Iraqi Geological Journal

Journal homepage: https://www.igj-iraq.org

Geotechnical Properties of Soils in Abu Al-Khasib City, Southern Iraq

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Received: 8 December 2022

Accepted: 14 February 2023

Published: 30 June 2023

Abstract

To investigate some geotechnical characteristics of the soils in a chosen area of Abu Al-Khasib city, Basrah Governorate, southern Iraq, nine boreholes that range in depth from 10 to 32 meters were drilled. Based on the results of standard penetration tests and particle size analysis the Quaternary deposits, which extend vertically to a depth of 32 meters, are divided into 8 layers with varying bearing capacities depending on their consistency and compactness. These layers are Medium stiff brown lean clay, soft and very soft gray lean clay, medium stiff gray lean clay, stiff gray lean clay, medium denes gray silty sand, denes gray silty sand , hard gray clay-silt-sand mixture and very dense gray silty sand. The first layer's bearing capacity is 140 kN/m^2, so it is considered as moderately adequate to support the isolated, strip,or raft shallow foundations of various light buildings in the study region, and soil improvement techniques, especially mechanical methods, are required. Different types of deep foundations such as piles and well foundations for heavy constructions must be extended to depths of 27 and 30 meters, which represents the 7th and 8th layers of high bearing capacity (640-760, 1100 kN/m^2 respectively) in the study area. Inorganic clays with low plasticity are the most common classification for samples. The soils of the study area are considered highly compressible soils and have medium expansion degree which must be taken into account when constructing shallow foundations to minimize damage to buildings. The percentages of sulphates, total dissolved salts, organic content, and gypsum content are minimal and considered ineffective, whereas the percentages of carbonates and chlorides are high and affect the safety of shallow foundations. In the study site, the groundwater is around 0.5 m deep.

Keywords: Basrah soils; Engineering stratigraphic sequence; Geotechnical properties; Chemical properties; Standard penetration test

1. Introduction

The geotechnical assessment of the soils under the surface of the planned constructions is an important factor for the safety of these constructions. This evaluation is done by determining the engineering stratigraphic sequence and estimating the bearing capacity of these layers and the rate of potential subsidence in them after construction to determine the type of foundation suitable for the construction's load. This depends on several important engineering properties such as unconfined compressive strength, shear strength of the soil and internal friction as well as soil permeability.

Geotechnical assessment is carried out through geotechnical investigations. Geotechnical properties are analyzed through several on-site tests, such as the standard penetration which is considered as the most important test, which it is possible through it to determine the consistency of cohesive soils and

DOI: 10.46717/igj.56.1F.12ms-2023-6-20

compactness of non-cohesive soils, and then to classify the engineering stratigraphic sequence and estimate many important properties of the soil such as bearing capacity, shear strength, compression coefficient, velocity of shear waves, and others (Das, 2002). These properties are also studied by several laboratory tests to identify the classification, engineering, and chemical properties of the soil.

Albadran and Mahmood (2006) studied the geotechnical properties and aerial distribution of bearing strata along the Shatt Al-Arab River bank from Qurna to Fao. They classify soils at study area to eight layers of different properties related to interfingering of sedimentary environments and numerous source of sediments. Essa (2022) studied the spatial distribution of some geotechnical properties of the soil of Basrah Governorate, southern Iraq using geographic information systems.He found that shear strength and bearing capacity are gradually increase with depth at non-cohesive soil in the western part, while they decrease in the cohesive soil in the eastern part.

The city of Abu Al-Khasib is characterized by its economic and tourist importance. This research is concerned with classifying the engineering stratigraphic sequence in a selected location and estimating many geotechnical properties that help in understanding and determining the nature of the shallow or deep foundations suitable for construction in it, and the potential issues that these buildings might suffer after they are constructed.

2. Location of the Study Area

The study area is sited in the district of Abu Al-Khasib - Basra Governorate / southern Iraq, at the intersection of longitude 47˚ 52' 32"E and latitude 30˚ 26' 03"N, as shown in Fig.1.

