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Geotechnical Study of the Soil for a Residential Project in Babil Governorate

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Abstract

This investigation focuses on the physical, chemical, and geotechnical properties of the soil at the Ashur (3) Residential Complex in southern Babil Governorate, along the Hilla–Najaf road ($32°25'32.2''$N, $44°24'50.6''$E). The study is based on site surveys and geotechnical investigations conducted to assess the soil characteristics of the project area. These soil properties are important for identifying the geological and engineering conditions of the site and for providing reliable data to guide structural and foundation design. A comprehensive investigation of the area was carried out, including the drilling of four boreholes with depths ranging from 15 to 17 m at different locations within the property. The evaluation was based on field data and laboratory tests performed on disturbed, split-spoon, and undisturbed soil samples collected from the site. Field and laboratory testing indicated that the site soil is predominantly silty clay with a small quantity of sand up to a depth of approximately 13.5 m. The soil was classified as high-plasticity clay, low-plasticity clay, high-plasticity silt, and low-plasticity silt, depending on depth and soil composition. At a depth of about 13.5 m, the soil changes from fine-grained deposits to medium-density sandy soil. Chemical analyses were performed on both soil and groundwater samples. The results show that the groundwater is slightly alkaline and has moderate to high salt content. Sulfate content in the soil ranged from 0.35% to 1.42%, while sulfate content in groundwater ranged from 641 to 732 ppm. Gypsum content ranged from 0.58% to 2.67%, while organic matter content was approximately 0.037%. The Standard Penetration Test (SPT) results showed that the N-value varied between 8 and 48. The groundwater table was observed at shallow depths, ranging from 0.10 to 0.25 m below the natural ground surface. Grain-size distribution analysis revealed clay content ranging from 3% to 71%, silt content from 20% to 43%, and sand content from 4% to 72%. Additional tests showed that the Liquid Limit (LL) ranged from 41% to 64%, the Plastic Limit (PL) from 11% to 29%, and the Plasticity Index (PI) from 13% to 43%. Soil activity index values below 0.6 indicate that the soil is inactive. The Static Method gave bearing-capacity values between 1.8 and 6.1 tons/m^2, whereas the Dynamic Method gave values between 4 and 16.4 tons/m^2, depending on depth. The results show that the soil at the project location requires geotechnical treatment or careful foundation design to ensure the stability and long-term safety of the residential complex.

Keywords: Geotechnical investigation, soil bearing capacity, Ashur Residential Complex, silty clay, groundwater table, sulfate content

1. INTRODUCTION

Geotechnical investigation is a fundamental stage in the planning, design, and construction of residential, commercial, and infrastructure projects. The safety and long-term serviceability of any structure depend greatly on the engineering behavior of the soil supporting its foundation. Soil is not a uniform construction material; rather, it is a natural geological deposit whose properties vary laterally and vertically according to depositional history, mineral composition, groundwater condition, weathering, and environmental influences. Therefore, before selecting the type and depth of a foundation, it is essential to determine the physical, mechanical, and chemical characteristics of the soil at the project site.

In civil engineering practice, geotechnical studies provide the basic information required to estimate soil bearing capacity, settlement behavior, shear strength, groundwater influence, and possible chemical hazards that may affect concrete and reinforcement. These studies are particularly important for residential complexes, where repeated foundation units, shallow excavations, and service networks may be affected by variable soil layers and shallow groundwater. Engineering geology also plays a central role in selecting suitable sites for major engineering and strategic projects, including city planning, road networks, and large housing developments [1]. A reliable geotechnical assessment reduces the risk of foundation failure, differential settlement, excessive deformation, concrete deterioration, and construction delays.

