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INFLUENCE OF WATER CONTENT ON THE SHEAR STRENGTH PARAMETERS FOR COHESIVE SOIL

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ABSTRACT

A laboratory program was performed for soil located in the Nile Delta in Egypt to study the shear behavior of cohesive soils in the range of plasticity. The soil's optimum water content was calculated. Also, the index properties (liquid limit - plastic limit - soil specific gravity) were determined. Then, seven direct shear tests and seven unconsolidated undrained Triaxial tests were done on compacted samples with loads from 100 to 400 kPa at the optimum moisture content (WcB = 18.20%) to define the shear strength parameters, at the dry side of optimum (Wc = 12.20% and 15.20%) and the wet side of optimum (Wc = 21.20%, 24.20%, 28.00%, and 35.00%). The shear box and triaxial tests were used at each water content to calculate the cohesion value and the internal friction angle. The results were compared, and A relationship was found between water content with the internal friction angle and the water content with the Cohesion. The findings demonstrate that raising the water content reduces the friction angle. Increasing the water content causes the Cohesion to rise till reaching the maximum value at the optimum moisture content. Then, the Cohesion decreases by increasing the water content till it reaches the minimum value. The Cohesion results in the direct shear test are less than in the triaxial test by a ratio from 3.00% to 14.00%. The internal friction angle in the direct shear test is less than in the triaxial test by 1.00 to 2.20 degrees.

KEYWORDS: Shear strength, Friction angle, Cohesion, Cohesive soil, Direct shear test, Triaxial test.

تأثير المحتوي المائي على معاملات قوي القص للتربة الطينية

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الملخص

تم تنفيذ برنامج معملي للتربة الواقعة في دلتا النيل بجمهورية مصر العربية لدراسة سلوك القص للتربة المتماسكة خلال مدي اللدونة. أولاً، تم إجراء إختباربروكتور لتحديد المحتوى المائي الأمثل للتربة والذي يمكن أن تصل فيه التربة إلى أقصى كثافة جافة لها تم تحديد العوامل المصنفة للتربة (حد السيولة - حد اللدونة - الوزن النوعي للتربة) لتصنيف التربة وحساب كثافة التربة. ثم تم عمل اختبار مقياس كثافة السوائل لتحديد نسبة الطين في التربة. أخيرًا تم إجراء سبع اختبارات باستخدام جهاز القص المباشروسبعة اختبارات باستخدام جهاز الضغط ثلاثي المحاور على عينات مضغوطة بأحمال من 100 إالي 400 كيلو باسكال عند محتوى الرطوبة الأمثل (Wc = ٪18.20)، في الجانب الجاف من المحتوي المائي الأمثل (٪12.20، و٪15.20 = Wc) اما بالنسبة للجانب الرطب من الأمثل (٪21.2، ٪24.20، ٪28.00، Wc = ٪35.00). تم حساب قيمة التماسك وزاوية الاحتكاك الداخلي عند كل محتوى مائي بواسطة كل من اختبار القص المباشر واختبار الضغط ثلاثي المحاور.

تم مقارنة النتائج والحصول على علاقة بين محتوى الماء مع زاوية الاحتكاك ومحتوى الماء مع التماسك. مما أظهرت النتائج أن زاوية الاحتكاك ϕ° تقل بزيادة محتوى الماء. كما يزداد التماسك (C) بزيادة المحتوى المائي حتى الوصول إلى القيمة القصوى عند محتوى الرطوبة الأمثل 18.20٪، ثم يتناقص التماسك بزيادة المحتوى المائي حتى الوصول إلى الحد الأدنى. يكون التماسك في اختبار القص المباشر أقل من اختبار الضغط ثلاثي المحاور بنسبة من 3.00٪ إلى 14.00٪. أما بالنسبة الي زاوية الاحتكاك فتكون في اختبار القص المباشر أقل من اختبار الضغط ثلاثي المحاور بمقدار من 1.00 إلى 2.20 درجة.
الكلمات المفتاحية: التربة الطينية ، اختبار ثلاثي المحاور، اختبار القص المباشر، معاملات قوي القص.

