Establishing the correlation of shear strength between consolidated – undrained and consolidated – drained triaxial tests of soft clay

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ESTABLISHING THE CORRELATION OF SHEAR STRENGTH BETWEEN CONSOLIDATED – UNDRAINED AND CONSOLIDATED – DRAINED TRIAXIAL TESTS OF SOFT CLAY

Tran Xuan Tho, Vo Thanh Long, Nguyen Le Du

ABSTRACT: The paper is focused on establishing the correlation of shear strength from consolidated – undrained triaxial test (CU) and consolidated – drained triaxial test (CD) of soft clay in Ho Chi Minh City. This is provided to the designers the estimation of shear strength c’, φ’ of CD tests based on the results of the CU tests.

Keywords: Shear strength, consolidated – undrained triaxial test, consolidated – drained triaxial test.

1. Introduction

In the foundation design calculations, the parameters of cohesion force c and internal friction angle φ are important role to define the bearing capacity and to evaluate the foundation stability. From the purpose of each construction, the shear strength parameters from different tests are used in the calculation. To calculate the long-term stability, the parameters c', φ' from the consolidated-drained triaxial test should be used.

However, the CD test is taking more time and expensive so c', φ' from the CU test are often used instead. This results in incorrect calculations. Therefore, establishing the correlation between shear strength CU triaxial tests and CD triaxial test is essential. Soft clay in the Ho Chi Minh City has been taken for the study.

2. Consolidated – undrained triaxial test (CU) and consolidated – drained triaxial test (CD)

To compare and establish the correlation of effective shear strength c', φ' between the experimental results CU and CD triaxial test, each pair of values c', φ' from CU and CD test results has the same physical properties. The undisturbed soil samples from low plasticity to high plasticity with different depths in Ho Chi Minh City has been selected to conduct the CU and CD triaxial tests.

2.1 Consolidated – undrained triaxial test (CU)

Consolidated - undrained triaxial test is given in ASTM D4767-95 [1].

Tran Xuan Tho, Ph.D.; Vo Thanh Long, M.Eng., Department of Geotechnical Engineering, Faculty of Civil Engineering, Ho Chi Minh City University of Technology, 268 Ly Thuong Kiet, Dist. 10, Ho Chi Minh City, Vietnam. Phone: +84 908.155.131. E-mails: txtho@yahoo.com
Nguyen Le Du, M.Eng., Faculty of Civil Engineering, Ho Chi Minh City University of Transport, Vietnam

Saturated soil sample: CU triaxial tests have been conducted on the cylindrical soil samples with height h = 8.0cm, diameter d = 3.91cm. The absorbent paper placed above, below and around the soil sample. The sample is sealed in thin rubber membrane then inserted into the compression chamber. After locking the water valve, the chamber pressure is increasing a first level of 20kPa for a period of approximately 15 minutes and the pore water pressure is also recorded. Then the chamber pressure is increasing to 30kPa and an increase in pore water pressure is recorded. Soil sample is considered as saturated if $B \geq 95\%$ ($B = \Delta u/\Delta\sigma_3$). If $B < 95\%$, the sample must be saturated by back pressure in the soil sample.

Isotropic consolidation: After the soil sample saturated, the chamber pressure is increasing to the first anticipated pressure σ'_3 (compression pressure = chamber pressure - back pressure). The water valve of soil samples is opening and the volume of water releasing from the soil sample over time is recorded. Until the excess pore water pressure dissipates and then the axial load is applied.

Axial loading: After soil sample consolidated completely, the chamber pressure is kept and the drainage valve is locked. The axial load is conducted with constant strain rate of 0.06mm/minute until the soil sample failed. In the process of loading increment, the readings for each axial deformation corresponding to the value of axial load and pore water pressure increment are recorded. CU triaxial test on three soil samples for low to high plasticity clay takes from 6 to 7 days.

2.2 Consolidated – drained triaxial test (CD)

Consolidated - drained (CD) triaxial test is given in BS 1377-90 [2].

The CD test procedure is the same as the CU test. However, it excepts that during the compression, the drainage valves are open and slow pressure velocity (0.0024mm/minute) applied in order to dissipate any excess pore water pressure in the sample. An experiment on three soil samples for CD triaxial test of high plasticity clay takes about 18 ÷ 21 days. The CU and CD triaxial tests were conducted on three soil samples with three values of the chamber pressure of 30kPa, 60kPa and 120kPa for high plasticity clay and 50kPa, 100kPa and 200kPa for low plasticity clay. Results of shear strength parameters c', φ' are reviewed, analyzed and compared to establish the correlation between the CU and CD triaxial tests.

