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The Classification and Engineering Properties of Soil in the City of Al-Medina, North of Basrah, Southern Iraq

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ABSTRACT

This research aims to study the classification and engineering properties of soil at a selected location in the Al-Medina district, north of Basrah Governorate. Two boreholes are drilled to depths of 15 and 30m. The samples are taken to the laboratory to conduct the classification tests. The particle size analysis indicates that the percentages of clay range from 3-56%, silt range from 4-60%, and sand range from 2-92%. According to the USCS, 10 samples are lean clay, 6 samples are lean clay with sand, 4 samples are silty sand, and 3 samples are sandy lean clay. The plasticity index ranges from 10 to 23%, while the liquid limit is from 30 to 49%. According to the plasticity chart, 13 samples are inorganic of low-plasticity clay, and 6 samples are inorganic of low-plasticity silt. Soils have medium plasticity, except two samples with high plasticity. 8 samples are highly compressible, and 11 are very highly compressible. 17 samples have high swelling potential, and two have very high swelling potential. Based on their bearing capacity, the N-values are utilized to divide the study area's soil into nine layers. In the research region, the groundwater level is 1.2 meters.

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الخواص التصنيفية والهندسية للتربة في قضاء المدينة- شمال البصرة/ جنوبي العراق

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الملخص

يهدف هذا البحث إلى دراسة الخواص التصنيفية والهندسية للتربة في موقع مختار في قضاء المدينة شمالي محافظة البصرة. تم حفر بئرين اختباريتين بعمق 15 و30 متراً، وأخذت النماذج إلى المختبر لإجراء الفحوص التصنيفية. يشير التحليل الحجمي للحبيبات إلى أن نسب الطين تتراوح من 3-56%، والغرين من 4-60%، والرمل من 2-92%. وفقًا لتصنيف التربة الموحد، فإن 10 عينات تعد من الطين الغريني، و6 عينات من الطين الغريني مع الرمل، و4 عينات من الرمل الغريني، و3 عينات من الطين الرملي الغريني. يتراوح معامل اللدونة من 10 إلى 23%، وحد السيولة من 30 إلى 49%. وفقًا لمخطط اللدونة، فإن 13 عينة هي طين لا عضوي منخفض اللدونة، و6 عينات غرين لا عضوي منخفض اللدونة. على وفق قيم معامل اللدونة فان التربة تعد ذات لدونة متوسطة، باستثناء عينتين ذات لدونة عالية. نسبة الى معامل الانضغاط فأن 8 عينات تعد شديدة الانضغاط، و11 عينة شديدة الانضغاط جدا. تظهر فحوص جهد الانتفاخ أن 17 عينة لديها جهد انتفاخ عال، واثنتان لديها جهد انتفاخ عال جدا. استعملت قيم مقاومة الاختراق القياسي لتصنيف ترب منطقة الدراسة على تسع طبقات على وفق سعة التحميل فيها. في منطقة البحث، يبلغ منسوب المياه الجوفية 1.2 مترا.

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Introduction

The classification properties of the soil at the sites proposed for building facilities are an important part of the geotechnical properties that are studied in soil investigations, and they provide useful information about the engineering behavior of the soil and the possibility of using it for engineering purposes (Al-Jawadi et al., 2021). Knowledge of the classification properties of soil is also necessary for developing preliminary designs and planning the work program at the construction site. Particle size analysis is a basic property of soil that reflects the nature and performance of this soil and helps in understanding and estimating the soil's ability to compact and load support capacity. It is the basis that must be referred to in any soil classification system. It plays a crucial role in defining numerous geotechnical properties including porosity, permeability, Atterberg's limits, bulk density, shear strength, optimum moisture content (OMC), maximum dry density (MDD), and hydraulic conductivity (Sen and Pal, 2014). The proportions of soil constituents like gravel, sand, silt, and clay are determined using sieving and sedimentation techniques. These ratios are used to classify the soil geometrically. Researchers and scientific institutions developed different classifications, some of which relied on classification tables; others relied on triangles to classify soil such as the Shepard triangle (1954) in Pettijohn (1975) and the triangle of the US Department of Agriculture textural (USDA, 1952). Engineers generally agree that the Unified Soil Classification System (USCS) is the most widely used. The American Society for Testing and Materials (ASTM) adopted it in 1969 as a technique for grading soil for building applications in compliance with ASTM 2487-D. To categorize various soil types, this system uses the findings of soil plasticity and particle size analysis. Published research did not address the study of geotechnical properties in the city of Al-Medina, but information was available from soil investigation reports completed at some sites near the city. However, some studies come within a series studying the geotechnical properties of soil in Basrah Governorate including the city of Qurna, north of Basra, adjacent to the study area. Albadran and Mahmood (2006) investigated the geotechnical properties of the bearing strata on the banks of the Shatt al-Arab including the city of Qurna, and categorized them into eight layers based on their bearing capacity. Mahmood et al. (2011) studied the gypsum content of the soil in selected areas of Basrah Governorate, southern Iraq, including the city of Qurna. The findings demonstrated that the gypsum content is extremely low (0.3%) and is thought to not affect the soil's engineering behavior. The soil in the city of Qurna is thought to have a low swelling potential, according to research by Abdel-Wahab and Mahmood (2015) that looked at the swelling qualities of soil in surficial bearing strata in certain regions of the Basrah Governorate.

