement in buildings.

For Baghdad city, the groundwater level during a certain season is variable due to sewers networks defects and leakages as well as human's activities. Therefore, the preparation of a map for groundwater level becomes necessary to give a preliminary idea for engineers and other investigators. The groundwater level data for 200 site points were digitally mapped through ArcGIS10.3 for the average groundwater levels data as they are affected by season, rate of rainfall and evaporation. Figure (3) presents the digital map for groundwater level of Baghdad City. The depth of the studied boreholes has been taken to only 30 m, the soil layers were divided into each 2m, which means 15 studied layers.

All the available data of the studied properties were used but due to the huge data in this study, it was found that it is more useful and practical to submit the values of the study area in Table (1) and use the minimum, maximum and average values of the properties for each layer to plot some correlations between these properties.

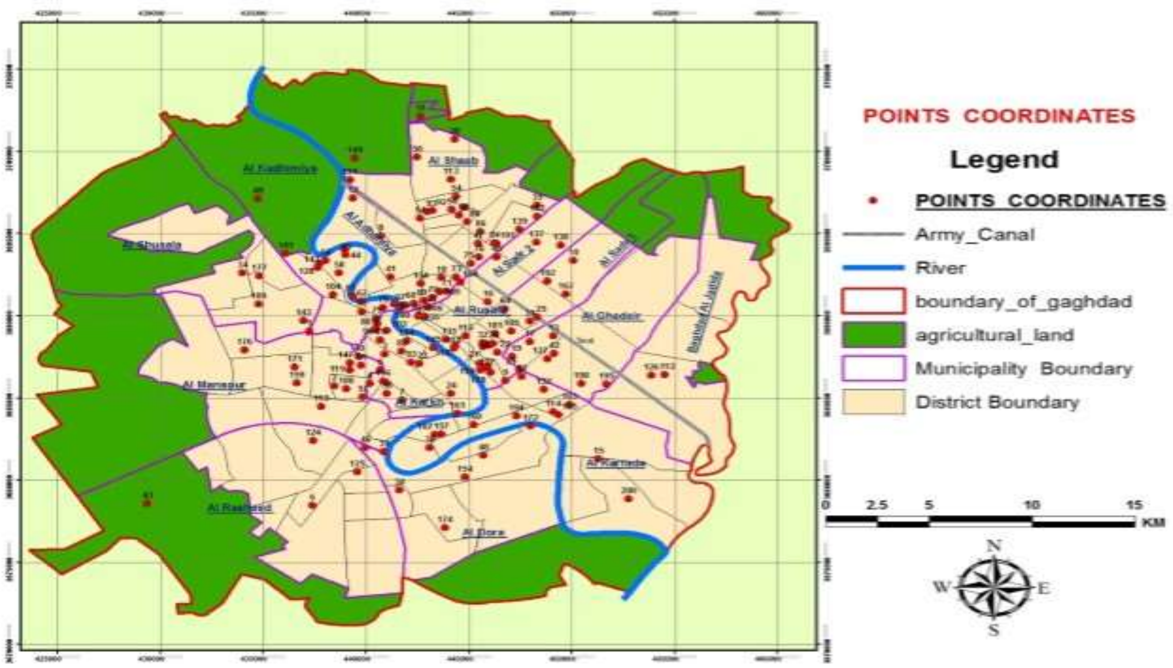

Figure 1: Site points location.

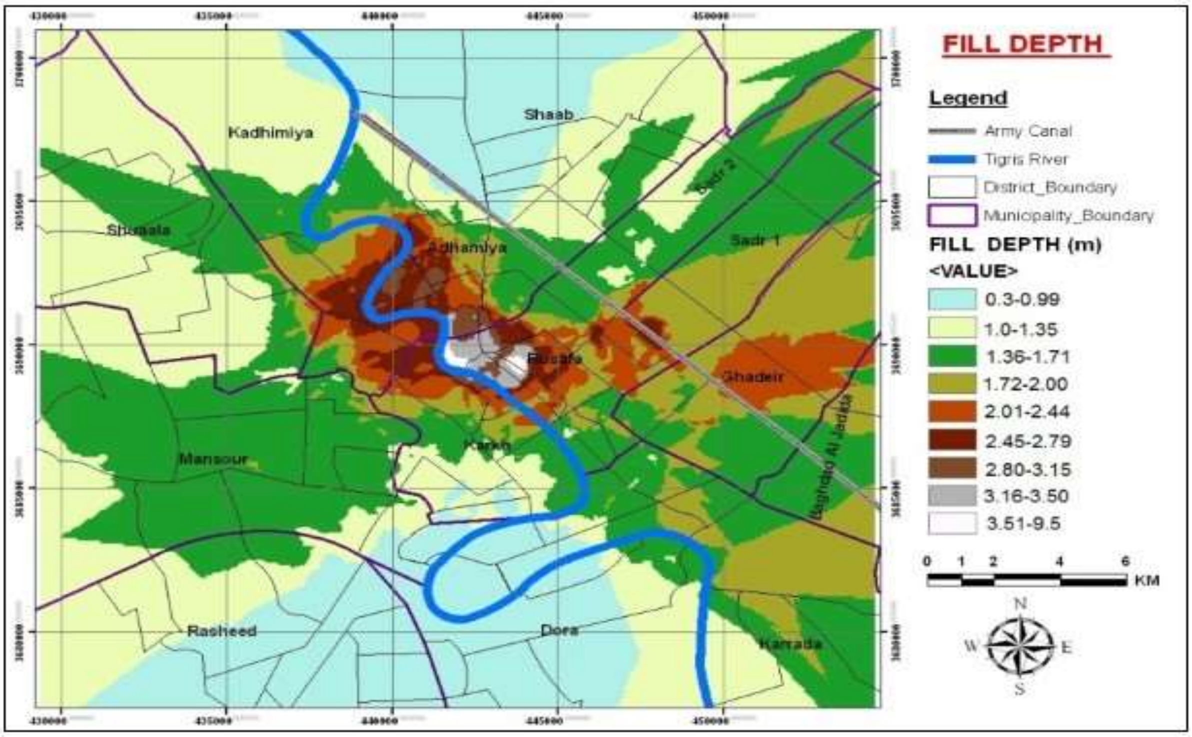

Figure 2: Fill layer depth for Baghdad City.

