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Evaluation on the Results of Multistage Shear Test

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ABSTRACT: Shear strength is a very important soil property to determine the stability of foundations, retaining walls, slopes and embankments. To solve those problems in geotechnical engineering, shear strengths are usually determined from laboratory tests performed on specimens prepared by compaction in the laboratory or undisturbed samples obtained from exploratory soil borings. In order to determine the shear strength parameters, the soil specimens are required at least 3 identical samples. To eliminate the effects of soil variability on the result, multistage testing is used to maximize the amount of shear strength information that can be obtained from only one specimen by using several confining pressures. Test results demonstrate that is possible and convenient to perform multistage shear test on compacted soil to measure shear strength. The direct shear tests were carried out using the multistage technique and the results are quite well comparable to those of traditional shear tests.

Keywords: Multistage Test, Shear Strength Parameters, Hyperbolic Stress-Strain Relationship, Direct Shear Test

1. INTRODUCTION

The most widely used laboratory equipments for investigating the strength and deformation behavior of soilsis either the triaxialor direct shear apparatus. The apparatus is versatile and can be used for the measurement of many parameters,including shear strength characteristics, consolidation characteristics and the permeability of soil. Its key features include facilities for the control of the magnitude (but not direction) of the principal stresses, the control of drainage, and the measurement of pore pressures [1].

In traditional tests, each specimen undergoes a phase of consolidation and shearing and thus supplies a single stress versus strain trend and of course only one state of stress at failure. A series of three or more specimens, consolidated at various stress levels, supplies an ensemble of stress data allowing identification of a failure envelope and thus shear strength parameters. Sometimes it is impossible to have a set of homogeneous or identical re-compacted specimens, for economic reasons or because some soils formations may be difficult to sample. In such circumstances the multistage shear testing technique appears to be an attractive alternative. This technique has been successfully used to determine shear strength parameters by just one sample.

Kenney and Watson [2] conducted multistage undrained tests (MCU). They report reasonable consistent between c' and ϕ' obtained from MCU tests with the values obtained by using conventional undrained tests (CCU). MCU tests were conducted by consolidating and loading it until about failure strain, then repeating the process twice again with two higher cell pressure. The total strain that the sample was subjected to during MCU test amounted to about 25%.

To avoid subjecting the sample of high strain, Sridharan and Narasimha Rao [3] investigated a new approach to multistage testing, which made use of Kondner's [4] hyperbolic stress-strain relationship for predicting the state of stress at failure from the stress-strain and pore-water pressure-strain curves of soils can be approximated by rectangular hyperbola, for which the equation is shown in (1).

$$\varepsilon_s/\tau = a + b\varepsilon_s \quad (1)$$

where:

ε_s =shear strain
τ =shear stress
a =y-interception of ε_s/τ and ε_s relationship
$= 1/E_i$ (from asymptotic value)
b =slope of ε_s/τ and ε_s relationship
$= 1/\tau_f$ (from asymptotic value)
E_i =initial tangent modulus and
τ_f =failure shear strength, with the normal stress, σ_n

Similarly for predicting pore-water pressure (u), Sridharan and Narasimha Rao [3] used (2).

$$\varepsilon/u = a_u + b_u\,\varepsilon \quad (2)$$

where:

a_u =y-interception of ε/u and ε relationship
b_u =slope of ε/u and ε relationship
$= 1/u_f$. and
u_f =pore-water pressure at failure

The multistage test suggested by Sridharan and Narasimha Rao [3] referred to as NMCU tests consisted of: a) assessing whether the soil lends itself to extrapolation using Kondner's method, b) consolidating the sample to a cell pressure and shearing it to 2 to 4% axial strain, c) repeating the consolidation-shear sequence at two higher cell pressure, d) using Kondner's method to predict failure stressed at each cell pressure, and e) using the results for all three cell pressure together to determine shear strength parameters. Sridharan and Narasimha Rao [3] report success using this method, however using Kondner's method the value of τ_{ult} and u_f predicted were higher than actual. Sridharan and Narasimha Rao [5] had suggested that in extrapolating data using Kondner's method better prediction is possible if one extrapolates only to a finite value of strain using (1) and (2) rather than to the asymptotic value of infinite strain. They had tentatively suggested using a strain of 15%

Even though the multistage testing technique has been used with some success in the past to determine shear strength parameters, to define undrained shear strength [6],[7] or effective shear strength both in unsaturated [8],[9] and saturated soils [3],[10] in triaxial apparatus and in direct shear apparatus [11] but still lacking in concerning and carrying out on the drain condition of testing especially in direct shear apparatus.

