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Laboratory Tests Based Strength Evaluation of Alluvial Soil: A Case Study

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ABSTRACT
This article represents an analysis of alluvial soil behaviour using laboratory tests where samples being collected from different parts of Khulna, Bangladesh. Bangladesh is a riverine country and 80% of soil in Bangladesh is alluvial. Especially, the Khulna region stands on the Gangetic alluvial soil track that poses a challenge to the foundation engineers. Determination of shear strength parameters comprising of cohesion (c) and internal friction angle (Φ) plays a vital role in soil mechanics. These parameters are often used in quantification of soil strength and thereby play an important role in designing the foundation. In this study, direct shear tests and triaxial tests have been conducted to investigate the shear strength parameters of alluvial soil. Four soil samples were collected from four distinct locations (Rupsha-22˚47'58.01" N, 89˚34'45.82" E; Boyra-22˚50'30.33" N, 89˚32'.63" E; Sonadanga-22˚49'7".00" N, 89˚32'47.07" E; Fulbarigate 22˚53'56.90" N89˚32'47.07" E) of Khulna. Test results show a significant change in the value of the internal friction angle of the soil samples while its shear strength parameter is measured by a direct shear test compared to triaxial testing on the undisturbed specimen. Whereas, the discrepancy of results is less significant for samples in remoulded conditions. The disparity of shear strength results obtained by different test methods has been explained by analyzing soil sample structure at different states.

Keywords:-*Direct shear test; Triaxial test; Angle of internal friction; Soil profile.*

INTRODUCTION

The process of civilization greatly depends on the process of urbanization and urbanization requires plenty of lands where buildings for shelter, business, and other usages can be constructed [33]. To accommodate a large number of people in a single land, multi-storeyed buildings are constructed at a great rate.

However, whether the building is a high rise or low rise the accurate soil behaviour regarding the construction must be known [15,26,31,32]. There are different standard test procedures to determine different properties of soil and their behaviour. Again, one property can be determined by various methods[39]. Therefore, engineers should have distinct knowledge about how the test result varies in different methods before testing and to decide which testing method is needed to be adopted [19, 37] . Moreover, the shear strength behaviour of soil during loading conditions is very important to know particularly for alluvial soil since this certain type of soil is highly compressible [1,24,30,36].

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Depending on the overall subject in which it is being evaluated, the term "soil" has several meanings [38]. The engineering property of soil refers to soil characteristics employed in geotechnical engineering [29]. One of the engineering features of soil is shear strength, which is the amount of internal resistance per unit area a soil mass can provide to fend off failure and prevent slide along any internal plane (Das, 2021). Shear failure is the main cause of soil failure. When the soil's maximum bearing capacity is insufficient to support the load on the foundation, the soil shears. Knowing the soil's shear strength is a need for all analyses, including slope stability and bearing capacity analyses [13,41].

Cohesion (c) and internal friction (Φ), two characteristics, make up the majority of the soil's shear strength. These two variables show whether or not the soil is cohesive. The degree of bonding between soil particles is gauged by cohesion. This can also provide insight into the behaviour of interior particles when the external load exceeds the soil's carrying capability [19]. When c>0 and =0, the soil may be classified as cohesive soil, and when c=0 and >0, it can be classified as cohesion less soil. However, cohesive soil is typically thought to have c>0 and >0.

The Coulomb-Terzaghi equation states that the shear strength of soil is given by the formula: s = c + tan, where tan is the coefficient of plane sliding friction and is the angle of internal friction, or the angle between the normal force and the resultant force. To assess shear strength characteristics, a variety of laboratory techniques are available, such as the direct shear test and the triaxial test [6,10]. The failure plane in a direct shear test is always horizontal; however, it may not be the sample's weakest plane. Progressive soil failure happens at the sample's margins and moves toward the centre [16]. Again, the shear box does not have a mechanism for detecting pore water pressure, making it impossible to calculate effective stresses from the undrained test [23]. But the mechanical behaviour of soil is greatly influenced by pore pressure and air pressure [17]. The regulating factor in the connection between normal stress and volume change is not the total normal stress, but rather the difference between the total normal stress and the pore pressure, which is the pressure of the fluid in the empty space [9,18,21] In contrast, multiple combinations of axial and confining stress may be applied in triaxial tests at a constant pace, and there is a method to calculate the pore water pressure [7]. In this experiment, the soil is held in place by a consistent confining pressure that is produced by the pressure of the surrounding soil and the water in the pores [11,40].