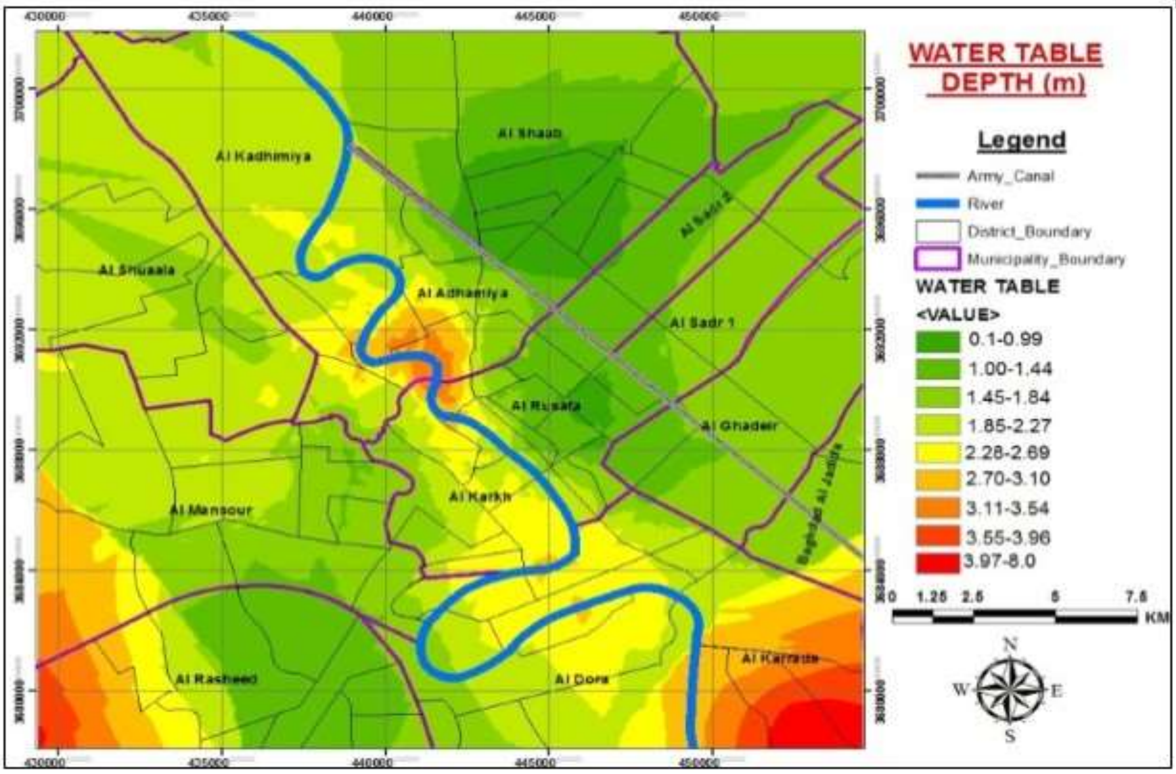

Figure 3: Water table depth for Baghdad City.

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Table 1: Properties values for the study area.

Property	Ranges		
	Min.	Max.	Av.
M.C	5	54	25.72
L.L	18	81	46
P.I	1	64	24
G_s	2.5	2.88	2.67
γ	11	22	15.6
SPT	2	129	33
e	0.1	1.271	0.724
P_c	43	1150	262
C_c	0.03	0.86	0.217
C_r	0.005	0.28	0.037
OCR	0.44	14	2.17
Q_u	8	846	179
Ø	2	49	29
Clay	0	87	21
Silt	0	95	31
Sand	0	97	45
Gravel	0	86	3
SO_3	0.01	17.7	0.89
Gypsum	0.02	23.7	2.39
$CaCO_3$	1.54	60.1	17.55
Organics	0.02	27	1.38
pH	6.7	10.7	8.5
Chloride	0.004	7.8	0.224

RESULTS AND DISCUSSION

Baghdad soil is of Holocene age (less than 10,000 years old) and the Tigris River flood sediments covered the area. The investigated data show that the fill layer in Baghdad ranges between 0.3-9.5m (but sometimes 15-18m which means as it is replaced the original subsoil strata) (NCCL, 1986; Hattab et al., 1986; Karim and Schanz, 2006). The fill layer is mostly made of ground and different mixed materials such as rubbish, debris, decomposed organic materials and crushed brick fragments. Although the water table ranges between 0.1-8.0m, but mostly is less than 3.0m below ground surface which means high water table (as noticed from the investigated data of the 630 boreholes).

Also Baghdad city is covered with a shallow layer of clay (mostly mixed with silt and sand), but the depths below that are mostly loose to medium silty sand (Karim and Schanz, 2006). It is worth to assure here that some spatial odd values along the depth can be seen due to the inhomogeneity of soil, but the average values still give reasonable and acceptable indications.

Fill layer depth
Different human activities through times developed the fill layer of Baghdad city with mixtures of soil fractions and different amounts of crushed brick and ceramic fragments, clothes, rubbish, and sometimes with gypsums, human bones and organic materials. The fill layer depth, content and behavior change from site to another and in most cases; it should be avoided to be used as a refill construction material in foundations. As shown in Figure (2), the thicker fill layer is located in the old parts of Baghdad and along both sides of Tigris River due to alluvial flood deposits. It shows a trend of decrease in sites far away from the river. The fill layer depth ranges between 0.3-9.5m. And more than 80% between 0.3-2.5m with average of 1.8m. As in Figure (2), higher levels are in its central part around Tigris River and to the eastern part, while lower levels are in central north and central south areas in addition to S and SW, N and NW and some parts of Western area.

Groundwater level
The groundwater level is fluctuated between increase and decrease in accordance to the seasonal variation, human and irrigation activities, and condition of the sewer networks depending on the soil permeability and the existing of organic materials. Figure (3) shows high water level along the east side of Baghdad (Rasafa) in the recent old flood areas and in the center and south of Karkh. Lower levels are shown beside the river due to high ill layers depth levels. In the south and south west of the city, lowest levels have been shown. The groundwater level depth ranges between 0.1-8m. With 85% between 0.1-3m and the average is 1.75m. Examining Figure (3), higher levels are in SW, SE and central part along NW-SE axis beside Tigris River. The lowest levels are noticed in N and NE, and in southwestern part.

