Iraqi National Journal of Earth Science

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Geotechnical Evaluation of Foundation Zone Soil and its Response to the Groundwater Fluctuation at the North Refinery Company Expansion Sites, Northern Salah Al-Din Governorate.

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Article information

Received: 05- Jan -2024

Revised: 10- Mar -2024

Accepted: 08- May -2024

Available online: 01- Jul – 2025

Keywords:
North Refineries
Foundations
Subsidence
Groundwater

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ABSTRACT

The study aims to conduct a geotechnical evaluation of the soil of four suggested sites for expansion in the North Refineries Company, northern Salah Al-Din Governorate. The study area is located on the southwestern limb of Makhul anticline within the Quaternary sediments to determine their suitability for the establishment of some engineering facilities, and to assess the quality of the groundwater through chemical analyses and developing a model that simulates the effect of groundwater fluctuation when establishment as new projects. Physical and engineering tests are carried out as well as chemical analyses. The moisture content ratios range between (6.39 -13.40%), specific gravity range between)2.67- 2.74). From the results of the grain size analysis of soil, the percentages of clay and silt are found to be the highest and based on Atterberg limits and according to the plasticity scheme, it is found that the types of soil are CL and ML classification the soil is into (medium plasticity, slightly plastic). The results of the engineering properties from the direct shear test show that the internal friction angle ranges between (21°-33°), cohesion strength between (56-81 kPa), and the results of the consolidation test show that the soil is over consolidation O.C.R. The chemical analyses indicate that the gypsum content is low to medium, and a neutral alkaline soil with an organic content range from low to high, and contains a high percentage of sulfates, fluorides and bicarbonates. The percentage of dissolved salts exceeds (0.5%) and is considered high. The electrical conductivity (EC) will also be high. The groundwater depths are measured by a groundwater depth detector for wells distributed in the study area and samples are taken from several water wells located near the facilities. The results of chemical analyses show that the classification of water according to (pH) is from moderate to weak alkalinity. When comparing the concentration of total dissolved salts of groundwater in the study area, it is found that the water of the study area is brackish water; and according to the classification of water depending on the values of total hardness, it is found that the water of the study area is of high hardness.

DOI: 10.33899/earth.2024.145256.1193, ©Authors, 2025, College of Science, University of Mosul.

التقييم الجيوتكنيكي لأسس التربة واستجابتها لتذبذب المياه الجوفية في مواقع توسعات شركة مصافي الشمال، شمالي محافظة صلاح الدين.

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معلومات الارشفة

تاريخ الاستلام: 05- يناير -2024

تاريخ المراجعة: 10- مارس -2024

تاريخ القبول: 08- مايو -2024

تاريخ النشر الالكتروني: 01- يوليو -2025

الكلمات المفتاحية:
مصافي الشمال
الأسس
الهبوط
المياه الجوفية

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الملخص

تهدف الدراسة الى إجراء تقييم جيوتكنيكي لنماذج من التربة المأخوذة من أربع مواقع مرشحة للتوسعات في شركة مصافي الشمال، شمالي محافظة صلاح الدين على الجناح الجنوبي الغربي لطية مكحول ضمن ترسبات العصر الرباعي لغرض تحديد صلاحيتها لإقامة بعض المنشآت الهندسية وتقييم نوعية المياه الجوفية من خلال إجراء التحليلات الكيميائية ووضع موديل يحاكي تذبذب المياه الجوفية في حال إنشاء مشاريع جديدة. تم إجراء الفحوصات الفيزيائية والهندسية كذلك التحاليل الكيميائية، تراوحت نسب محتوى الرطوبة بين (% 6.39-13.40)، اما قيم الوزن النوعي فتراوحت ما بين (2.67 – 2.74). ومن نتائج التحليل الحجمي بنوعيه الرطب والجاف للتربة وجد بأن نسبة الطين والغرين هي الأعلى، واستنادا الى نتائج حدود اتربيرك وحسب مخطط اللدونة تبين ان نوع التربة CL, ML، وصنفت التربة الى (Medium plastic و Slightly plastic) اما نتائج فحص القص المباشر ، فأن زاوية الاحتكاك الداخلي تراوحت بين (21°-33°) والتماسك بين (56-81 كيلو باسكال). ومن خلال نتائج فحص الانضمام، تبين ان التربة مفرطة الانضمام O.C.R. من خلال نتائج التحاليل الكيميائية لمحتوى الجبس كانت النسبة واطئة الى متوسطة وهي تربة متعادلة القلوية ذات محتوى عضوي يتراوح بين الواطئ والعالي وتحتوي على نسبة عالية من الكبريتات والفلوريدات والبيكاربونات وان نسبة الاملاح المذابة تزيد عن نسبة (0.5%)، وبذلك فأن قيمة EC)) ستكون عالية أيضا. تم قياس اعماق المياه الجوفية لآبار موزعة على منطقة الدراسة وأخذ عينات لعدد من آبار المياه الموجودة بالقرب من المنشأت. إجريت التحليلات الكيميائية للنماذج المائية وبينت نتائج هذه التحاليل ان مياه منطقة الدراسة هي Brackish Water وحسب قيمة (pH) صنفت من معتدلة الى قلوية ضعيفة. واعتمادا على قيم العسرة الكلية، وجد أن مياه منطقة الدراسة هي من النوع العسر جداً.