The soils of Iraq, especially those within the central and southern alluvial plain, are known for their variability. This variation is related to the geological history of the Mesopotamian plain, periodic flooding, sedimentation by the Euphrates and Tigris river systems, changes in depositional environments, groundwater fluctuation, and local drainage conditions. In many parts of central and southern Iraq, shallow groundwater, fine-grained alluvial deposits, sulfate-bearing soils, and soluble salts are common engineering concerns. Such conditions may reduce bearing capacity, increase compressibility, cause swelling or shrinkage in clayey soils, and accelerate chemical attack on buried concrete structures. Therefore, geological and geotechnical evaluation is an essential part of construction planning, especially when soil improvement or special foundation treatment is required to meet the technical objectives of a project [3].

Borehole drilling remains one of the most reliable methods for investigating subsurface geological and geotechnical conditions. It allows the identification of soil stratification, collection of disturbed and undisturbed samples, measurement of groundwater depth, and execution of in-situ tests such as the Standard Penetration Test (SPT). These field data, when combined with laboratory tests, provide an integrated understanding of the soil profile and its engineering behavior. Borehole investigations also help identify possible construction challenges and make it easier to select appropriate solutions to reduce risks to structural stability [2]. In addition, chemical testing of soil and groundwater is necessary in areas where sulfates, salts, gypsum, and organic matter may be present, because these components may affect concrete durability and the long-term performance of foundations.

The present study investigates the geotechnical characteristics of the soil at the Ashur (3) Residential Complex in Babil Governorate, central Iraq. The project site lies along the Hilla–Najaf road and is located within the alluvial plain region. The area is characterized by shallow groundwater and fine-grained deposits, making it important to evaluate the soil before construction. The study aims to determine the soil stratification, groundwater condition, grain-size distribution, plasticity, activity, shear strength, bearing capacity, settlement behavior, and chemical properties of the soil and groundwater. The results are intended to support foundation design and to identify the engineering precautions required for safe construction.

2. STUDY AREA AND GEOLOGICAL SETTING

The residential complex is located in Hilla, the capital of Babil Governorate in central Iraq. Hilla is situated approximately 100 km south of Baghdad and lies within the alluvial plain region. The project site is positioned along the Hilla–Najaf road at approximately $32°25'32.2''$N and $44°24'50.6''$E. The study area is relatively flat, which is typical of the Mesopotamian alluvial plain. However, a low-lying depression is located approximately 500 m from the project site. This depression holds stagnant water because of poor drainage, which contributes to the high groundwater table in the surrounding area.

Groundwater was encountered at very shallow depths in all boreholes. As shown in Table 2, groundwater levels ranged from 0.10 to 0.25 m below the natural ground surface (N.G.S.). Surface water was also observed in some parts of the construction site, which supports the field observation that drainage conditions are poor. Because of this shallow groundwater condition, groundwater samples were collected for chemical analysis. The chemical analysis indicated that the groundwater is moderately alkaline and contains moderate to high salt concentrations. Sulfate concentrations were also recorded, which is important because sulfate-bearing groundwater may attack concrete foundations and buried structural elements.

Geologically, the project site belongs to the Quaternary deposits of the alluvial plain. These deposits generally consist of fine-grained sediments, especially silty clay and clay, with occasional layers of sandy soil. The soil profile recorded in the boreholes confirms this geological setting. Fine-grained silty clay and clay dominate the upper soil layers up to approximately 13.5 m below N.G.S., while the deeper layers show a transition toward medium-density sand and silty sand. The shallow groundwater condition, combined with the fine-grained soil, indicates that the foundation design must consider drainage, settlement, and chemical durability.

3. MATERIALS AND METHODS

The geotechnical investigation was conducted through a combination of fieldwork, in-situ testing, sample collection, and laboratory testing. The objective was to evaluate the physical, mechanical, and chemical properties of the soil at the residential project site. The investigation included four boreholes drilled at different locations within the project area. Borehole depths ranged from 15 to 17 m, as shown in Table 2. The boreholes were drilled using rotary drilling and flight auger methods in accordance with relevant ASTM procedures, including ASTM D-1452 and ASTM D-5783. A drilling diameter of 0.10 m was used.