Location of the study area

According to Figure (1), the study area is situated in the Al-Medina district, north of the Basrah Governorate in southern Iraq, at the junction of longitude 47.271928º E and latitude 30.957992º N.

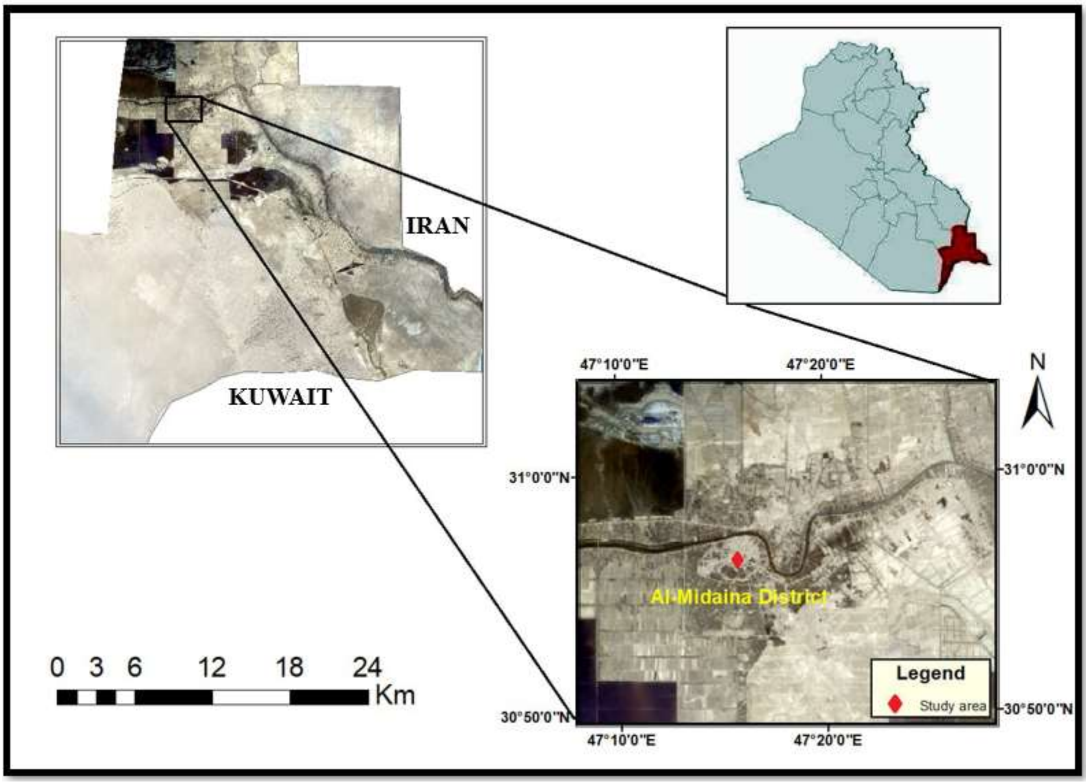

Fig. 1. Map of Basrah and location of the study area.

Aim of study

At a specific location in the Al-Medina district, north of the Basrah Governorate, the research aims to investigate the classification properties of soil represented by particle size analysis and Atterberg's limits in different bearing strata, and to demonstrate their significance and influence on the engineering behavior of these soils.