The results of physical soil properties are summarised in Table 1. The CU and CD Triaxial test results are shown in Table 2.

3. Establishing the correlation of shear strength between CU and CD triaxial tests

The soil sample of M13 has $\varphi'_{CU} < \varphi'_{CD}$ and $c'_{CU} < c'_{CD}$. The No of M13 has significantly different results compared to other 15 soil samples so No of M13 soil sample should be removed from the soil sample collection statistics. The correlations of shear strength (φ'_{CU} and φ'_{CD}; c'_{CU} and c'_{CD}) according to the water content as shown in Figure 1, 2 indicate that two curve relationships (φ'_{CU} and φ'_{CD}; c'_{CU} and c'_{CD}) with the water content of the soil samples are almost parallel. In other hand, the relationship between effective shear strength parameters from CU and CD triaxial tests is a linear function to the water content of soil samples.

Table 1: Results of physical properties of soil samples

No of sample	Water content	Bulk unit weight	Saturated unit weight	Degree of saturation	Void ratio	Particle specific gravity	Liquid limit	Plastic limit	Plasticity index	Liquidity index
	W	**γ**	γ_{sat}	S_r	e_o	G_s	W_L	W_P	I_P	I_L
	(%)	(kN/m^3)	(kN/m^3)	**%**	**-**	**-**	**%**	**%**	**%**	**-**
M01	89.52	14.5	14.7	98.1	2.364	2.59	75.2	38.0	37.2	1.38
M02	99.08	14.3	14.4	99.0	2.611	2.60	93.4	53.6	39.8	1.14
M03	82.59	14.9	15.1	98.4	2.207	2.63	77.4	38.5	38.9	1.13
M04	72.69	15.5	15.6	99.5	1.922	2.63	70.2	37.8	32.4	1.08
M05	92.55	14.7	14.7	98.9	2.461	2.63	83.5	45.3	38.2	1.24
M06	77.18	15.2	15.3	99.2	2.023	2.60	73.5	40.5	33.0	1.11
M07	111.16	14.0	14.0	99.0	2.909	2.58	95.5	54.0	41.5	1.38
M08	95.74	14.3	14.5	97.5	2.534	2.58	79.5	40.5	39.0	1.42
M09	31.52	17.5	18.4	82.0	1.045	2.72	40.3	20.5	19.8	0.56
M10	33.20	18.9	19.0	98.2	0.923	2.73	43.3	21.5	21.8	0.54
M11	25.12	19.0	19.6	86.9	0.783	2.71	30.4	17.3	13.1	0.60
M12	85.39	15.0	15.0	99.8	2.259	2.64	70.5	37.1	33.4	1.45
M13	94.35	14.6	14.6	99.4	2.467	2.60	83.4	43.7	39.8	1.28
M14	88.52	14.5	14.7	96.8	2.377	2.60	82.1	36.9	45.2	1.14
M15	101.59	14.4	14.4	99.4	2.648	2.59	93.5	52.3	41.2	1.20
M16	27.21	19.6	19.8	96.1	0.773	2.73	36.9	15.8	21.1	0.54

Table 2: Results of CU and CD tests of soil samples

No of sample	**Water content W (%)**	**CU triaxial test**		**CD triaxial test**		**Description**
		c'_{CU} (kN/m^2)	φ'_{CU}	c'_{CD} (kN/m^2)	φ'_{CD}	
M01	89.52	12.3	22°17'	8.3	25°50'	Organic clay, high plasticity
M02	99.08	10.8	19°09'	7.5	22°07'	Organic clay, high plasticity
M03	82.59	8.2	24°05'	6.7	27°23'	Organic clay, high plasticity
M04	72.69	12.7	18°53'	8.8	21°15'	Organic clay, high plasticity
M05	92.55	10.6	21°03'	7.7	24°28'	Organic clay, high plasticity
M06	77.18	12.4	20°16'	8.5	22°53'	Organic clay, high plasticity
M07	111.16	12.0	17°23'	7.5	20°23'	Organic clay, high plasticity
M08	95.74	17.2	21°47'	12.9	25°01'	Organic clay, high plasticity
M09	31.52	17.8	26°53'	15.5	28°02'	Clay, low plasticity
M10	33.2	15.3	22°22'	13.2	23°40'	Clay, low plasticity
M11	25.12	11.3	26°47'	9.7	28°02'	Clay, low plasticity
M12	85.39	15.2	22°11'	9.7	25°53'	Organic clay, high plasticity
M13	94.35	12.0	25°18'	12.2	25°35'	Organic clay, high plasticity
M14	88.52	12.6	20°15'	8.2	23°30'	Organic clay, high plasticity
M15	101.59	11.1	19°35'	8.0	23°02'	Organic clay, high plasticity
M16	27.21	17.9	25°22'	15.1	27°09'	Clay, low plasticity