During drilling, three types of soil samples were collected: disturbed samples, split-spoon samples, and undisturbed samples. Disturbed samples were collected from drilling cuttings around the auger shaft and were used mainly for classification, grain-size analysis, Atterberg limits, and chemical testing. Split-spoon samples were obtained during the Standard Penetration Test (SPT) in accordance with ASTM D-1586. These samples were used to support field classification and strength interpretation. Undisturbed samples were obtained using Shelby tubes in accordance with ASTM D-1587. The Shelby tubes had a diameter of 100 mm and a length of 450 mm. Static jacking was used to reduce sample disturbance. After extraction, the undisturbed samples were sealed with wax at both ends and transported carefully to the laboratory for density, strength, and consolidation testing. Table 1 summarizes the sample types, extraction methods, and applicable laboratory tests.

Table 1. *Sample types, extraction methods, and applicable laboratory tests*

Sample Type	Extraction Method	Applicable Laboratory Tests
Disturbed Samples (DS)	Collected from drilling cuttings around the auger shaft	Chemical analysis, specific gravity, grain-size distribution, consistency tests, and Atterberg limits
Split-Spoon Samples (SS)	Obtained during the Standard Penetration Test (SPT)	Chemical analysis, density, grain-size distribution, consistency, and strength-related tests
Undisturbed Samples (US)	Extracted using Shelby tubes	Strength tests, consolidation tests, and density measurements

The Standard Penetration Test (SPT) was conducted at different depths in each borehole to evaluate soil resistance and estimate bearing capacity. The test was performed according to ASTM D-1586. The SPT equipment consisted of a split-spoon sampler with an internal diameter of 35 mm, an external diameter of 50.8 mm, and a length of 460 mm. The sampler was driven into the soil using a 63.3 kg hammer falling from a height of 760 mm along a guide rod. The N-value represents the number of blows required to drive the sampler 300 mm after the initial seating penetration. Low blow counts indicate soft or loose soil, while high blow counts indicate stiff, dense, or resistant soil. SPT tests were conducted at depths ranging from 1.5 to 17 m. The SPT results and corresponding bearing-capacity estimates are presented in Table 6.

Groundwater levels were measured 24 hours after borehole drilling was completed to allow stabilization of the groundwater table. The groundwater depths are listed in Table 2. Groundwater samples were also taken for chemical analysis because the shallow groundwater may affect construction activities, foundation performance, and concrete durability.

Table 2. *Groundwater table depths relative to the natural ground surface*

Borehole No.	Borehole Depth (m)	Borehole Diameter (m)	Groundwater Level Below N.G.S. (m)
1	15	0.10	0.20
2	15	0.10	0.25
3	15	0.10	0.10
4	17	0.10	0.20

After fieldwork, laboratory testing was performed on the collected soil samples. The laboratory program was designed to evaluate the physical, engineering, and chemical properties of the soil. The physical tests included grain-size analysis, natural water content, Atterberg limits, and soil activity. The engineering tests included direct shear testing, consolidation testing, and interpretation of SPT data. The chemical tests included sulfate content, gypsum content, organic matter content, total soluble salts, and groundwater chemical analysis. ASTM and BS standards were followed where applicable.

4. RESULTS AND DISCUSSION

The laboratory and field results indicate that the soil at the project site is mainly fine-grained in the upper layers and becomes more sandy at greater depth. The soil profile consists mainly of silty clay and clay up to approximately 13.5 m below N.G.S., with a transition to silty sand or sandy soil below this depth. This variation in soil type reflects the alluvial nature of the site and the changes in depositional conditions across depth.

