

Geotechnical Assessment and Soil Improvement of Al-Hilla Gas Station Site, Babylon, Iraq

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Abstract

This paper studies the geotechnical properties of the soil at Al-Hilla Gas Station, based on investigations conducted in 2024. The study included digging four boreholes to a depth of 15 m. The evaluation was based on fieldwork and laboratory test results for both disturbed and undisturbed soil samples taken from the study site. The results showed that the type of soil is silty clay containing a small percentage of sand up to a depth of 6.5 m and is classified as highly plastic clay and low plasticity. Beyond a depth of 6.5 -15 m, the soil is classified as medium to high density sandy silt. A chemical analysis results indicated that the groundwater is slightly basic, while the salts content ranged from medium to high. The water also contained a high percentage of sulphates. The organic matter content ranged between 0.54-5.77%, the total soluble salts between 9.14-17.21%, and the gypsum content between 5.87-10.43%. The average number of hits (N) for standard penetration test (SPT) was between 9-43, the groundwater level was 3.90 m, and the moisture content (MC) ranged between 9.1-28.4%. The liquid limit (L.L.) ranged from 36-51%, the plastic limit (P.L) from 18-21%, and the plasticity index (PI) from 20-33%. The average soil effectiveness value was around 0.50, classifying the soil as inactive. The soil bearing capacity ranged between 2.16-2.56 tons. For the dynamic method, the bearing capacity ranged between 5.15-5.24 tons/m². Several engineering treatments can be used depending on type of soil, groundwater level, and type of structure. Based on the results, this study recommends that the best type of treatment is soil replacement, by removed surface layers and replaced with gravel or clean, compacted sand.

Keywords: Al-Hilla Gas Station; Borehole; Soil treatments; Bearing capacity; investigations; Geotechnical evaluation.

التقييم الجيوتكنيكي وتحسين التربة لموقع محطة غاز الحلة ، بابل ، العراق

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الخلاصة

يتناول هذا البحث الخصائص الجيوتكنيكية للتربة في محطة غاز الحلة، استناداً إلى التحريات التي أجريت عام 2024. تضمنت الدراسة حفر أربعة آبار بعمق 15 متراً. واستند التقييم إلى العمل الحقلّي ونتائج الفحوصات المختبرية لعينات التربة المضطربة وغير المضطربة المأخوذة من موقع الدراسة. أظهرت النتائج أن نوع التربة هو طين غريني يحتوي على نسبة صغيرة من الرمل حتى عمق 6.5 متر، ويُصنف على أنه طين عالي اللدونة ومنخفض اللدونة. أما على عمق يتراوح بين 6.5 و15 متراً، فنُصنف التربة على أنها غرين رملّي متوسط إلى عالي الكثافة. أشارت نتائج التحليل الكيميائي إلى أن المياه الجوفية كانت قاعدية قليلاً، بينما تراوح محتوى الأملاح بين المتوسط والمرتفع. كما احتوت المياه على نسبة عالية من الكبريتات. تراوح محتوى المادة العضوية بين 0.54 - 5.77%، والأملاح الذائبة الكلية بين 9.14 - 17.21%، ومحتوى الجبس بين 5.87 - 10.43%. تراوح متوسط عدد الإصابات لاختبار الاختراق القياسي بين 9 و43، وبلغ منسوب المياه الجوفية 3.90 متر، وتراوح محتوى الرطوبة بين 9.1 و28.4%. وتراوح مدى حد السيولة بين 36 و51%، وحد اللدونة بين 18 و21%، ومؤشر اللدونة بين 20 و33%. بلغ متوسط قيمة فعالية التربة حوالي 0.50، مما يُصنفها على أنها غير نشطة. وتراوح قدرة تحمل التربة بين 2.16 و2.56 طن/م²، بالنسبة للطريقة الديناميكية، تراوحت قدرة التحمل بين 5.15 و5.24 طن/م². يمكن استخدام معالجات هندسية متعددة حسب نوع التربة، ومستوى المياه الجوفية، ونوع المنشأة. بناءً على النتائج، توصي هذه الدراسة بأن أفضل أنواع المعالجة هو استبدال التربة، بإزالة الطبقات السطحية واستبدالها بالحصى أو الرمل النظيف المضغوط.