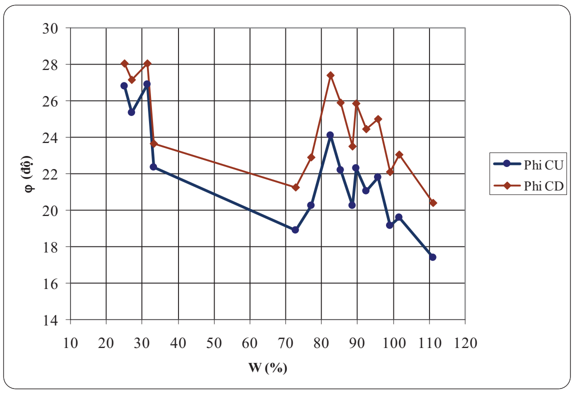

Figure 1: Correlation function of φ'_{CU} and φ'_{CD}

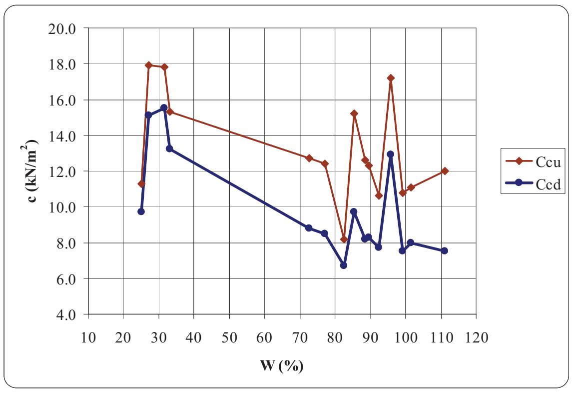

Figure 2: Correlation function of c'_{CU} and c'_{CD}

It is remarked that the water content is larger, the different between c'_{CU} and c'_{CD}, φ'_{CU} and φ'_{CD} is larger and vice-versa.

The shear strength parameters between the CU and CD tests are more different when the water content is larger. When the water content is smaller, the shear strength parameters between the CU and CD tests are as the same. When the water content is equal to zero ($W \approx 0$) then shear strength parameters between CU and CD tests are almost similar because both graphs do not have any the presence of pore water pressure.

It is also demonstrated that when the water content is higher, the difference between the parameters of shear strength of CU and CD tests are significantly large.