Grain-size distribution and soil classification. Grain-size distribution is essential for soil classification and for understanding engineering behavior [5]. Sieve analysis and hydrometer analysis were used to determine the percentages of sand, silt, and clay. Hydrometer analysis was used for fine-grained particles passing sieve No. 200 (< 0.075 mm). The results showed that clay content ranged from 3% to 71%, silt content ranged from 20% to 43%, and sand content ranged from 4% to 72%. These results indicate that the upper soil layers are mostly silty clay and clay, while the deeper layers contain a greater proportion of sand. Based on the Unified Soil Classification System (USCS), the soil includes high-plasticity clay (CH), low-plasticity clay (CL), high-plasticity silt, low-plasticity silt, and silty sand.

Atterberg limits and plasticity. Atterberg limit tests were performed to evaluate soil consistency and plasticity. The Liquid Limit (LL) ranged from 41% to 64%, the Plastic Limit (PL) ranged from 11% to 29%, and the Plasticity Index (PI) ranged from 13% to 43%. Table 3 provides the general classification of soil based on the Plasticity Index. According to these values, the soils at the site range from medium-plasticity to high-plasticity soils. The measured values in Table 4 confirm that several samples fall within the high-plasticity range, which is important because plastic clayey soils may be susceptible to volume change and settlement when groundwater conditions fluctuate.

Table 3. *Soil classification based on Plasticity Index (PI)*

Plasticity Index (PI)	Soil Description
0	Non-plastic soil
1–5	Slightly plastic soil
5–10	Low-plasticity soil
10–20	Medium-plasticity soil
20–40	High-plasticity soil
> 50	Very high-plasticity soil

Water content and soil activity. Water has a major effect on the behavior of fine-grained soils. It influences interparticle pressure, pore water pressure, compressibility, shear strength, and volume-change behavior [7]. The natural water content ranged from approximately 25.1% to 30%. This relatively high moisture content is mainly related to the shallow groundwater table and the fine-grained silty clay soil at the site. High moisture content may cause difficulties during compaction, increase the possibility of swelling and shrinkage, and reduce soil cohesion.

Soil activity values were calculated to evaluate the potential swelling behavior of the clay fraction. As shown in Table 4, the activity index ranged from 0.57 to 0.625, with an average value of approximately 0.6. According to the classification in Table 5, the soil is considered inactive. This indicates that the clay minerals present in the soil have limited swelling potential and are not expected to cause severe expansion or shrinkage under normal conditions.

Table 4. *Soil activity values for selected borehole samples in the study area*

Borehole No.	Depth (m)	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	LL (%)	PL (%)	PI (%)	Activity Index
1	2–2.5	63	25	12	0	58.0	22.0	36.0	0.57
2	6.5–7	48	24	28	0	47.0	17.0	30.0	0.625
3	10–10.5	58	25	17	0	57.0	22.0	35.0	0.60
4	10.5–11	65	29	6	0	59.0	21.0	38.0	0.58

Table 5. *Soil classification based on activity index [6]*

Activity Index (A)	Soil Classification
< 0.75	Inactive soil
0.75–1.25	Normal-activity soil
1.25–2.0	Active soil

Bearing capacity from the Dynamic Method. The bearing capacity of the soil was estimated using the Dynamic Method based on SPT N-values. As shown in Table 6, the N-values ranged from 8 to 48. These values indicate that the soil resistance generally increases with depth. The calculated bearing capacity ranged from 4 to 16.4 tons/m^2, depending on depth. The Meyerhof equation was used to estimate the dynamic bearing capacity:

$$q_{\text{ult}} = \left(\frac{D_f}{B} \times 0.33 + 1 \right) \left(\frac{B + 0.3}{B} \right)^2 \frac{N}{0.08}.$$

The results indicate that shallow foundation design must account for the relatively weak upper fine-grained soils and the shallow groundwater condition.

