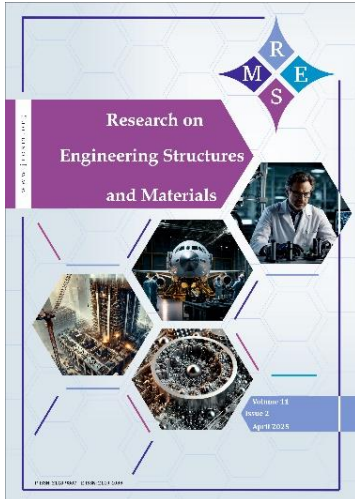




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Comparison of shear strength testing methods and bearing capacity estimation for problematic soils in Mosul city, Northern Iraq

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Abstract

The study aims to investigate the strength characteristics, as represented by shear parameters, of various soil types that pose numerous engineering problems in and around Mosul, Iraq. Five soils, including low-plasticity clay, high-plasticity clay, silty organic soil, fill organic materials (10.2%), and gypseous soil (63.4%), were selected for the study, having serious geotechnical problems like swelling, collapse, high organic content, and high gypsum content. The testing program includes direct shear, residual shear, unconfined compression, oedometer, chemical tests, and the index properties of the study soils. The results generally showed that direct shear tests yield strength parameters that lead to overvaluation of bearing capacity. In contrast, unconfined compression tests yield more conservative results, and residual shear tests yield the smallest values due to the test conditions. The results indicated that shear properties can vary significantly across test methods, highlighting the need for careful interpretation of bearing capacity values. Taking safety considerations into account, the bearing capacity may range from 50 to 150 kN/m². Also, for the design of shallow foundations on Mosul soils, any available field or laboratory strength test for soil should be used in combination with tests that identify geotechnical issues in the soil, relying primarily on the test that yields the lowest value—or at least a reasonable value with engineering judgment—for the strength parameters.

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1. Introduction

The city of Mosul in Iraq is constantly expanding, and its construction rests on a variety of soil types. Since shear properties are important in determining soil bearing capacity, which is essential in foundation design, it is vital to highlight these soils and their shear values. Recognizing that shear strength parameters can vary with testing methods helps engineers make more informed decisions. The shear strength parameter is a key factor in evaluating soil bearing capacity and stability [1]. Many factors influence the shear strength, including the roughness of the soil particles' surfaces, the soil's mechanical properties, and the applied load. The shear strength at the interface, soil cohesion, angle of internal friction, and residual strength increase with increasing interface roughness. In contrast, the shear strength tends to remain constant with increasing shear displacement [2]. Shear resistance criteria are important for slope stability analyses to avoid landslide failure [3].

A fundamental understanding of shear behavior at the interface with foundation elements is important in the design of many geotechnical structures. The parameters of soil and surface characteristics that may control shear load-transfer mechanisms and shear strength at the interface between surfaces with structured roughness and cohesionless (sandy) soils require

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further study [4]. The shear strength of expansive soils is very important for engineering stability, not only because it shows typical variability with changes in moisture retention but also because it exhibits significant attenuation due to swelling-shrinkage behavior, fissuring, and over-consolidation [5]. [6] Investigate the impact of a humid, hot environment on the residual strength characteristics of soil, and study how changes in soil microstructure correlate with strength reduction in cycle tests. The soil's saturated shear strength continued to decrease because the interaggregate connections remained broken. In contrast, the deterioration of the intergranular connection in the aggregate was relatively slow, and the angle of internal friction in the soil showed a slight decrease, even remaining constant at a later stage. Several comparative studies were conducted to highlight differences between shear coefficients obtained from direct and residual shear tests, noting their effects on the geotechnical properties of clay soils [7–9].

Some previous studies have focused on the geotechnical properties of clay soils, both low- and high-plasticity, found in certain parts of Iraq, with an emphasis on soil resistance and shear strength [10–17]. The geotechnical properties of low-plastic-clay soil from Mosul, with added sand, have been studied by [18]. The researchers focus on resistance and shear properties, as measured by direct shear testing, unconfined compressive strength, and residual shear strength. The study results showed that increasing the amount of coarse, non-cohesive material, such as sand, increased shear strength to varying degrees depending on the test type, and led to a notable increase in bearing capacity of soil [18]. Other research has focused on the geotechnical properties and engineering problems associated with alluvial or clayey silt soils, which are abundant on riverbanks and in areas with dense vegetation, such as forests. These soils present several engineering challenges, including high organic and salt content and high susceptibility to collapse [14,19,20]. Gypsum formations cover vast areas of Iraq and are mixed with clay, silt, and sandy soils in varying concentrations. The presence of gypsum affects the engineering properties of soils, especially when they are exposed to water, which can cause gypsum to dissolve, thereby impacting soil strength, compressibility, and stability. Therefore, this topic has received considerable attention from researchers [21–26].