Geology and geomorphology of the study area

The study area is located within the Mesopotamia Alluvial Plain region, which is the southern portion of the unstable Arabian Plate, and includes the Zubair Sub-Zone (Budy and

Jassim, 1987). Geologically, the study area mainly includes Quaternary sediments from the Pliocene to the Miocene (Al-Sultani et al., 2023). Geomorphologically, Al-Medina district is located within the unfolded zone according to the divisions of the tripartite tectonic sectors of Iraq, which in turn are divided into nine physiographic sectors.

The Delta Plain sector includes the Al-Medina district (Al-Sayyab et al., 1982). In this region, the Holocene processes of sedimentation, erosion, and sea level change are significant factors. The enormous amounts of silt and clay carried by the Tigris and Euphrates rivers, as well as the Aeolian sediments brought in by winds and dust storms, also had an impact (Karim and Salman, 1988). Significant natural geomorphological phenomena in flatlands are represented by human-caused sediments such as minor historical hills and old canals, which formerly housed ancient civilizations (Al-Turaihi, 2023).

Materials and Methods

To fulfill the study's objective, the results of soil investigations completed at the Basrah Construction Laboratory at a selected site in the city of Medina are utilized following BS 5930-2015, where two boreholes, 100 meters apart, are drilled to depths of 15 and 30m using the ACKER excavator and a continuous flight auger. Undisturbed, disturbed, and partially disturbed samples were taken from different depths of each borehole. The samples are saved and transferred to the laboratory to conduct laboratory tests of the classification properties represented by particle size analysis and Atterberg's limits tests (liquid limit and plastic limit) following BS 1377: 1990. A full day after the excavation finish, the site's groundwater level is measured. The soil of the research region is categorized using the field N-values of the standard penetration test into layers relative to its bearing capacity according to the classification of Terzaghi and Peck (1967). The unified classification is also used to indicate the nature of the soil in these layers.

Results and Discussion

The results of the particle size analysis and Atterberg's limits of the soil in the research region are presented in Table (1). The percentage of clay in it ranges from 3% at a depth of 14.5 m to 56% at a depth of 3.5 m, and the percentage of silt ranges from 4% at a depth of 15.5 m to 60% at a depth of 4.5 m. While the percentage of sand ranges from 2% at a depth of 3.5 meters to 92% at a depth of 15.5 meters. Figure (2) shows the proportions of clay, silt, and sand at different depths in the study area.

Table 1: Classification properties of soils in the study area.

Layer No.	Depth (m)	Clay%	Silt%	Sand%	L.L%	PI%	USCS
1st layer	0-1	43	40	17	46	22	CL
2nd layer	1-5	38-56	43-60	0-2	33-49	13-23	CL
3rd layer	5-10	22-40	35-58	13-26	30-44	11-19	CL
4th layer	10-12	47	43	10	36-39	14-18	CL
5th layer	12-14	28	42	30	35-42	13-18	CL
6th layer	14-16	3-4	4-6	91-92	/	/	SM
7th layer	16-24	32-35	53-56	9-14	34-40	10-15	CL
8th layer	24-26	24	52	12	/	/	CL
9th layer	26-30	4-5	28-35	60-68	/	/	SM

L.L: Liquid limit; P.I.: Plasticity index; USCS: Unified soil classification system.

