A CORRELATION ANALYSIS OF SHEAR PARAMETERS OF PLASTIC CLAY DETERMINED FROM DIRECT SHEAR AND TRIAXIAL SHEAR TESTS

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ABSTRACT
In this research, the main objective is to establish the correlation function between the shear strength parameters of plastic clay obtained from Direct Shear (DS) test and the Triaxial Shear (TS) test. For this, hundred soil samples collected from the deltas of major rivers of Vietnam including Mekong River Delta in the South and Red River Delta in the North were analyzed and shear strength parameters (c and φ) were determined by TS test and DS test. Standard correlation coefficient was used to validate the degree of correlation of shear parameter variables. Results show that the degree of correlation of the analyzed variables is very high (R > 0.9) in between TS test and DS test. Thus, correlation function obtained from this study can help in the selection of appropriate laboratory method for determining ‘c’ and ‘φ’ values of plastic clay of Vietnam deltas for the stability analysis of foundations of civil engineering structures in coastal plains.

Key words: Shear Resistance Parameters, Soft Soil, Direct Shear Test, Triaxial Shear Test.
1. INTRODUCTION

Vietnam is having about 3,260 km long coastline. A number of rivers are forming deltas at the mouth of major rivers debouching into sea. The narrow, flat coastal lowlands extend from south of the Red River Delta to the Mekong River Delta. Determination of geomechanical properties of deltaic soils is required for the proper designing of the foundation of civil engineering structures in this area. A number of roads and bridges are being built in this coastal area. Therefore, appropriate soil testing is required to be carried out for the assessment of ground condition and soil treatment [1].

Shear strength parameters such as internal friction angle ‘φ’ and unit cohesive force ‘c’ are known very important inputs for the assessment of foundation stability of roads, bridges and ports on soft soil ground [2]. These parameters can be determined from different laboratory tests such as Direct Shear (DS) test and Triaxial Shear (TS) test with different schemes (UU – Unconsolidated Undrained, CU – Consolidated Undrained, and CD - Consolidated Drained). Each method has different advantages and disadvantages which make them both popular in determining the vaules of the shear strength parameters [3]. In fact, with same soft soil types or samples, the values of these factors determined from different mentioned methods are much different [4]. Soil shear strength determined from the various experiments such as DS test, field vane test, TS test following UU or CU diagram, and unconfined compression test, allow more choices of input parameters consideing stability of ground. However, in view of the cost factor in conducting some of the field tests and laboratory tests, it is desirable to evaluate the results of simple cost effective tests which can be used for the determination of shear strength of the soil for design purpose. Therefore, the correlation established between the experimental parameters on the shear strength of the soil may reduce the cost. In this research, the main objective is to establish the correlation function between the shear strength parameters of plastic clay soil through experimental results of DS test and TS test conducted on the hundred deltaic clay soil samples collected near the coastal area of Vietnam extending from Mekong River Delta in the south to Red River Delta in the North.

2. BASIC THEORY OF SHEAR STRENGTH AND SHEAR STRENGTH PARAMETERS [3]

Shear strength (τ) of a soil mass is the internal resistance per unit area that the soil mass can offer to resist failure including sliding along any plane inside it [3]. According to Mohr [5] shear cohesion is assumed to be constant and not dependent on the effects of stress, while the frictional resistance changes directly with the effects of stress magnitude. The equation of limited shear stress is of the form:

\[ \tau = \sigma \tan \varphi + c \]  

(1)

where c - unit cohesion, σ - normal stress on the failure plane, and φ - angle of internal friction.

In saturated soil, the total normal stress at a point is the sum of the effective stress (σ’) and pore water pressure (u). The Mohr-Coulomb failure criterion, expressed in terms of effective stress, will be of the form:
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\[ \tau = \sigma' \tan \phi' + c' \]  
\hspace{1cm} (2)
where \( c' \) - cohesion and \( \phi' \) - friction angle which are based on effective stress.

As a matter of fact, the shear strength parameters of a certain soil \( c' \) and \( \phi' \) are constant. Shear strength of the same type of soil will not be the same, depending on its physical state (level of destructive natural structure, density, humidity), as well as experimental conditions (laboratory method, machinery structure, size samples, cutting speeds etc.).

3. LABORATORY EXPERIMENTS

3.1. Direct Shear (DS) Test [3]
The DS test is the oldest experiment proposed by Coulomb which uses a box cutter type appliance for determining the shear strength parameters. It is based on the basis of prior assumptions that the sliding of soil samples under the effect of the different pressure levels, and soil samples will be cut by a pair of lateral torque (Figure 1). The DS test is often applied for the consolidated clays and sands.