Triaxial testing comes in three different flavours: consolidated drained triaxial testing, consolidated undrained triaxial testing, and unconsolidated undrained triaxial testing [22,34. The triaxial tests' soil specimen can be reused or left alone. The condition of the soil at which it may be said to be in its natural state is referred to as an undisturbed specimen. The damaged specimen must be reshaped into the proper test-related form. Understanding the possible impacts of sample disturbance and choosing the right laboratory testing protocols are necessary when sampling and testing soils to evaluate engineering parameters like monotonic and cyclic undrained shear strengths [14]. Therefore, based on the kind of soil to be tested, one must select the suitable testing technique before measuring the shear strength characteristics of soil. Triaxial testing is typically chosen to study soil behaviour and plan earthworks [12,25].

This paper presents an analysis of shear strength parameters of alluvial soil based on direct shear test and triaxial test. Furthermore, the study shows a comparison on how sample types affect the shear strength. Also, this article provides argumentation behind the variation of soil strength obtained from different test types and gives recommendation for appropriate test method for alluvial soil.

RESEARCH METHODOLOGY

At first, a brief literature review was performed regarding the shear strength parameters of soil, its behaviour, different test method to determine the parameter, their advantages and disadvantages, and characteristics. In order to move further with the study, four samples (samples 1, 2, 3, and 4) were obtained via block connection from various areas of Khulna, Bangladesh, at variable depths (ranging from 1.5 to 2.1 m). Following that, the general and index characteristics of the soil were identified for future investigation. Identification of the specific gravity, liquid limit, plastic limit, plasticity index, etc. are among the index features. To establish the soil's shear strength values, sample 1 and sample 2 underwent undisturbed unconsolidated undrained triaxial testing. After the triaxial test, the samples underwent unconsolidated undrained (UU) direct shear testing to ascertain the soil samples' shear strength values. The identical process was then carried out once more for soil samples 3 and 4 in the remoulded state. Finally, an analysis and graphic presentation of the parameter values acquired from various laboratory tests was done.

MATERIAL COLLECTION

In the study, soil samples that were collected were used as test materials. Four key places were used to gather the samples. The locations of the soil samples are shown in Table 1. Block samples from each site were taken in accordance with the [5] standard. A square box measuring 0.46m x 0.46m was placed upside down in the intended location and labelled while remaining apart from the box. The dirt was then dug up to a depth of 2.13 m to create a soil column. The box was hauled upward once the soil's bottom was cut at the correct depth. The filled block was then used to gather soil samples.

***Table 1:**-Location of the collected soil samples.*

Soil Sample	Location
01	Rupsha (22˚47’58.01” N, 89˚34’45.82” E)
02	Boyra (22˚50’30.33” N, 89˚32’.63” E)
03	Sonadanga (22˚49’7”.00” N, 89˚32’47.07” E)
04	Fulbarigate (22˚53’56.90” N, 89˚32’47.07” E)

TEST METHODS

Liquid limit determination test

(ASTM-D4318, 2010)[4] was followed to determine the liquid limit of soil. The relative consistency of a cohesive soil can be clear by a ratio called the liquidity index LI (Das & Das, 2008). The equipment needed for the test is a set of 114 mm-diameter porcelain evaporating dishes, as illustrated in Figure 1; a pulverising tool, such as a mortar and pestle with rubber covering, a U.S. No. 40 sieve, a spatula that is 75 mm long and 19 mm wide, a balance that is accurate to 0.01

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g, distilled, demineralized, or tap water, drying trays with covers, such as metal cans with lids, to prevent moisture loss, a mechanical liquid limit device, and a spatula.