This study aims to determine the strength and resistance properties of soils found in northern Iraq, specifically in Mosul and its surrounding areas, which are experiencing significant urban expansion. The study also aims to compare the bearing capacity of the soils under investigation and to review the geotechnical complications associated with the soils, providing appropriate recommendations for foundation types and designs for various structures.

2. Materials of The Study

Five soil types were selected that cover almost the entire city of Mosul (divided by the Tigris River into two parts: the right and left banks), the surrounding areas, and many populated areas and cities in Nineveh Governorate. The samples were collected between 1.0 and 3.0 m below the ground level, which corresponded to the depths of most buildings' foundations in the city. Table 1 shows some geotechnical properties of soils used in the study. Figure 1 shows soil particles and the locations of the materials used in the study.

Low-plasticity clay soils are found in many residential areas of Mosul and its outskirts, and are among the most common soil types in northern Iraq [27,28]. High-plasticity clay soils are prevalent in parts of northern Mosul [27,28]. Furthermore, clay-silty soils with high gypsum content are found south of Mosul, extending to the southern borders of Nineveh Governorate [27,28]. Silty soils, with high organic content, are widespread along the banks of the Tigris River and in the forests of Mosul. Very high-organic-content soil deposits are concentrated in the center of Mosul, including the city's historic and archaeological areas and its markets. Many soil investigation reports for building, and several studies, show that the soil fill materials with high organic content are soils that have accumulated as a result of previous construction work; although they are not naturally deposited soils, they can reach depths of more than 10 meters in some locations [27,29].

Table 1. Geotechnical properties of soils used in the study

Soil type		Low plasticity clay	High plasticity clay	Low plasticity Silt	Organic soil	Gypsum soil
Sampling depth (m)		1.0	3.0	1.5	2.0	2.5
Soil condition at the site	Water content (%)	15	23.2	11.2	19.3	20.7
	Dry density kN/m ³	15.5	16.4	13.6	14.1	16.1
Atterberg limit	Liquid limit (w/c %)	46	87	27	35	30
	Plastic limit (w/c %)	26	38	22	N.P.	21
	Plasticity index (w/c %)	20	49	7	N.P.	9
Grain size analysis	Sand (%)	7	13	20	13	45
	Silt (%)	51	33	70	77	33
	Clay (%)	42	54	10	10	22
U.S.C.S	Group symbol	CL	CH	ML	OL	CL-ML
Compaction	Max. unit weight, (γ, kN/m ³)	15.59	13.65	17.68	14.59	16.66
	Optimum water content (w/c %)	20.5	18	12.6	23.2	10.0

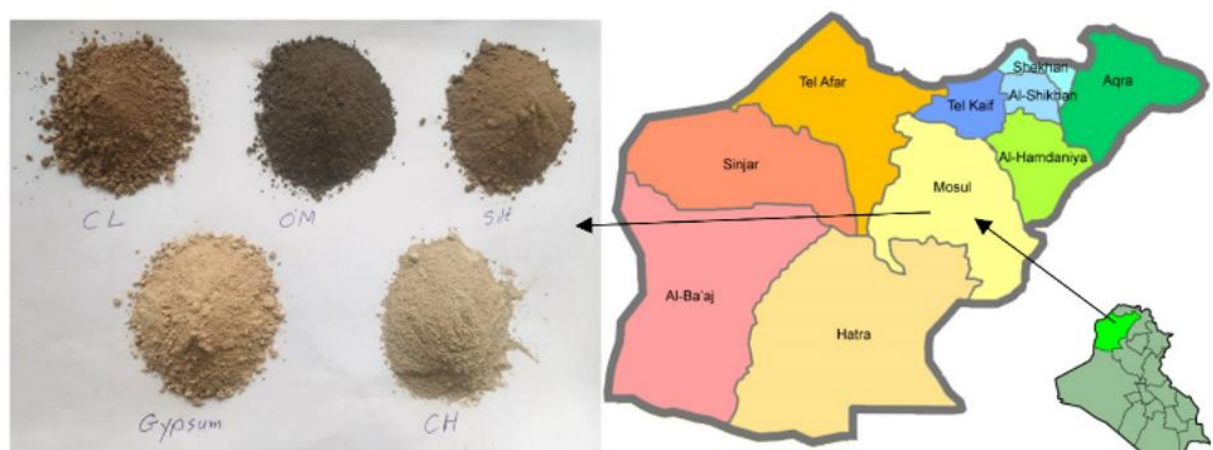


Fig. 1. Picture of soil particles used in the study

3. Methodology

The soils collected for the study's tests were oven-dried at 100°C except for gypseous and organic soils, which were dried at 60°C, cleaned, and sifted through the specified sieve for each test