1. INTRODUCTION

The main characteristic that rules the stability of the soil mass under loads is the shear strength. Soil shear strength aids in the design of civil engineering structures, slope stabilization, earth slope protection, earth dams, fabricated excavations, and so on. All soil engineering issues are strongly related to the soil's shear strength, defined as the maximum shear stress it can sustain. It is characterized by cohesion (c) and friction angle (ϕ). The two parameters mentioned primarily define the soil's maximum ability to resist shear stress under defined load. The shear strength of cohesive soil has been the subject of numerous investigations and research projects. In this paper, we'll highlight a few of these significant results and goals.

The findings of a lab experiment on compacted clay (PL = 23.00%) explored the compacted moisture content's impact on the clay's shear strength [1]. To determine the shear strength characteristics, shear box tests were performed on samples compacted at the optimal water content (w = 24.00%). The study showed the following results: Increasing moisture contents and decreasing suction to the optimal water content gradually decreases the friction angle. Around the optimum moisture content, the cohesiveness component of shear strength gets its maximum value and then reduces.

Also, the unsaturated shear strength of soil behavior has been discussed [2]. Studies confirm that the shear strength of unsaturated soils is still in the stage of the researcher's goals. Therefore, several direct shear tests were carried out to investigate the unsaturated shear strength of Middle Delta Nile Clay in Egypt to obtain a unique equation for calculating the shear strength of unsaturated clay at different water content (Wc). Samples were tested. The filter paper technic measured matric suction at several water content values.

The shear strength variation of silty-clay soil types is plotted for various S (%) [3]. The triaxial test was used to calculate the shear strength parameters of slightly saturated to almost saturated compacted soils for different initial saturation levels, S (%). At the optimum degree of saturation, shear strength achieves its maximum value after initially rising with the degree of saturation, then dramatically declines with continued growth past the optimum value. Changes follow a comparable profile of internal friction angle (ϕ) in soil shear strength. Maximum " ϕ " (27.3°) for the silty-clay type of soil under test is reached at the optimum saturation level (44%). Shear strength (τ) and the angle of internal friction (ϕ) curves obtained similar patterns. Still, the Cohesion (c) curve reached an opposite pattern. It shows that the silty-clay soil type's shear strength is greatly affected by the component (ϕ). Nevertheless, Cohesion steadily declines as S (%) increases, and it has minimal impact on the soil's shear strength.

Dafalla discussed in his study the influence of clay and water content on direct shear tests on clay-sand mixes [4]. It was concluded that when the clay content is high, the Cohesion and angle of internal friction of a very moist clay-sand mixture sharply decrease.

The water on compacted clay material was discussed using a triaxial compression test. With more water present, the cohesiveness exponentially decreased, and with more compaction, the Cohesion exponentially increased. Internal friction angle has unusually high values of the shear strength parameter. It is a two-dimensional quadratic function of water content and degree of compaction. With more water present, it drops in a convex quadratic parabolic curve. With more compaction, it increases in a concave quadratic parabolic law [5].

The shear strength parameters of Nebraska's over-consolidated clayey soils are used to examine the slopes' long-term stability. Unconfined compression tests, consolidated drained triaxial tests, and consolidated undrained triaxial tests were performed to assess the failure process in such soils. After triaxial tests, each test's initial and final moisture content was monitored to monitor changes in the samples' water content [6].

Twenty high plasticity index clayey soil specimens have been employed, each performing geotechnical identification tests. The shear test box and unconfined compression tests were conducted to verify the shear strength parameters of the samples obtained by compression in their compaction properties. Compaction traits have been found to significantly impact unconfined compressive strength more than other physical features of soil samples. Although the geotechnical characteristics of any samples collected are very similar, variations in the strength parameters were determined [7].

The triaxial test was used to determine the shear parameters of loess under two different drainage scenarios: the consolidated drained (CD) test and the consolidated undrained (CU) test. Based on the findings, confining pressure and water content play the most prominent roles in determining how strong loess is under shear. The stress-strain curve for loess clearly exhibits strain-softening behavior as the moisture content rises. When the moisture content is below the plastic limit, the cohesiveness drops marginally with an increase in moisture content; however, The cohesiveness dramatically decreases as the water content reaches the plastic limit. With the adjustment in water content, the internal friction angle didn't significantly reduce [8].