DOI: 10.33899/earth.2024.145256.1193,

Introduction

The geotechnical assessment of the soil is the first basic step in assessing the feasibility and importance of engineering projects, which is an integral part of geological studies, since the soil is very important from an engineering point of view, because of its tolerance to the various types of foundations, as it must be ensured that it does not fail under the influence of the loads imposed on it. So, the engineer must deal carefully with the soil and carry out all the necessary tests, and take them into account during the design of the engineering (Al-Rashdi, 2004). Additionally, the effect of groundwater on foundations by corrosion salts threatens the safety of facilities, where the salts lead to corrode the concrete and cause weakness in the concrete foundation. An example of this is the presence of gypsum in the region, which means that groundwater contains corrosive soluble sulfates, as well as pyrite, as the water that passes over this mineral will contain a high percentage of sulfate (Saleh et al., 2012). As for the previous studies on the region, Luxury (2013) studied some geotechnical properties of river terrace sediments in industrial facilities in Baiji; the study showed that it is a heterogeneous soil, and the results reflect the medium to high liquid limit. In addition, a study of the consolidation index and swelling index in clay soil is of greater value than in sandy soil (Al-

Darwish, 2013). Some geotechnical properties in selected sites of Baiji City show that fine soil is of low to medium plasticity, and that the study of granular grain size analysis shows that the soil is heterogeneous in properties, vertical distribution, and non-cohesionless soil

Aim of study

The study aims to find some geotechnical properties for construction of some engineering establishments for four proposed sites as expansion in the North Refineries Company in Salah Al-Din Governorate in addition to determining the quality of groundwater in the area affecting soil properties, as well as developing a model that simulates the fluctuation of groundwater and effective stress of the soil.

Location of the study area

The study area is located in the north of Salah Al-Din Governorate in the city of Baiji on the southwestern limb of the Makhul anticline between longitudes (43°16'40”) -(43°33'20") E, and latitudes (34°40'5") and (35°10'40") N (Fig. 1).

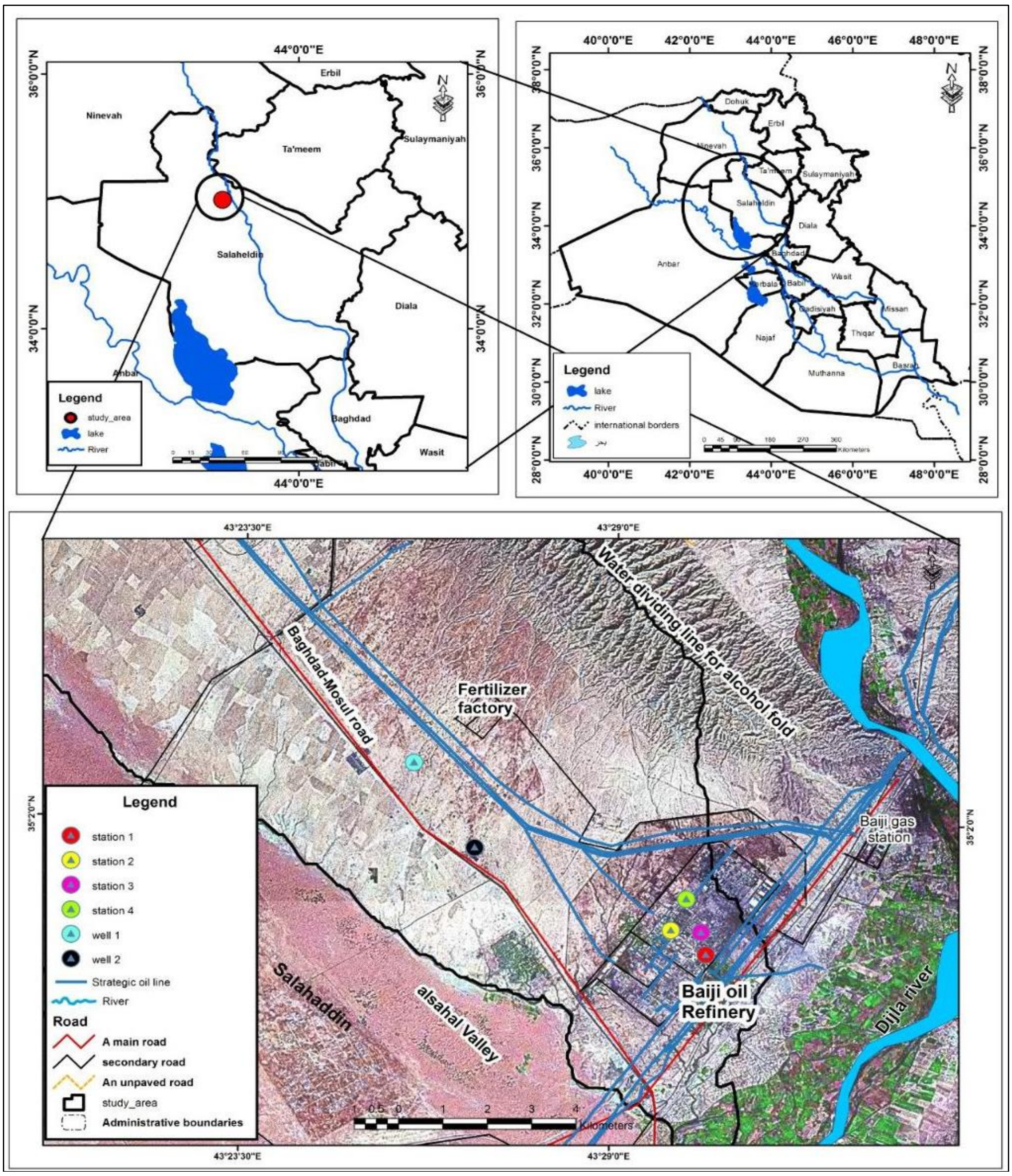

Fig. 1. A map showing the study area.