3. Geological and Geomorphological of Study Area

Geologically the study area is located at the Zubair subzone of the Mesopotamia which represents the southern part of the unstable Arabian platform (Budy and Jassim,1987).Geomorphologically, the study area is located within the delta plain section (Seedy and Mollah, 1990). Erosion, sedimentation, climate and sea level changes during the Holocene period and played a major role in the development of the delta region and the nature of its sediments. It is believed that there is an active role for the huge quantities of clay and silt carried by the Tigris, Euphrates and Shatt al-Arab rivers from the north, the Karun from the east and the Batin River from the west in the formation of the sediments of the region where the river channels are spreading, forming the floodplain for them (Albadran and Albadran,1997). During the Quaternary period, the upper part of Dibdibba Formation, Hammar Formation and the recent fluvial flood clay, silt and windy particles had been deposited (Gunatilake,1986).

4. Materials and Methods

Field investigations included the excavation of 9 boreholes at the site, ranging in depth from 10-32 m. The boreholes were drilled by the rotary drilling method using flight continuous auger by the drilling team of the Basrah construction laboratory by the Hyundai excavator. Disturbed samples were taken from the drilling auger and partially disturbed samples by the split spoon sampler, while the undisturbed samples were taken by Shelby tube with a diameter of 4 inches and from different depths of the boreholes.

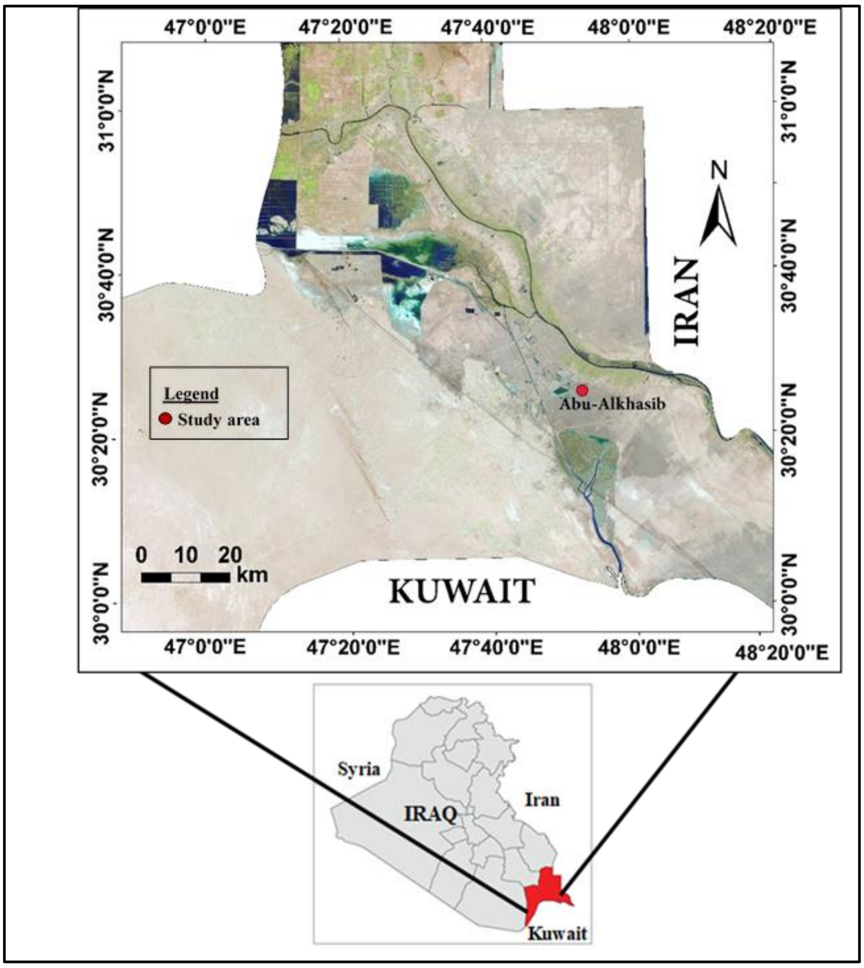

Fig.1. Map of Basrah and location of the study area

The standard penetration test (SPT) was performed at a depth per 1.5 m. This test includes measuring the resistance of the soil to penetrate the split barrel sampler with a length of 45 cm, outer diameter 51mm and inner diameter 38 mm. It is pushed into the soil by means of a drop hammer with a standard weight of 63.5 kg falling from a fixed height of 76 cm on the sampler rods to which the split sampler is connected (Mahmood, 2002). The number of blows leading to the penetration or pushing of the last 30 cm of the length of the tube inside the soil represents the penetration resistance (N_{field}-value) that is used to identify the consistency of the cohesive soils and the degree of compactness of non-cohesive soils. The ground water level in the boreholes was measured 24 hours after drilling. In-situ investigations have been completed under BS 5930-2015.