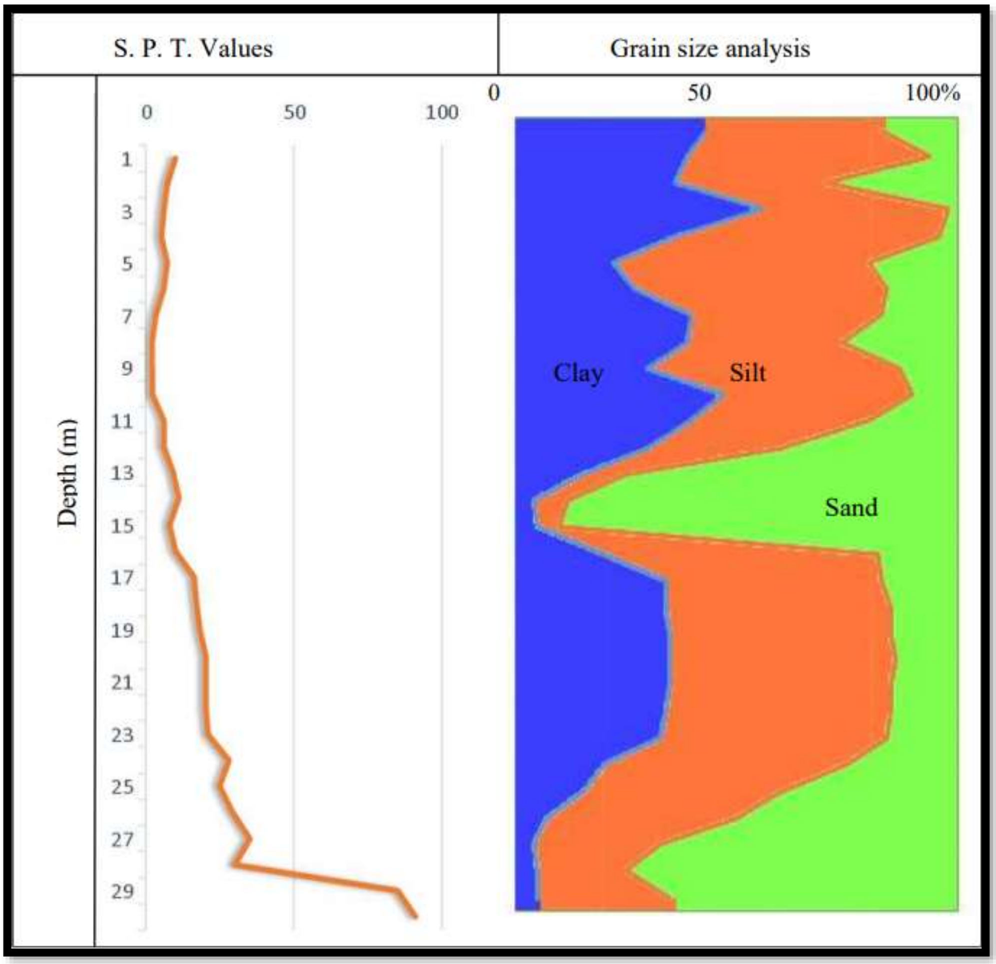

Fig. 2. SPT N-values and grain size analysis in the study area.

These values are used to classify the soil according to the Unified Soil Classification System according to the specification ASTM D 2487-17. The results show that 10 samples are lean clay with a percentage of 43.5%, 6 samples are lean clay with sand with a percentage of 26.1%, 4 samples are silty sand with a percentage of 17.4%, and 3 samples are sandy lean clay with a percentage of 13%. Soil engineering behavior is significantly influenced by grain size. Deposits with a variety of various-sized particles are typically stronger than those with uniform grading; in general, the larger the particles, the higher the strength is (Bell, 2007). The majority of the soils found in the field are blends of different soil types. Engineers find that soil with high concentrations of silt and clay is the most problematic. When the amount of water in these materials varies, their physical qualities also do. The engineering characteristics of soils including strength, volume change, hydraulic conductivity, settlement, compression, and shear resistance can be significantly impacted by even small amounts of fines (Al-Shayea, 2001). Sand containing as few as 10% fine particles can make the soil nearly impermeable. Adding a small amount of clay improves the binding properties between sand and gravel grains. Five properties of clayey soil that affect their engineering behavior include cation exchange capabilities, plastic behavior when wet, catalytic abilities, swelling, and low permeability (Brendan, 2021). According to Kennedy and Mahmood (2023), silts are non-plastic particles that become fundamentally unstable in the presence of water and have a tendency to become fast when saturated. This means that they take on the properties of viscous fluids and can flow. Silt is fairly impervious, difficult to compact, and highly susceptible to frost heaving. Sandy soils are often considered to have weak structures, poor water retention properties, high permeability, and high sensitivity to compaction. The resistance of loose sand deposits improves with increasing silt content (Karim and Alan, 2017). Atterberg's limits are investigated in 19 samples of boreholes at varying depths. The findings indicate that the plasticity index values range from 10 to 23%, and the liquid limit values range from 30 to 49%. According to ASTM D 2487-17, the plasticity chart, which is crucial for identifying fine-grained soils, is utilized to categorize the soils based on these values. As seen in Figure (3), the chart indicates that 13 samples are inorganic low-plastic clay (CL) and 6 samples are inorganic low-plastic silt (ML).