Geology of the Study Area

The soil of Baiji is derived from the erosion of sedimentary rocks of older formations and contains gravel, sand, silt, and clay; and it appears in the form of alluvial fans of the Quaternary period, especially the rocks of the Makhul Mountain Range having the most important rocks of Miocene period represented by gypsum, limestone and clay of Fatha Formation, and sandstone, siltstone and claystone of Injana Formation. Fatha and Injana formations are exposed at the southwestern limb of the fold. Topographically, the site generally appears to be a flat area interspersed with a very slight undulation, and to the east of the site at a distance of about 3.5 km, there is Makhul Mountain, which borders the study area from the east and northeast, whose fold is one of the most important structural phenomena trending southeast-northwest, and at the same time, this fold represents part of the western boundary of the Low Folded Zone (Jassim and Goff, 2006).

Methodology

The samples are prepared for laboratory tests for physical tests including a specific gravity test according to the American Standard (ASTM D854-14, 2014), grain size analysis with its sieve and wet varieties according to the American Standard (ASTM D422-63, 2007) (Reapproved, 2014), test of the consistency limits (Atterberg Limits) according to the American Standard (ASTM D4318-10, 2007), calculation of moisture content according to standard (ASTM D2216-10, 2010). As for the engineering tests, a direct shear test is done for soil according to the American Standard (ASTM, D 3080-03, 2004); this test includes measuring the elements of shear strength of soil represented by the angle of internal friction (Ø) and cohesion resistance (C). Consolidation test is done according to the American Standard (ASTM D2435-11, 2011) to calculate the (Coefficient of Consolidation), and then to find the (Void ratio), swelling index, the percentage of (O.C.R.) and Pre-Consolidation pressure (PC), chemical analyses of the soil including the percentage of gypsum, the percentage of organic matter, the total dissolved salts, the measurement of pH, the Electrical Conductivity (EC)), and the content of bicarbonate chlorides. These tests are carried out in the laboratories of Tikrit University, in the colleges of Science, Agriculture, and Engineering. Four of the most important sites proposed for industrial facilities establishments in the refineries are sampled. The coordinates of sample sites are recorded using a GPS, as well as all the necessary field tools are prepared, from a tape measure to calculate the thickness of sediment. Drilling is done by a hydraulic excavator to collect disturbed and non-disturbed samples at depths ranging between 2.5-5 m. The analysis of the major and minor positive and negative ions and elements, pH, electrical conductivity, and total dissolved salts of water samples taken from a water well.

Physical Properties

Moisture Content

The moisture content expresses the percentage (M%) of water present in the soil sample, and in another words, it is the ratio of the mass of water (Mw) to the mass of granules or solids (Md) in the mass of soil (Abboud and Zarrak, 2015).

$$M\% = [(M2-M3)/(M3-M1)] \times 100 \qquad (1)$$

where (W%) moisture content., (M2) The mass of the pot with moist soil in gm.

(M3) The mass of the pot with dry soil in gm.

(M1) The mass of the empty pot in gm.

Moisture content values range between (6.39 and 13.40%) (Table 1).

Table 1: The moisture content in soils of the study area.

No.	Sampling depth(m)	Moisture Content
ST1	5	6.39
ST2	4	13.40
ST3	3.17	11.33
ST4	2.5	8.14

Specific Gravity (G_S)

It is expressed as the ratio of weight or mass from the volume of a substance to the weight or mass of the same volume of water at a certain temperature (ASTM D854-14, 2014) at a temperature of 20° and is calculated by the equation:

$$(G_S)(at\ T_1 C^{\circ}) = \frac{W_3}{(W_1+W_3)-W_2} \ldots\ldots\ldots (2)$$

$(G_S)(at\ T_1 C^{\circ})$= specific gravity at test temperature.
W1= Volumetric vial weight + water weight up to (500 mL.
W2 = Water weight + bottle weight + soil weight.
W3= Water weight dry.

The specific gravity values range between 2.67-2.74 (Table 2).

Table 2: The specific gravity values of the study area sites and their classification by (Das, 1982).

No.	Sampling Depth(m)	Specific Gravity	Soil Type
ST1	5	2.67	clay
ST2	4	2.74	Silt
ST3	3.17	2.69	Silt
ST4	2.5	2.72	Silt

Grain Size Analysis

Sieve analysis includes the separation of coarse grains such as gravel and sand into different sizes by manual or mechanical sieving, which is determined by weighing the soil on a set of sieves with standard openings and according to the specification (ASTM D422-63, 2007) is used to examine the grains with sizes greater than (0.075 mm) to find soil wet analysis used, and wet analysis to find the percentages of particles whose sizes are less than (0.075 mm) according to the specification (ASTM D422-63, 2007). Figure 2 shows the grain size analysis of the soil of the study area, and Table 3 shows the results of this analysis and its classification.