The principles of soil compaction were investigated, and a correlation between the soil's moisture level and the undrained strength of compacted clay was found. Furthermore, when the shear strength curve for various compaction attempts was created, it was evident that the shear strength of clayey soil decreased exponentially as the water content gradually increased [9].

The Cohesion and friction of clay soil have been estimated depending on moisture content [10]. Clay soils of the classifications CH and CI are employed. The kind of soil and the amount of clay (greater than 25%) are used to choose soil samples. The triaxial test and direct shear were performed on each sample at strain rates of 0.625 mm/min and 1.25 mm/min. For unconsolidated undrained (UU) conditions, direct shear tests and triaxial tests are run. The outcomes caused soil cohesion to decrease as moisture content increased.

2. MATERIALS

Materials for this study were derived from soil found in the Delta Nile (30.776197, 31.272762) at a 1m or more depth. The soil has been confirmed free of roots and seeds. Then the samples were moved to the Soil Mechanics and Foundations Laboratory at Mansoura University to start laboratory tests. The soil was dried and ground prior to testing.

3. EXPERIMENTAL PROGRAM

In This paper, the shear behavior of cohesive soils in the range of plasticity is studied by two methods the direct shear test and the Unconsolidated Undrained triaxial test at different water contents from 12.2% to 35% with loads from 100 to 400 kPa. Also, Atterberg limits, the proctor test, and the hydrometer test were used to determine the soil's index properties.

3.1 Proctor Tests

The Proctor compaction test was carried out as a geotechnical laboratory testing procedure to accurately evaluate soil compaction's properties and establish the optimum water content at which soil can achieve its maximum dry density.

3.2 Atterberg Limits

Liquid and plastic limit tests were also performed According to (ASTM: D4318-05, 2005) [11]. Therefore, the liquid limit, plastic limit, and soil plasticity index could all be measured using these test procedures.

3.3 Hydrometer Test

Hydrometer Test was performed to determine the percentage of clay in the soil, according to (ASTM D422, 2007) [12].

3.4 Direct Shear Test Procedures

To get the shear strength parameters, seven shear box tests were carried out on samples compacted at the optimum water content (Wc = 18.20%), at the dry side of the optimum water content (W = 12.20% and 15.20%), and at the wet side of the optimum (Wc = 21.20%, 24.20%, 28.00%, and 35.00%).

A direct shear test was performed at the soil mechanics and Foundation engineering laboratory, Mansoura University, Egypt, according to (ASTM: D3080-11, 2011) [13].

3.5 Unconsolidated Undrained Triaxial Test Procedures

To measure the shear strength parameters, seven Unconsolidated Undrained Triaxial tests were performed on samples compacted at the optimum water content (Wc = 18.20%), at the dry side of optimum (W = 12.20%, and 15.20%), and at the wet side of optimum (Wc = 21.20%, 24.20%, 28.00%, and 35.00%).

Unlike regular saturated soil testing, the saturated specimen is consolidated first and then sheared undrained. This test was conducted by applying isotropic confinement and immediately applying undrained shear. Tests were performed at Soil Mechanics and Foundation Engineering Laboratory at Mansoura University, Egypt. (UU)triaxial shear tests were conducted on compacted samples at a maximum dry density at optimum moisture content according to (ASTM: D2850-03a, 2007) [14].

3.6 Soil Properties

After performing the previous laboratory experiments, the soil sample employed in this study is classified as CH according to the Unified Soil Classification System. As a result, the percentage of clay in the soil is 41.40%, the proportion of sand is 9.00%, and the proportion of silt is 49.60%. The following Table clarifies the soil properties.

Table 1: Soil Properties

The optimum water content	18.20 %	Liquid limit (LL)	72.71 %
Dry density, gm/cc	1.66	Plastic limit (PL)	28.41 %
Specific gravity (Gs)	2.62	Plasticity index (PI)	44.30 %

4. RESULTS AND DISCUSSIONS

4.1 Direct Shear Test

Seven direct shear tests were performed with normal stresses of 100 kPa, 200 kPa, 300 kPa, and 400 kPa. Cohesion and the internal friction angle values were estimated by interpolating three data points. The Cohesion and the friction angle values are given in Table 2.