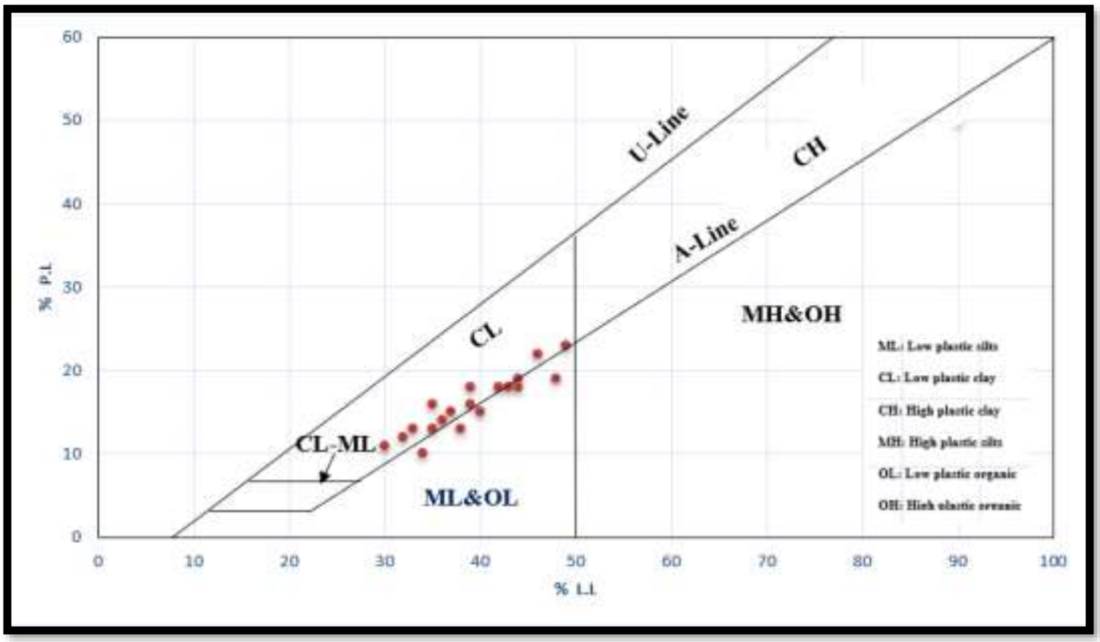

Fig. 3. Plasticity as per the USCS classification scheme for study area soils (ASTM D 2487-17).

Atterberg's limits have a wide importance for civil and geotechnical engineering and agronomic applications in the ceramic industry and brick manufacturing (White, 1949). Because the type of clay mineral and its proportionate amount in the soil influence the liquid and plastic limits, the absorbed water surrounding the clay particles also contributes to the soil's plasticity. The Atterberg's limits in clayey soils are affected by the clay content and type of clay (Panwar and Ameta, 2013). The clay percentage is an influential factor in the liquid limit values of the soil. Clay particles carry a negative charge on the surface; the water molecules are dipolar and attracted toward the clay surface. The plasticity coefficient depends on the grain size of the soil. As the grain size decreases, both the liquid and plastic limits increase, but the liquid limit ratio increases more. When some silt is added to the clay, the liquid and plastic limits are reduced, but the liquid limit is at a higher rate. The plasticity index falls with increasing sand content because the intermolecular attraction force between soil particles weakens, lowering the liquid limit and consequently the plasticity index (Sen and Pal, 2014). Nath and DeDalae (2004) noted that increasing the liquid limit of the soil leads to an increase in its plasticity index and a decrease in the angle of internal friction, as well as an increase in compressibility and permeability. Burmister (1949) classified soil plasticity into types according to its plasticity index as shown in Table (2).

Table 2: Cohesive soil classification based on plasticity index (PI) (Burmister, 1949).

PI	Description
0	Nonplastic
1-5	Slightly plastic
5-10	Low plasticity
10-20	Medium plasticity
20-40	High plasticity
> 40	Very high plasticity

The results indicate that the research area's soil normally has medium plasticity, with a plasticity index ranging between 10 and 19% except two samples, in which the plasticity indexes are 22 and 23%, which are considered to have high plasticity.