Table 3: Grain size analysis and (USCS) Classification for study area soil.

No.	Plasticity limit	Liquidity limit	Plasticity Index	Gravel ratio%	Sand ratio%	Clay ratio%	Silty ratio%	Classification Soil
ST1	22.2	32.9	10.7	3	13.1	44.10	39.8	CL
ST2	20	23.6	3.6	2.7	7.60	40.12	49.58	ML
ST3	28.11	32.25	4.14	3.9	18.25	37.58	40.27	ML
ST4	27	0	3	3	17.9	33.87	45.22	ML

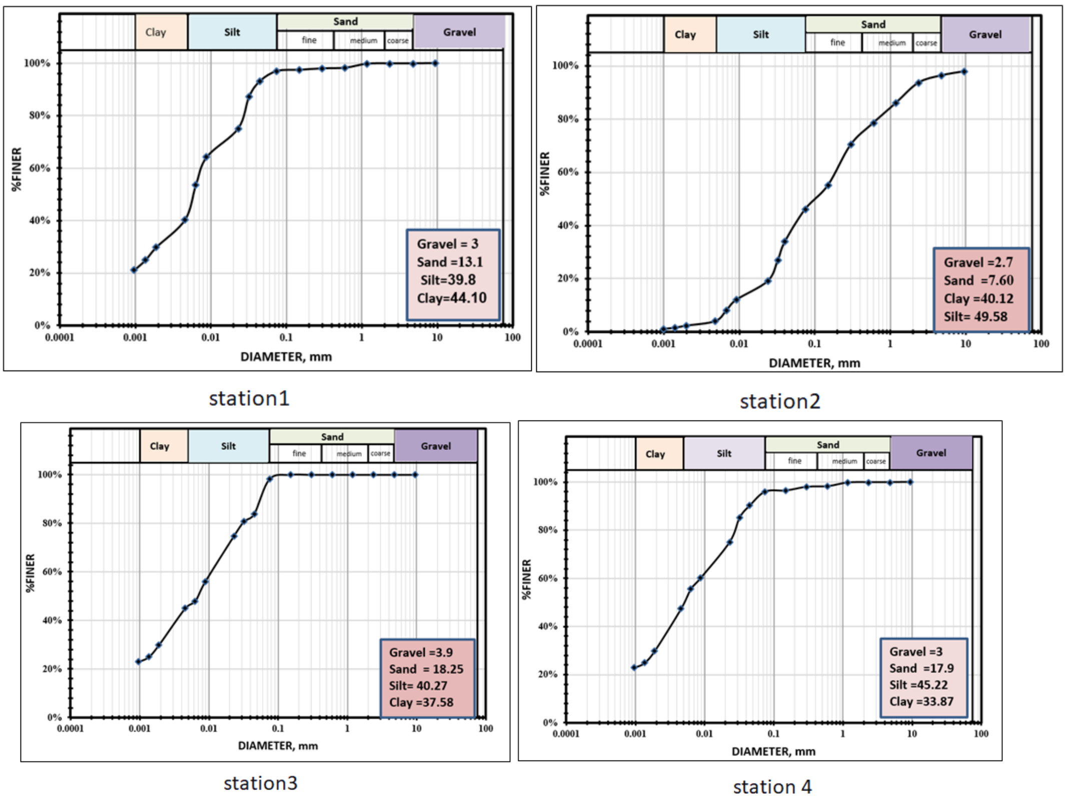

Fig. 2. Grain size analysis of the soil of the study area for stations (1, 2, 3, 4).

Atterberg Limits

Abboud and Zirak (2015) explained that the Atterberg limits are the relative ease with which the soil can be broken down; that is, the first to set the boundaries of the soil is Atterberg, and these limits were named after him as Consistency Limits. They are defined as the moisture content of the soil, in which the soil moves from one state to another. The soil is classified according to the plasticity scheme as in Figure 3. Through the numerical difference between the liquidity limit and the plasticity limit, the plasticity index can be calculated and indicates the water content at which the soil remains in the plasticity state, and the results are listed in Table 4.

$$PI = LL - PL \ldots\ldots\ldots..(3)$$

Where: PI = Plasticity Index, LL = Liquidity Limit and PL = Plasticity Limit.

Fig. 3. Classification of soil according to the plasticity scheme.

Table 4: The results of the plasticity limits and liquidity limit in addition to the soil plasticity index and its classification according to (Das, 2010) for the study area test.

NO	P. L	L.L	P. I	Classification Soil
ST1	22.2	32.9	10.7	Medium plastic
ST2	20	23.6	3.6	Slightly plastic
ST3	28.11	32.25	4.14	Slightly plastic
ST4	27	30	3	Slightly plastic

Engineering Tests

Direct Shear Test

The shear test of the soil is defined as the process of sliding a specific part of the soil over another part in the soil mass. As for the shear strength, it is the force shown by the soil against sliding that occurs inside it as a result of an external force imposed on it. If shear arises inside the soil and is caused by the direct pressure applied to the soil, and that stress exceeds the maximum shear force that initially causes movement or sliding of soil grains on each other (Majeed, 2004). Figure(4) illustrates the relationship between vertical stress and shear stress through direct shear test samples, and Table (5) shows the results of the direct shear test of samples.