Classification, engineering, and chemical laboratory tests on various soil samples were carried out under BS 1377-1990. Classification tests included measuring soil moisture content, liquid limit values, plasticity index, and grain size distribution analysis. The data were used to classify soils under the Unified Soil Classification System (USCS) and estimate their coefficient of compressibility and swelling potential. Engineering tests included calculation of soil bearing capacity, uniaxial compressive strength, shear strength and internal friction angle. Chemical tests were carried out to calculate the percentages of sulfates (SO_4%), total soluble salts (T.S.S%), organic content (Org%), gypsum content (Gyp%), carbonates ($CaCO_3$%) and chlorides (Cl%).

5. Results and Discussion

5.1. Geotechnical Properites of Soil

The standard penetration resistance values (N_{field}-values) and the results of the grain size distribution analysis of the nine boreholes were used to prepare one representative borehole, Table 1 and Fig.2, which shows that the engineering stratigraphic sequence in the study area is divided into eight layers as follows:

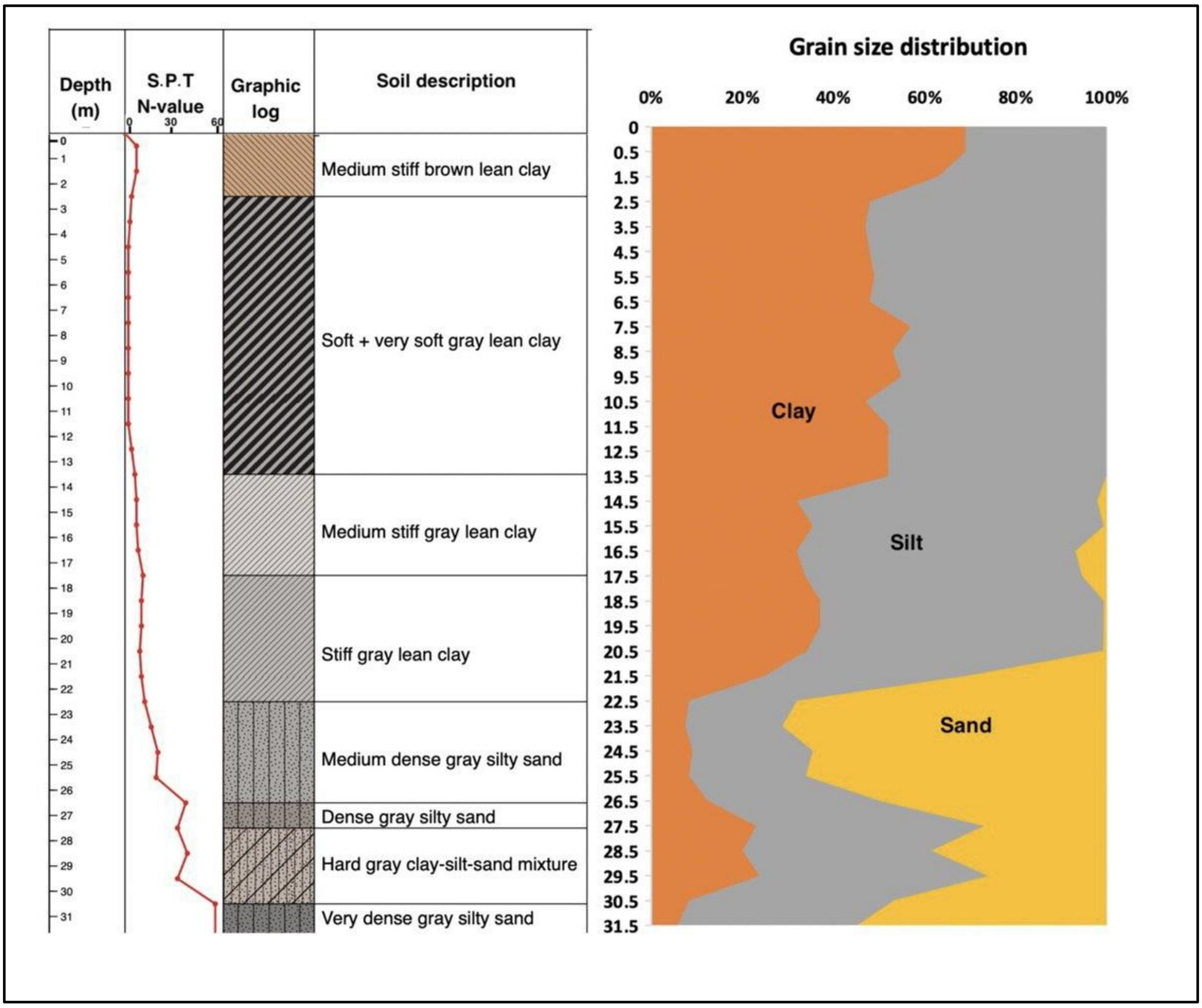

Fig. 2. N_{field}-values, grain size distribution analysis and engineering stratigraphic sequence in the study area

Table 1. Classification and geotechnical properties of soils in study area.

Layer No.	Depth (m)	SPT N-values blows/30cm	Clay %	Silt %	Sand %	L.L%	PI%	USCS	Bearing capacity kN/m^2 BS 8004:1986
1st layer	0-2	7	63-69	31-37	/	41-42	17-20	CL	140
2nd layer	2-13	2-4	47-57	43-53	/	32-38	12-17	CL	40-75
3rd layer	13-17	6-8	47-55	43-54	0-10	39-40	17-18	CL	120-150
4th layer	17-22	9-11	33-59	26-47	1-41	26-37	9-16	CL	180-220
5th layer	22-26	12-20	23-29		71-77	/	/	SM	240-400
6th layer	26-27	37	43		57	/	/	SM	740
7th layer	27-30	32-38	25-31	27-35	34-48	37-38	11-16	CL	640-760
8th layer	30-32	>50	6-9	40-42	51-52	/	/	SM	1100

- Medium stiff brown lean clay layer (CL): This layer extends from the surface of the earth to a depth of 2 meters and has a thickness of 2 meters and represents the layer on which the shallow foundations of constructions in the region are based. N-value are 7 blows/30cm. Clay ranges between 63-69% and silt between 31-37%, liquid limit values (LL) range between 41- 42% and plasticity index (PI) between 17-20%. The