![Figure 1 Diagram of the DS test arrangement [3]](image)

The DS test can be performed on similar specimens at various normal stresses. The normal stresses and the corresponding shear stress values obtained from a number of tests are plotted on a graph from which the shear strength parameters are determined (Figure 2). Shear strength parameters determined from the DS Test are the cohesion \( (C_{DS}) \) and internal friction angle \( (\phi_{DS}) \).
3.2. Tri-axial Shear Test (TST) [3]
The TS test is one of the most reliable methods available for determining shear strength parameters, which can overcome some fundamental disadvantages of direct shear tests. In this test, soil samples are cut according to an unintended weakest plane instead of intended weakest plane in the DS test, the constant horizontal pressures effect on the entire soil samples, whereas vertical pressure levels increased gradually until the sample was cut. A diagram of the TS test layout is shown in Figure 3.

Several tests on similar specimens can be conducted by varying the confining pressure. With the major and minor principal stresses at failure for each test the Mohr’s circles can be drawn and the failure envelopes can be obtained (Figure 4). In general, three standard schemes of the TS Test are conducted such as Consolidated-Drained (CD) scheme, Consolidated-Undrained (CU) scheme, and Unconsolidated-Undrained (UU) scheme. However, in this study, we considered only two schemes namely the CU and UU.

3.2.1. Unconsolidated-Undrained (UU) scheme [3]
In this scheme, drainage from the soil specimen is not permitted during the application of chamber pressure $\sigma_3$. The test specimen is sheared to failure by the application of deviator stress, and drainage is prevented. As the drainage is not allowed at any stage, the test can be performed quickly. The pore water pressure in the soil specimen will increase with the application of chamber confining pressure. Shear strength parameters determined from the UU scheme are unconsolidated - undrained cohesion ($C_{UU}$) and unconsolidated-undrained friction angle ($\phi_{UU}$).

![Figure 3 Schematic diagram of the TS equipment [3]](image)
3.2.2. Consolidated-Undrained (CU) scheme [3]

In this scheme, the saturated soil specimen is first consolidated by an all-around chamber fluid pressure, those results in drainage. After the pore water pressure generated by the application of confining pressure is dissipated, the deviator stress, on the specimen is increased to cause shear failure. During this phase of the test, the drainage line from the specimen is kept closed. Because drainage is not permitted, the pore water pressure will increase. Shear strength parameters determined from the CU scheme are consolidated-undrained cohesion (\(C_{\text{CU}}\)) and consolidated-undrained friction angle (\(\phi_{\text{CU}}\)) in the case of total stress and consolidated-undrained cohesion (\(C'_{\text{CU}}\)) and consolidated-undrained friction angle (\(\phi'_{\text{CU}}\)) in the case of effective stress.

4. CORRELATION ESTABLISHING PRINCIPLES

Correlation analysis is a term used to denote the association or relationship between two (or more) quantitative variables. This analysis is fundamentally based on the assumption of a straight line with the construction of a scatter plot or scatter diagram [a graphical representation of the data] with one variable on the X-axis and the other on the Y-axis. Let us understand this with an example. The end result of a correlation analysis is a Correlation coefficient whose values range from -1 to +1. A correlation coefficient of +1 indicates that the two variables are perfectly related in a positive [linear] manner, a correlation coefficient of -1 indicates that two variables are perfectly related in a negative [linear] manner, while a correlation coefficient of zero indicates that there is no linear relationship between the two variables being studied [6].

Let’s have two random variables \(x\) and \(y\), we suppose a statistical correlation of these variables each other, that quantity is called the correlation coefficient denoted as \(R\) [6]. When correlation coefficient \(R \neq 0\), between two random variables \(x\) and \(y\) will be the dependence \(y = y(x)\). In order to describe the correlation with a chart and a function, replacing the actual point of the chart with a curve or a straight line. One of the alternative methods of practical points to determine a curve or a straight line is the least squares method. When empirical regression curve closes correlation lines or the correlation coefficient \(|R| \sim 1\) while the regression function of linearly form \(y = ax + b\). Through random variables would determine the factors \(a\) and \(b\).

The correlation coefficient \(R\) is a variable quantity from -1 to +1, if \(R < 0\), the negative correlation value, if \(R > 0\), the value correlated, if \(R = 0\) means no correlation [7].
The degree of correlation was assessed through correlation factor by Kalomenxki as follows:

- If $0.0 < |R| < 0.5$, the degree of correlation is very weak;
- If $0.5 < |R| < 0.7$, the weak correlation level;
- If $0.7 < |R| < 0.9$, the high correlation level;
- If $0.9 < |R| < 1.0$, the degree of correlation is very high.