Fig.1:-*Liquid limit determination procedure.*

A manually operated system made composed of a brass cup and carriage that were built in accordance with the plan, a combined grooving tool and gauge that complied with dimensions and an oven with a thermostat that could maintain temperatures. The dirt paste was used in this test to partially fill the liquid limit device. Then, the groove carved through the dirt paste. The liquid limit device's handle was then revolted at a rate of 120 rpm. The number of blows was then applied after it was watched until the soil paste's two sides were 12 mm apart. Since the number of blows after adding water varied each time, this procedure was performed five times. The semi-log paper was then used to graph the relationship between water content and the number of blows. The slope of this graph, which is referred to as the flow curve, corresponds to the flow index. The water content was finally estimated against 25 strikes using this curve. The soil's liquid limit is represented by the measured value.

The plastic limit determination procedure

(ASTM-D4318, 2010)[3] was followed to determine the plastic limit of soil. A balance sensitive to 0.01gm, a watering bottle with distilled, demineralized, or tap water, a porcelain evaporating dish measuring approximately 114mm in diameter, a mortar and pestle with a rubber cover, a U.S. No. 40 sieve, a spatula measuring approximately 75mm long and 19mm wide, a thermostatically controlled drying oven capable of maintaining temperatures of 110 50C for drying moisture samples, drying tares with covers, and The tares and coverings need to be identified as matching pairs before being weighed. The soil sample must also be rolled on a rolling surface, such as a ground glass plate or a piece of glazed or unglazed paper. Additionally, the operator utilised a 3 mm diameter rod as a reference to determine the thread size. After adding water, the soil paste was rolled into a thread of a diameter of 3 mm as shown in Figure 2 until crumble.

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Fig.2:*-3mm diameter oven-dried tread*

The wet sample's weight was then calculated. The wet sample was obtained in the oven after the weight was taken. The dry sample's weight was calculated after drying. Three distinct moisture content readings were recorded when the technique was repeated. The sample's plastic limit was determined by taking the average of three moisture content measurements.

Direct Shear Test

(ASTM-D3080, 2012) was followed for conducting the direct shear test. The equipment needed is the direct shear machine, mitre boxes, wire saws, rubber sheets for remoulding, balances, drying ovens, spatulas, and timers.

The specimen size employed in the direct shear test for the undisturbed specimen was 60 mm x 60 mm x 47.6 mm. Using a mitre box, the sample from the sizable undisturbed specimen was cut. The undisturbed specimen before trimming is shown in Figure 3.

Fig.3*:-Undisturbed specimen before trimming*

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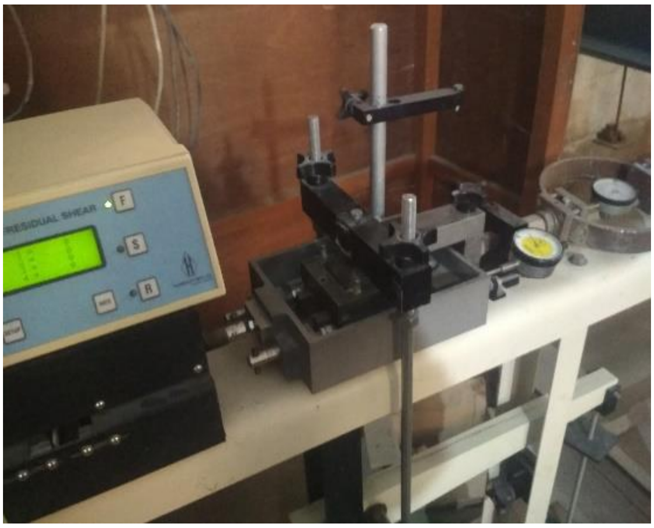

Fig.4:-*The shear test device is prepared for the test*

Fig.5:-*Preparation of remolded specimen*

Fig.6:-*Specimen trimming to get the desired diameter*

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From the trimmings, the water content was measured. The regular load was then applied after counterbalancing the apparatus. The specimen was set on the shear box, which was brought into a humid environment, as illustrated in Figure 4. The upper grating or porous stone was then put in place after the upper frame was attached to the lower frame. The loading block was then positioned following that. After that, the platform was fastened into place with the loaded shear box in it. The chosen normal load was then applied. Readings were taken throughout the exam. The shorn undisturbed specimen from the machine was instantly removed from the machine and covered in a rubber sheet for testing the remoulded specimen. The specimen was then meticulously remoulded, as seen in Figures 5 and 6. Every effort was made to reduce moisture loss from the soil and did this in a humid chamber. The samples of undisturbed soil and remoulded soil are shown in Figures 7(a) and 7(b), respectively.