bearing capacity of this layer is 140 kN/m2, the unconfined compressive strength is 84 kN/m2 and the shear strength is 47.6 kN/m2. The results show the lack of bearing capacity in this layer and its necessary need to improve the soil in different methods especially mechanical methods to make it safer in the stability of constructions with shallow foundation.
- Soft and very soft gray lean clay (CL): This layer extends from a depth of 2-13 meters and has a thickness of 11 meters. N-values are between 2-4 blows/30 cm. The clay ranges between 47-57% and the silt between 43-53%, the liquid limit values range between 32-38% and the plasticity index between 12-17%. Bearing capacity values are 40-75 kN/m^2, unconfined compressive strength is 25-50 kN/m^2 and shear strength is 13.6-27.2 kN/m^2.
- Medium stiff gray lean clay (CL): This layer extends from a depth of 13-17 meters and has a thickness of 4 meters. N-values range from 6-8 blows/30cm. The clay ranges between 47-55%, silt between 43-54%, sand between 0-10%, liquid limit values range between 39-40% and plasticity index between 17-18%. Bearing capacity values are 120-150 kN/m^2, unconfined compressive strength is 67-100 kN/m^2 and shear strength is 40.8-54.4 kN/m^2.
- Stiff gray lean clay (CL): This layer extends from a depth of 17-22 meters and has a thickness of 5 meters. N-values range from 9-11 blows/30 cm. The clay ratios range between 33-59%, silt between 26-47%, the percentage of sand between 1-41%, the values of the liquid limit range between 26-37% and the plasticity index between 9-16%, which represents the end of the cohesion sediment layer. Bearing capacity values range from 180-220 kN/m^2, unconfined compressive strength between 100-134 kN/m^2 and shear strength between 61.2-74.8 kN/m^2.
- Medium denes gray silty sand (SM): This layer extends from a depth of 22-26 meters by a thickness of 4 meters. Standard penetration resistance values (N-value) are between 12-20 blows/30 cm. The percentage of fine grains (Clay and silt) ranges between 23-29% and the percentage of sand between 71-77% and represents the beginning of the non-cohesive sediments that represent the surface of Dibdibba Formation in the area. The bearing capacity of this layer is between 240-400 kN/m^2, shear strength is 81.6-136 kN/m^2 and the internal friction angle is between 31-33^o.

