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Geotechnical Characterization and Shear Strength Analysis of Gypsum-Rich Soil in the University of Tikrit, Center of Iraq

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ABSTRACT

The results obtained from the geotechnical investigations are essential and useful in designing engineering projects. Additionally, they can help in identifying future problems surrounding the project and provide appropriate solutions to these problems. The physical properties are utilized in the classification of soils for engineering purposes. This study identifies some geotechnical properties of the designed models. Geotechnical tests are conducted to evaluate the engineering properties of the soil samples at the University of Tikrit to identify their weak zones, down to a depth of 3 meters. The values of specific gravity range between 2.41-2.46 due to the high gypsum content in the soil. Models with low moisture content are observed with moisture content values ranging between 2.78 and 8.11%. Atterberg limit tests are conducted, and the examination failed in models containing small proportions of clay, except for three models, where the Atterberg limits are found (St.4, St.6, St.7). The liquidity index values are (22.14, 22.95, 23.37) respectively, while the plastic limit values are (19.57, 20.14, 21.35) for the same models. The results show that the soil is of type (SM). Proctor compaction tests are performed, where the maximum dry density values range between (1.691 and 1.778 g/cm³), while the optimum moisture content values range between (12.7 and 15.2%). As for shear resistance parameters, the cohesion values (C) range between 40 and 49 kPa, and the internal friction angle values (Ø) range from 30° to 35°.

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التقييم الجيوتكنيكي وتحليل قوة القص للتربة الغنية بالجبس في جامعة تكريت، وسط العراق

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الملخص

إن النتائج المستحصلة من التحريات الجيوتكنيكية تكون اساسية ومفيدة في تصميم المشاريع الهندسية بالاضافة إلى انهُ يمكن التَعَرُفُ من خلالها على المشاكل المستقبلية المحيطة بالمشروع والتوصل الى الحلول المناسبة لهذه المشاكل، ويُستفاد من الخواص الفيزيائية في تصنيف الترب للأغراض الهندسية. تم في هذه الدراسة إيجاد بعض الخصائص الجيوتكنيكية لنماذج منطقة الدراسة، حيث تم اجراء الفحوصات الجيوتكنيكية لغرض تقييم خصائص تربة جامعة تكريت هندسيا ومعرفة انطقة الضعف فيها ولعمق (3) امتار . تراوحت قيم الوزن النوعي مابين (2.41 و 2.46) بسبب وجود الجبس بنسبة عالية في التربة. ظهرت النماذج ذات محتوى رطوبي منخفض تراوحت قيمها ما بين (2.78 و 8.11%)، تم إجراء فحص حدود اللدونة، وقد فشل الفحص في النماذج التي تحتوي على نسب قليلة من الطين باستثناء ثلاثة نماذج تم العثور فيها على حدود اللدونة وهي في (St.4, St.6, St.7). حيث بلغت نسبة حدود السيولة (22.14، 22.95، 23.37) على التوالي، في حين بلغت نسبة حدود اللدونة (19.57، 20.14، 21.35) لنفس النماذج. وأظهرت النتائج أن الترب من النوع (SM). تم اجراء فحص الرص حيث تراوحت قيم الكثافة الجافة القصوى ما بين (1.691 و 1.778 غم/سم3)، بينما تراوحت قيم المحتوى الرطوبي المثالي ما بين (12.7 و 15.2%). أما بالنسبة لمعاملات مقاومة القص، فقد تراوحت قيمة مقاومة التماسك (C) ما بين (40 و 49 كيلو باسكال) وتراوحت قيم زاوية الاحتكاك الداخلي (Ø) من (30° الى 35°).

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Introduction

The construction process requires knowledge of the nature of the soil and its impact on the stability and sustainability of the structure, in addition to the effort that this facility will produce on the surface of the earth and the materials beneath it. Because the soil bears the loads of the facilities built on it (Elijah et al., 2013); therefore, it is necessary to study its mechanical and physical properties to adapt this study to the size of the project or the origin based on it. Construction experiments in several countries have proven that the exorbitant amounts spent on addressing some defects after construction significantly exceed the amounts spent on conducting a study or evaluating the land before construction (Al-Aseebi, 2018). The results obtained from geotechnical investigations are fundamental and useful in designing engineering projects. Through these investigations, it is possible to identify future problems encountered in the project and to find the appropriate solutions. The physical properties of soil are also used to classify soil for engineering purposes (Al-Tikrity, 2021). This study discusses the geotechnical properties of soil in the study area to evaluate it for engineering purposes and to determine the degree of its bearing capacity when establishing engineering structures and buildings. This will lead to a more accurate understanding of soil behavior during and after the construction of these structures. This evaluation requires conducting some laboratory tests on representative soil samples prevailing in the study area, consisting of eight samples distributed at eight stations and at different depths.

Location, tectonics, and geomorphology of the study area

The University of Tikrit is located in the center of Salah Al-Din Governorate in central Iraq about 200 km north of Baghdad Governorate on the international road linking Baghdad-Tikrit-Mosul, where it is located between two longitude lines (43 ° 38' 30" - 43 ° 38' 43") east, linear width between latitudes (34 ° 40' 16" - 34 ° 40' 22"). It is bordered to the north by the Baiji district, to the south by the Tikrit district center, and to the east by the Tigris River (Fig. 1). The area of the studied site is 340000 m^2. Tectonically, the study area is located within the Unstable Shelf, where the area includes many surface and subsurface structures as a result of the above structural situation (Buday, 1980). The study area is a part of the sedimentary plain, as the sedimentary plain area continues to decline with an asymmetric syncline fold, which allows the sedimentation process to continue due to surface and non-surface tectonic movement formation and this basin receives the products of the weathering processes of the mountainous area (Al-Faraji, 1990). Geomorphologically, the study area is located within the recent deposits plain of Salah Al-Din Governorate in the north of Iraq. This area is generally characterized as a flat land that does not contain any ripples, heights, or depressions compared to the surrounding areas, which is fed by the Tigris River, and the height of the Earth's surface is between (122 and 128) m above sea level (Ahmed and Al-Jubouri, 2005; Al-Tikrity, 2021).