Fig.7(a):-*Undisturbed soil sample (oven-dried)*

Fig.7(b):- *Remolded soil sample (oven-dried)*

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Triaxial Testing

The test was conducted following the (ASTM-D2850, 2017) standard method for the unconsolidated undrained condition. A sizable undisturbed sample was used to create the undisturbed specimen for testing. A vertical trimming lathe was used to trim the sample to the required diameter in a humid environment. The specimen was put in the mitre box and cut to the desired height after reaching the requisite diameter. On the trimmed sample, the water content was then calculated. Using a split mould with a circular cross-section, the material was compacted in six layers to create the remoulded specimen. Before the following layer's material was added, the top of each layer was scarified. The specimen was prepared, and then the mould was taken out. The mass and water content were then calculated. The sample was set on the elliptical base after being noted according to the sample criteria. The specimen was then put under a 50 kPa confining pressure by the water in the chamber. At a steady rate of 0.5–2% strain per minute, the load rose on the sample. The load values for particular deformations were recorded during the test. Following that, mathematical calculations were used to calculate the shear strength parameters and depict the graphs. For confining pressures of 100 kPa and 150 kPa, the same process was used. Figure 8 depicts the triaxial apparatus.

Fig.8:- *Triaxial testing device*

RESULTS AND DISCUSSION

The measured index properties and the general properties of soil samples have been presented in Table 2.

Table 2:-*General and index properties of the soil samples*

Sample no.	Liquid limit (%)	Plastic limit (%)	Plasticity Index (%)	Sand (%)	Silt (%)	Clay (%)
1	47.39	26.18	21.21	11	45	44
2	45.48	27.32	18.16	12	49	39
3	43.20	28.28	14.92	8	44	48
4	44.26	27.76	16.5	7	51	42

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The direct shear test was performed on soil samples 1 and 2 in the undisturbed condition. To more clearly see the distinction between the direct shear test and triaxial test, the values of the angle of internal friction have been displayed after the direct shear test and triaxial test have been performed on the undisturbed soil sample 1 and 2. The graph demonstrates that while the shear strength parameter of soil samples is evaluated using various techniques, there is a noticeable shift in its value. The direct shear test depicted in Figure 9 is used to estimate the 19.47-degree angle of internal friction for soil sample 1.

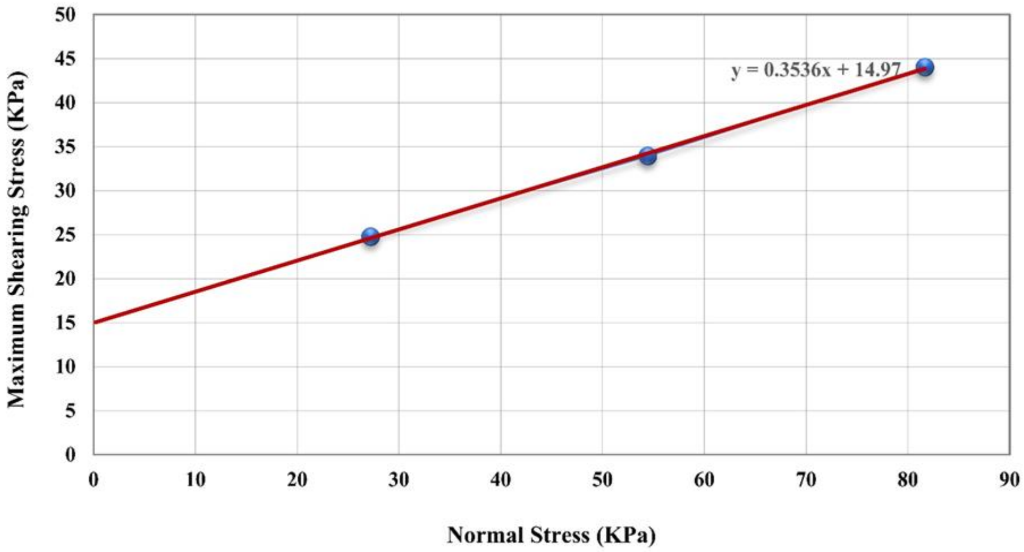

Fig.9:- *Maximum shearing stress vs. normal stress from the direct shear test of soil sample 1*