- Denes gray silty sand (SM): This layer extends from a depth of 26-27 meters with a thickness of 1 meter, with a penetration resistance value (N-value) of 37 blows/30 cm. The percentage of fine grains is 43% while the percentage of sand is 57%. The bearing capacity is 740 kN/m^2, shear strength is 251 kN/m^2 and the internal friction angle is 38.8º.
- Hard gray clay-silt-sand mixture (CL): This layer extends from a depth of 27-30 meters with a thickness of 3 meters. N- values range from 32-38 blows/30cm. Clay ratios range between 25-31%, silt 27-35% and sand between 34-48%. The liquidity limit ranged between 37-38% and the plasticity index between 10-16%. The bearing capacity ranged from 640-760 kN/m^2, shear strength between 217.6-258.4 kN/m^2 and internal friction angle between 36.8 º-39.2º.
- Very dense gray silty sand: This layer extends from a depth of 30-32 meters where the end of the depth of the investigations. Its N-value exceed 50 blows/30 cm. Clay ranges between 6-9%, silt between 40-42% and sand between 51-52%. The bearing capacity is 1100 kN/m^2, shear strength is 374 k/m^2 and the internal friction angle is 42º.
- The seventh and eighth layers are prepared to carry the piles of the heavy installations to be built in the city of Abu Al-Khasib in the future. These soils were affected by natural consolidation factors resulting from the overburden pressure during sedimentation processes, which leads to increased bearing capacity, shear resistance and reduced permeability (Lambe and Whitman, 1969).
- The plasticity chart in Fig. 3 shows that all the samples analyzed are inorganic low plasticity clay (CL), only one sample from the seventh layer and a depth of 28-29 meters that is organic low plasticity silt.

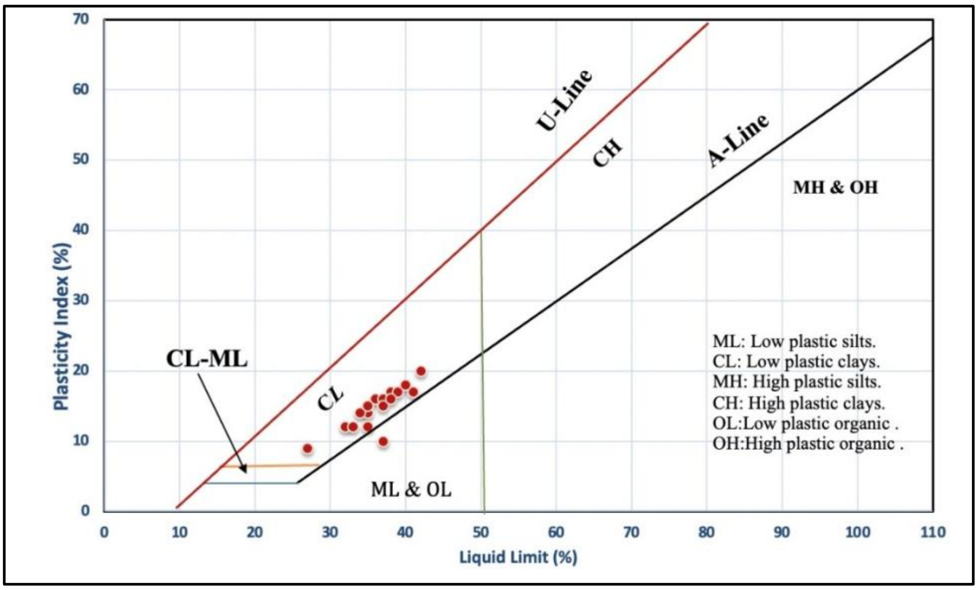

Fig. 3. Plasticity diagram for the USCS classification of study area soils according to ASTM D 2487 in (Hunt, 2005)

Table 2 shows how soils have been classified according to the plasticity index. The soils of 19 among the 21 samples tested are considered to be medium plastic, with plasticity index ranging from 7 to 17%, while the soils of the other two samples are considered to be highly plastic, with index ranging from 18 to 20%.