requiring disturbed samples. The tests require that undisturbed samples (for direct shear and oedometer tests) be prepared from soil lumps or a Shelby tube, with an average of more than three specimens (per test). Furthermore, immediately after extraction from the field, the samples were preserved along with their water content to ensure they were subjected to as little disturbance as possible. The samples for the unconfined compression and residual shear test were prepared from disturbed samples, depending on the compaction characteristics parameters. The specimens were prepared under suitable laboratory conditions and tested using equipment in the geotechnical laboratory at the College of Engineering, Mosul University, as shown in Figure 2, and tested in an average of three samples with an acceptable standard deviation according to the specifications listed in Table 2.



Fig. 2. Equipment used in the study, left: direct shear, middle: unconfined compression, right: residual shear.

Table 2. Tests and specifications of soils

Test category	Test name	Standard specifications
Type of samples	Disturbed samples (DS)	[30]
	Undisturbed Samples (US)	[31]
Soil Classification	Atterberg Limits (LL and PL)	[32]
	Grain Size Analysis	[33]
	U.S.C. S	[34]
Moisture-density relation	Compaction test	[35]
Oedometer tests	Consolidation test	[36]
	Swelling test	[37]
	Collapse test	[38]
Strength tests	Unconfined compression	[39]
	Direct shear test	[40]
	Residual Shear Strength	[41]
Chemical tests	Sulphate content (SO ₃ %)	[42]
	Total soluble salts (T.S.S %)	
	Gypsum content (CaSO ₄ .2H ₂ O)	
	Organic matter content (%)	

4. Calculation of Bearing Capacity

The bearing capacity of the study soils was estimated using the general Meyerhof gross bearing capacity equation [43], based on strength parameters obtained from the direct shear and residual shear tests.

$$q_{ult.} = \dot{c} N_c F_{cs} F_{cd} F_{ci} + q N_q F_{qs} F_{qd} F_{qi} + \frac{1}{2} \gamma B N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i} \quad (1)$$

Where:

($q_{all}=q_{ult}/F.O.S$)

q : $\gamma \times D_f$ (effective stress at the level of the bottom of the foundation); D_f : depth of foundation (supposed to be 1.5 m); c' : effective cohesion

γ : unit weight of soil

B : width of foundation (the foundation is supposed to be a square with $B = 1.5$ m)

N_c, N_q, N_γ bearing capacity factors, $F_{cs}, F_{qs}, F_{\gamma s}$: $F_{cd}, F_{qd}, F_{\gamma d}$: depth factors, $F_{ci}, F_{qi}, F_{\gamma i}$: load inclination factors[44–47].

The bearing capacity from the unconfined compression test was estimated using the Buisman bearing capacity equation for a foundation on saturated clay. (43)

$$q_{ult.square} = \underbrace{5.14 \left(1 + \frac{0.5 \frac{B}{H} - 0.707}{5.14} \right)}_{N_c (square)} c_u + q \quad (for H < 0.707B) \quad (2)$$

Where:

H : the depth of the soil layer under the base of the foundation, and taken as ($1.0m < 0.707B$) to give minimum values of N_c and q_u/fN_c and $q_{ult.}$, c_u : the undrained shear strength (Stress, $q_u/2$).

The assumption of saturated clay (zero internal friction angle, $\phi = 0$) was intentionally adopted for comparative purposes and to simulate a worst-case scenario. This assumption is justified by the field conditions in Mosul city, where the groundwater table is remarkably shallow and close to the ground surface in many areas, creating potentially saturated, undrained conditions.

The purpose of specifying the safety factor, width, and depth of the foundation is to facilitate comparison with the parameters used in the load-bearing capacity equation. The safety factor (3) is appropriate for the soil used in this study, as it is cohesive fine soil according to the aforementioned classification. As for the selection of the foundation width and depth (1.5 meters), these dimensions are used for shallow foundations commonly employed in standard buildings in the city of Mosul and its outskirts.