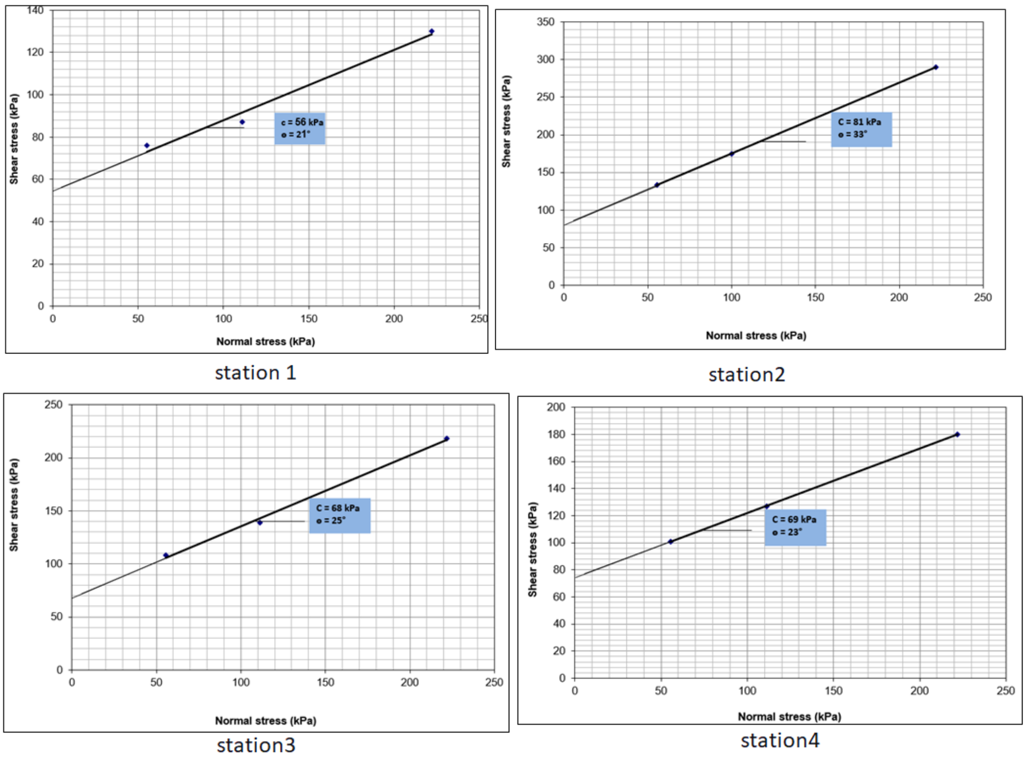

Fig. 4.
The relationship between normal stress and shear stress through the direct shear test of study samples for stations (1, 2, 3, 4).

Table 5: Results of direct shear test of study samples.

No	Ø	C (kpa)
1	**21**	**56**
2	**33**	**81**
3	**25**	**68**
4	**23**	**69**

Consolidation Test

Consolidation is a process of time–dependent saturated clayey soil when subjected to an increased loading (Das, 1982). The subsidence of the soil occurs when it is exposed to the stresses of the foundations erected on it, and this subsidence is not flexible and is the result of the compression of steel columns or concrete, or rolling of granules, or slipping in void spaces. The undisturbed samples are prepared by carving them by hand, and the test is carried out by a device known as the odometer. The ratio of the height of the sample to its diameter is (1:2.5), and using different weights (1, 2, 4, 8, 16, 8, 4, 2, 1, 0.5 kg). Minutes until the passage of a period of (24) hours, the time intervals are taken with each of the weights mentioned above, so the readings that represent the change in the thickness had been taken of the sample (ΔH) by the graduated disc, then the sample is left after lifting the weights gradually for (24) hours after lifting each weight, then the rebound process or called swelling occurs, and then the resulting readings are recorded to draw the (Rebound curve). Figure 5 shows the compression test schemes for the soil models of the study area. Through this test, the following properties are found:

Void Ratio (e)

A ratio of the volume of voids to the volume of the solid (Zayed, 2001), which is an indication of the density of the soil and is calculated by the following relationship:

$$e = \frac{\Delta H}{Hs} \quad \text{..........} \; (4)$$

Compression Index (C_c)

Used to calculate the consolidation when subjected to the loads during the expected construction of the soil. It is expressed by a curved slope of the relationship between the ratio of voids and the log p. The compression coefficient is calculated according to the following equation (Wilun, 1975):

$$C_c = \frac{e2 - e1}{log\, g\left(\frac{P2}{P1}\right)} \; \text{..........} \; (5)$$

Swelling Index (C_r)

It is also obtained from the void ratio versus the applied pressure curve. The swelling index is the slope of the unloading portion (Zayed, 2001).

$$C_r = \Delta e / \Delta \log p \; \text{............} \; (6)$$

Pre-consolidation Pressure P_c

It represents the highest weight previously applied to the soil, and the value of pre-consolidation pressure is of great use in knowing the geological history of the soil. Table 6 shows the results of the consolidation test (Capper, 1974).