Table 2: Final results for cohesion and friction angle

NO	Wc %	C (kPa)	Φ °
1	12.20	136.00	34.90
2	15.40	239.50	23.10
3	18.10	281.90	15.70
4	21.30	229.60	13.10
5	24.10	170.60	9.60
6	28.10	130.10	4.80
7	35.00	79.70	2.10

In Fig. 1, the Cohesion (C) kPa and the angle of friction ϕ° for different water contents were obtained.

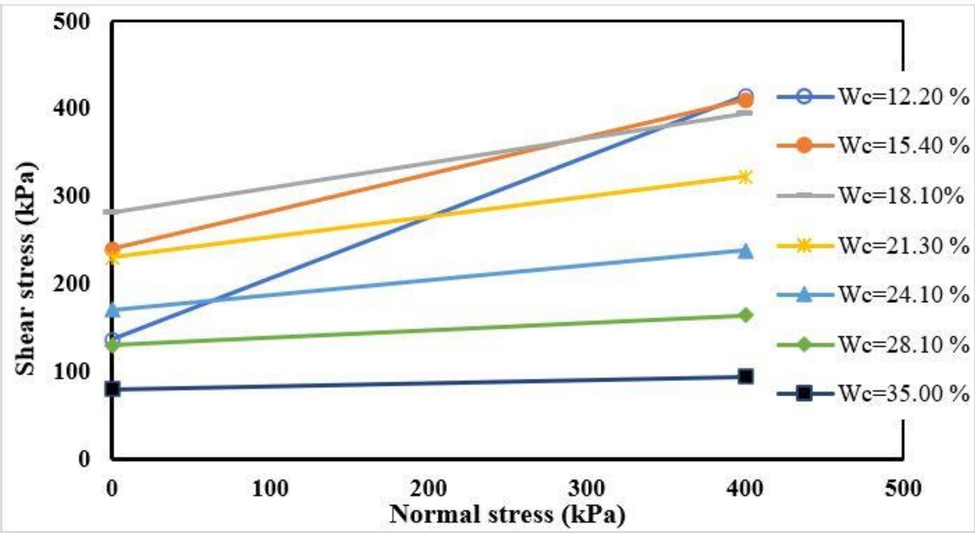

Fig. 1: Shear stress and normal stress relationships at water contents from 12.2% to 35%

In Fig. 2, the relation between the water content and the internal friction angle was clarified after doing seven direct shear tests. The test results show that the angle of friction ϕ° is decreased by increasing the water content as shown in the previous Table 2. At the minimum water content Wc = 12.20, the internal friction angle was maximum value ϕ° = 34.90°, at the maximum water content Wc = 35.00 % the internal friction angle was the minimum value ϕ° = 2.10°.