Bearing capacity from the Static Method. The Static Method was based on laboratory shear strength parameters. Table 7 shows that cohesion values (C_u) ranged from 1.8 to 6.1 tons/m^2, while the internal friction angle ranged from 6° to 10°. These values indicate that the cohesive soil varies from weak to medium and relatively strong consistency with depth. Bearing capacity was calculated using the following equation:

$$q_{\text{ult}} = CN_c + \gamma D_f N_q + 0.5\gamma_{\text{sub}} B N_\gamma.$$

The allowable bearing capacity values for selected foundation depths are provided in Table 8. The allowable bearing capacity was estimated as 5.3 tons/m^2 at 1.0 m foundation depth and 6.8 tons/m^2 at 2.0 m foundation depth. These values show that careful foundation design is required, especially because of the shallow groundwater table and the variable fine-grained soil profile.

Table 6. *Standard Penetration Test (SPT) results and estimated bearing capacity*

Depth (m)	SPT (BH.1)	SPT (BH.2)	SPT (BH.3)	SPT (BH.4)	Average SPT	Bearing Capacity (tons/m^2)
1.5	8	8	–	–	8	4.00
3.5	17	–	13	–	15	7.80
4.0	–	–	–	15	15	7.80
5.0	–	21	–	–	21	9.30
6.5	18	–	11	–	14	7.30
7.0	–	–	–	12	12	6.00
9.5	29	9	21	24	21	9.30
12.0	13	28	14	26	20	9.10
14.5	–	–	18	25	21	9.30
19.0	52	18	–	–	35	13.00
17.0	–	–	–	48	48	16.40

Table 7. *Results of laboratory engineering tests*

Borehole No.	Depth (m)	C_u (tons/m^2)	Internal Friction Angle (ϕ_u, degrees)
BH.1	2–2.5	1.90	7
	5–5.5	2.40	8
	8–8.5	4.30	6
	11–11.5	6.10	6
BH.2	2–2.5	2.20	7
	5.5–6	3.00	9
	7.5–8	4.37	9
	10.5–11	4.10	8
BH.3	2–2.5	1.80	10
	5–5.5	2.60	10
	8–8.5	4.30	9
	11–11.5	4.70	9
BH.4	2.5–3	1.80	9
	4.5–5	3.70	6
	10.5–11	5.40	7

Table 8. *Allowable bearing capacity for selected foundation depths*

Foundation Depth (m)	Allowable Bearing Capacity (tons/m^2)
1.0	5.3
2.0	6.8

Settlement behavior. Consolidation tests were carried out on selected undisturbed soil samples. The results are shown in Table 9. The values of initial void ratio (e_0), compression index (C_c), recompression index (C_r), overburden pressure (P_o), and preconsolidation pressure (P_c) indicate that the cohesive soils are generally overconsolidated. The predicted settlement is within permissible limits; however, the shallow groundwater table and fine-grained soil still require attention during foundation design and construction.

Table 9. *Consolidation test results*

Borehole No.	Depth (m)	e_0	C_c	C_r	P_o (tons/m^2)	P_c (tons/m^2)
BH.1	5–5.5	0.808	0.117	0.023	10.06	14.0
BH.2	7.5–8	0.845	0.124	0.069	14.64	16.5
BH.3	11–11.5	0.780	0.146	0.037	21.16	19.0

Chemical characteristics of soil and groundwater. Chemical testing was performed because sulfate, gypsum, organic matter, and soluble salts can significantly affect foundation performance and concrete durability. Sulfate ions may react with cement compounds and form expansive products such as gypsum and calcium sulfoaluminate, which may cause cracking and deterioration of concrete. Table 10 shows that sulfate content in the soil ranged from 0.35% to 1.42%. Because these values are significant for engineering design, sulfate-resistant cement and protective coatings such as bituminous layers are recommended for foundations and buried concrete elements.