$$O.C.R = \frac{Pc}{Po} \; \text{..............} \; (7)$$

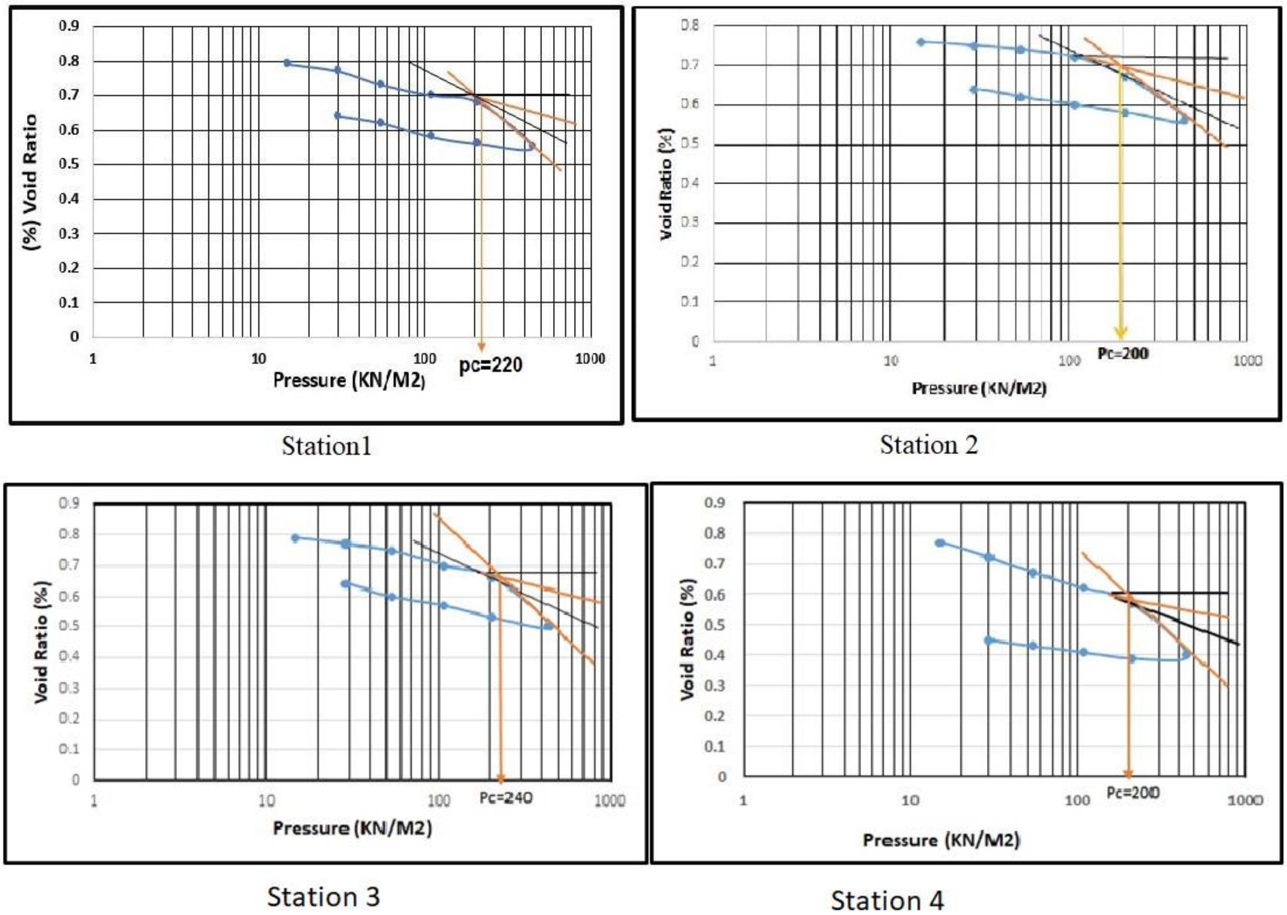

Fig. 5. Consolidation test schemes for soil Samples of the study area.

Table 6: The results of the consolidation test.

No.	Depth (m)	γ_d kN/m^3	Cc	Cr	e	Po kN/m²	Pc	OCR
ST1	5	14.11	0.0125	0.0012	0.6135	70.55	220	3.11
ST2	4	14.18	0.003	0.0005	0.637	56.72	200	3.52
ST3	3.17	15.7	0.0133	0.0022	0.5223	49.76	200	4.01
ST4	2.5	15.8	0.022	0.001	0.5403	39.5	240	6.07

Where: Void Ratio (e), Compression Index (C_c), Swelling Index (C_r), Over-consolidation Soil (OCS), Pre-consolidation Pressure (P_c), Pressure Caused by the Weight of the Soil (P_o).

Chemical Analysis

The chemical properties of the soil are a very important factor in predicting the chemical behavior of the soil and the extent of the soil's tolerance to external factors affecting it, such as erosion and weathering processes. Tables (7,8,9) show the results of the chemical analysis of the soil.

Table 7: The results of gypsum content and classification of gypsum soils depending on (Al-Barazanji, 1973), and pH values and classification based on Ryan et al. (2003), and TDS results for some samples of the study area.

No.	Gypsum%	Classification	pH	Classification	TDS
ST1	12.4	Medium gypsum	7.88	Neutral alkalinity	2490
ST3	8.1	Low gypsum	8.15	Neutral alkalinity	2160

Table 8: The results of the chloride and organic matter ratio of some study area (8 Samples).