In this paper, a series of single and multistage testing is performed using direct shear apparatus as drained condition to investigate on the shear strength parameters of the single stage-multistage comparative study. The preparation of the soil specimens is controlled as the field condition by using field dry density and optimum moisture content (OMC).

2. METHODOLOGY

2.1 Preparation of Specimens

The red KhonKaen loess soil sample was collected as disturbed sample at a depth of 3-4 m. The index properties and compaction characteristics are shown in Table.1.

Table.1Properties of soil

Property	KhonKaen loess soil
Specific gravity (G_s)	2.64
Liquid limit (LL)	21.2%
Plastic limit (PL)	14.3%
Unified Soil Classification System (USCS)	SM-SC
OMC	9.25 %
$\gamma_{d\ max}$	2.02 g/cm^3
$\gamma_{d,field}$	1.81 g/cm^3

The experimental program was a parametrical study aiming at studying the effect of important reconstituted conditions of soil such as initial water content, initial dry density on shear strength parameters. As using disturbed samples, they were prepared in ‘identical’ fashion by controlling initial water content as OMC and initial dry density as the field dry density (that is about 89.6% of compaction) by using hydraulic jack slowly pressing to 60 mm in squared width and 20 mm in height.

2.2 Single Stage Procedure

To perform the shear strength testing, a two-stage loading procedure was used in each of these tests. In the first stage, a consolidation was applied. In the direct shear test, the consolidation was applied by applying a vertical load to the horizontal plane, becoming the eventual failure plane. In traditional tests, each specimen undergone a phase of consolidation and shearing and thus supplied a single stress versus strain trend and of course only one state of stress at failure [7]. A series of 3 or 4 specimens, consolidated at various confining stress levels, supplied an ensemble of stress data allowing identification of a failure envelope and thus shear strength parameters.

In this paper, the series results of single stage testing were carried out in direct shear apparatus to compare with the results of multistage series. Single stage tests were conducted till 8-15% strain on four samples at confining pressures of 100, 200, 300 and 400 kPa. And the loading rate was 0.002% strain per minute for direct shear test as drained condition required.

2.3 Multistage Procedure

A multistage test induces more than one consolidation and shearing on the same soil specimen loaded inside a direct shear box. Specimen preparation and initial test stages of saturation are identical to those of traditional direct shear. Especially the saturation stage in triaxial test, it is required more or less 5 days to gain the value of B (pore pressure) parameter more than 0.9 and to finish the settlement in this process. This method enables substantial homogeneity of the results and appreciable time consuming.

After saturated and consolidated specimen in stage I is finished, in the shearing stage the specimen is sustained to produce a significant amount of shear stress. Then the specimen is released from horizontal stress. To start the next stage, the specimen is subjected to a higher normal stress before the following shearing stage takes place.

In this paper, the strain for each compression stage has been carried up to only 3% in each test. In all cases, the peak value of shear strength are expected for strain values greater than 8%, as is the case of many clayey and silty-clayey soils of medium to low plasticity [7] and also as is the case of many not dense condition of compacted soil. The normal stress and loading rate in multistage test were used the same as a series in single stage test. In the results of direct shear test, the test was conducted to not failure but carried to 3% of strain in each stage, and the ultimate peak values are predicted by making use of Kondner's hypothesis [4].

3 RESULTS AND DISCUSSION

Direct shear tests were carried out in both single stage and multistage test saturated specimens with normal stresses of 100, 200 ,300 and 400 kPa. The single direct shear testing result on saturated condition is shown in Fig.1.