1. Introduction

It is no secret that knowledge of the soil, its form, and its engineering, physical, and chemical properties has a significant impact on the success of construction projects. Knowledge of the soil's bearing capacity, type, and various properties directly determines the choice of foundation type and materials. Therefore, it has become necessary to study the factors that affect the establishment of different projects and facilities, both from the design and implementation aspects, as well as those that contribute to their sustainability and performance. This ensures reduced the cost and effort, whether for maintaining existing projects or when new projects ones in the future. Preparing these studies requires conducting borehole tests, where the number, depth, and distance between pits depend on the size and importance of the project. In most cases, such studies are very expensive [1]. The natural soil we deal with was formed as a result of the influence of physical and chemical factors on the Earth's crust over thousand to millions years. As a result, the main characteristics of the soil were developed [2]. During this long period, soil has been exposed to numerous effects and fluctuations in natural conditions, where new soil is constantly being formed. External factors such as wind, water movement, and temperature fluctuations play a significant role in changing the composition of the soil, in addition to earthquakes and volcanoes, which are equally important. Therefore, the physical, engineering, and chemical properties of the soil at the industrial buildings site, along with the problems it is exposed to and the impact of groundwater were studied and evaluated for engineering purposes. This was done to achieve a more accurate and better understanding of its behaviour when constructing facilities. In addition to the projects that deal with different soil layers, and then the correct and scientific understanding of some of the problems that the soil is exposed to, as familiarity with the physical properties of the soil can be used to evaluate the soil [3], and these properties include: Grain Size Analysis of the soil, Atterberg & Consistency Limits (Liquidity Limit and Plasticity Limit) and Plasticity Index., and Moisture Content (Content Water). Soil Activity (Clay Activity) Where the granular gradation of the soil is the basis that can be referred to in any soil classification system, as for the indicative properties of the soil (properties Index (including the consistency index (consistency Index) and the liquidity index (liquidity Index) and the durability index (Index Toughness) as well as soil permeability and shear resistance and classification of clay soil can be obtained from attreberg limits, as they all share in knowing the behaviour of the soil and give an impression of whether the soil is exposed to the phenomena of shrinkage and swelling as well as estimating the mineral content of the soil. Also, knowing the chemical properties of the soil helps in determining the type of materials and treatments used in the foundations. [4]. This study included the study of some chemical properties of the soil and according to the information available about the study area, it included the sulphate ion (SO_4) and the soil content of organic matter (OM) and the percentage of total dissolved salts (TDS). The engineering properties of the soil determine (bearing capacity and settlement), and thus it determines the suitability of the soil for the purpose of constructing various buildings from an engineering point of view [5]. This study included the study of soil resistance represented by the value of (N) in the standard penetration test (SPT) as well as the cohesion resistance and the angle of internal friction that we obtain from the direct shear test of the soil and the joining properties represented by the joining coefficients, as calculating them gives the possibility of knowing the soil's bearing of the loads placed on it, to know type of soil and thus choose the best treatment.

2. Materials and Methods

2.1: Study Area Location and Soil Sampling

The study area is located in Babylon Governorate, within the industrial site of Hilla city, about 100 km southeast of Baghdad. The area is relatively flat with a ground elevation of 32m, and the water table is at A depth of 3.9 m. According to the geotechnical borehole Figure 1, the site consists of up to 15.0 m of light to dark brown clayey and silty sand soil Figure 2. All soil samples were properly secured using sealed plastic bags for laboratory analysis. Figure 2 shows a location map of the boreholes in the study area, and Table (1) represents the boreholes coordinates’

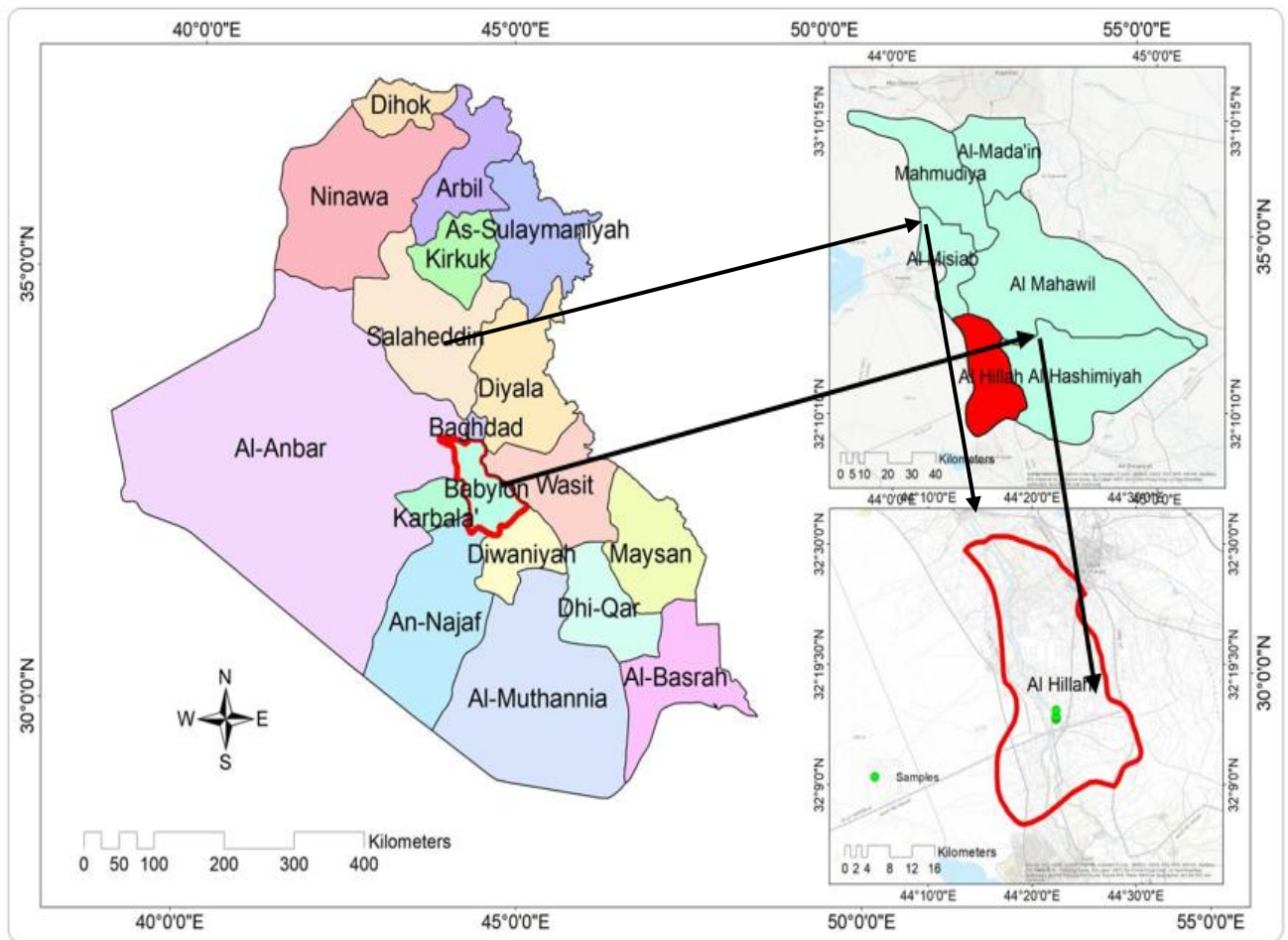


Figure -1 The location map of the study area including the satellite image of Al-Hilla Gas Station