5. RESULTS AND DISCUSSION

A number of soil samples were collected from the deltas of major rivers near the coastal areas of Vietnam, extending from north to south. Out of these hundred samples were analyzed for the determination of physical properties of soil at various laboratories. Mainly liquid and plastic limits, which determine the range of plastic behaviour of the soil were considered for analysis.

Results indicated that most of the plastic clay soil samples have plasticity index $I_p > 17\%$, clay particles content of $15\% \div 70\%$, viscosity of $0.75 < IL \leq 1$ and natural moisture $W = 35\% \div 95\%$. Whereas sandy clay, soil samples have plasticity index $7\% < I_p \leq 17\%$, clay particles content of $15\% - 60\%$, viscosity of $0.75 < IL \leq 1$, and natural moisture $W = 20\% \div 50\%$.

5.1. Correlation of Shear Strength Parameters of the TS Test with UU Scheme and the DS Test

A total of 113 pairs of samples, which have similar geotechnical properties, were selected for correlation analysis of the shear strength parameters of $C_{\text{UU}}$ and $C_{\text{DS}}$. Regarding $\varphi_{\text{UU}}$ and $\varphi_{\text{DS}}$ correlation, a total of 34 pairs of samples, which have similar geotechnical properties, were selected. Analysis of data is shown in Table 1.

Table 1 Main values of parameters of the TS test with the UU scheme and DS test

<table>
<thead>
<tr>
<th>No</th>
<th>Values</th>
<th>$C_{\text{UU}}$ (kG/cm$^2$)</th>
<th>$C_{\text{DS}}$ (kG/cm$^2$)</th>
<th>$\varphi_{\text{UU}}$ (radian)</th>
<th>$\varphi_{\text{DS}}$ (radian)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Minimum</td>
<td>0.053</td>
<td>0.029</td>
<td>0.010</td>
<td>0.050</td>
</tr>
<tr>
<td>2</td>
<td>Maximum</td>
<td>0.383</td>
<td>0.184</td>
<td>0.100</td>
<td>0.150</td>
</tr>
<tr>
<td>3</td>
<td>Mean</td>
<td>0.174</td>
<td>0.089</td>
<td>0.039</td>
<td>0.111</td>
</tr>
<tr>
<td>4</td>
<td>Standard deviation</td>
<td>0.063</td>
<td>0.033</td>
<td>0.026</td>
<td>0.027</td>
</tr>
</tbody>
</table>

Correlation analysis of this data was also done and shown in Figure 7. Results show that $C_{\text{UU}}$ and $C_{\text{DS}}$ have very high positive correlation as the correlation coefficient is very high ($R = 0.946$) (Figure 5a and Equation 3). Very high negative correlation is constructed for $\varphi_{\text{UU}}$ and $\varphi_{\text{DS}}$ as the correlation coefficient is also very high ($R = 0.949$) (Figure 5b and Equation 4).
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Figure 5 Correlation of the Ts test with the UU scheme and the DS: (a) $C_{UU}$ vs $C_{DS}$, (b) $\phi_{UU}$ vs $\phi_{DS}$

$$C_{UU} = 1.84C_{DS} + 1.16 \ (kG / cm^2), \ \ R = 0.946$$  \hspace{1cm} (3)

$$\phi_{UU} = -0.99\phi_{DS} + 0.15 \ (radian), \ \ R = 0.949$$  \hspace{1cm} (4)

5.2. Correlation of Shear Strength Parameters of the TS Test with the CU scheme and the DS test

5.2.1. With Total Stress
A total of 101 pairs of samples, which have similar geotechnical properties, were selected for correlation analysis of the shear strength parameters of $C_{CU}$ scheme and $C_{DS}$ in the case of total stress. Regarding the correlation of $\phi_{CU}$ and $\phi_{DS}$, a total of 79 pairs of samples, which have similar geotechnical properties, were selected. Analysis of data is shown in Table 2.
Table 2 Main values of parameters of the TS test with the CU scheme and DS test in the case of total stress

<table>
<thead>
<tr>
<th>No</th>
<th>Values</th>
<th>( C_{\text{CU}} ) (kG/cm(^2))</th>
<th>( C_{\text{DS}} ) (kG/cm(^2))</th>
<th>( \varphi_{\text{CU}} ) (radian)</th>
<th>( \varphi_{\text{DS}} ) (radian)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Minimum</td>
<td>0.034</td>
<td>0.018</td>
<td>0.091</td>
<td>0.036</td>
</tr>
<tr>
<td>2</td>
<td>Maximum</td>
<td>0.208</td>
<td>0.199</td>
<td>0.427</td>
<td>0.161</td>
</tr>
<tr>
<td>3</td>
<td>Mean</td>
<td>0.105</td>
<td>0.093</td>
<td>0.264</td>
<td>0.096</td>
</tr>
<tr>
<td>4</td>
<td>Standard deviation</td>
<td>0.030</td>
<td>0.034</td>
<td>0.055</td>
<td>0.022</td>
</tr>
</tbody>
</table>

Correlation analysis of this data was also done and shown in Figure 8. Results show that \( C_{\text{CU}} \) and \( C_{\text{DS}} \) have very high positive correlation as the correlation coefficient is very high (\( R = 0.949 \)) (Figure 6a and Equation 5). Very high negative correlation is constructed for \( \varphi_{\text{CU}} \) and \( \varphi_{\text{DS}} \) as the correlation coefficient is also very high (\( R = 0.950 \)) (Figure 6b and Equation 6).