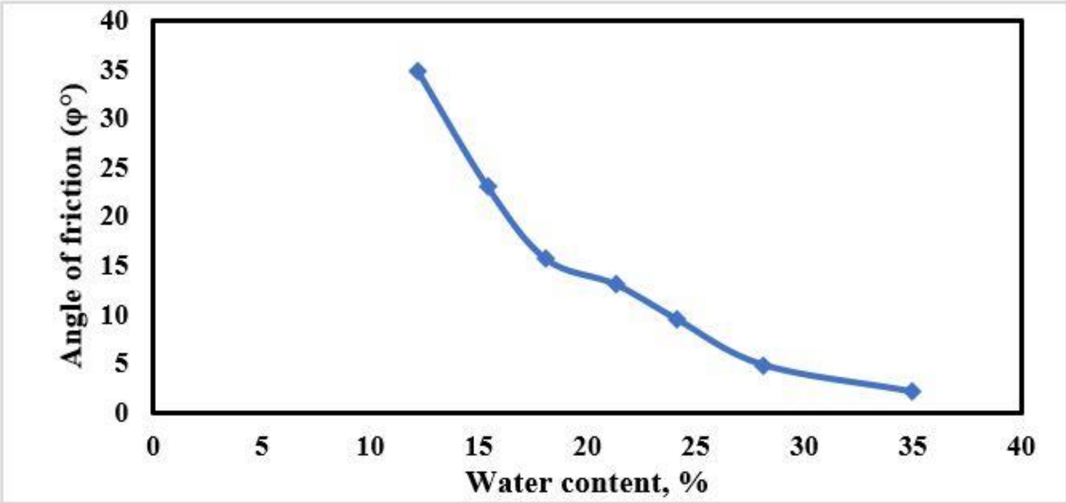

Fig. 2: Relation between friction angle φ and water content

The relation between the water content and the Cohesion (C) is obtained in Fig. 3 after doing seven direct shear tests. The test results show that the Cohesion increases by increasing the water content till reaching the maximum value of C = 281.90 kPa at the Optimum Moisture Content of 18.20 %, then the Cohesion decreases by increasing the water content till reaching the minimum C = 79.70 kPa at the maximum water content Wc = 35.00%.

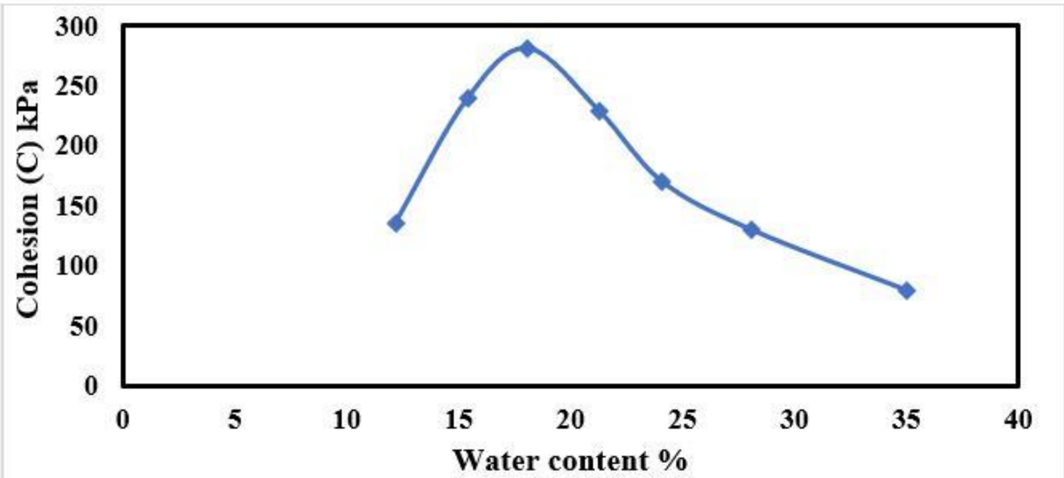

Fig. 3: Relation between Cohesion and water content

4.2 Triaxial Test

Seven Unconsolidated Undrained triaxial tests (UU) were performed at normal stresses of 100 kPa, 200 kPa,300, and 400kPa. Cohesion and the internal friction angle values were estimated by Mohr's circles. The Cohesion and the friction angle values are given in Table 3.

Table 3: Final results for Cohesion and the internal friction angle

NO	Wc %	C (kPa)	Φ °
1	12.10	140.40	36.20
2	14.90	262.50	24.80
3	18.30	301.00	17.90
4	21.30	268.30	15.20
5	24.50	198.70	11.30
6	27.90	150.70	6.90
7	35.30	91.50	3.10

Fig. 4 shows the Cohesion (C) kPa and the internal friction angle ϕ° at different water contents.

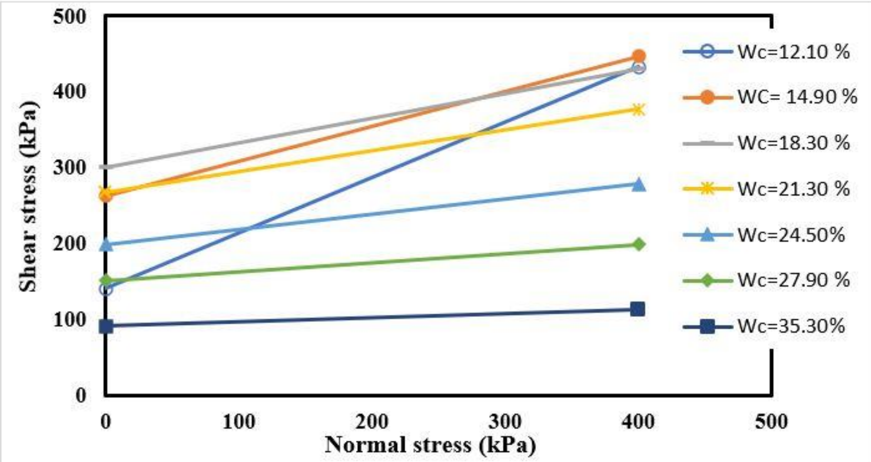

Fig. 4: Relation between shear stress and normal stress at water content from 12.20% to 35.00%