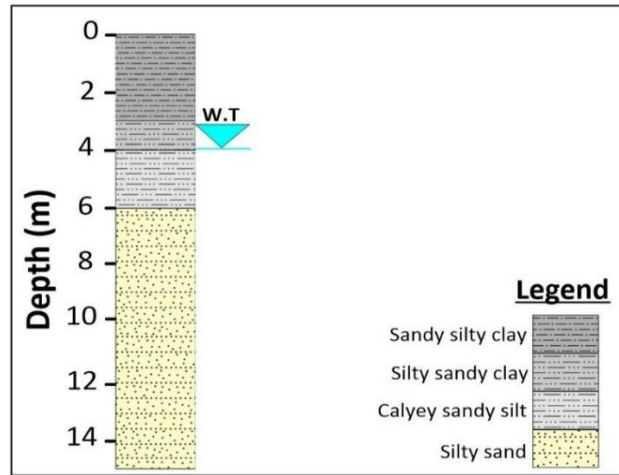


Figure -2 Soil profile in the study area

Table 1- Boreholes coordinates

BH. No.	Depth m	Coordination		Activity
		E	N	
1	15	442641.06	322600.64	Drilling ,SPT,DS,US
2	15	442640.74	322600.29	Drilling ,SPT,DS,US
3	15	442641.02	322601.43	Drilling ,SPT,DS,US
4	15	442640.33	322600.74	Drilling ,SPT,DS,US

2.2 Geology of the study area

Babylon Governorate (study area) is located in the unstable shelf within the sedimentary basin [6], and within the stable shelf According to modern classification of Iraq, [7]. From a geological perspective, the area consists of recent deposits from the Quaternary period (Pleistocene and Holocene) [8]. The results of the geotechnical studies in Babylon Governorate have shown weakness in the upper soil layers [9].

2.3 Sampling and Testing Methods

The research included studying the physical, engineering, and chemical properties of soil in the study area by drilling four boreholes using the rotary drilling method, following American Society for Testing standards [9]. A mechanical auger with a diameter of 10 cm was used to drill to a depth of 15 m (Figure 1, Table 2). During this stage, three types of soil samples were obtained:

A. Disturbed Samples (DS): Collected from drilling products according to depths recorded in the borehole logs (0.5–1.5 m or deeper as needed). These samples were crushed and taken during drilling for laboratory tests [9].

B. Samples Spoon Split(SS): Obtained using the standard sampler during the Standard Penetration Test (SPT) at different depths, depending on soil layer changes.

C. Undisturbed samples (US): Collected using a Shelby tube and suitable hydraulic presses to minimize disturbance, according to ASTM standards [9].

These were taken at depths (1–2) m or when soil layer changes were observed, and then carefully transported for laboratory testing.

Table2- Explains the types of models, how to use them, and the type of laboratory tests

Type of sample	Method of executed	Test carried on a sample
1) Disturbed sample (DS)	Helical auger of machine	Consistency, grain size distribution, chemical analysis, specific gravity.
2) Undisturbed Sample(US)	Shelby Tube	Strength tests, consolidation tests, density.
3) disturbed sample SS	Split Spoon	Consistency tests, grain size, chemical tests, density, strength.

2.3.1 In -Site Testing (field test)

This part of the work is carried out in an overlapping manner from the work part , where on-site tests of the soil of the study area are carried out during the drilling process for the test holes by conducting a standard penetration test and measuring the groundwater level as follows:

1. Standard Penetration Test

The standard penetration test (SPT) is one of the important field tests to calculate the soil bearing capacity on-site for all depths and in each test hole. It also determines the relative density of sandy and gravelly soil (cohesionless soil) and the soil consistency (Consistency) of cohesive silty clay soil (Soil Cohesive) based on the specifications [10]. The SPT device consists of a (Spoon Split) tube with an internal diameter of (35 mm) and an external diameter of (50.8 mm) and a length of (460 mm) is pushed into the ground by an iron hammer weighing (63.3 kg) moving on an iron column (760 cm long) where the number of blows (Blows-N) is calculated to descend to a distance of (300 mm). If the soil is soft, penetration will be fast and with a small number of blows. If the soil is hard, the penetration will be slow and with more blows. During the drilling work, a SPT test was conducted for different depths of the test holes ranging from (1.5 to 15) m for each test hole.

2. Groundwater level

` The groundwater level where it was measured from the surface of the natural ground during the month of October, 2024 after a period of 24 hours had passed since the completion of drilling work for each test hole. The groundwater level in the test hole was fixed, which is a level that can change during the seasons of the year. Water samples for the test holes were taken and sent to the laboratory to conduct a chemical analysis of the groundwater, the water table was encountered, as observed during the time of exploration at depths of (3.90) m, below the existing ground level. The water level measurement was conducted according to [9].

2.3.2. Laboratory Test

Laboratory tests are conducted on soil samples in addition to the field tests that were conducted (standard penetration test) SPT. The research included determining the required laboratory testing program as well as conducting physical, chemical and engineering tests for the soil of the study area. The tests required to be conducted on each sample were also determined depending on the type of test sample (US, DS and SS) and according to ASTM and BS specifications for each test.