Moisture content (M.C)
The natural moisture content was determined at sites of the tests in different times and is varying with seasons change as it is related to the average desiccation from the ground surface. According to Table (1), for the study area and for the total 30m depth, the minimum value is 5%, the maximum is 54% and the average is 25.72%. Figure (4) shows these results. The average line seems to be reasonable in comparison with the fluctuation of the minimum and maximum values. In general, low values are located in eastern part (right of Tigris River), while higher values in the western part (left to the river). Most high values are concentrated around the central part in both sides of the river and central of the western part. The higher values are located in NW and E parts, while lower values are in SE and also in western part. Higher values are in the eastern part.

Index properties (Liquid limit and plasticity index)
Atterberg's limits and their corresponding fundamental theories are giving very useful indication to classify the soil and define the swelling properties of the clayey soils, they also helps to show soil susceptibility to liquefaction. It was found that the higher values are in the eastern part (right to the river) particularly in its NE (right), while lower values are located in western part. Higher values are also located in SW. Also, it is clear that along Tigris River, low values are located with higher values in its right side (to the east). With increasing depth, L.L decreases to be 41%. Tigris River passes through low values particularly in its central and southern parts. At greater depths 22-30m, L.L values are within the range of 42-49%.

The distribution of P.I with depth is similar to large extent to that of L.L and M.C at six depth intervals. Higher values in the western part right to the river. Generally, for deeper part 22-30m, the P.I. values are ranged between 21-26%. Referring to Table (1), the study area minimum value is 18%, the maximum value is 81%, and the average is 46 %. The high liquid limit (> 60%) indicates high swelling soil. The P.I minimum, maximum, and average values for the study area are 1%, 64%, and 24% respectively. In general, for the study area, the average last P.I value indicates moderately plastic soil. Figures (5) and (6) show these results.

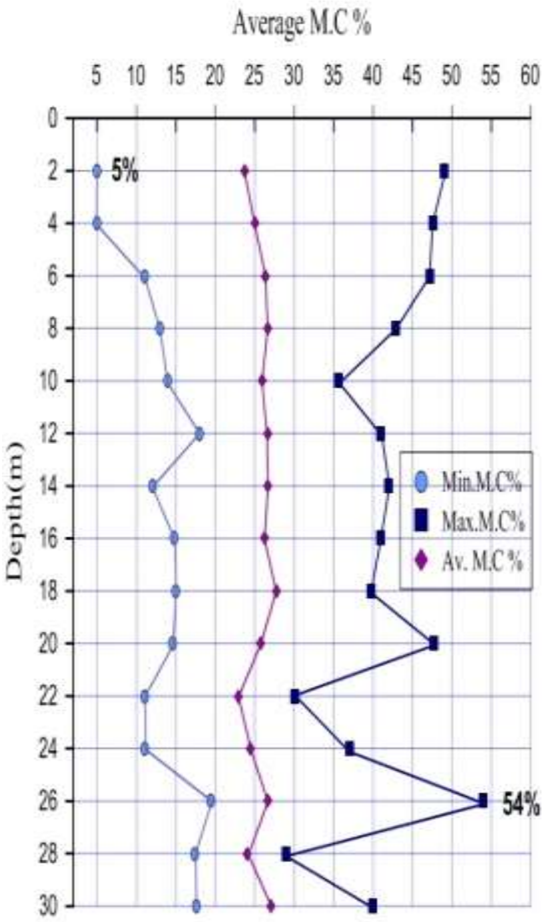

Figure 4: Average M .C % versus depth.

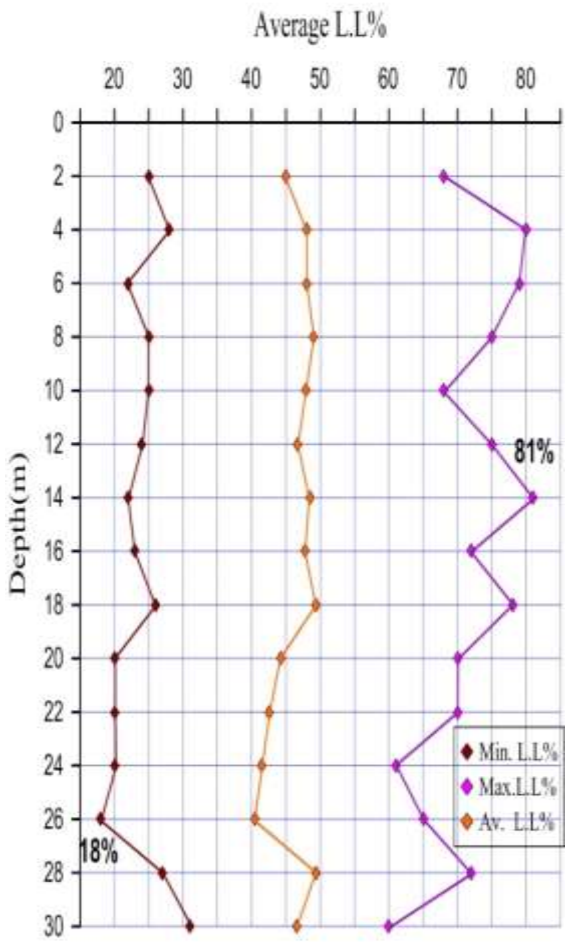

Figure 5: Average L.L % versus depth.

Specific gravity (G_s)

The distribution of specific gravity exhibits higher values in eastern part (2.75-2.68) while lower values in western part (2.65-2.7) at shallow depth 2-4m. Tigris River passes through intermediate values (2.67-2.69). At intermediate depth 6-8m, the values are 2.67-2.78 except its central eastern part with lower values (2.60-2.72). With deeper part, the values in eastern part are still higher (2.68-2.78) with respect to western part (2.56-2.67). The river passes through intermediate values with lower ones particularly in it's up to north part. With increasing depth, the values decrease to 2.63-2.67 with increasing values from W to E. The minimum, maximum and average values for the study area are 2.5, 2.88 and 2.67 respectively.