In consideration of the hyperbolic stress-strain relationship, the hyperbolic model represents the nonlinear stress-strain curve of soil using hyperbola. It can be seen that transforming the hyperbolic equation result in a linear relationship between $\varepsilon_s/\tau$and ε_s, shown in (1). The validity of Kondner's hypothesis is shown in Fig. 2. The stress dependent stress-strain behavior of soil is represented by varying the initial tangent modulus, E_i, and the failure shear strength, τ_f with the normal stress, σ_n.

These plots do produce straight line relationships and as such indicate that the behavior of soils lends itself to prediction by Kondner's technique. The failure shear stress (τ_f) for single tests have been predicted from asymptotic values and using (1) for failure strains of 10, 15, and 20%.

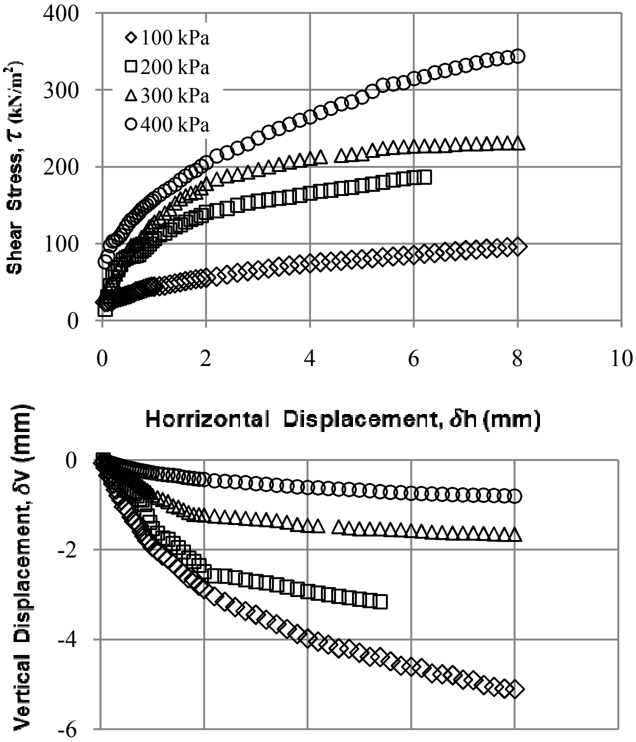

Fig.1 Testing results in single stage direct shear test

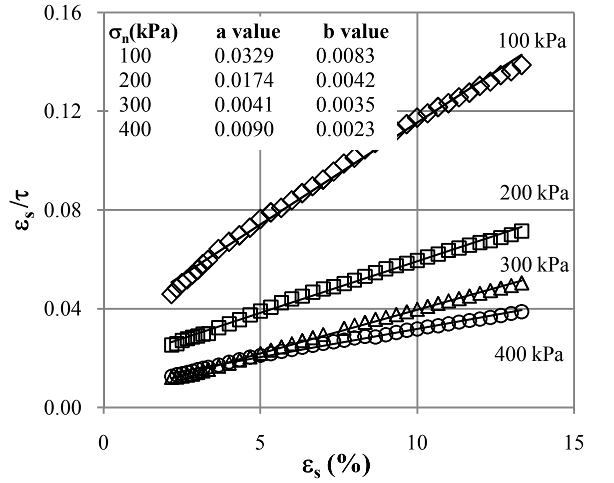

Fig.2 Hyperbolic representation of stress-strain curve in single stage direct shear test

The predicted and experimentally obtained values of τ_f are presented in Table. 2. Also presented in this table is value of percentage agreement, which is the ratio if predicted to experimentally obtained values. A study of Table. 2 shows that the value of τ_f predicted by using ε_s approaching infinity is always higher than experimental values. Agreement with experimental value is better when value of strain used is about 15%.