The relation between the water content and the internal friction angle is obtained in Fig. 5. The test results showed that the internal friction angle ϕ° is decreased by increasing the water content as demonstrated in Table. 3, at the minimum water content Wc = 12.10 the internal friction angle was maximum value ϕ° = 36.20°, at the maximum water content Wc = 35.30 % the friction angle was the minimum value ϕ° = 3.10°.

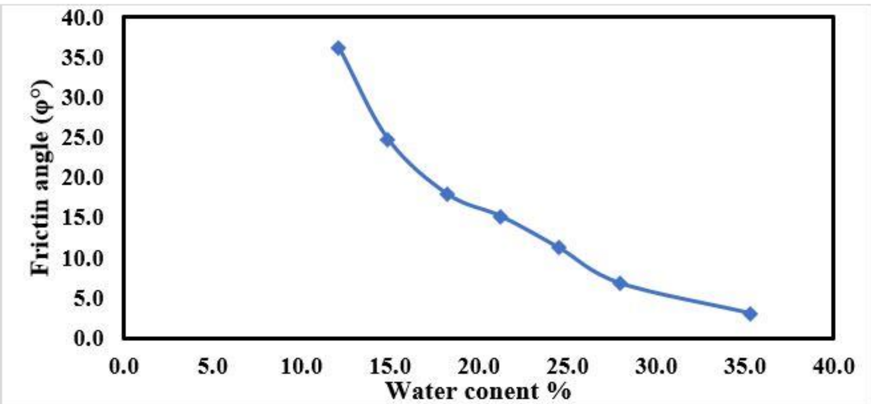

Fig. 5: relation between the friction angle & the water content %

The relation between the water content and the Cohesion (c) is obtained in the following figure Fig. 6. The test results showed that cohesion increases by increasing the water content until reaching the maximum value C = 301.00 kPa at the Optimum Moisture Content of 18.20%. Then the Cohesion decreases by increasing the water content till reaching the minimum C = 91.50 kPa at the maximum water content Wc = 35.30%.

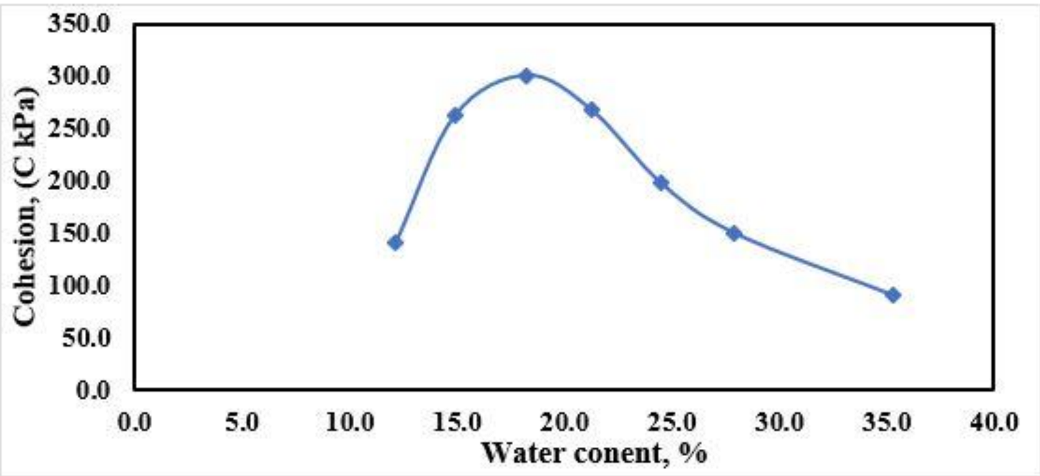

Fig. 6: Relation between Cohesion & water content

After performing the direct shear tests and triaxial tests on the soil at the following water contents of 12.20%,15.20%,18.20%,21.20%,24.20%,28.00%, and 35.00%, By comparing the Cohesion results in the direct shear tests and the triaxial tests at the same water content and making a relationship between water content and Cohesion (c) as shown in Table 4.