Dry unit weight (γ_d)

Concerning the dry unit weight values increase toward east particularly in middle part (right side of the river) reaching 22 kN/m^3, but decrease in the western part. Tigris River passes through lower values particularly in its upper parts. At intermediate depth, the values of dry unit weight decrease with depth, increase towards E (15.35-17.8 kN/m^3) and decrease towards W (14.82-15.93 kN/m^3). At deeper parts, the values decrease towards most high values are located in the N and NW parts. While the line of minimum and maximum values of dry unit in Figure (7) shows some fluctuation, the average line of dry unit shows almost around convergent values. The range of minimum and maximum dry unit weight is 11-22 kN/m^3 with an average value of 15.6 kN/m^3 for the study area.

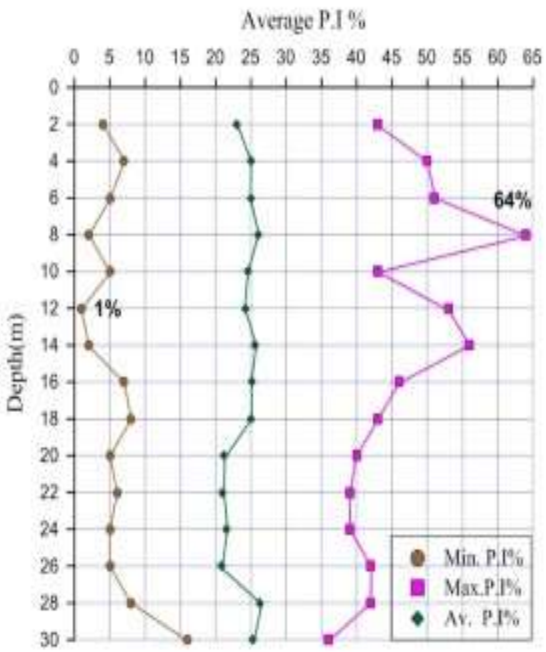

Figure 6: Average P.I % versus depth

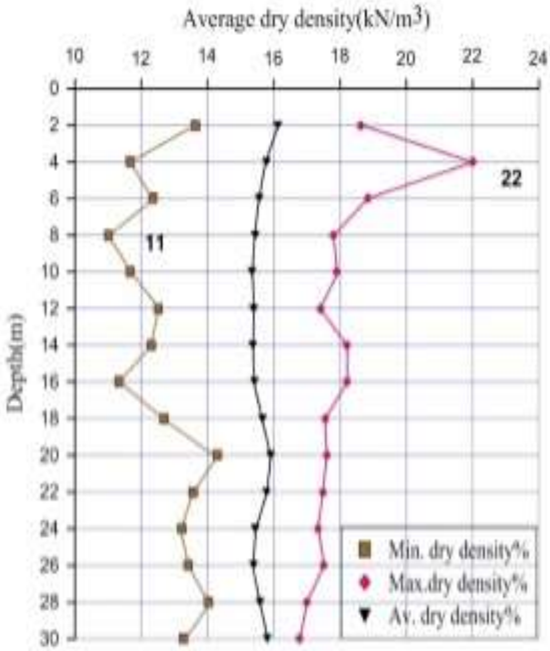

Figure 7: Average γ_d versus depth.

Standard penetration test (SPT, N- value)

The standard penetration test (N-values) is (In general); in the western part has lower values than eastern part. At shallow depths 2-4m, the values are ranging between 2-63 with higher values in SW and NE, while smaller N-values are located in N, NW and SE. Tigris River passes through low values in its central and upper parts. At greater depths 6-8, and 10-12m, the same distribution is noticed but with decreasing extent of these values. The values are generally lower than the shallower depth and also it is noticed increasing values toward central east. At greater depths, the N-values decreases (around 40) while increases toward south (around 46). In deeper parts, higher values are concentrated in central part around the river and southern part of the area while they are decreasing toward edges. The line of minimum and maximum values of SPT in Figure (8) shows some fluctuation, whereas it is so clear that the average SPT value increases with depth. The minimum and maximum SPT values are 2 and 129 and the average SPT value for the study area is 33.

Unconfined compressive strength (Q_u)

The unconfined compressive strength values at depths 2-8m, are noticed to be higher to the east of the river and the lowest one is to the west of the river , while intermediate values are along both sides of the river. Most low values are concentrated in S and SW. With deeper parts 10-22m, the higher values are located in its SE part and decrease toward NW while the intermediate values are along the upper part of Tigris River. Figure (9) shows some irregular values for unconfined compressive strength, sometimes the high values indicate gypsum presence in the soil; whereas the low values indicate weak soil that could be resulted from non-uniform fill. For the study area, the minimum and maximum values are 8 and 846 kN/m^2, the average of all the study area is 179 kN/m^2.

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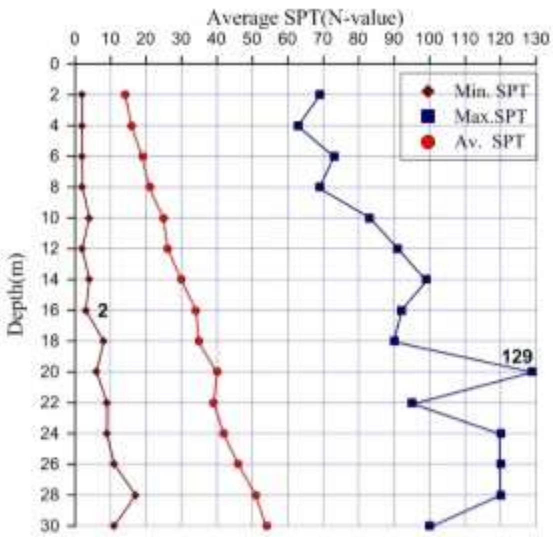

Figure 8: Average SPT versus depth.

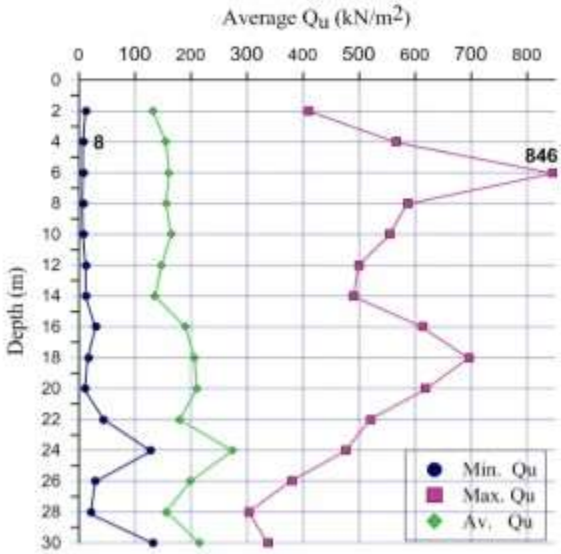

Figure 9: Average Q_u versus depth.