5. Results and Discussion

The index and geotechnical properties, especially the shear characteristics, of five problematic soils were determined. The soils are widely distributed across northern Iraq, particularly in and around Mosul city.

5.1 Geotechnical Parameters of Problematic Soils

Table 3 presents the parameters and the primary geotechnical issues associated with each soil used in this study, compared with the reference soil (low-plasticity soil). The problems of these soils have direct or indirect effects on their strength and bearing capacity. The obtained parameters of the soils used in the study show a clear geotechnical problem that exceeds the allowable limits. Geotechnical problems like swelling, collapse, high organic content, and high gypsum content often control the design of the foundation and lead to conservative values of allowable bearing capacity of soil, as shown in the bearing capacity results.

5.2 Shear Strength Characteristics of Soils

Table 4 shows the results of the shear strength characteristics of soils used in the study, represented by effective cohesion (c') and effective internal friction angle (ϕ'), obtained from different tests (unconfined compression, direct shear, and residual shear test). From Table 4 and Figure 3, the single most prominent observation to emerge from the data comparison was that the unconfined compression values give a misleading understanding of the strength of the five soils under study. Whereas the least problematic soil (CL) exhibits intermediate-to-weak shear strength parameters, the most problematic soils (OL and CL-ML) yield the highest strength values. The results must be interpreted with the test conditions in mind.

Table 3. Main geotechnical problems of the soils used in the study

	Soil type	Low plasticity clay (CL)	High plasticity clay (CH)	Low plasticity Silt (ML)	Organic soil (OL)	Gypsum soil (CL-ML)
Oedometer tests	Compression index (Cc)	0.15	0.18	0.23	0.31	0.15
	Pre-consolidated pressure (Pc, kN/m ²)	120	130	130	220	210
	Swell pressure (kN/m ²)	75	350	Nil	Nil	Nil
	Swell percentage (%)	1.6	22	Nil	Nil	Nil
	Collapse Index *(%)	Nil	Nil	2.2	2.5	0.9
Chemical tests	Sulphate content (SO ₃ %)	0.03	0.34	0.25	1.1	0.47
	Total soluble salts (T.S.S %)	1.2	5.4	3.2	8.5	2.45
	Gypsum content (CaSO ₄ .2H ₂ O)	5.5	5.0	1.3	18.4	63.4
	Organic matter content (%)	1.2	1.5	1.1	10.2	5.5
Main geotechnical problem	low plasticity clay (CL)	Reference soil				
	High plasticity clay (CH)	High shrinkage and swelling (plasticity index, P.I.> 35, very high swelling potential) [48]				
	Low plasticity Silt (ML)	Moderate collapse and high compressibility (collapse index, C.I.>2 and Compression index, Cc> 0.2) [38, 49]				
	Organic soil (OL)	Medium organic soil (organic content >6.0) [50] Moderate collapse and high compressibility (collapse index, C.I.>2 and Compression index, Cc> 0.2)				
	Gypsum soil (CL-ML)	gypseous soil (Gypsum content% > 50 consider Gypcrete**) [51]with high gypsum-soluble materials				

*Collapse Index was calculated at a stress level of 200 KN/m²

*Gypcrete is a hardened, natural soil layer rich in secondary gypsum (calcium sulfate), forming in arid/semi-arid regions where sulfate-rich water evaporates, leaving gypsum to cement soil particles like sand and clay into a crust or mass. It is a significant geological feature in dry climates, often found near the surface, that acts as an evaporite deposit, poses construction challenges due to potential instability and settlement, and serves as a raw material for plaster.

The heterogeneous composition of organic soil, which may include stones, gravel, or debris from previous buildings, can give a false indication of unconfined compressive strength. In addition, the low moisture content of the gypseous soil sample is a notable limitation during the unconfined compressive strength test, yielding high values that do not accurately reflect the soil's condition under higher moisture levels, which can lead to significant soil settlement or collapse due to gypsum dissolution. With the exception of organic soils (OL), significant differences, especially in silty soil (ML), can be observed in the internal friction angle values obtained from direct shear tests and those from residual shear strength tests, due to the difference in the soil type and the test condition. The fact that there is a predetermined failure plane in the direct shear test, one of the test's limitations, may result in relatively high values of effective internal friction angle (ϕ') in low-shear-strength soils, such as silty soils. In contrast, the residual shear strength test does not have a predetermined failure plane, which explains the significant variation in the internal friction angle