1. Physical Properties of Soil: Includes Atterberg Limits & Consistency, Moisture Content [the presence of water has two important effects on the behavior of different types of soil: the first is that it creates pressure between soil particles, especially clayey ones, and the second is that it creates pore pressure which affects the behavior of the soil [11]. Soil plasticity is also an indicator of moisture content and , grain size analysis is considered the basis for soil classification and inference of its properties (Bowles, 1984), The grain size gradient distribution curves for soil samples taken from test pits in the study area were found through sieve analysis , while the wet analysis method (Hydrometer) was relied upon in determining the percentages of fine particles (silt and clay) passing through sieve No. 200(less than 0.075 mm), and when the percentage of materials passing through sieve greater than 12% of the sample weight, or approximately 50 gm.

2. Engineering Properties of Soil: Includes are Standard Penetration Test (S.P.T) , Shear Test and Settlements.

3. Chemical Properties of Soil: Includes are Percentage of sulphate ions (% SO_3) , Percentage of organic matter (OM) , Total soluble salts (T.S.S) ,Gypsum content and Chemical analysis of groundwater . The origin of organic matter is either plant or animal, and plants are considered the main source of organic matter as they result from the decomposition and decay of plants, coal, and pieces of shells. Soil that contains organic matter can be distinguished by a high percentage of its black or dark lead color, in addition to its smell emanating from those organisms [18]. Organic matter is considered from an engineering point of view to have undesirable properties, and its undesirable effects include the following:

- a. Decrease in bearing capacity and increase in compressibility (Compressibility) [2].
- b. Increased possibility of swelling and shrinkage (Shrinkage and Swelling) as a result of a change in the moisture content as it absorbs large amounts of water up to (5) times or more of the weight it occupies, where the volumetric change in the organic soil that absorbs water can lead to the phenomenon of swelling (Swelling).

Salts are the most common salts in soil, especially sodium, magnesium and calcium sulphate salts [2]. Gypsum deposits are the most important sources of sulphates, as the continuous evaporation of gypsum water ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) leads to the precipitation of calcium sulphate salts (CaSO_4),.The importance of the sulphate ion (SO_3) comes from the fact that it attacks concrete and reacts with cement compounds (aluminates). The

products of this reaction are gypsum and calcium sulfoaluminates. These reactions are accompanied by an increase in volume, leading to expansion and disintegration of concrete. Organic matter is usually found at shallow depths, but in some cases it is found at great depths as a result of ground movement, earthworms, and some other possible reasons [19].

As for all soil salts that are soluble in water, as the degree of solubility of salts varies according to their nature, chloride salts are generally easier to dissolve than carbonates and sulphates, and the degree of solubility is affected by temperature, pH value, and the amount of dissolved CO₂ gas, in addition to the evaporation process and humidity [20]. The importance of this test comes to estimate the proportions of salts that cause corrosion of concrete and pipes in addition to reinforcing steel. When their solubility is freely soluble in water, they greatly affect the degree of damage to concrete [17].

3. Results and discussion

The American and British international specifications (BS and ASTM) were used in conducting laboratory tests on soil samples from the study area to determine their physical, engineering, and chemical properties, as follows:

3.1 Physical Properties of Soil

3.1.1 Grain Size Analysis

The particle size analysis of soil samples from the boreholes showed that the percentage of sand ranged from 17-91%, silt from 6-42%, and clay from 2-58%. Based results, the soil was classified as silty clay containing a small percentage of sand up to 6.5 m below ground level. This soil is further categorized as highly plastic clay and low plastic clay, varying with depth. At depths of 6.5-15.0 m, the soil is classified as medium to high-density silty sand Figure 3.

3.1.2 Atterberg Limits

The percentages of the liquid limit (L.L.) ranged from (36-51 %) and the plasticity limit (P.L.) ranged from (18-21%). Thus, the plasticity index (P.I.) has a value ranging from (20-33%) as shown in Tables 3. Based on the unified soil classification (USCS), the soil is highly plastic clay (HC) and low plasticity (LC) and highly plastic and low plasticity alluvial. These percentages fluctuate with depth for all sites. The plasticity index is considered one of the important properties of the soil, as the soil can be classified accordingly as in fig.4 and Table 3.