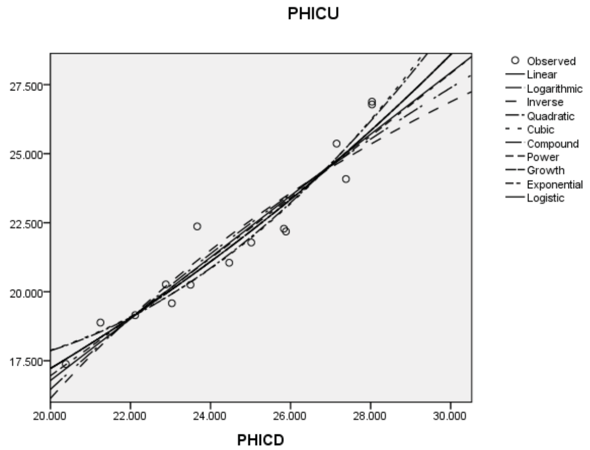

Figure 3: Regression function between φ'_{CU} and φ'_{CD}

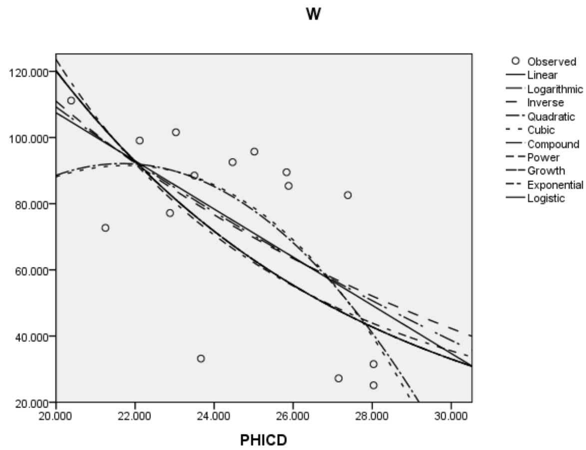

Figure 4: Regression function between φ'_{CD} and W

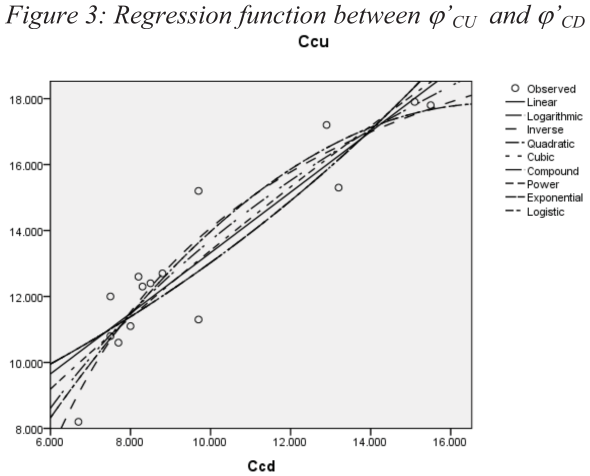

Figure 5: Regression function between c'_{CU} and c'_{CD}

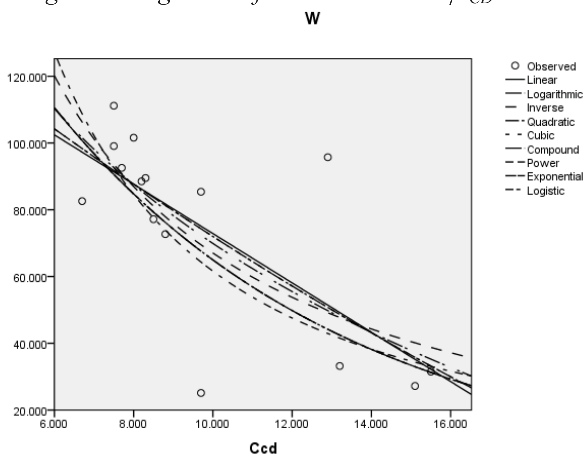

Figure 6: Regression function between c'_{CD} and W

From the experimental results of CU and CD triaxial tests, after removing the No of M13 soil sample, the statistical regression softwares of EView 4.0 and SPSS 16.0 have been used to examine the relationship between shear strength parameters of CU and CD graphs and the water content through the correlation matrix.

The EView 4.0 and SPSS 16.0 programs also have been applied to examine the regression function by the minimum squares method as shown in Figure 3, 4, 5 and 6 to find the correlation function of shear strength between CU and CD triaxial tests. The results are shown in Table 3.

Table 3: Correlation of shear strength between CU and CD triaxial tests

Shear strength parameters	Correlation function	Formula	Correlation coefficient R^2
Internal friction angle	$\varphi'_{CD} = \varphi'_{CU}\left(1+\frac{0.01W}{m}\right)$	(1)	0.988
Cohesion	$c'_{CD} = \frac{c'_{CU}}{1+\frac{0.01W}{n}}$	(2)	0.952

Where:

+ m, n: Coefficients; m = 5,855; n = 2,009;
+ φ'_{CU}: effective internal friction angle from CU triaxial test (degree)
+ φ'_{CD}: effective internal friction angle from CD triaxial test (degree)
+ W: water content (%).

4. Conclusions

Effective shear strength parameters c', φ' from CU and CD triaxial tests are significantly different. With the same soil sample, the value of effective internal friction angle from CU triaxial test is less than the value of effective internal friction angle from CD triaxial test ($\varphi'_{CU} < \varphi'_{CD}$). Cohesion value is the opposite ($c'_{CU} > c'_{CD}$).

The correlation between shear strength tests of CU and CD triaxial tests according to the water content W(%) of soil is set in relation of $\varphi'_{CD} = \varphi'_{CU}\left(1+\frac{0.01W}{m}\right)$ and $c'_{CD} = \frac{c'_{CU}}{1+\frac{0.01W}{n}}$, where m = 5,855 and n = 2,009

5. References

[1] ASTM D4767-95 – *Standard Test Method for Consolidated – Undrained Triaxial Compression Test for Cohesive Soils*.

[2] BS 1377:1990 – *Methods of Testing for soils for Civil Engineering Purposes*.