values obtained from the two tests. It is widely recognized that organic soils (OL) exhibit unpredictable or uncharacteristic results in various engineering tests. As the organic matter content increases, the soil displays increasingly erratic behavior during these evaluations. Consequently, these soils must be handled with extreme caution in engineering projects. As shear strain increases toward the residual state, any initial structure or apparent cohesion from organic fibers is destroyed, causing effective cohesion to approach zero. However, the residual friction angle is governed primarily by the ultimate arrangement, orientation, and intrinsic interparticle friction of the residual mineral and decomposed organic matrix. Because the fundamental soil fabric and particle surface characteristics remain unchanged after large displacement alignment, the residual friction angle reaches a steady-state value that is almost entirely independent of the original structure or initial cohesive bonds.

Table 4. Shear parameters of soils used in the study

Test type	Parameter	Soil type				
		CL	CH	ML	OL	CL-ML
Unconfined compression	Stress (q_u) (kN/m ²)	73.4	107	99.1	135.1	222.6
	Optimum water content (w/c%)	16.5	22	10.1	19.0	9.5
Direct shear	Cohesion (c) (kN/m ²)	14	35	4	11	40
	Eff. internal friction angle (ϕ')	26	27	28	19	34
Residual Shear Strength	Eff. cohesion (c') (kN/m ²)	0	10	5	1	5
	Eff. internal friction angle (ϕ')	9	6.3	10.2	18.8	12.1

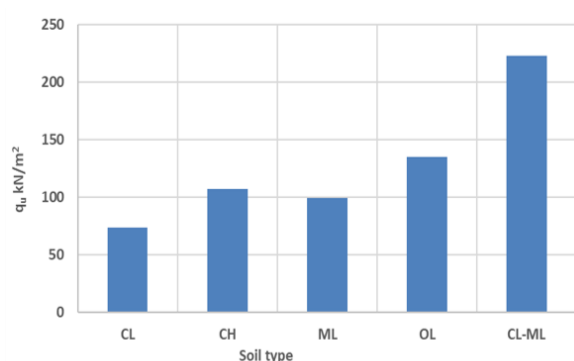


Fig. 3. The unconfined compression strength of the soils of the study

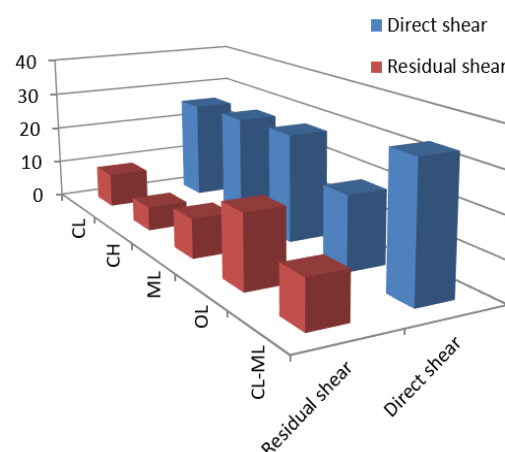


Fig. 4. The effective internal friction angle values of the study soils from the direct shear test

Table 4 and Figures 4 and 5 show the results of the direct shear test and the strength parameters (c' and ϕ') of soils used in the study. Once again, although direct shear testing is supposed to yield more reasonable values than unconfined compression testing, (CH and CL-ML) soils produced the highest shear modulus values. While the testing conditions account for the worst-case scenario of fully saturated soil with a consolidated drained test (slow test with a rate of 0.007mm/min), determining the test's failure level may lead to overestimates of the shear parameter values.

The results of the strength parameters (c' and ϕ') obtained from residual shear strength are presented in Table 4 and Figures 4 and 5. The results showed a logical and expected decrease in the internal friction angle of soils due to the test's nature, which yields a residual shear value after failure. Furthermore, a significant decrease in cohesion values is observed, approaching almost zero. This result is expected in this test because the expected residual shear value depends on the frictional force between the particles only. In the residual shear test, the device allows for continuous, unlimited displacement in one direction. This continuous rotation forces the platy clay particles to rearrange in a way so that they are perfectly parallel to the shear plane. This mechanism makes the resistance caused solely by sliding friction between the smooth surfaces of the particles and complete destruction of bonds and cohesive strength.