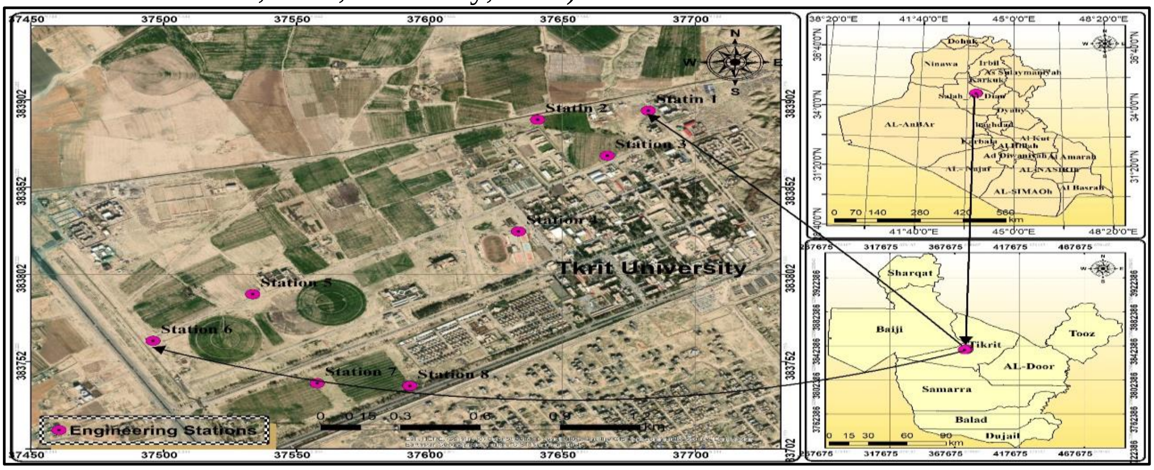


Fig. 1. Location map of the study area.

Geology of the Study Area

The ages of the sediments and rocks in and around the study area range from the Middle Miocene to the Holocene. The Fatha Formation (Middle Miocene) represents the oldest exposed formation at north of Tikrit City near the city of Baiji (not exposed in the study area) and represents a secondary gypsum source of the studied area; it consists of several sedimentary cycles characterized by a succession of marl and limestone layers topped by anhydrite or gypsum (Jassim and Goff, 2006). Injana Formation (Upper Miocene-Pliocene) is composed of a clastic sequence of fining upward cycles of calcareous sandstones, siltstones, and claystone deposited dominantly in the river environment (Al-Janabi, 2008; Al-Aseebi, 2018). This formation is exposed at the southwestern edge of the Makhoul fold between the Fertilizer Plant and the Baiji Refinery and is believed to be the source of sand and mud deposits in some parts of the study area.

Quaternary deposits cover large areas of Iraq in the sedimentary flood plains, river terraces, and the filled valleys between the ancient hills, forming a continuous cover in the study area. These deposits consist of clay, silt, sand, and gravel deposits that cover most of the study area, and the gravel varies in size from gravel to boulders and is poorly coherent, which leads to a good layer of water penetration into groundwater reservoirs (Al-Ani, 1997).

The sedimentary facies of these groupings are divided into four facies (clayey gravel, sandy-clay gravel, sandy gravel, and sandy-clay gravel), while the gypsum-containing soil covers most of the area. As it contains deposits of gravel, sand, silt, and clay and gypsum-rich, and the thickness of this layer varies from 3 to 4 m and sometimes up to 7 m (Al-Daffa'i, 2002), it is classified as a gypcrete as the gypsum content in these deposits is more than 50% and the interface material is often clay and sometimes sand (Basi et al., 1990). It is believed that the source of gypsum in the soil is the movement of water and its transport by surface runoff and the fluctuation of the groundwater table, where it has been moved to the unsaturated zone mediated by the capillary property, especially in areas where the water table approaches the Earth's surface (Al-Mufaraji, 2013). Figure 2 describes the lithological description of the wells in the study area using the program (Rockwork 13).

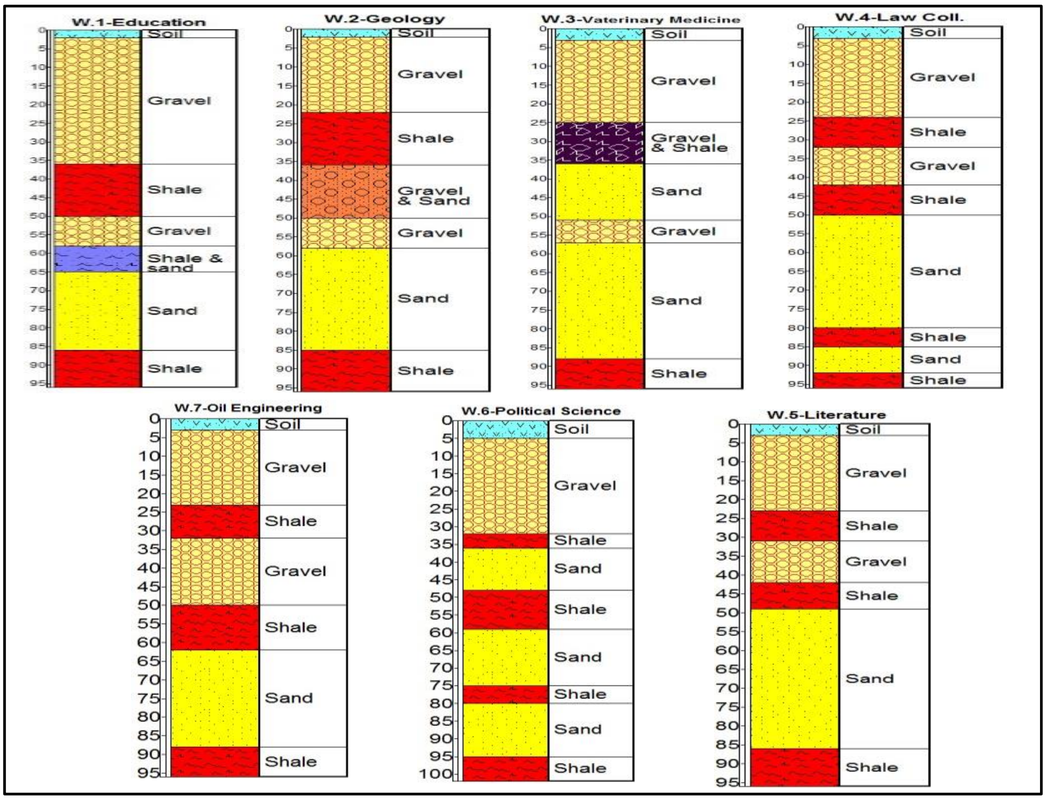


Fig. 2. Lithological column and description of wells in the study area.