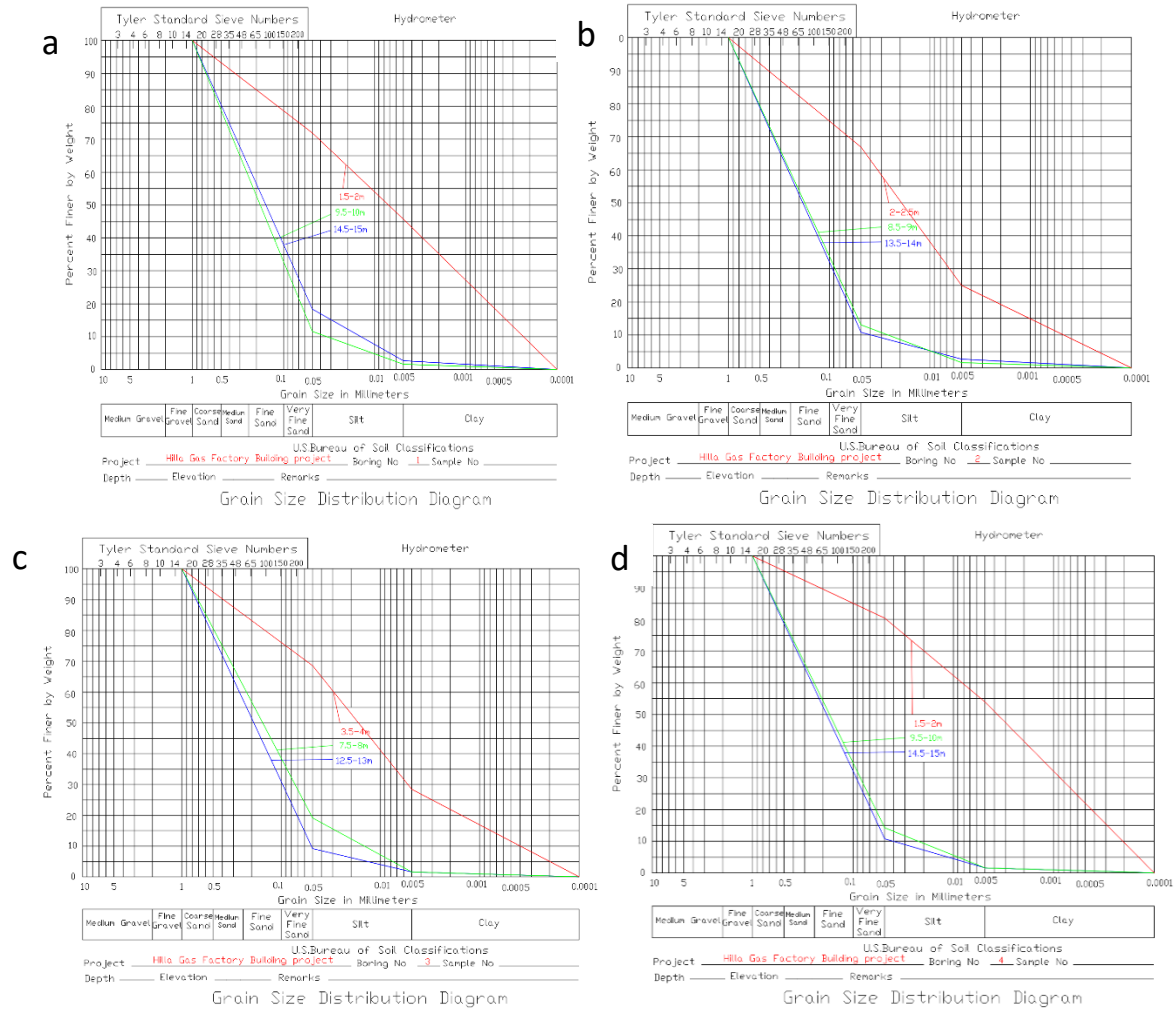


Figure -3 Results of sieve analysis for boreholes a:(B.H.1), b:(B.H.2), c:(B.H.3), d:(B.H.4).

3.1.3 Activity of Soil (A)

The average soil activity values for the study area ranged between (0.476 - 0.522) and are shown in Table 4, where it was found that the average soil activity value for the study area is (0.50), which is a low value and the soil in the study area is classified as ineffective depending on its degree of activity. Values of Activity (A) in Table .4 less than 0.75 are termed inactive clays. Normally active clays have activities between 0.75-1.25. The samples with activity more than 1.25 are active clays. The soil samples have an activity of less than 0.75. This means that the samples are of inactive clay.

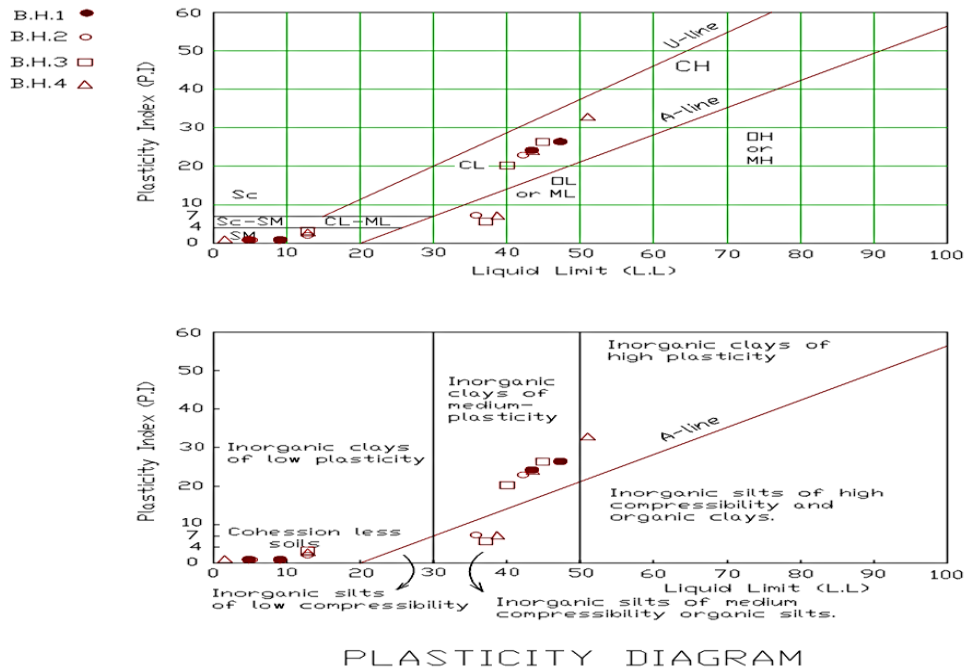


Figure -4 Plasticity chart for soil in the study area

Table 3- Plasticity Index and Liquid Limit PL=LL-PI

Type of sample	B.H. No	Depth (m)	System of classification Sieve & Hydrometer				Properties index					
			Clay %	Silt %	Sand %	Gravel. %	PL %	LL %	PI %	Mc	LI	A
US	1	4.5-5	42	25	33	0	21	41.0	20.0	25.6	0.230	0.476
DS	4	3.5-4	46	23	31	0	19	43.0	24.0	6.2	-0.533	0.522

3.1.4. Moisture Content

Moisture content ranged between 9.1–28.4%, indicating medium levels. This condition causes problems related to soil consolidation, swelling, shrinkage, and reduced cohesion. The silty clay composition and shallow groundwater table contribute to the high moisture content.