Compression coefficient in the research area's soils

The plasticity index and the liquid limit are utilized to calculate the soil's compression coefficient (Cc), and many mathematical relationships were developed in this field. Park and Lee (2011) used the liquid limit to calculate the compression coefficient from the relationship:

$$\mathbf{Cc = 0.014LL - 0168} \text{ …………(1)}$$

According to Coduto et al. (2011), Table (3) illustrates the classification of soil based on its compression coefficient.

Table 3: Soil classification according to degree of compressibility (Coduto et al., 2011).

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

According to the results, 8 samples are deemed highly compressible whose compression index values are between 0.252 and 0.35, and 11 samples are deemed extremely highly compressible, whose index values are between 0.364 and 0.518. Compressibility characterizations of fine-grained soils are often the most important parameters for **the** settlement evolution of founded layers. These characteristics are described by using the compression index (Cc) and the coefficient of consolidation (Cv) (Abbasi et al., 2012). Clayey soil compressibility is influenced by a variety of parameters including the clay's mineralogical characteristics, plasticity, percentage of silt and sand, pore water characteristics, cementation loading history, void ratio, and natural water content (Kifae et al., 2018).

Potential for swelling in the research area's soils:

Clay soils have a characteristic called swelling that causes them to swell and get bigger when the moisture content rises. One of the most dangerous engineering issues with structures is swelling because the earth puts a lot of pressure on the floors and foundations during this process, which can lead to cracks in the building, especially in lightweight buildings. The swelling potential can be estimated based on the plasticity index as shown in Table (4).

Table 4: The connection between the soil's plasticity index and swelling potential (Hakari and Purank, 2010).

Plasticity Index	Swelling Potential Degree
<10	Low
10-20	Medium
20-35	High
35 and above	V. high

The results show those 17 samples, in which the plasticity index ranges between 10 and 23% are considered to have a high swelling potential, and two samples, in which the plasticity index ranges between 22-23% are considered to have a very high swelling potential.

Engineering stratigraphic sequence in the city of Al-Medina:

The soil of the study area can be geometrically classified into 9 layers based on the cohesive soils' consistency (clay and silt), the non-cohesive soils' compactness (sand and gravel), and their bearing capacity. These layers are determined by the N-values of the standard penetration test (SPT) at various depths of the boreholes. The results of the grain size analysis, and the values of Atterberg's limits are listed in Table (1).

First layer: Stiff brown lean clay with sand (CL). This layer is the base for the shallow foundations of buildings in the area. It is one-meter-thick and descends from the earth's surface to a depth of one meter, 10 blows/30 cm is the N-value. There's 43% clay, 40% silt, and 17% sand. The plasticity index (PI) is 22% and the liquid limit value (LL) is 46%. This layer has a 192.8 kN/m^2 bearing capacity, an unconfined compressive strength of 128.5 kN/m^2, and a shear strength of 97 kN/m^2. The first layer's bearing capability is adequate to support the shallow foundations of various light-colored buildings in the research area. And it can be enhanced using a variety of techniques, particularly mechanical techniques to provide safety for the stability of the construction.

Second layer: Medium-stiff brownish gray lean clay (CL). This layer has a thickness of 4 meters and ranges in depth from 1 to 5 meters. The range of N-values is 5-7 blows/30 cm. The clay varies from 38 to 56%, the silt from 43 to 60% and sand from 0-2%, the liquid limit values from 33 to 49%, and the plasticity index from 13 to 23%. The unconfined compressive strength is 62.5-87.5 kN/m^2, the shear strength is 49-67 kN/m^2, and the bearing capacity values range from 94-131 kN/m^2.

Third layer: Soft and very soft gray lean clay with sand (CL). This layer is 5 meters thick and reaches a depth of 5 to 10 meters. The range of N-values is 2-3 blows/30 cm. There is a range of 22-40% for clay, 35-58% for silt, 13-26% for sand, 30-44% for liquid limit values, and 11-19% for the plasticity index. Unconfined compressive strength is 25–37.5 kN/m^2, bearing capacity is 40–55 kN/m^2, and shear strength is 20–30 kN/m^2.

Fourth layer: Medium-stiff gray lean clay (CL). This layer is 2 meters thick and reaches a depth of 10 to 12 meters. The N-value is 30 cm / 6 blows. The percentage of sand is 10%, the clay content is 47%, and the silt content is 43%. The plasticity index ranges from 14 to 18%, while the liquid limit values are between 36-39%. 112.5 kN/m^2 of bearing capacity, 75 kN/m^2 of unconfined compressive strength, and 58 kN/m^2 of shear strength are measured.