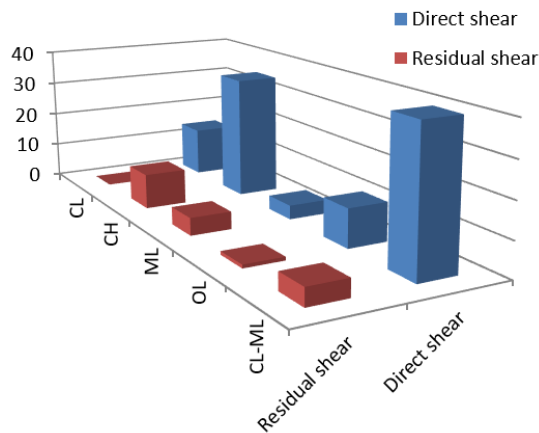


Fig. 5. The cohesion values of the study soils from the direct shear test

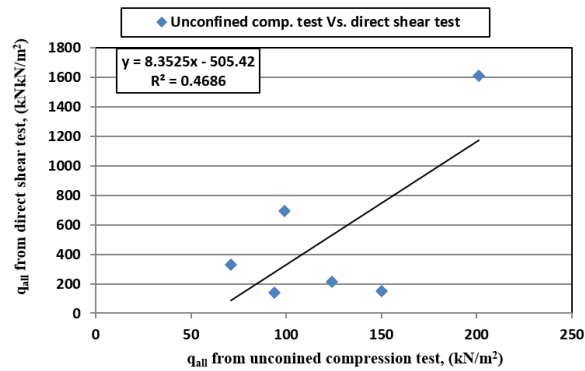


Fig. 6. The relation of allowable bearing capacity values of the study soils obtained from the different shear tests, with the coefficient of determination (R^2) between the types of tests

5.3 Bearing Capacity Estimation

Soil bearing capacity is the primary objective when conducting shear resistance tests and determining soil shear strength coefficients. Table 5 presents the bearing capacity of the study soils, calculated according to the assumptions outlined in the study's methodology. The experimental data yielded bearing-capacity results that are controversial, and there is no consensus on which values are suitable for foundation design. Furthermore, there is no clear correlation between the results of the soil bearing capacity calculated from any two shear strength tests in the study. As shown in Figure 6, there is no logical or statistically reliable relationship between the laboratory tests of the direct shear test and the unconfined compression test. The correlation coefficient (R^2) among the test method or the calculation method for load-bearing capacity values is very low for all relations in Figure 6. The differences in the method and nature of the test, the preparation of the specimen, and the method used to calculate the bearing capacity from each test provide a possible explanation for the differences in the calculated bearing capacity results.

Generally, the direct shear test yields overestimated allowable bearing capacity values due to test conditions, and it is recommended that these values not be used directly without first assessing the main geotechnical problems of the soils. The unconfined compression test yielded more conservative allowable bearing capacity values. The equation used to calculate the bearing capacity from unconfined compressive strength is for saturated soils (angle of internal friction = 0), so it yields lower values (worst-case conditions). This option is suitable for soils with engineering issues, such as gypsum, organic, and silty soils, due to their high potential for saturation. Meanwhile, calculating bearing capacity from direct shear testing uses effective shear modulus values that are somewhat higher, resulting in larger values. Nevertheless, it showed some high values for the CL-ML soil. The high bearing capacity of gypsum soil stems from its high cohesion, which is due to the soil being in a dry state; the soil is strong as a result of the cementitious nature of the gypsum binder. The residual shear test yields the lowest allowable bearing capacity, with some CL soil values underestimated and considered safe design estimates for post-failure scenarios. Figure 7 presents a comparison of the bearing capacities of the soils used in the study, and the dotted rectangle indicates the approximate reasonable range of bearing capacity (50 to 150 kN/m²) for a similar situation. The bearing capacity results were used in different locations of structural design in Mosul City and the surrounding area, as shown in Table 6. The soils recorded in Table 6 were the same soils used in this study, and the shear strength parameters were obtained from different types of laboratory and field tests. Although the shear strength values obtained from laboratory tests (particularly the unconfined compressive strength test and the direct shear test) and various field tests are similar to or even higher than those obtained from the study, the bearing capacity values took into account the prominent geotechnical issues for each soil type. The bearing

capacity used for these locations has approximately the same range suggested by this study, as shown in Figure 8. Generally, the use of bearing capacity values requires suitable experience and sufficient knowledge of the soil type and the associated geotechnical problems. Problems like significant soil settlement, collapse due to gypsum dissolution, and wetting and drying cycles should be considered before bearing capacity estimation.