Table 4: comparison between the Cohesion in shear and triaxial test

NO	Direct Shear test		Triaxial test	
	Wc %	C (kPa)	Wc %	C (kPa)
1	12.20	136.00	12.10	140.40
2	15.40	239.50	14.90	262.50
3	18.10	281.90	18.30	301.00
4	21.30	229.60	21.30	268.30
5	24.10	170.6	24.50	198.70
6	28.10	130.1	27.90	150.70
7	35.00	79.70	35.30	91.50

It was discovered that the Cohesion rises as the water content rises until it reaches the maximum value at the optimum water content, then declines as the water content rises until it reaches its minimum value at the maximum water content Wc = 35.00% in both tests as shown in the following figure Fig. 7, The Cohesion in a direct shear test is less than the triaxial test by a ratio from 3.00% to 14.00%.

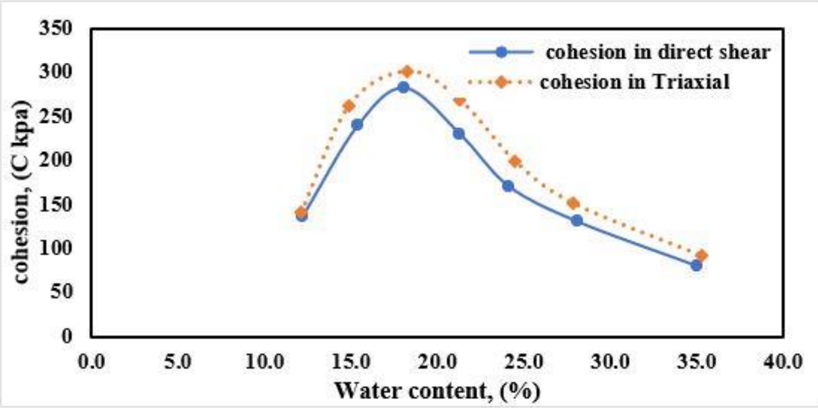

Fig. 7: Comparison between the Cohesion in direct shear and triaxial test at water content from 12.2% to 35%.

By comparing the internal friction angle results in the direct shear test and the triaxial test at the same water content, as shown in Table 5, a relationship was made between the water content and the internal friction angle.

Table 5: Comparison between the friction angle in direct shear and triaxial test

NO	Direct Shear test		Triaxial test	
	Wc	ϕ°	Wc	ϕ°
1	12.20	34.90	12.10	36.20
2	15.40	23.10	14.90	24.80
3	18.10	15.70	18.30	17.90
4	21.30	13.10	21.30	15.20
5	24.10	9.60	24.50	11.30
6	28.10	4.80	27.90	6.90
7	35.00	2.10	35.30	3.10

The test results obtained that the internal friction angle ϕ° is decreased by increasing the water content, as shown in Fig. 8. At the minimum water content Wc=12.2%, the internal friction angle was maximum value, on the other hand, at the maximum water content Wc=35 % the friction angle was the minimum value in both tests. Therefore, the friction angle in the direct shear test is less than that of the triaxial test by 1.00 to 2.20 degrees.

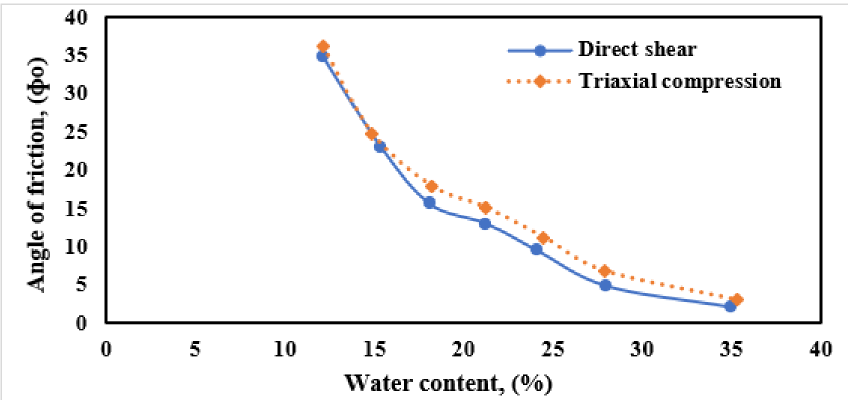

Fig. 8: Comparison between the friction angle in shear and triaxial test at water content from 12.2% to 35%.