Table 2. Classification of cohesive soils according to their plasticity(Al-Kasabi, 2006)

Plasticity index %	Plasticity
0	Non plastic
< 7	Low plastic
7-17	Medium plastic
>17	Highly plastic

Compression index (C_c), which is often used to describe normally consolidated clays, is one way to indicate the compressibility of clay. Is it possible to extract the values of the compression index by laboratory method using consolidation test. Skempton (1944) in Wesley (2003) linked the compression index to the liquid limit (LL) by using the following expression:

$$C_c = 0.009 \text{ (LL-10)} \quad (1)$$

Table 3 shows the degree of compressibility of fine soils (Coduto,1999). The compression index of 21 samples from study area had been estimated. The results vary between 0.153-0.288 with average 0.224. So, the soils of study area are considered as highly compressible soils. With increasing clay percentage and higher liquid limit, the compression index rises.

Table 3. Soil classification according to degree of compressibility (Coduto, 1999)

Rang of compression index	Compressibility classification
0-0.05	Very slightly compressible
0.05-0.10	Slightly compressible
0.10-0.20	Moderately compressible
0.20-0.35	Highly compressible
>0.35	Very highly compressible

5.2. Swelling Potential in Soils

Some clay is characterized by its ability to swell and shrink when the moisture content changes. These soils cause many problems for engineering foundations built on them, so they must be studied first and treated before constructing on them. The degree of swelling is affected by various factors such as the type and proportion of clay minerals, the water content, the structural composition of the soil, and the overburden pressure (Al-Kawam and Mahmood, 2022). The degree of swelling in the soil can be estimated by various direct laboratory methods which indicate clay activity,free swell,swelling potential and swelling pressure, and many indirect methods. Table 4 shows the degree of expansion in the soil according to its liquid limit (Chen, 1988). The results show that the liquid limit values in the soils of the study area range between 32- 42% at a rate 38.4%. Thus, these soils are considered to have medium expansion degree.

Table 4. Classification of swelling soils according to liquid limit and degree of expansion. After (Chen, 1988).

Liquid limit%	Degree of expansion
20-30	Low
30-40	Medium
40-60	High
60-70	Very high

5.3. Chemical properties of the soil

- Sulfates (SO4): The soils contain sulfates of calcium ($CaSO_4.2H_2O$), magnesium ($MgSO_4$), sodium ($NaSO_4$) and potassium (KSO_4). The presence of sulphates in excess of 5% is dangerous and leads to the fragmentation of concrete and construction failure (NCCL, 2001). Sulfate values in the soils of the study area range from 0.1% at depths of 14, 15 and 21 meters to 0.31% at a depth of 4 meters at a rate of 0.16%. Sulfate levels in the study area are low and do not affect the safety of construction.
- Total soluble salts (T.S.S.): is the percentage of total salts present in the soil to the weight of the soil (Al-Zubaidi, 2006). Soluble salts are dangerous at 10% (NCCL, 2001) because they increase strain between clay soil layers (Duncan and Stephen, 2005). The change in soil salinity affects soil stability due to salt dissolving caused by a change in soil moisture (Kleiner et al., 2010). The percentage of soluble salts in the study area ranged from 1.3-6.1% at a rate of 3.34% and did not affect the engineering behavior of the soil.
- Organic content (Org.%): Organic matters are the remains of plant and animal origin found in the soil as pure matters or a mixture with sand, silt and clay as binders (Hunt, 2005). It increases compressibility, reduces shear strength and bearing capacity, and damages the foundations. Organic content less than 0.5% is considered ineffective to engineering behavior, content between 0.5-2% is relatively effective, and content more than 2% is considered as very effective (Mahmood, 1997). The organic content in the study area ranged between 0.42-1.57 % at a rate of 0.99% and is considered as ineffective to relatively effective.
- Gypsum content (Gyp%): The dissolving of gypsum ($SO_4.2H_2O$) due to rain and ground water leads to reduced bearing capacity, and damage of constructions due to soil collapse (Mahmood, 2007). The gypsum content in the soils of the study area ranges between 0.22-0.67% with an average of 0.33%. The gypsum content is effective if it exceeds 2.5% (NCCL, 2001) and therefore, the gypsum content is not influential in the engineering behavior of the soil in the study area. According to Barzanji (1973), soils of the study area are considered non-gypsiferrous soil when the percentage of gypsum in them is less than 0.3%, and very slightly gypsiferrous soil when the percentage of gypsum is between 0.3-3%.
- Carbonates (CO3): Carbonates are found in soil as calcium carbonate ($CaCO_3$), magnesium ($MgCO_3$), sodium ($NaCO_3$) and potassium (KCO_3). The presence of carbonate reduces the alkalinity of concrete, making it susceptible to acid attack, and its solubility leads to the formation of cavities in the soil (Al-Zubaidi, 2006). 30% or more of calcium carbonate is hazardous and leads to engineering problems such as soil weakening, differential settlement and collapse (Allen, 2005). The results show that the percentage of calcium carbonate in the study area ranges between 45-49% with an average of 46.1% and is hazardous to the engineering behavior of the soil. Calicum carbonate is found in high proportions in river sediments resulting from the weathering of limestone rocks in