Materials and Methodology

Data Collection

The available information about the study area is collected by literature survey, i.e., reviewing theses, dissertations, research papers, and scientific reports. This information is utilized in the current study. Additionally, field reconnaissance tours are conducted in the area to identify modeling locations. Preliminary information about the geological and topographical characteristics of the selected sites is also obtained to be used in the fieldwork and to gain a detailed understanding of the area.

Field Work

The fieldwork process consists of the engineering work, which includes taking 8 soil samples from eight selected stations at varying depths within the study area. The eight samples are taken from proposed empty areas for the future construction of scientific departments, dormitories, and a residential complex for university professors, for engineering evaluation of soil properties. The sampling is also performed near the geoelectric profiles. The engineering work was completed on February 20, 2022. The samples are collected over five days using a hydraulic excavator (backhoe) belonging to the university. The depths of the samples range from 1 to 3 m due to the high concentration of gypsum content within these depths, which caused problems in the presence of water. Beyond this depth, gypsum layers disappear because the gypsum here is considered to be transported from the Fatha Formation. As it is known, when constructing these buildings, we need to study and evaluate the soil. Studying up to (3) m is sufficient for soil evaluation, especially when constructing buildings ranging from one to four stories deep, and includes both cohesive (clay and silt) and non-cohesive (sand) soils. Additionally, some samples are obtained from trenching using a geological hammer to acquire unconsolidated sedimentary samples. GPS coordinates are recorded for each sampling location utilizing the Universal Transverse Mercator (UTM) system, which is later processed and converted into geographic coordinates for mapping. Each sample is safely stored in a sealed plastic bag, and a unique sample number is assigned. Photographs of the trenching and coordinates of the wells in the study area are also documented in Plate 1. A and B.

Plate 1. (A) Excavation process for sample collection. (B) Process of gathering and selecting the samples, and storing them.

Laboratory work

The laboratory work involves conducting some tests on soil samples collected from eight stations distributed in the study area, including:

Physical Tests: These tests are conducted in the Department of Applied Earth Sciences, College of Science, Tikrit University, and at the National Center for Construction Laboratories, Kirkuk. These are: specific gravity, moisture content, grain size analysis, and plasticity limits.

Engineering Tests: Include: compaction test and direct shear test.

Results and Discussion

Physical Tests

1. Specific Gravity: The specific gravity is measured according to the American standards (ASTM, D 854-02, 2004). The test values are calculated experimentally in the study area for the samples at eight stations distributed across the study area, and they range between 2.41 and 2.46, with an average of 2.43. It is observed that the specific gravity values are close, as one of the main reasons is the presence of gypsum in a high percentage. Gypsum is considered a mineral with a low specific gravity. Despite the presence of high proportions of gypsum in the study area samples, their specific gravity tends to be somewhat higher. Due to the mineral composition of the soil components in the study area, it is known that the presence of fine materials such as silt and clay directly affects the specific gravity values. These materials cause a significant increase in the specific gravity values of the soil (Al-Aseebi, 2018) (Table 1).

2. Moisture Content: The moisture content is measured according to the American standards (ASTM D2216-80, 2004). The moisture content values for the soil in the study area range between 2.78% and 8.11%, with an average of 5.37%. Through the laboratory test results related to moisture content, it is observed that these values are relatively low. One of the reasons is that the modeling process is specifically conducted in September when the groundwater level in the area is low. Additionally, the high temperatures and low rainfall contribute to the evaporation of water in the soil. Furthermore, gypsum absorbs water and incorporates it into its chemical composition, retaining two water molecules (Al-Tikrity, 2021). The scarcity of clayey soils in the area, known for their low permeability and high water retention, also plays a role. Clayey soils with their capillary property caused water to rise; therefore, the moisture content increases (Hassan et al., 2022). The decrease in moisture content has a positive impact on the foundations of engineering structures in the study area. The presence of water can lead to the dissolution of gypsum as the soil in the region contains high proportions of gypsum. Moreover, the presence of water reduces the shear resistance elements such as the internal friction angle (Ø) and cohesion (C) (Table 1).

Table 1: Values of the specific gravity and moisture content for deposits in the study area.

Station No.	Depth (m)	Specific Gravity	Moisture Content %
1	1.0	2.41	2.78
2	1.25	2.45	3.43
3	1.5	2.44	4.21
4	1.75	2.43	5.59
5	2.0	2.46	6.92
6	2.5	2.42	7.42
7	3.0	2.43	8.11
8	1.5	2.45	4.54
Average		2.43	5.37

3. Grain Size Analysis: The percentages of soil particles with different sizes are determined using granulometric analysis by separating the deposits into coarse-size groups represented by gravel and sand, and fine-size groups represented by clay and silt. This is done through two stages: sieve analysis and wet analysis according to the (ASTM, D422, 2004) and (ASTM, D-421, 2004). Size distribution curves are plotted for eight stations as shown in Figure 3. These plots illustrate the relationship between the cumulative percentage passing through the sieves with particle diameters for both sieve and wet (hydrometer) size gradation, integrated for each station model.