3.2 Engineering Properties of Soil

3.2.1 Bearing Capacity

Two methods were relied upon to calculate the soil capacity, namely: the dynamic method, which depends on the number of hits (N) of the standard penetration test (SPT) in the field, and the static method, which depends on the results of laboratory tests. Dynamic method is number of blow ranged between (8 - 48) hits, and based on this, the capacity ranged between (5.15-5.24) tons/m² for depths of (1.0 - 3) m, respectively, and was calculated based on the equation (Meyerhof, 1965) as follows:

$q_{ull} = N / 0.08 [(B + 0.3) / B]^2 (1 + 0.33 D_f / B)$ Table 4 and 5. Figure .5 shows the value of the number of blow N for the standard penetration test for each test hole with the depth of soil.

Static method, In this method, the bearing capacity is calculated based on engineering tests, as shown in Table. 6, where the values of soil cohesion (Cu) ranged between (2.16-2.56) tons/m² and the values of the internal friction angle Øu ranged between (4-10) degrees. The bearing capacity is calculated based on the following equation from Meyerhof's and for different depths:

$$q_{ult} = C N_c S_c d_c + \gamma D_f N_q S_q d_q + 0.5 \gamma_{sub} B N_\gamma S_\gamma d_\gamma \text{ (vertical load)}$$

Table 4- shows the results of the standard penetration test (SPT) for the study area.

Depth (m)	SPT(N) Total for 300mm BH.1	SPT(N) Total for 300mm BH.2	SPT(N) Total for 300mm BH.3	SPT(N) Total for 300mm BH.4	Average SPT(N) Total for 300mm
1-1.5		12	18		13
1.5-2	13			14	15
3-3.5	12	9	9	11	11
4.5-5		15	13		12
5.5-6	14			10	10
7.5-8		14	22		18
8.5-9	27			24	25
10.5-11		21	29		25
11.5-12	32			25	28
12.5-13		30			30
13.5-14			41		41
14.5-15	38	31		43	37

Table 5- Estimated net allowable bearing capacity (T/m²) for Raft footing (based on SPT results)

BH.No	Depth of footing	Footing width B	q _{all} (Ton/m ²)	Foundation type
	M	M		
All Boreholes	1	35	5.15	Separate, combined, raft
1 to 4	2	35	5.20	Separate, combined, raft
	3	35	5.24	Separate, combined, raft

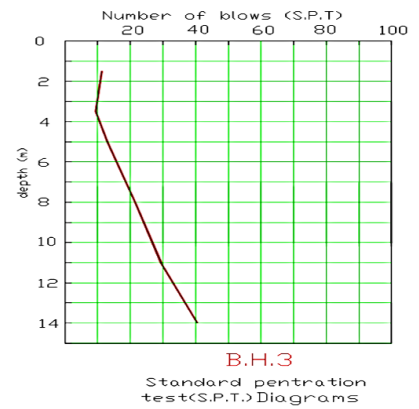
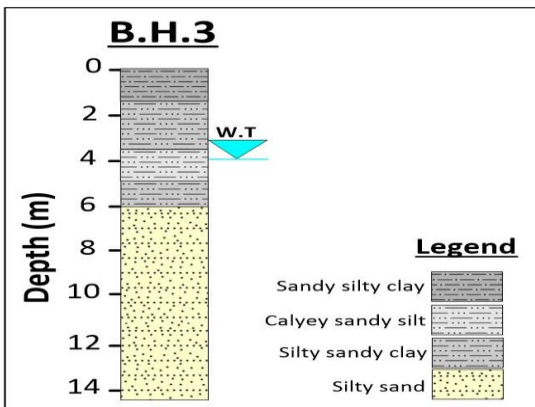
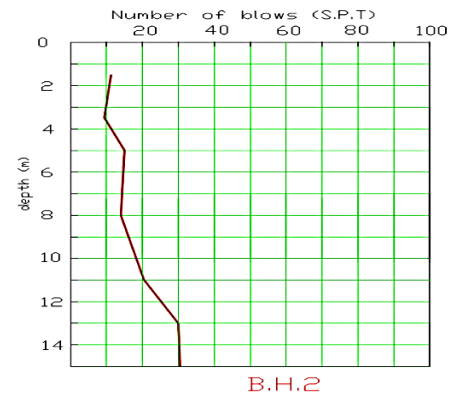
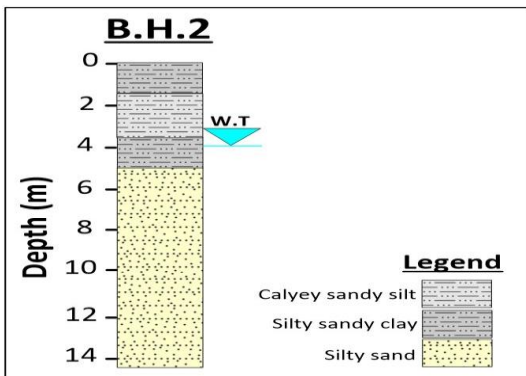
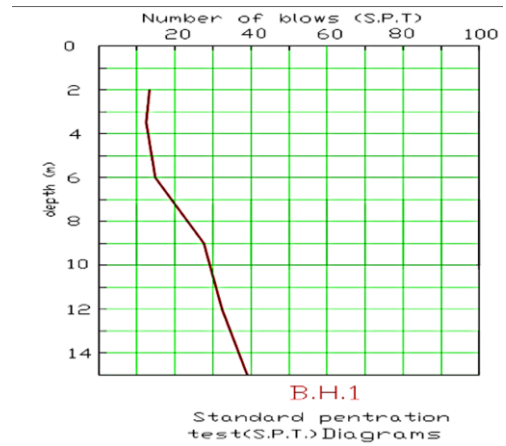
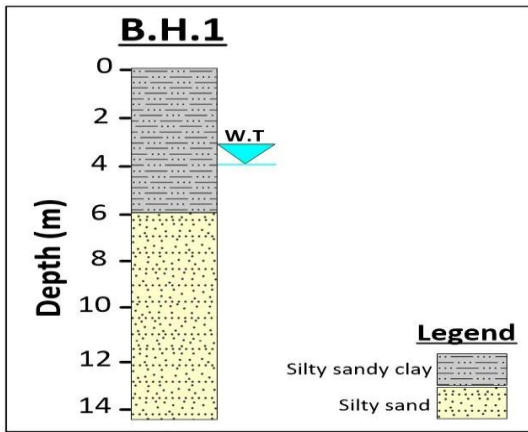