Since Kondner's technique was found to be valid for KhonKaen Loess soil, it is possible to conduct the multistage direct shear test to predict failure stresses. Fig.3 presents the plot of ε_s/τ versus ε_s for multistage direct shear test carried up to 3% strain in each stage that are predictably linear Table.3 presents the values of τ_f predicted from asymptotic value. As can be seen from the Fig.4, the

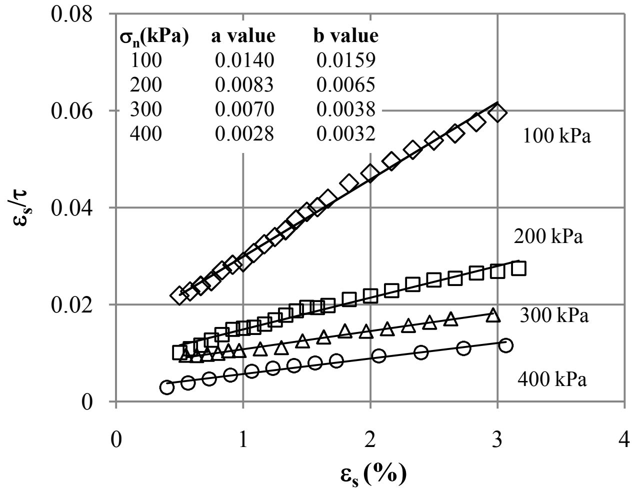

Fig.3 Hyperbolic representation of stress-strain curve in multistage direct shear test

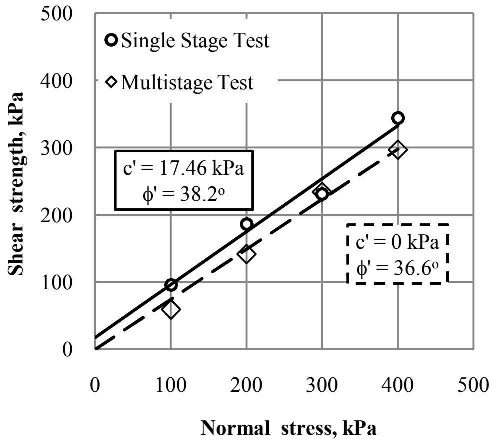

Fig.4 Failure Envelope in Direct Shear Test

predicted results of strength parameters in multistage test are relatively validity by giving the quite lower value of internal friction angle (about 4% of error) with no cohesion. So the prediction of failure stresses using Kondner's relation is nearly perfect when results are extrapolated to a value of finite strain determined by analyzing data of single stage test.

4 DISCUSSION AND CONCLUSIONS

Testing results demonstrate that is possible and convenient to perform multistage shear test on compacted soil to measure shear strength. The drained direct shear test was carried out by using the multistage technique and, as shown, the results are quite well comparable to those of traditional shear tests. The proposed multistage shear testing procedure can be used to evaluate the shear strength parameters from a single test.

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Table. 2: Predicted and Experimental values of τ_f in single stage direct shear tests.

σ_n, kPa	Experimental Value of τ_f, kPa	Asymptotic Value of 1/b	Percentage Agreement	Predicted Value of τ_f Using (1) for Shear Strain of 10%, kPa	Percentage Agreement	15%, kPa	Percentage Agreement	20%, kPa	Percentage Agreement
100	96.2	120.5	125.3	86.3	89.7	95.3	99.1	100.6	104.6
200	186.5	238.1	127.6	168.4	90.2	186.6	100.0	197.2	105.7
300	231.1	263.2	113.8	226.2	97.9	237.3	102.7	243.3	105.3
400	343.9	434.8	126.4	312.5	90.9	344.8	100.3	363.6	105.7
Average Percentage Agreement			123.3		92.2		100.5		105.3

Table.3: Predicted Values of $\tau_f$forKhonKaen Loess Soil

σ_n, kPa	Experimental Value of τ at 3% Strain, kPa	Value of τ_f Obtained from Asymptotic Value, kPa	Predicted Value of τ_f Using (1) for Shear Strain of 15%, kPa
100	50.4	62.9	59.4
200	115.3	153.8	141.8
300	166.1	263.2	234.4
400	265.2	312.5	297.0

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