Through the results obtained from the granulometric analysis, it is observed that sand and silt dominate in all models, indicating that the soil has poor gradation. The clay content is very low in all stations, as well as the gravel content. The results of the sieve analysis and classification based on the Unified Soil Classification System (USCS) for the eight stations in the study area show an increase in the percentage of sand and silt in the soil. The sand content ranges from 38.21 to 60.99%, increasing with depth. The silt content ranges from 27.85 to 57.33%, decreasing with depth. The clay and gravel content are very low, with clay ranging from 0.49 to 8.92% and gravel ranging from 0.0 to 5.0%. The soil is sandy and silty as classified according to USCS based on the size analysis curves (Table 2).

Table 2: Soil Classification in the Unified Soil Classification System.

Station No.	Depth (m).	Gravel %	Sand %	Clay %	Silt %	Soil type
1	1.0	3.97	38.21	0.49	57.33	ML
2	1.25	1.03	48.16	2.01	48.80	ML
3	1.5	1.0	49.03	1.98	47.99	SM
4	1.75	0.0	54.95	7.01	38.04	SM
5	2.0	5.0	53.14	1.98	39.88	SM
6	2.5	2.96	56.17	8.92	31.95	SM
7	3.0	4.10	60.99	7.06	27.85	SM
8	1.5	1.02	49.11	2.01	47.86	SM
Average		2.38	51.22	3.93	42.46	

The soil type symbols ML it is means Silt (Low Plasticity) and SM it is means Silty Sand, or in the caption above.

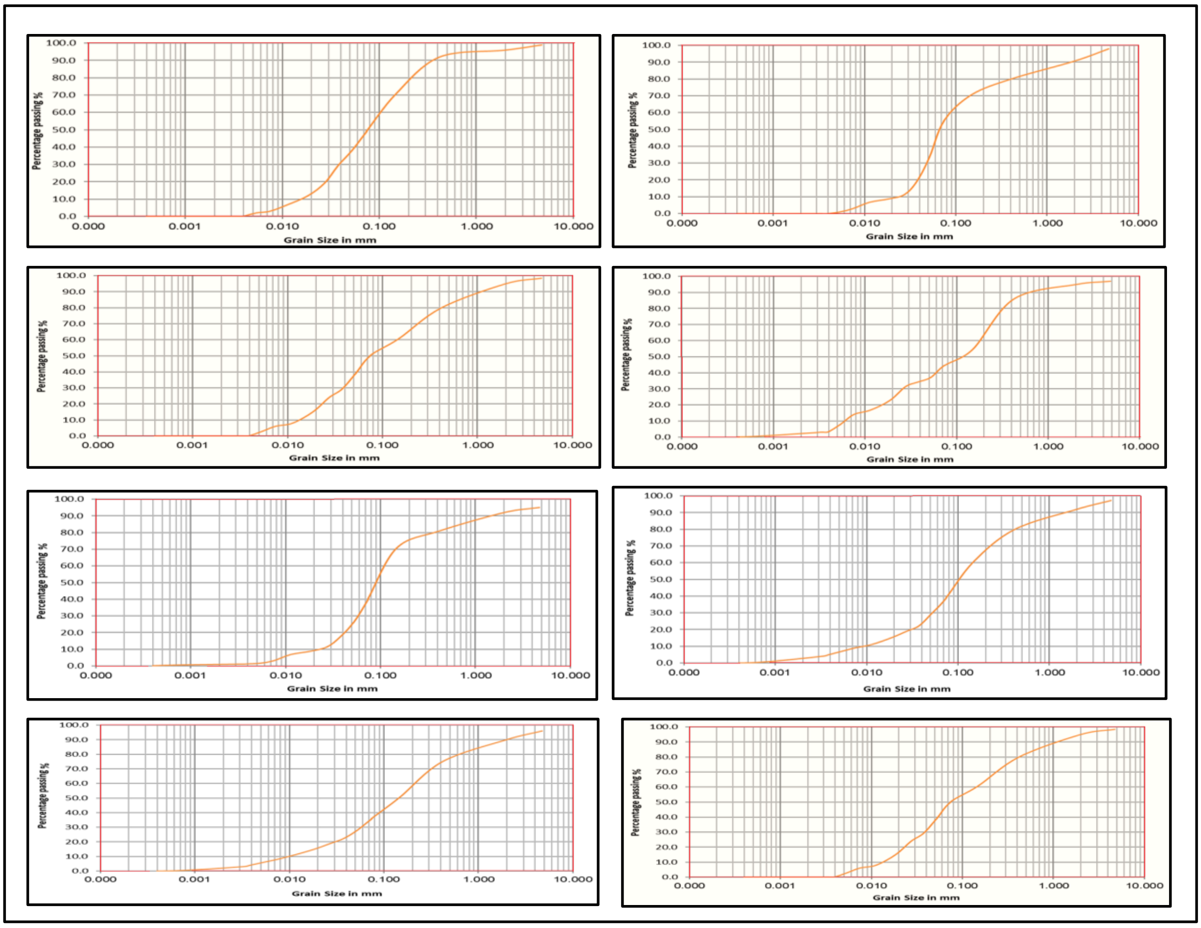


Fig. 3. The volumetric analysis of the studied stations (from St.1 at left to St.8 at right).

4. Atterberg Limits: The plasticity limits of the three stations (St.4, St.6, and St.7) are successfully determined with liquidity limit ratios of (22.14, 22.95, 23.37) respectively as shown in Figures (4, 5 and 6), which show the liquidity limit chart for the study area models. Meanwhile, the plasticity limits ratios for the same models are (19.57, 20.14, 21.35). The plasticity index values for the three models are exhibited in Table 3. According to the ductility chart (Fig. 7), it is evident that stations (St.4, St.6, St.7) fall within the sandy silty (SM) portion of the chart. The liquidity limit values for the soil in the study area are described based on Kerbs and Walker (1971), indicating that the soil has a very low to low liquidity limit according to Table 4. Additionally, the plasticity index values for the soil are described based on Al-Ashu (1991), revealing that the soil is somewhat non-plastic to moderately plastic according to Table 5.