Internal friction angle (Ø)

The internal friction angle values are higher to the right of the river while the lowest in the left side with intermediate values along both sides of the river. At depths 6-8m, higher values appeared in the center with lower ones in both sides of the river. At depths 10-12m, the same distribution appeared, i.e., the values are higher in the right than the left side. At more depths 16-18m, higher values in the W while lower values in E and S parts. At deeper parts 22-24m; higher values are in the right side of the river with lower values in the SW. The minimum and maximum values of angle of internal friction as in Figure (10) are found as 2^o and 49^o. The average value for the study area is 29^o. The values are varied due to the percentages of the granular soils.

Soil fractions (clay, silt, sand and gravel)

At shallower depths of 2-8m, high contents of clay are in the right of the river while the lowest are in the left. At depths 14-16m the contents are low around the river. In deeper parts 22-24m, more clay contents are present, but they are mainly concentrated in SW part with little amount in eastern part at depths 28-30m. At shallower depths of 2-8m, higher values of silt contents are present in the eastern part of the river while the lowest are in the west and medium along Tigris River. At deeper parts 10-18m; the reverse is true where high contents are in western than in the eastern. After depth 22-24m, the values become less with higher amount along the river.

The sand contents show higher amount in west than east at shallow depths, also higher amount along the river and higher in southern part than northern part. At depths 6-8m, the same distribution is noticed to some extent with lower content, but higher amount is observed along the NW-SE part. Similar distribution is noticed to depth 16-18m where higher content in S and SE. After depth 22m higher amount in the W than E and after 28-30m, the reverse is true. The gravel contents are noticed to be low at shallow depths of 2-4m, except along upper part of the river and NE. At depths 6-8m, they become rare or neglected. But with more depths 10-12m, the contents increase in center beside the river, and after 16-18m increases around central part of river and SW. At the deeper part 22-30m, gravel content increases in western part with little in the center.

Referring to Figures (11-14), the minimum content for clay, silt, and sand and gravel percentage values for the study area is found to be 0, but the maximum percentages are 87, 95, 97, and 86% respectively. Figure (15) shows clearly that along the total depth of 30m and below 4m, the gravel percentage range is 0-5%, regardless of the odd 11% in the first layer. The clay and silt fractions show a decrease in values with depth, and only the sand content exhibits increase with depth. The figure also shows that the average silt is about 1.5 times the clay in all the 30m depth of the study area. Moreover, the soil is sandy clayey silt from 0-12m and clayey silty sand below this depth.

It is very important to clarify here that Baghdad soil fraction average percentages for the total depth of 30m are about: clay=21%, silt=31%, sand=45 % and gravel=3%.

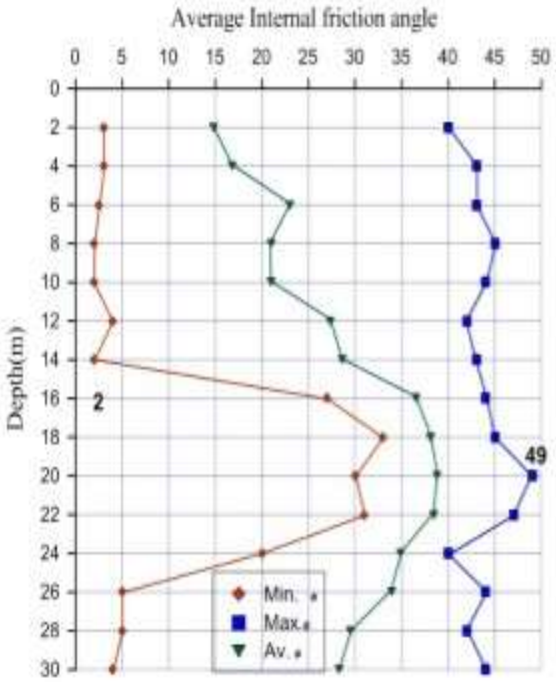

Figure 10: Average Ø versus depth.

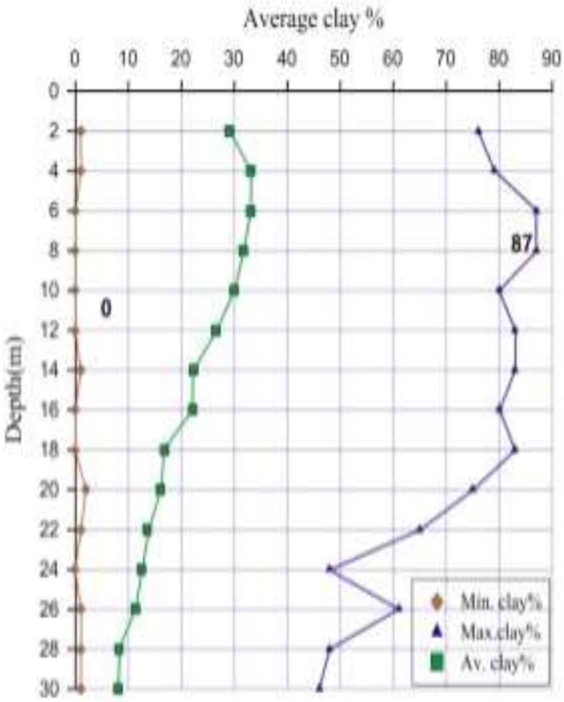

Figure 11: Average clay % versus depth.