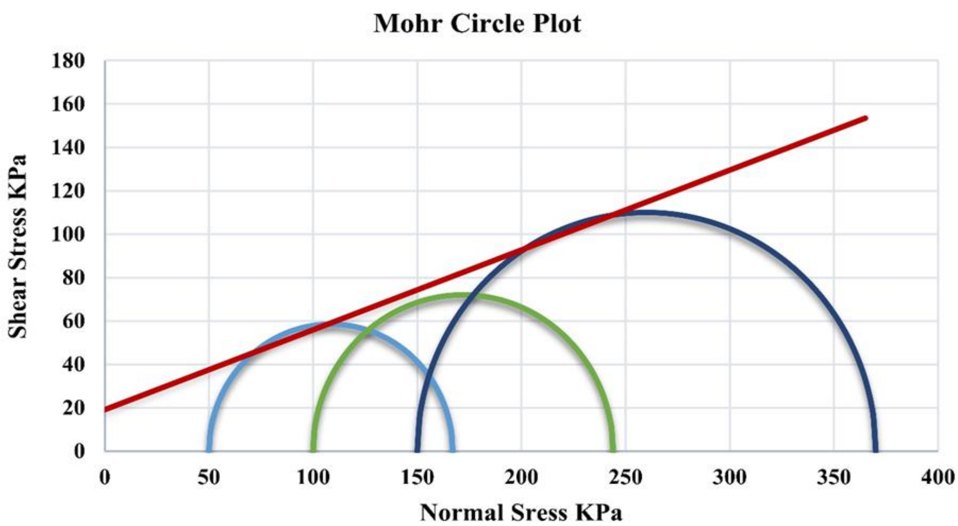

Fig.10:- *Mohr circle plot from the triaxial test of the soil sample 1*

However, when the same soil is tested using triaxial testing, the observed internal friction angle increases to 21.2 degree, as shown in Figure 10. Again, the observed

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angle of internal friction for soil sample 2 is 18.29 degree according to the direct shear test shown in Figure 11, whereas the value for the triaxial test is 21degree as shown in Figure 12. For the two soil samples, the change in angle ranges from 1.73 to 2.71 degrees.