No.	Depth (m)	O.M	Cl (meq/l)
ST1	5	1.09	1.20
ST3	3.17	0.89	7.60

When the percentage of Cl is greater than 0.1% in the soil, this high percentage can cause a risk to the foundations that must be avoided before starting the design, using a protective layer of concrete with a thickness of (5-15) cm around the foundations (Bowles, 1984). The percentage of organic matter in the soil is high if it exceeds 1%, but it is possible that 0.5% and sufficient for the soil to avoid problems with its strength, especially if it is saturated and has a high clay content (Baver, 1972).

The presence of sulfates in the soil leads to their solubility in water at a rate of (2.6 $g.l^{-1}$) (Hamza et al., 2010). The sulfate salts included in the components of concrete (aggregates and cement) are some of the most dangerous salts in the soil and groundwater, as they spread between the parts of the concrete and interact with cement compounds leading to the expansion of concrete and corroding it, while the salts in the soil and groundwater are interacting with cohesive concrete and its effect is transmitted by capillary property (Al-Zubaidi, 1998). The electrical conductivity of the soil is a measure of the salts in it; therefore, it will be a source of salts dissolved in groundwater, as in Table 9.

Table 9: The results of bicarbonate ion, sulfate, and electrical conductivity for some models of the study area.

NO	Samples depth(m)	HCO_3 (meq/l)	EC at 25°	SO_4%
ST1	5	3.80	3.75	16.30
ST3	3.17	2.04	3.27	8.03

Calculation of Total, Neutral, and Effective Stresses

The presence of groundwater in the soil can reduce the bearing capacity of the soil, which is one of the engineering properties of soil that determines the ability of soil to withstand external loads, and the extent of subsidence that may occur due to the water affects the shear coefficients, cohesion and angle of internal friction (Khalaf et al., 2020). One of the objectives of this study is to determine the possible land subsidence resulting from groundwater withdrawal, and this subsidence cannot be analyzed without knowing the stresses inside the soil and the change in these stresses when the soil moisture changes. As the water inside the soil plays an important role in calculating these stresses, and any load shed on the soil will be distributed on the soil grains, and the water in the voids as well, the water does not contribute to bearing any percentage of this load when the soil is not saturated. But??? when the soil is saturated, the water inside the voids will bear a part of this load; so the stresses inside the soil change when groundwater is withdrawn. This is described in the method of calculation below in this study, the total stress σ_t, U neutral stress **(**Pore water pressure) s, and effective stress $\bar{\sigma}$ is calculated for different depths of the wells of the study area samples, where the fluctuation of the groundwater level at a depth of (3 m).

Subsidence Calculation

One of the most important problems of foundations is the subsidence of the soil, as all types of soils can be subjected to subsidence, but to varying degrees, and the degree of subsidence varies from place to place according to the causative factor. So, the complete subsidence of the origin may occur once, or it may be heterogeneous (Ranjan, 2016). The subsidence is calculated by the compression index (Cc) since the compression index represents the slope of the consolidation curve (Fig. 5). Therefore, the subsidence can be calculated using the compression index. The subsidence values of the stations (1, 2, 3, 4) in the study area are shown in tables (10, 11, 12, 13). The subsidence is calculated according to the following equation (8) and the results are shown in Table (14).

$$\Delta h = \frac{\Delta e}{1+e_o} \times H \quad (8)$$

Table 10: Results of stress calculations for the first station.

Depth (m)	σt (KN/m^3)	U (KN/m^3)	$\bar{\sigma}$ (KN/m^3)
1	14.11	0	14.11

2	28.22	0	28.22
3	42.33	0	42.33
4	61.33	10	51.33
5	80.33	20	60.33
6	99.33	30	69.33
7	118.33	40	78.33

Table 11: Results of stress calculations for the second station.

Depth (m)	σt (KN/m^3)	U (KN/m^3)	σ¯ (KN/m^3)
1	14.18	0	14.18
2	28.22	0	28.22
3	42.54	0	42.54
4	62.34	10	52.34
5	82.14	20	62.14
6	101.94	30	71.94
7	121.74	40	81.74

Table 12: Results of stress calculations for the Third station.

Depth (m)	σt (KN/m^3)	U (KN/m^3)	σ¯ (KN/m^3)
1	15.7	0	15.7
2	31.4	0	31.4
3	47.1	0	47.1
4	66.48	10	57.06
5	85.86	20	66.72
6	105.24	30	76.38
7	124.62	40	86.04

Table 13: Results of stress calculations for the four stations.

Depth (m)	σt (KN/m^3)	U (KN/m^3)	σ¯ (KN/m^3)
1	15.8	0	15.8
2	55.3	0	55.3
3	102.7	0	102.7
4	165.9	10	155.9
5	244.9	20	214.9
6	339.7	30	279.7
7	450.3	40	350.3

Table 14: The subsidence values of the study area stations.

Station	subsidence (cm)
1	0.283
2	0.259
3	0.353
4	0.496

Groundwater Hydrochemistry

The study included chemical analyses of water samples taken from two wells, represented by positive ions (Cations), including sodium ions (Na^+), potassium (K^+), calcium (Ca^{++}), magnesium (Mg^{++}), as well as negative ions (Anions), including chloride (Cl^-), sulfate (SO_4^{--}), and bicarbonate (HCO_3^-), in addition to measuring the physical and chemical properties of groundwater, represented by electrical conductivity (EC), total dissolved solid salts (TDS), and pH. Table (15) shows the results of chemical analyses of water samples.