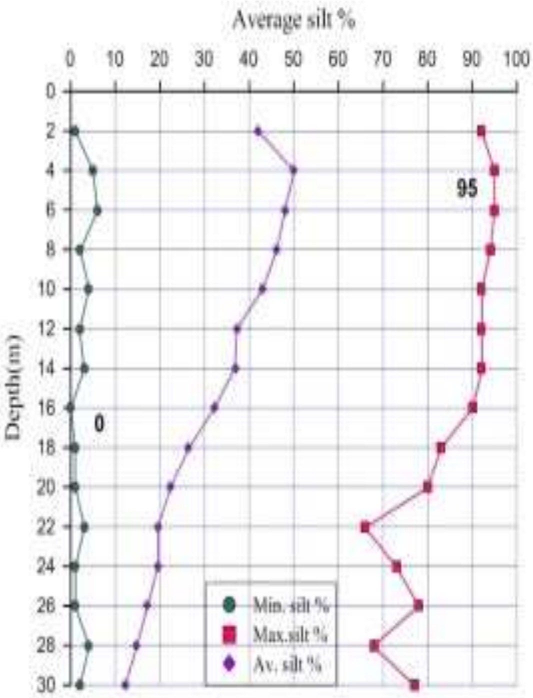

Figure 12: Average silt % versus depth.

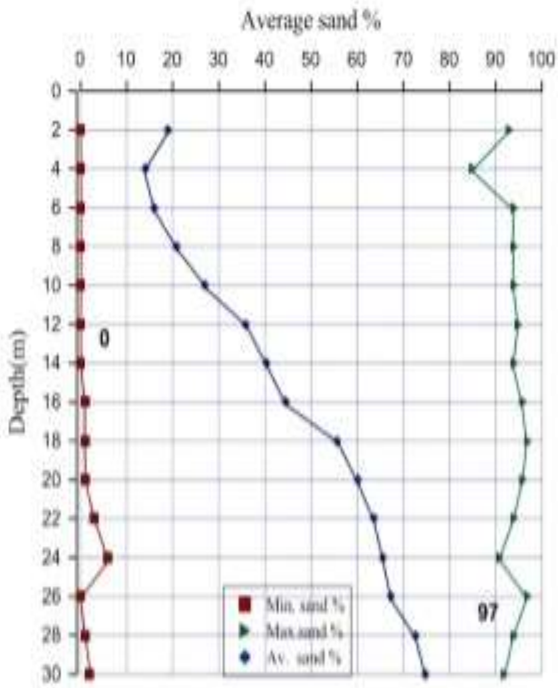

Figure 13: Average sand % versus depth.

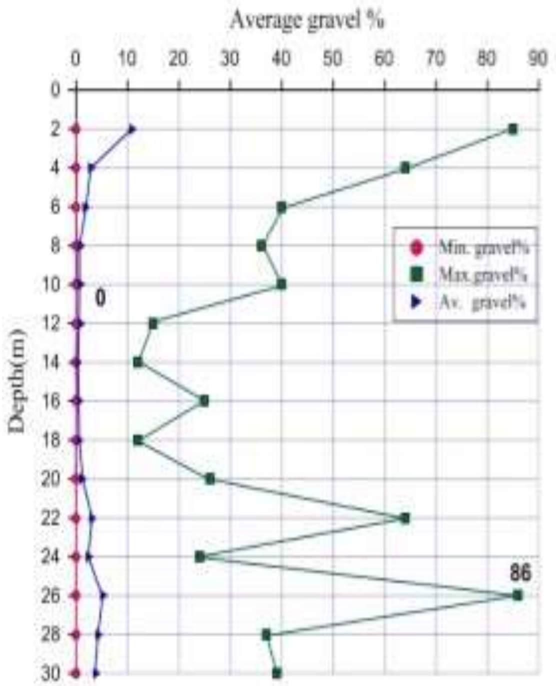

Figure 14: Average gravel % versus depth.

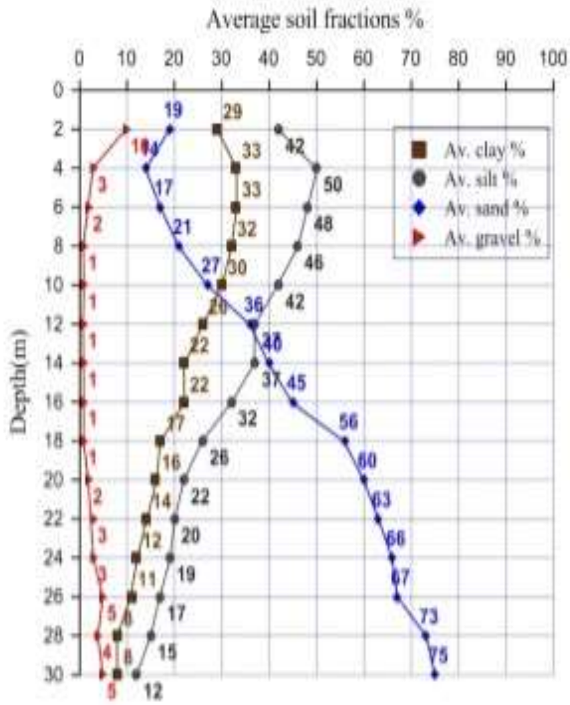

Figure 15: Average soil fractions % versus depth.

Consolidation parameters (e_o, P_c, C_c, C_r and OCR)

The values of initial void ratio at shallow depths 2-8m are noticed to be higher in the west side while low in the east and southern part, but the values in the west become lower at depth 4-8m. At deeper parts, higher values are noticed in the upper part than the southern.

For the effective preconsolidation pressure values at shallow depths 2-8m, are found higher in W, lower in E, intermediate along central (NW/SE) and high in the center. At deeper parts, higher values are found in SE along the river, while being intermediate along upper part of the river. Low values of compression index are noticed in most areas except NW-SE and E central parts. While higher values are found in E and W at deeper parts.

For the swelling index, low values are noticed at shallower depths in most areas except small part along southern course of the river. At intermediate depth 8-10m, the values increase particularly in W more than in E. Then, a decrease is noticed in most areas at depth 10-12m, followed by another increase at deeper parts. Concerning overconsolidation ratio higher values are found in E, low in W, intermediate along the river with an observable increase in central part. At deeper parts, a noticeable increase is noticed in Western part of the river. It can be noticed through Figures (16-20) that the initial void ratio shows wide difference in the first two layers depth 0-4 m between the minimum and maximum values 0.1 and 1.271 which referred to overcosolidated layers and swelling soil layers respectively. Below this depth, a clear drop can be noticed; the minimum starts to increase and the maximum starts to decrease to the most normal values, which can be presented well by the average values line. These average values stay around until the 22m depth when they start to increase clearly with depth. The average void ratio for the study area is 0.724. The average preconsolidation pressure and compression index values show an increase in 10-18m depth, in reverse to that, the average swelling index values tend to decrease at these depths. The average OCR value decreases rapidly at depths between 2-10m. The study area average values of P_c, C_c, C_r and OCR are 262 kN/m^2, 0.217, 0.037 and 2.17 respectively.