Table 10. *Sulfate content in the study area*

Borehole No.	Depth (m)	Sulfate Content (SO_3, %)
BH.1	1–1.5	0.35
BH.2	5.5–6	0.71
BH.3	11–11.5	1.15
BH.4	14.5–15	1.42

Organic matter was detected at a value of approximately 0.037%, as shown in Table 11. Organic matter is usually found in shallow soil layers but may also appear at greater depths because of soil movement, biological activity, or depositional processes [9, 11]. Although the measured organic matter content is low, organic material may reduce bearing capacity, increase compressibility, and increase water retention when present in large quantities [13, 14].

Table 11. *Organic matter content in soil*

Borehole No.	Depth (m)	Organic Matter Content (%)
BH.1	1–1.5	0.037

Total soluble salts were also evaluated because soluble salts can affect soil behavior, concrete durability, and reinforcement corrosion. The measured total soluble salt content ranged from 1.93% to 5.0%, exceeding the commonly accepted critical level of 0.5% for engineering considerations [15]. This indicates that chemical protection measures should be incorporated into foundation design. Groundwater analysis also indicated moderate to high salt concentrations and alkaline conditions. Therefore, concrete mix design, foundation protection, and site drainage should be selected carefully.

5. CONCLUSIONS AND RECOMMENDATIONS

The geotechnical investigation of the Ashur (3) Residential Complex site in Babil Governorate shows that the project area is underlain mainly by fine-grained alluvial soils in the upper layers. Silty clay and clay dominate the soil profile down to approximately 13.5 m below the natural ground surface, while sandy and silty sand layers appear below this depth. The soil composition varies considerably with depth, reflecting the alluvial depositional environment of the region.

The soil at the site is classified according to the Unified Soil Classification System as low-plasticity clay (CL), high-plasticity clay (CH), high-plasticity silt, low-plasticity silt, silty sand (SM), poorly graded sand (SP), and well-graded sand (SW), depending on the depth and sample location. Plasticity results indicate that the soil ranges from medium to high plasticity. However, the calculated activity index values are generally less than 0.75, indicating inactive soil. Therefore, severe swelling or shrinkage is not expected under normal conditions, although moisture variation and shallow groundwater must still be considered in design.

The groundwater table is very shallow, ranging from 0.10 to 0.25 m below the natural ground surface. This condition increases the possibility of excavation difficulties, construction instability, reduced effective stress, and long-term moisture-related problems. A suitable drainage and dewatering system is therefore essential during foundation construction. Filtration pumps should be used carefully during dewatering to prevent the removal of fine soil particles.

The SPT N-values ranged from 8 to 48, indicating that soil resistance increases with depth. The Dynamic Method gave bearing-capacity values between 4 and 16.4 tons/m^2, while the Static Method showed cohesion values ranging from 1.8 to 6.1 tons/m^2 and internal friction angles ranging from 6° to 10°. The allowable bearing capacity was estimated as 5.3 tons/m^2 at 1.0 m foundation depth and 6.8 tons/m^2 at 2.0 m foundation depth. These results indicate that shallow foundations may be possible only with careful design, but soil improvement or foundation modification may be needed depending on structural loads.

Chemical testing showed that sulfate content in the soil ranges from 0.35% to 1.42%, while groundwater contains sulfate concentrations between 641 and 732 ppm. Total soluble salts are also relatively high. These chemical conditions can affect concrete durability, especially in foundations and buried structural elements. Therefore, sulfate-resistant cement, bituminous protection, and suitable concrete cover should be used to reduce chemical deterioration. Periodic monitoring of groundwater and soil chemistry is also recommended.

Based on the field and laboratory results, the soil at the project site requires careful geotechnical treatment and foundation planning. Soil improvement, drainage control, appropriate foundation selection, sulfate-resistant materials, and groundwater management are necessary to ensure the long-term stability of the residential complex. Before construction, the final foundation design should be based on structural loading, allowable settlement, and the detailed soil profile. Continuous site monitoring during excavation and foundation construction is recommended to verify the assumed geotechnical conditions and to adjust engineering measures if unexpected soil or groundwater conditions are encountered.

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