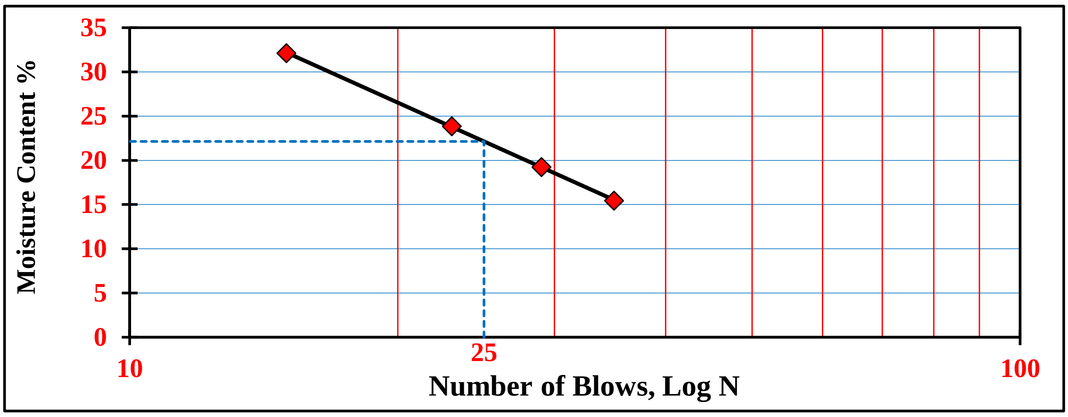


Fig. 4. Liquidity limit diagram for station 4.

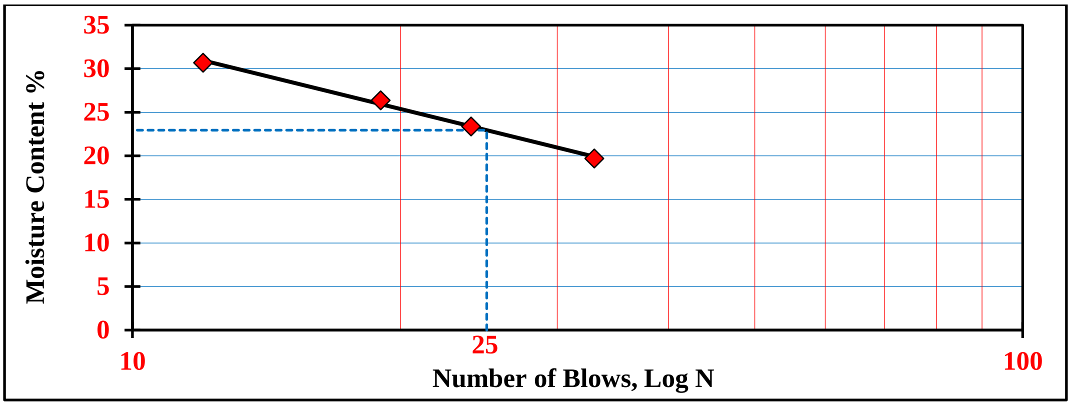


Fig. 5. Liquidity limit diagram for station 6.

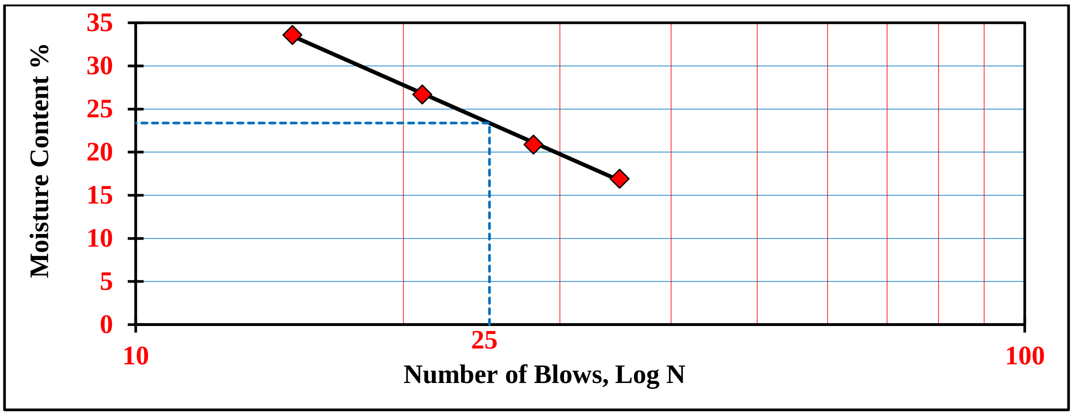


Fig. 6. Liquidity limit diagram for station 7.

Table 3: Values of the Atterberg limits for study area stations.

Station No.	Depth (m)	Liquid Limit	Plastic Limit	Plasticity Index	Soil Type
1	1.0	–	non- Plastic	non- Plastic	ML
2	1.25	–	non- Plastic	non- Plastic	ML
3	1.5	-	non- Plastic	non- Plastic	SM
4	1.75	22.14	19.57	2.57	SM
5	2.0	–	non- Plastic	non- Plastic	SM
6	2.5	22.95	20.14	2.81	SM
7	3.0	23.37	21.35	2.02	SM
8	1.5	–	non- Plastic	non- Plastic	SM