Fifth layer: Stiff gray sandy lean clay (CL). This layer has a thickness of two meters and a depth of twelve to fourteen meters. The typical range for penetration resistance levels (N-value) is 9–11 blows/30 cm. There is 28% clay, 42% silt, and 30% sand. The plasticity index ranges from 13 to 18%, whereas the liquid limit is from 35 to 42%. The layer's unconfined compressive strength ranges from 114.5 to 142 kN/m^2, bearing capacity is between 171 and 214 kN/m^2, and shear strength is between 86 and 108 kN/m^2.

Sixth layer: Loose gray silty sand (SM). This layer has a thickness of two meters and a penetration resistance value (N-value) of eight to ten blows per 30 centimeters. It continues to a depth of fourteen to sixteen meters. The proportion of sand is between 91 and 92%, and the proportion of fine grains is between 8 and 9%. The internal friction angle is 29º, the relative density is between 0 and 15%, and the bearing capacity is less than 100 kN/m^2.

Seventh layer: Very stiff gray lean clay (CL). This layer has a thickness of 8 meters and reaches a depth of 16 to 24 meters. The range of N-values is 16–21 blows/30 cm. The ranges of clay ratios are 32–35%, silt 53–56%, and sand 9–14%. The plasticity index is between 10 and 15%, and the liquid limit varie**s** from 34 to 40%. The unconfined compressive strength ranged from 213.3 to 279.1 kN/m^2, the shear strength from 160 to 210 kN/m^2, and the bearing capacity from 300 to 407 kN/m^2.

Eighth layer: Hard brown sandy lean clay (CL). This layer has a thickness of two meters and reaches a depth of 24-26 meters. Its N-value is 30 cm/77 blows. There is 24% clay content, 52% silt, and 12% sand. There is 760 kN/m^2 of bearing capacity, 258.4 kN/m^2 of unconfined compressive strength, and 217.6 kN/m^2 of shear strength.

Ninth layer: Very dense gray silty sand (SM). This layer has a thickness of 4 meters and reaches a depth of 26 to 30 meters at the end of the research. The range of its N-value was 79–91 blows/30 cm. The proportion of sand is between 60 and 68%, and the proportion of fine grains is between 32 and 40%. There is an internal friction angle of 42º, a shear strength of 374 k/m^2, and a bearing capacity of 1100 kN/m^2.

The eighth and ninth layers are ready to support the future piles of massive construction that will be constructed in Al-Medina. Natural consolidation elements brought about by the overburden pressure during sedimentation processes had an impact on these soils, resulting in decreased permeability, increased bearing capacity, and shear resistance (Lambe and Whitman, 1969).

Groundwater level:

According to the data, the study area's groundwater level is 1.2 meters, which is relatively near the surface of the earth. The rise in water levels leads to the activation of chemical and physical weathering processes, which affect the soil’s bearing capacity. It also leads to the corrosion of foundations, especially concrete, if mixed with acidic wastewater. The presence of groundwater affects the mechanical engineering properties, as it leads to changing the value of the effective stress acting on the soil reducing the bearing capacity, and rusting the steel reinforcement, which leads to the weakness of the concrete and makes it susceptible to breakage, especially when the water contains sulfate ions and chlorides. It also leads to the subsidence of foundations, cracking of floors, peeling of paint, and whiteness of walls (Emhanna and Douas, 2022).

Conclusion

In the research area's depths, cohesive and non-cohesive quaternary deposits can be divided into nine bearing strata with varying bearing capacities, compactness, and consistency. The first layer's bearing capacity is adequate to support the shallow foundations of various light-colored buildings in the study region, and it can be strengthened mechanically to increase its stability. Piles of various kinds must be extended for heavy construction to a depth of 24 to 26 meters, which corresponds to the study area's eighth and ninth high-bearing strata. Soils are lean clay, lean clay with sand, silty sand, and sandy lean clay. Most samples are inorganic low-plasticity clay, and the others are inorganic low-plastic silt. To prevent damage to buildings, it is important to consider the high degree of compressibility and expansion of the soils in the studied region when creating shallow foundations. The study indicates that the area's groundwater table lies near the surface of the earth, which has an impact on the soil's bearing capacity.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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