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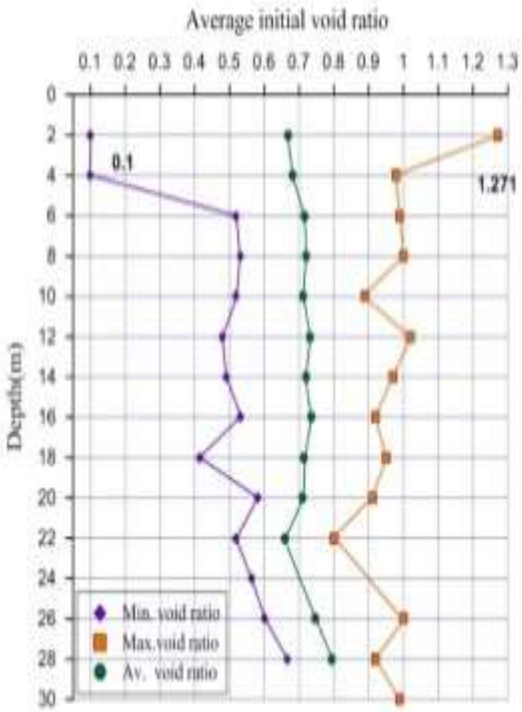

Figure 16: Average eo versus depth.

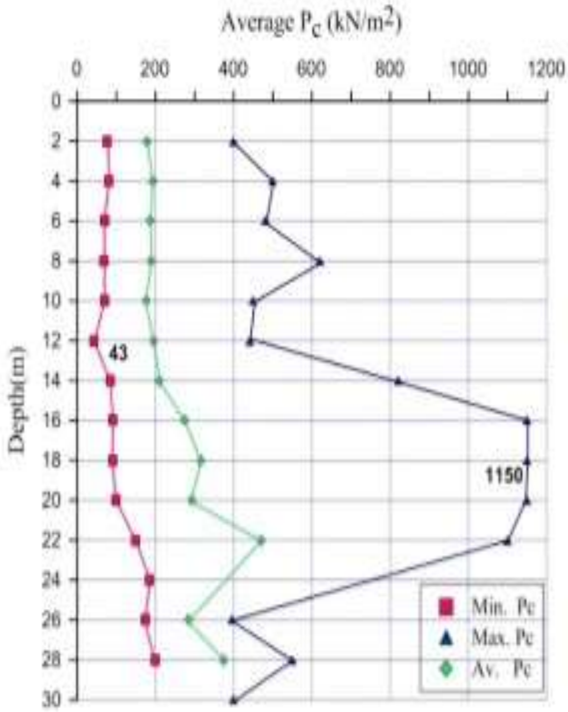

Figure 17: Average P_c versus depth.

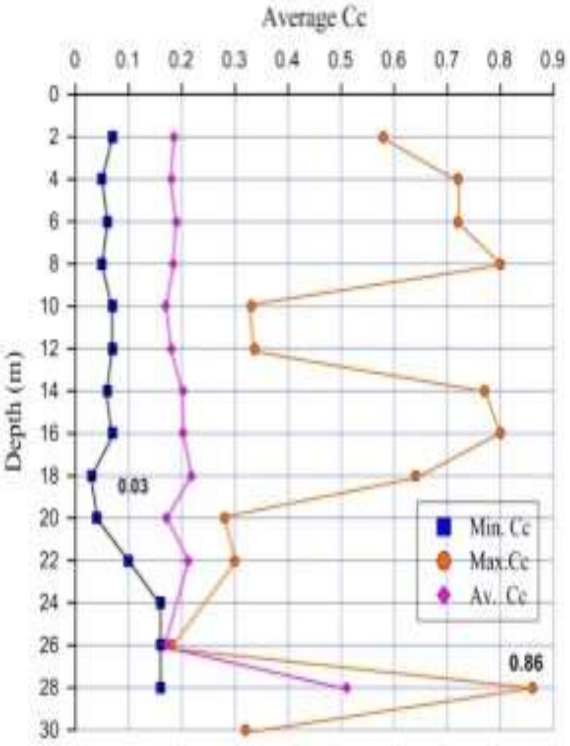

Figure 18: Average C_c versus depth.

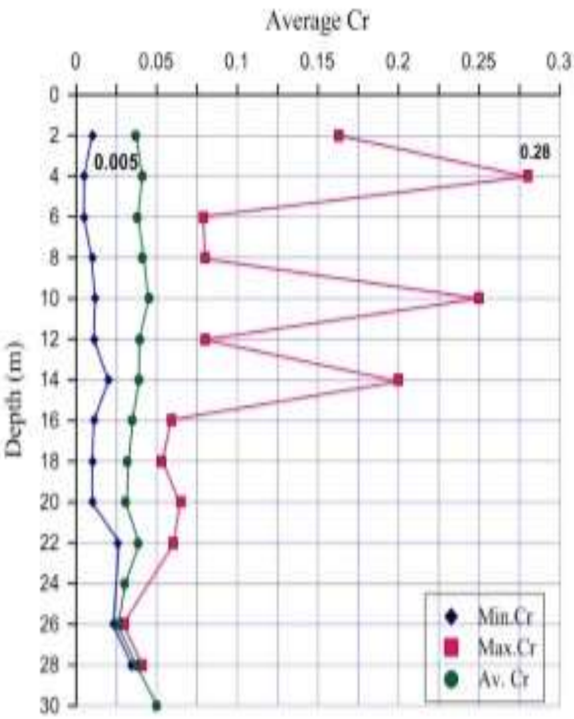

Figure 19: Average C_r versus depth.