Figure -5 soil profile and SPT blow with depth through boreholes

Table 6- Strength parameters (unconfined & triaxial test and direct shear test results with depth)

BH. No	Depth m	Triaxial test		Direct shear test		γ gm/c m ³	γ ^{wet} gm/cm ³	γ ^{dry} gm/cm ³	Qu T/m ²
		Undrained Cu T/m ²	Undrained ϕ_u	Drained C T/m ²	Drained ϕ				
BH.1	2.5-3	2.36	6	-	-	1.67	1.66	4.72	
=	4.5-5	2.45	10	-	-	1.68	1.34	4.90	
=	8.5-9	-	-	0.00	29	1.75	1.36	-	
=	11.5-12	-	-	0.00	31	1.81	1.42	-	
BH.2	3.5-4	2.33	7	-	-	1.67	1.53	4.66	
=	7.5-8	-	-	0.00	17	1.69	1.31	-	
=	10.5-11	-	-	0.00	24	1.71	1.32	-	
BH.3	2.5-3	2.17	7	-	-	1.58	1.57	4.34	
=	5.5-6	2.56	10	-	-	1.69	1.34	5.12	
=	7.5-8	-	-	0.00	25	1.71	1.33	-	
=	10.5-11	-	-	0.00	30	1.76	1.37	-	
BH.4	2.5-3	2.26	4	-	-	1.69	1.67	4.52	
=	3.5-4	2.16	9	-	-	1.65	1.53	4.40	
=	8.5-9	-	-	0.00	31	1.73	1.35	-	

Table.7 allowable bearing capacity T/m² ranged from (5.18 -6.93 T/m²) . Through the results of the shear test on soil samples extracted from test pits and the standard penetration test (SPT) table 4,5 and the results of which are shown in table.7 , the results indicated that the cohesive soils had a consistency ranging from weak to medium to strong, while for the non-cohesive soils, their consistency ranged from weak to medium to dense.

Table 7- show allowable bearing capacity T/m²

Df= the depth of foundation (m)	allowable bearing capacity T/m ²
(1.0) m	(5.18) T/m ²
(2.0) m	(6.00) T/m ²
(3.0) m	(6.93) T/m ²

3.2.2. Soil Settlement

By conducting a consolidation test on some soil samples extracted from borehole test, it was found that the expected consolidation of the study area is within acceptable limits and that the cohesive soil is excessively compact. Table 8. shows the results of the consolidation test. It was found that the soil is normally slightly over consolidated clay at a depth of about 5.0m. below N.G.L. The compressibility of the soil can be described as moderate compressible, the value of the compression index and swelling index are ranging from (0.150-0.177) and (0.019-0.026), respectively. Volume Change Coefficient: m_v : (0.00024-0.00029) m² /MN, Vertical Consolidation Coefficient v_v : (0.00043-0.00055) m² / yr.

Table 8- Show the results of the consolidation for the study area.

No of BH	Depth m	Parameters of Consolidation test								
		γ_t g/cm ³	Mc	e_0	C_c	C_r	P_c T/ m ²	P_o T/ m ²	mv m ² /MN	C_v m ² /yr
BH.1	4.5-5	1.68	25.6	0.716	0.150	0.022	11.5	7.30	0.00026	0.00045
BH.2	3.5-4	1.67	9.1	0.668	0.143	0.019	10.5	6.68	0.00024	0.00043
BH.4	2.5-3	1.69	1.0	0.832	0.177	0.026	10.0	5.10	0.00029	0.00055