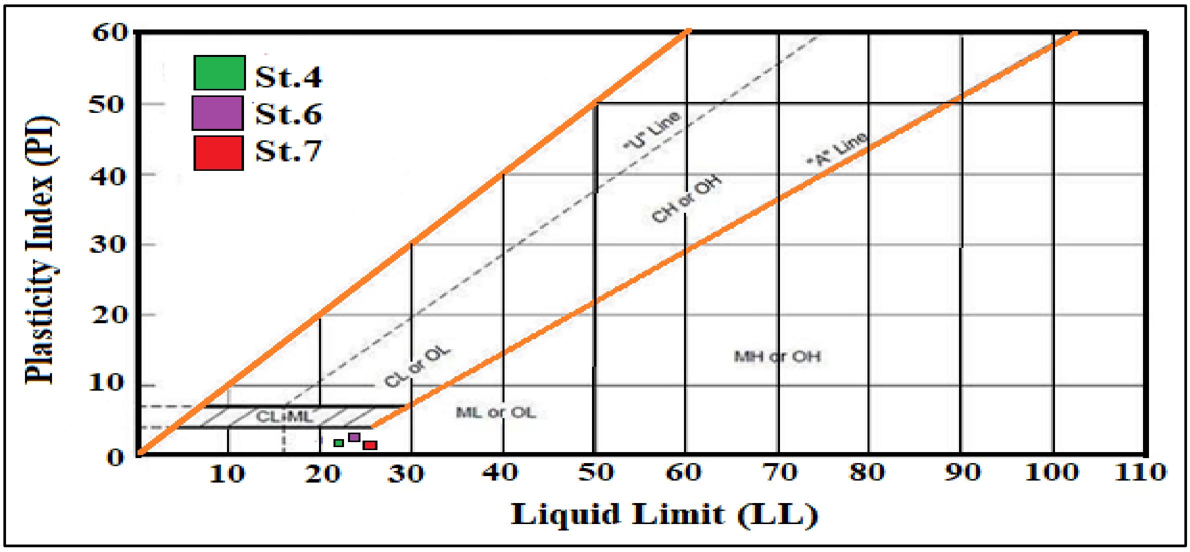


Fig. 7. Plasticity chart for study area stations (ASTM D2487-06, 2006).

Table 4: Description of the soil liquidity limit values (Kerbs and Walker, 1971).

Description	Liquid Limit (LL) %
Very low liquid limit	< 20
low liquid limit	20 – 25
Intermediate liquid limit	25 – 50
High liquid limit	50 – 70
Very high liquid limit	70 – 90
Extra high liquid limit	> 90

Table 5: Soil classification according to the plasticity index (Al-Ashu, 1991).

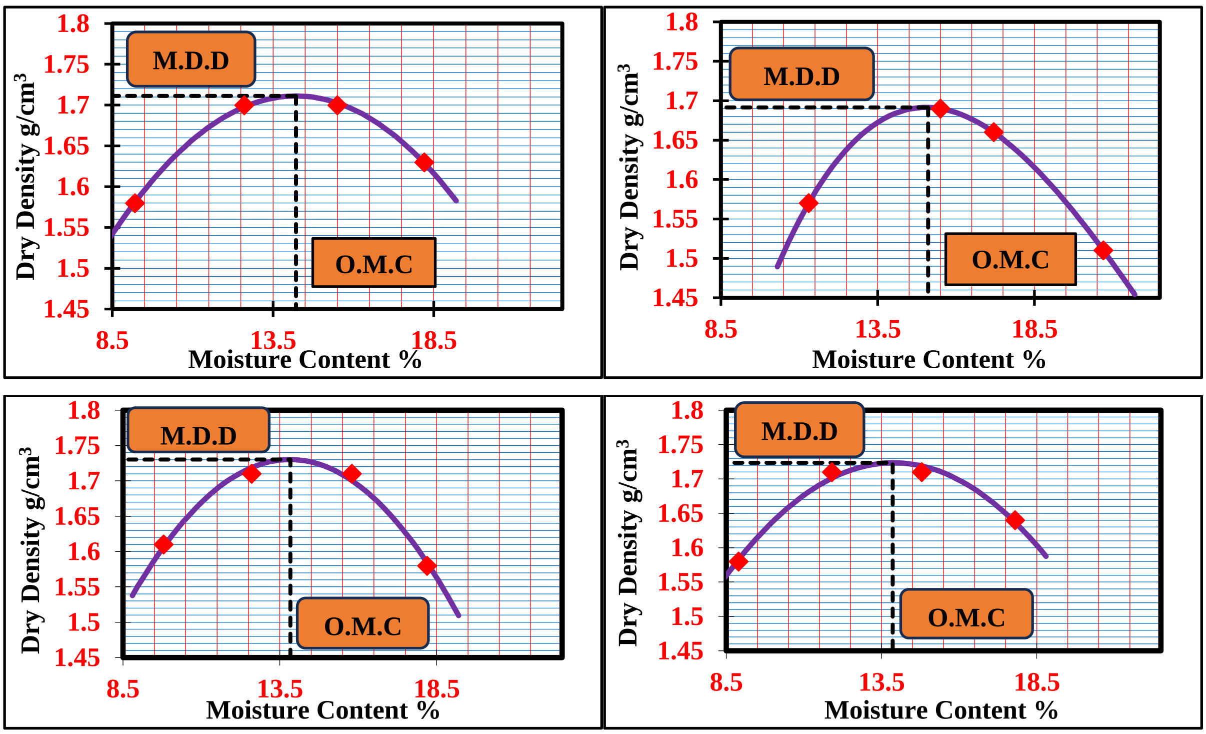
Description	Plasticity index
non-plastic soil	0
moderately plastic soil	1 – 5
low-plasticity soil	5 – 10
medium-plasticity soil	10 – 20
high-plasticity soil	20 – 50
very high plasticity soil	> 50

Geotechnical Soil Tests

Some geotechnical tests are conducted on the soil of the study area, and the most important of these tests are:

1. Compaction Test: It is conducted on eight samples of the study area (St.1, St.2, St.3, St.4, St.5, St.6, St.7, St.8). The maximum dry density values of the soils range from (1.691 to 1.778 gm/cm^3) with a highest density observed in sample (St.6), and the lowest in sample (St.2). The optimal moisture content values vary from (12.7% to 15.2%) with the highest values found in samples (St.6, St.7), and the lowest in sample (St.5). The resulting different values can be attributed to the mineral structures and particle sizes. The results show similarities among the study samples due to the convergence of particle size distribution, in addition to somewhat similar mineral composition as shown in Figure 8 and Table 6.

2. Direct Shear Test: It is conducted on eight stations, obtaining cohesion values (C) ranging between 40 and 49 kPa, and internal friction angles (Ø) ranging between 30° and 35°. The increase in cohesion values is attributed to the presence of clay in the soil composition. Additionally, the tests reveal an increase in the internal friction angle values due to higher gypsum content in the soil and its lower clay content, as shown in Figure 9. The values of cohesion and internal friction angle for the study samples are presented in Table 7.