Table 5. Bearing capacity of soils used in the study (kN/m²)

Soil type	Test type					
	Unconfined compression		Direct shear		Residual Shear	
	qult.	qall.	qult.	qall.	qult.	qall.
CL	213	71	993	331	51	17
CH	298	99	2083	694	149	50
ML	372	124	638	213	121	40
OL	283	94	426	142	167	56
CL-ML	602	201	4830	1610	162	54

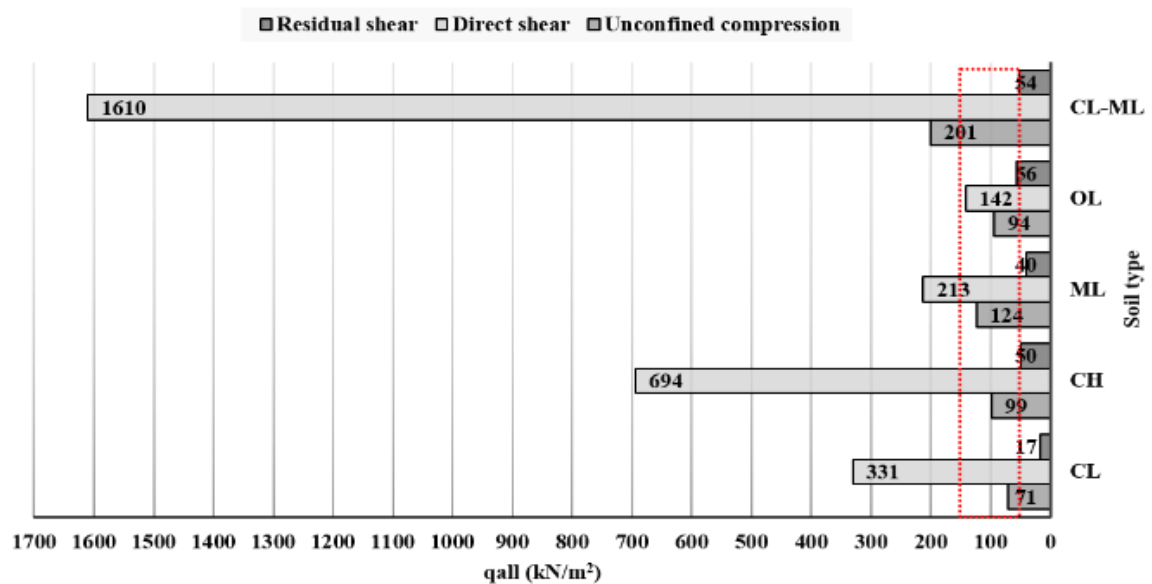


Fig. 7. Comparison of bearing capacity of soils used in the study (kN/m²)

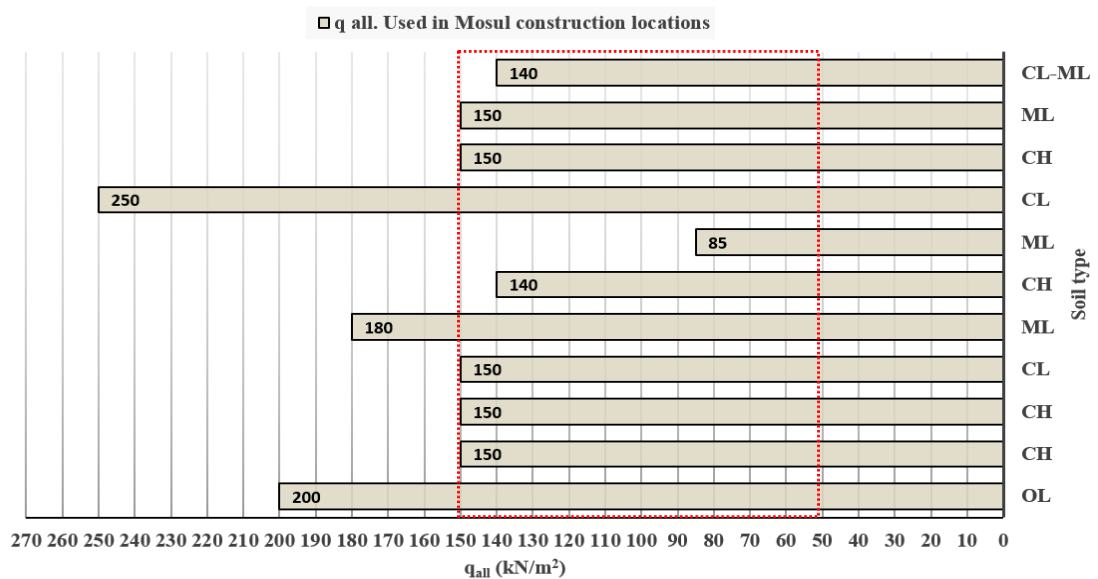


Fig. 8. Bearing capacity of soils used in different locations of construction in Mosul and around (kN/m²)