3.3. Chemical Properties of Soil

3.3.1. Sulphate Content in Soil

The chemical tests of the soil samples were analyzed for sulphates, organic matter content, TSS, and gypsum content. The results are summarized in Table 9. It is clear that the value of sulphate as SO₄ % is in the range of (2.73-4.85 %). The percentage of organic matter of soil samples is varied from 0.54 to 5.77 %. The percentage of organic matter in the soil can be described as high if it exceeds (1%), but the percentage of (0.5) % may be sufficient to be problematic for the strength of the soil. In general, when the percentage of organic matter in the soil ranges between (2-3%), it changes the resistance of the soil to its compressibility as mentioned by [18]. The proportion of dissolved salts in the soil of the study site ranged between (9.14-17.21) % for different depths, and the proportion is considered high if it reaches more than (0.5) % because it increases the strain (Strain) in the clay soil layers, as the salts work to change the inter-particle distances, and then the salts work as one of the main compounds for emotion [19] [20]. The gypsum content in the study area was studied for the risks it poses to soil resistance and to the differential settlement of buildings and foundations and the occurrence of gaps and cavities due to the solubility of gypsum in the groundwater that floods these soils or passes through them. It also has an effect on concrete because the sulphate ion reacts with the lime (Slacked lime Ca(OH)₂ present in Portland cement to form crystalline gypsum and the volumetric expansion of gypsum exerts a cracking effect on concrete. The presence of gypsum also reduces the maximum dry density and increases the percentage of moisture content, reduces soil resistance and the possibility of swelling of gypsum soils and then works to change the composition of the soil or push the structures and foundations in the event of saturation of these soils, and since gypsum is soluble in water, which leads to the effect of gypsum soils when exposed to changes in the percentages of water content due to fluctuations in the groundwater level or water leakage into it, which leads to the dissolution of part of the gypsum content in it and the enlargement of the gaps originally present in the soil mass, which leads to the subsidence of the soil under the applied loads. As for the study area, the percentage of gypsum ranged between ((5.87-10.43) %), and for different depths, and the percentage of gypsum is considered dangerous for foundations if it is greater than (5%) of the model.

Best treatment is using sulphate resistance Portland cement (S.R.P.C), for concrete foundation in contact with soil, add an amount of bitumen layer with a thick depending on type of design, minimum cement content is 410 kg for cubic meter at all sides of concrete, maximum (water to cement) ratio is 0.50 by weight, the foundation protection with three layers from bitumen after concrete reinforcement below ground level due to high chloride percent of content. Table .10 shows the percentage of sulphate in the soil of the study site.

Table 9- Results of chemical analysis for soil

No. of BH	Depth (m)	SO ₃ (%)	Gyp. (%)	TSS (%)	ORG (%)	Cl%
BH.1	1-1.5	2.73	5.87	9.14	5.77	0.036
=	2.5-3	3.11	6.69	11.62	2.28	0.032
BH.2	4.5-5	3.52	7.57	12.43	1.10	0.029
=	6.5-7	4.17	8.96	14.51	0.81	0.025
BH.3	8.5-9	4.43	9.52	16.36	0.69	0.022
=	10.5-11	4.85	10.43	17.21	0.62	0.018
BH.4	12.5-13	3.90	8.38	13.70	0.54	0.015

3.3.2. Chemical analysis of the groundwater

The results of the chemical analysis were as shown in Table.10, where the results of the chemical analysis of the groundwater indicated that the water was slightly alkaline, while the salts the percentage ranged from medium to high, and the water also contained quantities of sulphates.

Table 10- Chemical analysis for ground water

BH .No	SO ₄ (mg/l)	Depth water (m)	Cl (mg/l)	pH	HCO ₃ (mg/l)	TH (mg/l)	TDS (mg/l)
1	1281	3.90	352	8.1	371	1126	5224
3	1286	3.90	355	8.2	376	1129	5228

4. Soil treatment

The weak and unsuitable soil at the Al-Hilla Gas Station construction site in Babil Governorate, Iraq, require improvement. Several engineering treatments are available, economically feasible, and can be applied depending on the soil type, groundwater level, and type of structure. The most prominent possible treatments are: [20]

1. Soil Replacement: Removing weak surface layers and replacing them with improved soil such as gravel or clean, compacted sand ,suitable when the weak layers are shallow and do not exceed 2–3 meters deep.
2. Dynamic Compaction: Dropping heavy weights from great heights to compact the soil. Effective for sandy or mixed soils containing voids.
3. Cement or Chemical Injection (Grouting) : Injecting binding materials into the soil to improve its properties, such as shear resistance or reducing permeability, used in deep foundations or areas with high groundwater.

4. Geosynthetics : It is using geogrids or geotextiles to support foundations or reinforce backfill.
5. Piles: It used when the topsoil is very weak, the loads are transferred to deeper, stronger layers via concrete or steel piles.
6. Soil Stabilization: Mixing soil with improving materials such as lime or cement to improve stiffness and reduce swelling, it effective for clayey soils with a high clay content.
7. Drainage and Reducing Groundwater Levels: Improving soil by draining water and reducing moisture content, especially in the presence of saturated soil, this leads to reduced shear resistance.

5. Conclusions and Recommendations

5.1. Conclusions

1. The soil of study area has highly variable properties, with significant variation in grain size across depth. Up to 6.5 m, the soil consists mainly of clayey and silty clayey soils, which are compressible and prone to swelling when saturated. Below 6.5 m, the soil becomes sandy and sandy silty, which has lower compressibility and better shear resistance.
2. According to the unified classification system (USCS) the coarse soil was dominated by poorly graded sand (SP), silty sand (SM) and well graded sand (SW), while the soft soil was dominated in the study area by low and high plastic clay (CL, CH) respectively.
3. The soil of the study area is generally considered an inactive soil.
4. The soil at the study area needs engineering treatments for the purpose of constructing engineering structures on it and development of existing buildings.
5. The depth of subsurface water ranges between (3.90) m to the natural ground surface level is considered to be near the surface this fluctuation negatively effects on the bearing capacity of soil.

5.2. Recommendations

1. proximity of subsurface water to the ground surface increases the possibility of a collapse, an integrated sewage project for the city is necessary, it must be lowered by pumping outward using pumps with a filtered outlet to prevent pumping fine particles from the soil with the water.
2. The groundwater is highly basic, and the water also contains harmful amounts of sulphates, which requires taking the necessary measures to protect the concrete.
3. Based on the analysis results, the best type of treatment is soil replacement, by removing surface layers and replacing them with improved soil such as gravel or clean compacted sand.

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