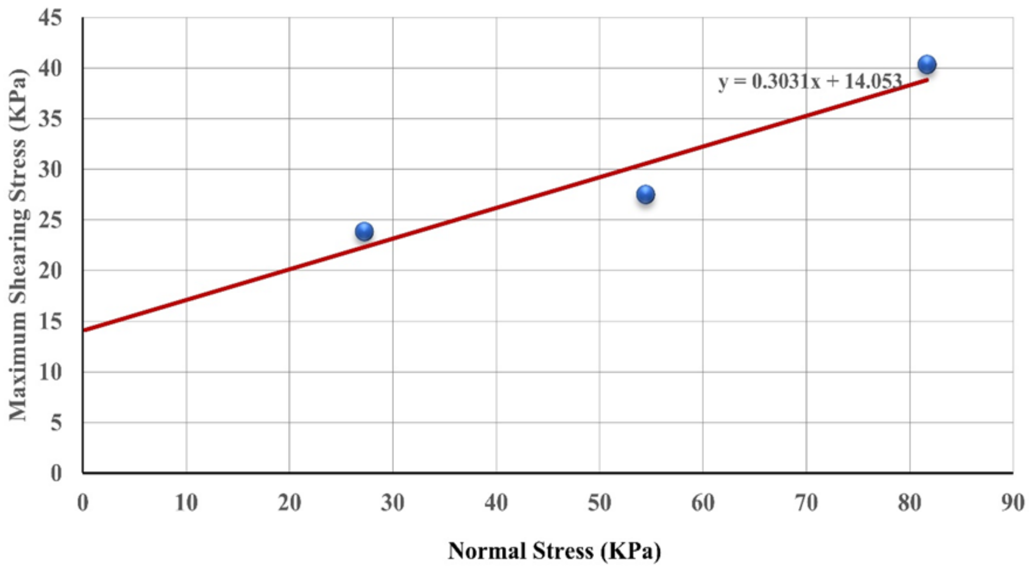

Fig.11:- *Maximum shearing stress vs. normal stress from the direct shear test of soil sample 2*

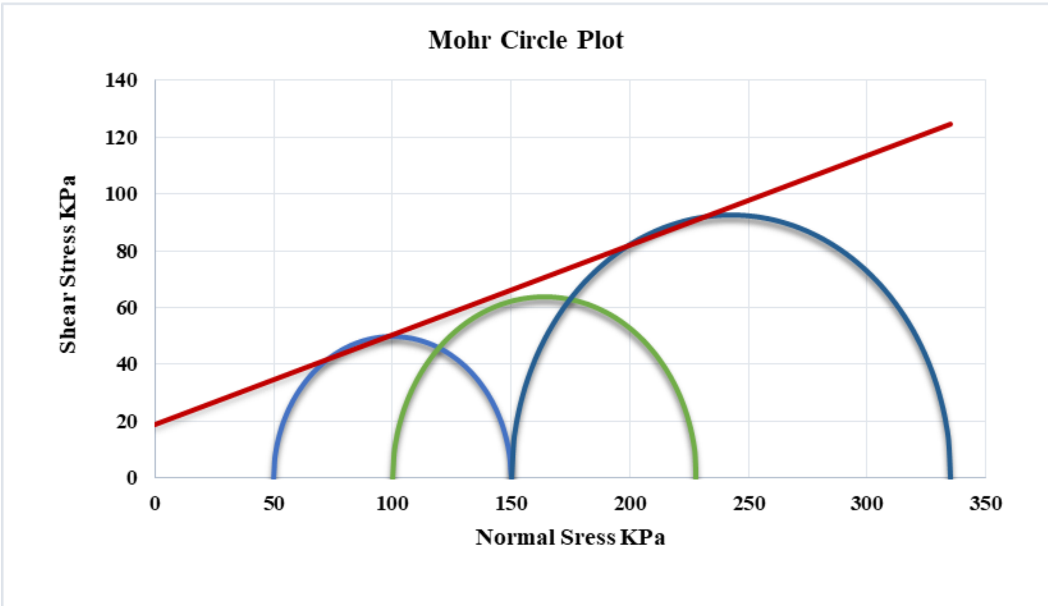

Fig.12:- *Mohr circle plot from the triaxial test of the soil sample 2*

It may be said that the direct shear test arrangement will produce lower soil shear strength than the triaxial test setting since the angle of internal friction has a proportionate connection with soil shear strength. Additionally, soil sample 1 exhibits a higher variation in the internal friction angle than soil sample 2. The soil's water content can be used to explain this occurrence. In both sets of testing, soil

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sample 2's plasticity index is higher than soil sample 1's. (Berre, 1973; Ladd, Foott, Ishihara, Schlosser, & Poulos, 1977) noted decades ago that clay anisotropy reduces as the plasticity index (PI) rises. On the same soil specimen, additional experiments including the direct shear test and the triaxial test were carried out in order to get a more trustworthy conclusion. The measurements on the remoulded specimens reveal that the soil sample 3's angle of internal friction is 16.7 for the direct shear test in Figure 13 and 16.66 for the triaxial test in Figure 14. Once more, for the direct shear test shown in Figure 15 and the triaxial test shown in Figure 16, the angle of internal friction for soil sample 4 is 17.24 and 17.2, respectively.