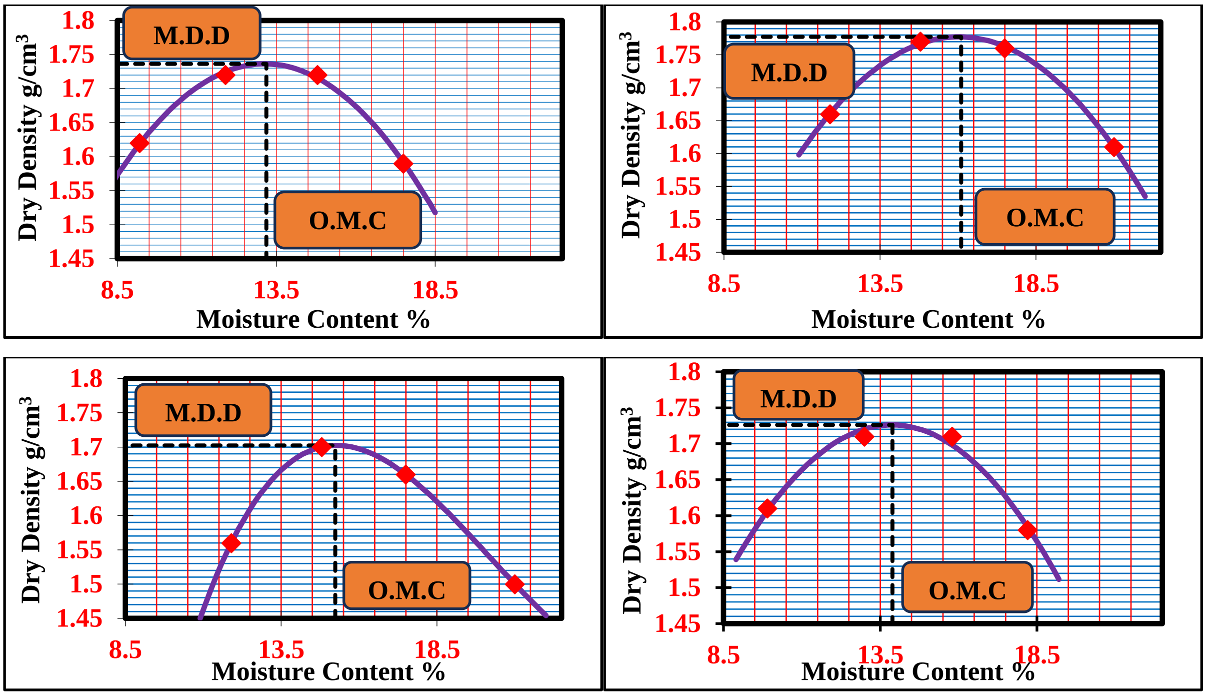
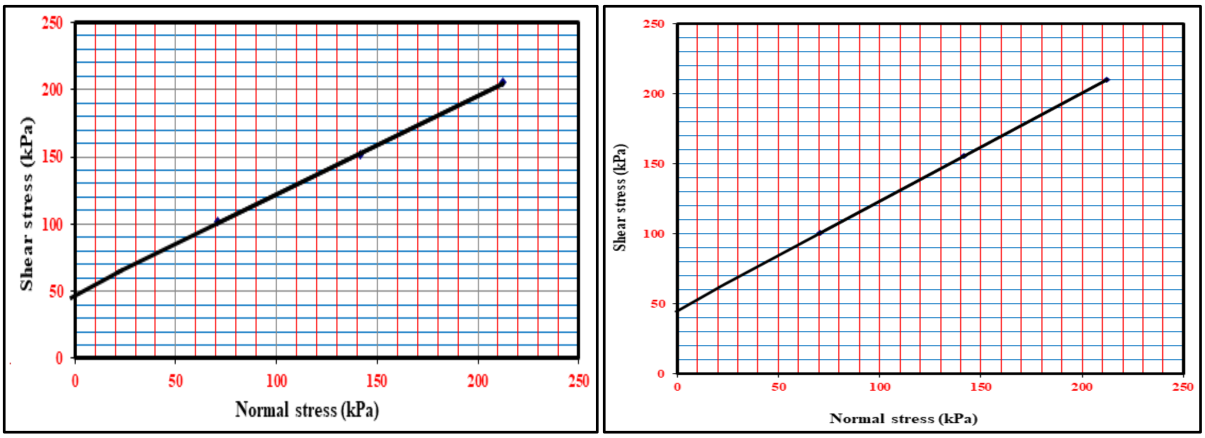


Fig.8. Relationship between dry density and moisture content for the studied stations (from St.1 at left to St.8 at right). Define here M.D.D it means Maximum Dry Density and O.M.C it means Optimum Moisture Content

Table 6: Results of the compaction tests for stations of the study area.

Station No.	Depth (m).	Dry Density (gm/cm^3)	Moisture Content (%)
1	1.0	1.71	14.1
2	1.25	1.691	15.1
3	1.5	1.730	13.8
4	1.75	1.724	13.9
5	2.0	1.735	12.7
6	2.5	1.778	15.2
7	3.0	1.702	15.2
8	1.5	1.728	13.9
Average		1.724	14.23