![Correlation plots](https://via.placeholder.com/150)

**Figure 6** Correlation of parameters of the TS test with the CU scheme and the DS: (a) \( C_{\text{CU}} \) vs \( C_{\text{DS}} \), (b) \( \varphi_{\text{CU}} \) vs \( \varphi_{\text{DS}} \)

\[
C_{\text{CU}} = 0.84C_{\text{DS}} + 2.71 \text{ (kG/cm}^2\text{)}, \quad R = 0.949 \tag{5}
\]

\[
\varphi_{\text{CU}} = 2.4\varphi_{\text{DS}} + 0.02 \text{ (radian)}, \quad R = 0.950 \tag{6}
\]
5.2.2. With Effective Stress

A total of 95 pairs of samples, which have similar geotechnical properties, were selected for correlation analysis of the shear strength parameters of $C'_CU$ and $C_DS$. Regarding the $\phi'_CU$ and $\phi_DS$ correlation, a total of 76 pairs of samples, which have similar geotechnical properties, were selected. Analysis of data is shown in Table 3.

Correlation analysis of this data was also done and shown in Figure 7. Results show that $C'_CU$ and $C_DS$ have very high positive correlation as the correlation coefficient is very high ($R = 0.949$) (Figure 7a and Equation 7). Very high negative correlation is constructed for $\phi'_CU$ and $\phi_DS$ as the correlation coefficient is also very high ($R = 0.949$) (Figure 7b and Equation 8).

![Figure 7](image)

**Figure 7** Correlation of parameters of the TS test with the CU scheme and the DS: (a) $C'_CU$ vs $C_DS$, (b) $\phi'_CU$ vs $\phi_DS$

<table>
<thead>
<tr>
<th>No</th>
<th>Values</th>
<th>$C'_CU$ (kG/cm²)</th>
<th>$C_DS$ (kG/cm²)</th>
<th>$\phi'_CU$ (radian)</th>
<th>$\phi_DS$ (radian)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Minimum</td>
<td>0.043</td>
<td>0.021</td>
<td>0.750</td>
<td>0.046</td>
</tr>
<tr>
<td>2</td>
<td>Maximum</td>
<td>0.164</td>
<td>0.253</td>
<td>0.990</td>
<td>0.171</td>
</tr>
<tr>
<td>3</td>
<td>Mean</td>
<td>0.092</td>
<td>0.115</td>
<td>0.844</td>
<td>0.108</td>
</tr>
<tr>
<td>4</td>
<td>Standard deviation</td>
<td>0.025</td>
<td>0.049</td>
<td>0.068</td>
<td>0.026</td>
</tr>
</tbody>
</table>

Table 3 Main values of parameters of the CU scheme and DS test in the case of effective stress
\[ C'_{cu} = 0.49C_{DS} + 3.61 \left( \text{kG/cm}^2 \right), \quad R = 0.949 \quad (7) \]

\[ \phi'_{CU} = 3.74 \phi_{DS} - 0.04 \left( \text{radian} \right), \quad R = 0.949 \quad (8) \]

6. CONCLUSIONS

In this research, the correlation functions were constructed between the shear strength parameters of adhesive soft soils through experimental results of the DS test and the TS test on the combination of hundred soft soil samples in the deltaic coastal area of Vietnam from Red River Delta in the North to Mekong River Delta in the South. Shear strength parameters \((C_{UU}, \phi_{UU}), (C_{CU}, \phi_{CU}), \text{and} (C'_{CU}, \phi'_{CU})\) determined from the TS test by two experimental schemes (UU and CU) were used to analyze the correlation function of shear strength parameters \((C_{DS}, \phi_{DS})\) determined from the DS test. Standard correlation coefficient was used to validate the degree of correlation of variables. Results show that the degree of correlation of the analyzed variables is very high \((R > 0.9)\). The correlation function analysis suggests that DS tests are equally reliable in comparison to TS tests and can be applied for the determination of shear strength parameters of plastic clay soil of not only deltaic area of Vietnam but also other regions of the world.

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