Table 6. Shear parameters and bearing capacity of some locations in Mosul city

Site	Depth of sample (m)	Type of soil	Laboratory strength tests		
			Shear characteristics from the direct shear		Shear characteristics from the unconfined compression
			C cohesion (kN/m ²)	φ Angle of friction (degrees)	Stress (qu) (kN/m ²)
School In the old city of Mosul	2	OL	24	26	----
Buildings of Nineveh Drug Company (Mosul, left banks)	1.5	CH	75	25.6	----
	2.5	CH	100	28	---
Cars Park in (Mosul, right banks)	4-10	CL	---	---	135-165
Building at the Mosul airport (Mosul, right bank)	0.1-4.0	ML	4	28	
Building in (Mosul, right banks)	2-10	CH			369-482
Building in (Mosul, right banks)	1.0	ML			
Hospital in Mosul, left banks)	6.0	CL	20	28	
Private University in Mosul, left banks)	5-15	CH	18-25	21-25	180-240
Health dispensary in Mosul, left bank	6.0	ML			60
Secondary electricity station west of Mosul city	1.5	CL-ML	25	27	

Site	Field strength tests			Allowable bearing capacity used for the site (kN/m ²)
	Results of Standard Penetration	Results of Dynamic Cone Penetration	Results of plate load	
	SPT (N) (Blows/30cm)	Number of Blows (N)/10cm	Allowable bearing capacity (kN/m ²)	
School In the old city of Mosul	---			200
Buildings of Nineveh Drug Company (Mosul, left banks)	---			150

Cars Park in (Mosul, right banks)	44-59			150
Building at the Mosul airport (Mosul, right bank)		2-12		180
Building in (Mosul, right banks)				140
Building in (Mosul, right banks)			85	85
Hospital in Mosul, left bank)				250
Private University in Mosul, left bank.				150
Health dispensary in Mosul, left bank.				150
Secondary electricity station west of Mosul city				140

6. Conclusions

Five soil types from the city of Mosul and its surrounding areas were selected to identify their geotechnical problems, study their strength properties, and estimate their bearing capacity. Based on the results obtained, the following conclusions can be drawn:

- The geotechnical problems in the soils of Mosul, in northern Iraq—such as settlement, collapse, swelling, and high organic and gypsum content—have a significant impact on the assessment of the bearing capacity of those soils. These problems are a notable limitation to indicating a high bearing capacity obtained from the bearing capacity equation.
- When estimating or approximating the allowable bearing capacity of soil in the city of Mosul, it is important to take into account that the strength coefficients depend directly on the type of test and the test conditions, which significantly affect the bearing capacity values.
- For the design of shallow foundations on Mosul soils, swelling tests are essential for high plasticity soil (CH); collapse and consolidation tests with organic content are required for silty soil (ML) and fill materials (OL); and consolidation tests with gypsum content are important for Gypsum soil (CL-ML).
- For the design of shallow foundations on Mosul soils, any available field or laboratory strength test for soil should be used in conjunction with tests that identify geotechnical issues in the soil, relying primarily on the test that yields the lowest value—or at least a reasonable value—for the strength parameters used to calculate bearing capacity.
- Test conditions had a significant impact on the strength parameters used in bearing capacity calculations, as evidenced by the variation in results, with the Direct shear tests yielding strength parameters that lead to overestimation of bearing capacity. In contrast, unconfined compression tests yield smaller values, and residual shear tests yield the smallest values due to the test conditions.
- For ordinary construction equivalent to a two- to five-story building resting on the soils used in this study at a depth of 2 to 3 meters, a bearing capacity of 50 to 150 kN/m² is suitable, provided other geotechnical issues are taken into account.

Further studies are needed on soils with engineering problems in and around the city of Mosul. Selecting the appropriate test method to obtain strength parameters that provide the best estimate of the bearing capacity required for structures subject to high soil pressures requires further study. In future studies, it is recommended to compare the bearing capacity values of soils obtained from field tests, such as plate load tests and standard penetration tests, with those from laboratory tests, taking into account the test conditions, as well as to study the effect of the gypsum content in the soil and the degree of saturation on the bearing capacity of problematic soils from Mosul city.

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