several layers of formations that the Tigris and Euphrates rivers pass through.Carbonates are also transferred to the soil by groundwater, seawater, rainwater,wind and industrial waste (Warren,2006).

- Chlorides (Cl): Chlorides are found in the soil as sodium chloride (NaCl), calcium (CaCl2), potassium (KCL) and magnesium (MgCl2). Chlorides are the suitable medium for chemical reactions that corrode rebar and increase the solubility and permeability of sulfate salts into concrete. The percentage of chlorides is high if it exceeds 0.1% (NCCL, 2001).The chlorides values in the study area range between 0.64-1.95%, which represents a risk to the foundations and rebar. The Shatt al-Arab and its many branches contribute to an increase in the percentage of chlorides salts in the soil.It is also attributed to the connection of groundwater with marine waters and tide processes, and the high evaporation rate in the area (Rivett et al., 2005).

5.4. Groundwater Level

The field tests shows that the ground water level in the study area is 0.5 meters and is very close to the surface of the earth. Groundwater in the city of Abu Al-Khasib is fed by rain, Shatt al-Arab water and its branching channels, as well as the influence of the city by tidal currents. This is aided by the high capillary property due to the cohesive soils dominating in the shallow bearing strata of the region.

The ground water level is affected by several factors, including the type of depositional facies, topography of the region, climate, weather factors, oceanic tides, earth tides, and various human activities (Todd and Mays, 2005). The position of ground water and its fluctuation has a significant effect on the bearing capacity of soil. Presence of water table at a depth less than the width of the foundation from the foundation bottom will reduce the bearing capacity and strength of the soil (Das and Biswas, 2014).

6. Conclusions

The engineering stratigraphic succession and geotechnical properties of soils in Abu Al-Khasib city have been investigated. Cohesive and non-cohesive soils that are part of the study area's quaternary deposits can be classified into eight bearing strata with varying lithology, colors, and thicknesses. These strata also have varying degrees of consistency and compactness.

The first layer's bearing capacity is 140 kN/m^2, so it considered as moderately adequate to support the isolated,strip,or raft shallow foundations of various light buildings in the study region, and soil improvement techniques, especially mechanical methods, are required. Different types of deep foundations such as piles and well foundations for heavy constructions must be extended to depths of 27 and 30 meters, which represents the 7th and 8th layers of high bearing capacity (640-760,1100 kN/m^2 respectivly) in the study area.

The majority of samples are classified as low plasticity inorganic clays. The soils of the study area are considered as highly compressible soils and have medium expansion degree which must be taken into account when constructing shallow foundations to minimize damage to buildings.

The percentages of sulphates, total dissolved salts, organic content and gypsum content are little and considered as ineffective, whereas the percentages of carbonates and chlorides are high and affect the safety of shallow foundations. The groundwater is around 0.5 m deep. The depth of the water table and its fluctuaton at the foundation bottom have an impact on the strength of the soil and the bearing capacity of the first layer.

Acknowledgements

The author is big grateful to M.Sc Saja N. Younis for her contribution to the preparation of this research.

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