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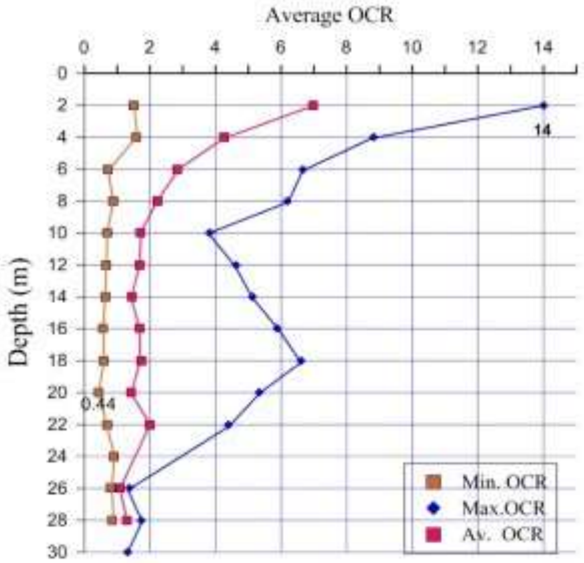

Figure 20: Average OCR versus depth.

Chemical properties

Concerning the variation of chemical properties values in Table (1) and due to bad effects of chemicals on foundations of structures, the maximum values should be considered. The maximum value of sulphates (SO_3) is 17.7 percent. The high values appear in the upper layers and decrease with depth. The average of the study area is 0.89% and this shows high degrees of concentration of sulphates content in Baghdad soil.

Gypsum maximum content is 23.7% and for the study area, the average is 2.39%. The maximum calcium carbonate is 60.1% and the average of study area is 17.55 %. In the same table, the maximum organic content is 27% and 1.38 % is the study area average value. The hydrogen power (pH) maximum value is 10.7 to assure the alkalinity of Baghdad soil. The study area average value is 8.5. The chloride maximum value is 7.8 percent and 0.224% is the study area average value

Geotechnical Properties: Trends and Relationships

Different relationships between the average values of geotechnical properties have been plotted and submitted to investigate the correlation between each other. The relationship between the dry unit weights, unconfined compressive strength, versus moisture content is mostly inverse relationship as can be shown in Figures (21) and (22), while direct relation is stated between compression indexes versus moisture content as presented in Figure (23).The variation of plasticity index, compression index, and swelling index with respect to liquid limit are shown in Figures (24-26), respectively.

In general, the figures show a direct proportional relationship between these variables regardless some odd variations. Figures (27) and (28) exhibit direct relationship between standard penetration test values against dry unit weight and unconfined compressive strength respectively, while Figure (29) shows an inverse relationship between compression index with respect to unconfined compressive strength. The plasticity index is direct proportional with the clay fraction percentage as shown in Figure (30). Almost, the same thing can be said about the relationship between compression index against initial void ratio in Figure (31), and about the relationship between swelling indexes against compression index in Figure (33). An inverse proportional relationship is between the overconsolidation ratio versus both of initial void ratio and compression index as exhibited in Figures (32) and (34) respectively.

CONCLUSIONS

The analysis of the data of hundreds soil investigation reports revealed the following conclusions:

1. As sediments of Baghdad are mainly inhomogeneous due to the accumulation of river floods during recent epoch (<10,000 years), so Baghdad soil stratification is non-uniform and erratic in nature, moreover, one may expect weak cementation and consequently a significant potential for liquefaction.
2. The soil stratification of Baghdad area down to depth of 30m consists of a fill layer followed by a clayey silt (or silty clay) soil. Below the clayey silt layer, a noncohesive layer of sand or silty sand layer exists. The fill layer depths are ranging between 0.3-9.5m. Higher values are indicated in the NW–SE trend along Tigris River and especially in central part of Baghdad, whereas lower values are indicated along NE–SW trend except sites near the river.
3. In general, the upper part is preconsolidated due to desiccation and the degree of consolidation decreases with depth. Baghdad soil can be generally described as overconsolidated soil with low to very low compressibility.
4. Groundwater is characterized by its high salinity due to the high sulphates contents. Groundwater levels are characterized by their shallow depth ranging between 0.1m in north of Baghdad and 8.0 m in south of Baghdad, both are in Rasafa. Its shallower values are in the northern and eastern parts, whereas the deeper parts are located in the central and south western parts.
5. Studying the geotechnical properties of Baghdad soil as reported in site investigation reports down to 30m depth revealed important ranges for some soil geotechnical properties such as M.C is ranging between 5-54%, L.L between18-81%, P.I between 1-64%, Gs between 2.5-2.88, γ_d between 11-22 kN/m^3, SPT between 2-129, Q_u between 8-846 kN/m^2, and Ø between 2-49^o. The minimum soil fractions contents are zero while the maximum contents are: clay=87%, silt =95%, sand =97% and gravel =86%. Silt fraction is always 1.5 times clay fraction and Baghdad soil fraction average percentages for the total depth of 30m are about: clay=21% , silt=31%, sand=45%, and gravel=3%.
6. The consolidation parameters values ranges are: initial void ratio between 0.1-1.271, P_c between 43-1150 kN/m^2, C_c between 0.03-0.86, C_r between 0.005-0.28 and OCR ranges are 0.44-14.
7. The ranges of chemical properties percentages contents are: sulphates content between 0.01-17.7 (high concentration of sulphates), Gypsum between 0.02-23.7, carbonate calcium ranges are 1.54-60.1, organic matter between 0.02-27, pH between 6.7-10.7 and chloride ranges are 0.004-7.8. Due to the average of pH value (8.5), Baghdad soil is considered as alkaline.
8. Leakage from old sewer networks affects soil properties and increases sulphates content, settlement, compressibility and decreases soil resistance to liquefaction.
9. The distribution of some studied geotechnical properties showed a wide scatter in some of the results due to the geotechnical nature of the soil where the composition and stratification are non-homogenous because of several reasons; geological, and human activities.
10. To study the variation of Baghdad soil properties with depth and the correlations between these properties were done. The SPT value and sand fraction percentage increase with depth, while clay, silt and OCR decrease with depth. Dry unit weight γ_d and Q_u are inversely proportioned with M.C and also the same inverse proportional relationship is noticed between C_c and Q_u, OCR with both of e_o and C_c. Also P.I, C_c, and C_r are proportional to L.L the SPT is proportional to both of γ_d and Q_u. The P.I is proportional to the clay fraction percentage in Baghdad soil.

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