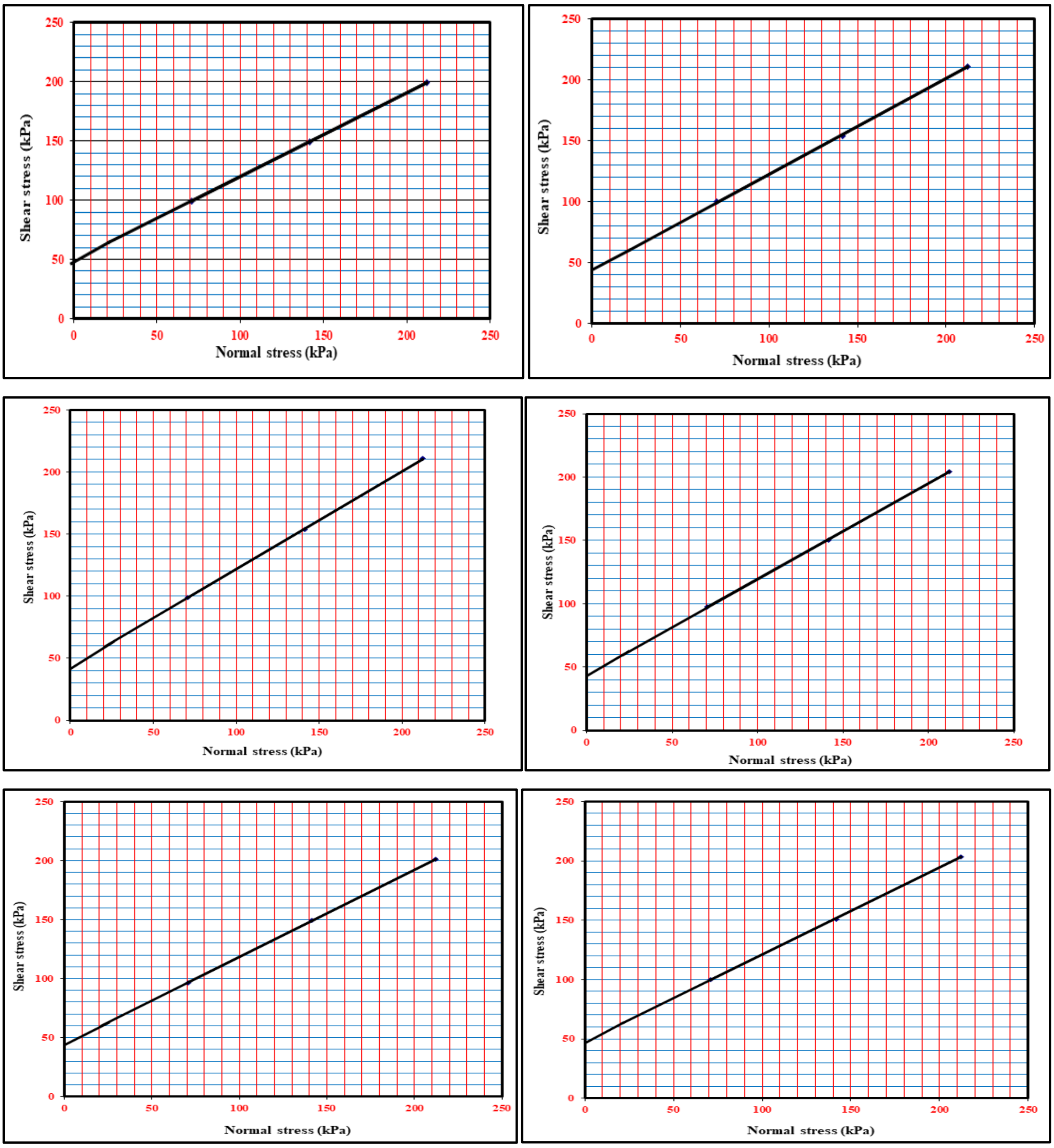


Fig. 9. Direct shear test for the stations (from St.1 at left to St.8 at right).

Table 7:. Cohesion value (C) and internal angle (Ø) for stations of the study area.

Station No.	C (kPa)	Ø°
1	49	30
2	46	31
3	49	32
4	43	30
5	40	33
6	41	34
7	44	35
8	48	32
Average	45	32

Conclusion

Through the results of the geotechnical properties study of the samples taken from the soils of the study area, there is a similarity in geotechnical properties, indicating the uniformity of the soils at all the sites. The soil in the study area is dominated by sandy and fine soils, which are sandy-silty soils with poor gradation and almost reach clay. They are of (SM) and (ML) types as soil models. It is also found that the ranges of soil specific gravity values recorded a relatively large convergence, and their percentage in the study area ranges between 2.41 and 2.46. The presence of gypsum in high percentages in the soil samples leads to a reduction in the specific gravity values because gypsum has a low specific gravity. It is also shown that the soil of the study area has low moisture percentages ranging between 2.78% and 8.11% because groundwater sources are far away, a lack of rainfall, and a high rate of evaporation. In addition, the modeling was conducted in September, and this low percentage is of utmost importance because the soil contains a high percentage of gypsum. Therefore, it is greatly affected by increasing moisture content. The results of the compaction examination also show convergence between the samples of the study area due to the similarity of the grain size gradation, as well as the similar mineral composition, which is represented by a high percentage of gypsum content and the rest of the soil minerals. As for the results of the direct shear test, they show that the values of shear resistance coefficients are similar for the soils of the study area due to the similar proportions of the sizes of sand and silt. We note that the values of cohesion resistance are rather high, and the angle of internal friction is high due to its gypsum content and low clay content. The presence of gypsum in the soil can have both negative and positive effects, depending on its quantity, soil type, and environmental conditions. One of the main issues it causes is its impact on soil structure, leading to changes in its physical and chemical properties. This can result in weakened soil and reduced resistance to erosion and weathering, especially in the presence of water, as it dissolves and leaves behind gaps and cavities, which pose a risk to structures built on top. On the positive side, one of the main benefits of its presence is increased soil cohesion in the absence of water, as the calcium in gypsum helps to enhance soil cohesion. Through the values obtained from the engineering tests conducted at various sites within the study area, it is evident that there is a potential for engineering problems to occur due to water infiltration and dissolution of gypsum minerals, which is present in high proportions in the selected models. Consequently, this could lead to soil subsidence, foundation instability, and building collapse, especially in vertical structures. The results obtained from the tests indicate the necessity of replacing the upper part of the soil according to the specified level for the foundation of the structures, with an insulating layer of salt-free clay soils using sulfate-resistant cement with a thickness determined by the foundation engineer. Additionally, attention should be paid to water supply and drainage pipes, ensuring the integrity of the connections and their maintenance to prevent water leakage into the foundations. It is also preferable to use raft foundations when constructing engineering buildings to avoid differential settlement that occurs due to the dissolution of gypsum.

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