Table 15: Results of chemical analyses of water samples.

No.	Ca ppm	Na ppm	K ppm	Mg ppm	Cl ppm	HCO_3 ppm	CO_3 ppm	SO_4 ppm	PH	T.H	EC μc/cm^3	T.D.S mg/l
Well 1	444.6	62.55	3.84	175.5	120.7	82.9	0	1740	7.40	1831.05	3810	3048
Well 2	440	106.34	10.55	353	568	97.6	0	2315	7.78	2547.30	8080	6464

Classification of water by pH value (Davis et al, 1966) is of weak alkalinity when comparing the concentration of total dissolved salts in the groundwater (Table 15) in the study area with the classification of Todd (2005), it is found that the water of the study area is brakish water, and according to the classification of water based on the values of total hardness (Todd, 2005), it is found that the water of the study area is of very high total hardness.

Groundwater Suitability for Industrial Purposes

The results of chemical analyses of water samples (Table 15) are compared with the standard specifications (Table 16) for water used in various industries (Salvato, 1982). It is shown that the study water is not suitable for all types of industries in the table as if it is suitable for a particular element, another element is not suitable, especially for the total hardness that is very high in the study area, as well as the concentration of the SO_4, which has a high effect due to its high concentration.

Table 16: The quality of water used for different purposes (Salvato, 1982).

Paper making	Refineries	Cement industry	Chemical industry	Food industry	Variable
9-6	9-6	8.5-6.5	9-6	8.5-6.5	Ph
-	-	4000	500	300	Basal
475	9000	-	1000	316	Total hardness
5.6	45.13	7.05	14.10	8.46	Cl^{-1}
-	11.86	5.20	17.69	5.2	SO_4^{-2}
0.99	10.97	-	9.98	5.98	Ca^{+2}
0.99	6.99	-	-	8.22	Mg^{+2}
Not suitable	**Not suitable**	**Not suitable**	**Not suitable**	**Not suitable**	**Suitable models**

Groundwater Uses for Building Purposes

When comparing the results of the chemical analyses of the study samples in Table (15) with the proposed limits, and according to the classification of Altoviski (1962) in Table (17), it is clear that they are also not suitable for building and construction purposes.

Table 17: The validity of water uses for building and construction purposes according to the Altoviski (1962).

Ions	Permissible limits of Altoviski (1962)
Na^+	1160
Ca^{++}	437
Mg^{++}	271
Cl^-	2187
$SO_4^=$	1460
HCO_3^-	350

Discussion

One of the most important factors affecting the behavior of the soil is the stress of time and the effect of water. The effect of groundwater appears clearly in the study area as the groundwater level changes seasonally, i.e., increasing in winter and decreasing in summer. This fluctuation in the groundwater level leads to loading and unloading in the soil layers periodically, and the decrease in water leads to soil subsidence. Moreover, the soil in the study area contains a percentage of gypsum, and as a result of the rise of water, gypsum dissolves, so voids are formed leading to the subsidence of the soil, and because the soil in the study area is over-consolidated, the subsidence in this case will be very little, and this is clear in Table (14) as the chemical analyses of the water show that it is neutral and of very high hardness, as well as the water of the study area is not suitable for industrial and construction purposes.

Conclusions

1. It is found that the exposed sediments in the study area are Quaternary sediments, from which the samples are collected.
2. The relatively high moisture content ratios of the samples explain the proximity of the groundwater table or the resulting fluctuation due to artificial water, as well as the modeling time and depth of the samples, which have an impact on the moisture content.
3. Varying specific gravity values indicate soil heterogeneity.
4. The soil of the study area is of low to medium plasticity and predominantly fine, as there is a relative predominance of fine sizes (clay) relative to the coarse sizes (silt), which are CL, ML.
5. The results of the direct shear test show that the soil is of the cohesive type.
6. The low value of the voids reflects the nature of the soil in the study area, which is fine and compact soil due to the convergence of the granules to each other.

7. The results of the consolidation test show that the compaction index of the soil is low due to the lack of voids and the evidence of varying swelling and that the soil is over-consolidated OCR.
8. Subsidence values are close to the homogeneity of the soil in the study area.
9. Through the results of the chemical analyses of the gypsum content, the ratio is medium to low, which is a neutral alkaline soil with an organic content ranging from high to low and contains a high percentage of sulfates, bicarbonates, and chlorides, and the percentage of dissolved salts exceeds (0.5%), which is considered high, so that the value of EC will also be high.
10. It is found that the water in the study area is brackish, and this water is classified as very hard, and according to the value of pH, the water is classified as weak alkaline.
11. The results of the analysis of the region's water are compared with the specifications of the suitability of using groundwater for various purposes, as it is not suitable for industrial uses except after some chemical treatments to modify some water properties, and is not suitable for building and construction purposes.
12. The presence of high concentrations of calcium ions in the water is the result of the process of dissolving gypsum, calcium carbonate, dolomite, or clay minerals in the soil in the study area.

Acknowledgements

The researcher extends her thanks to everyone who extended their help to me, to the residents, and the respected editor-in-chief and editorial staff members of the INJES magazine.

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