SUMMARY AND CONCLUSIONS

The results and discussions indicate the following conclusions:

1. The internal friction angle ϕ° is decreased by increasing the water content.
2. The Cohesion increases by increasing the water content until reaching the maximum value at the optimum moisture content. Otherwise, the Cohesion decreases by increasing the water content till it reaches the minimum value.
3. The cohesion results of the cohesive soil obtained from the direct shear test are less than that obtained in the triaxial, by a ratio from 3% to 14%.
4. The internal friction angle results in the direct shear test are less than that of the triaxial test by 1.00 to 2.20 degrees.
5. The difference between the shear strength parameters obtained from the direct shear box and the triaxial test is insignificant in the unconsolidated undrained condition. Therefore, we recommend using the direct shear test because it is easier and cheaper.

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REFERENCES

[1] Cokca E., Erol O., Armangil F., (2004), "Effects of compaction moisture content on the shear strength of an unsaturated clay," Geotechnical and Geological Engineering, 22(2), 285–297.

[2] El-Hosani R.K. A., Mohamed H. I. K., Elkamash. H, W., Moubark A., Moubark. H. A., (2021). "Shear Strength Behavior of Unsaturated Clay" Life Sci J, 18(5), 1–8.

[3] Palani K. A., Maurya, S., Gupta, M., Chitra, R., (2020). Degree of initial saturation and shear strength of soil in a triaxial loading. Int J Emerg Technol Innovative Res, 7(4), 805-812.

[4] Dafalla, M. A., (2013). Effects of clay and moisture content on direct shear tests for clay-sand mixtures. Advances in Materials Science and Engineering, 2013.

[5] Huzhu, Z., Hanbing, L., Jing, W., Weizhi, D., (2017), "Investigation of the effect of water content and degree of compaction on the shear strength of clay soil material," Functional Materials, 24(2), 290–297.

[6] Bahmyari H., (2018). "Shear Strength Characteristics and Failure Mechanism of Slopes in Overconsolidated Soils of Nebraska", University of Nebraska-Lincoln, Lincoln. NE.

[7] Yilmaz B., Türköz M., (2022), "Determination of shear strength parameters of compacted high plasticity clay soils based on different laboratory tests, " Turkish Journal of Engineering, 6 (4), 313 - 319.

[8] Wang Y., Xie W., Gao G., (2019), " Effect of different moisture content and triaxial test methods on shear strength characteristics of loess, " E3S Web of Conferences, (Vol. 92, p. 07007). EDP Sciences.

[9] Ghosh R., (2013), " Effect of soil moisture in the analysis of undrained shear strength of compacted clayey soil, " Journal of Civil Engineering and Construction Technology, 4(1), 23 –31.

[10] Vedwala K. M., Priyank H. P., Vishal N. P., (2020), "Effect of Compaction Moisture Content on Strength Parameters of Unsaturated Clay using Triaxial Test," International Journal of Trend in Scientific Research and Development (IJTSRD), 4(4), 888-891.

[11] ASTM: D4318-05. (2005), " Method of Test for Liquid Limit, Plastic Limit, and Plasticity Index of Soils, " Test Method Ls-703/704, 27(27), 1–2

[12] Standard, A. S. T. M. (2007). Standard Test Method for Particle-Size Analysis of Soils. In Annual Book of ASTM (American Society of Testing Material) Standards, 04.08. ASTM International West Conshohocken, PA.

[13] ASTM, D. 3. 9. (2011). Standard test method for direct shear test of soils under consolidated drained conditions. D3080/D3080M, 3(9).

[14] ASTM: D2850-03a. (2007), " Standard Test Method for Unconsolidated-Undrained Triaxial Compression Test, " December 3–8.