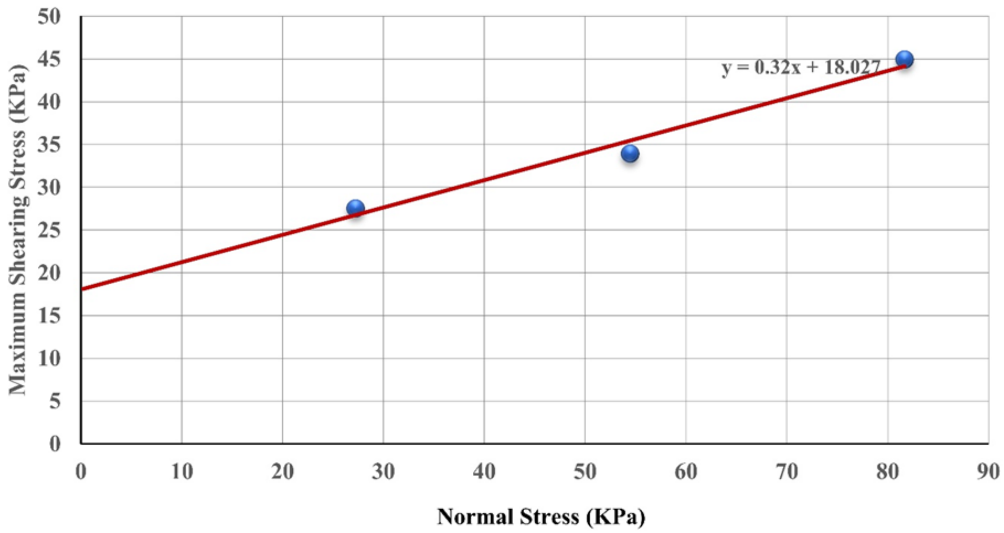

Fig.13:- *Normal stress vs. maximum shearing stress from the direct shear test of soil sample 3*

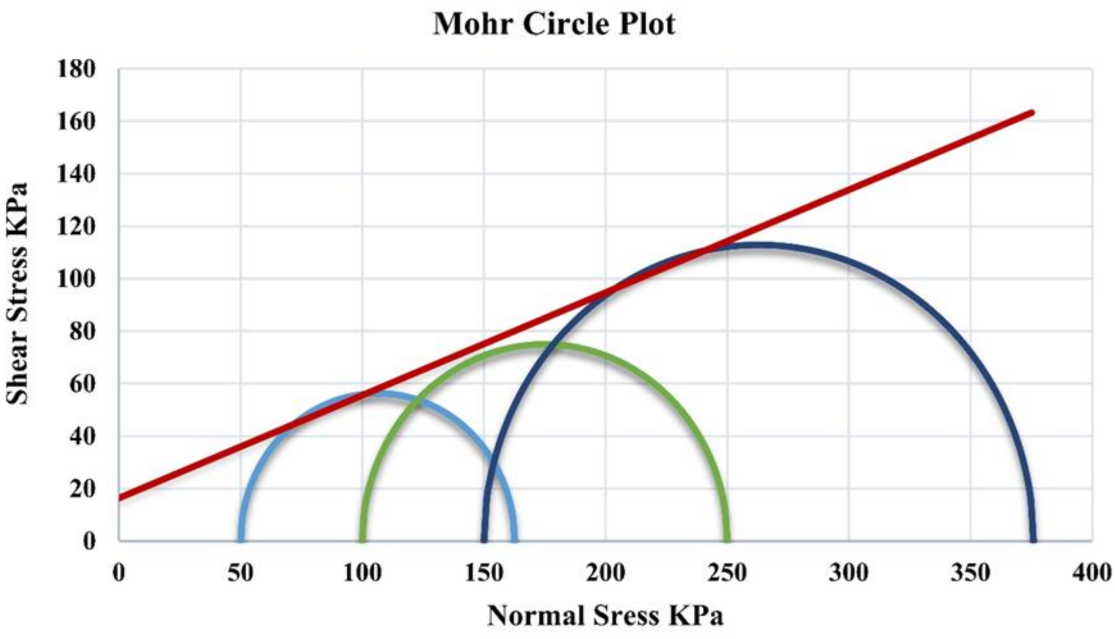

Fig.14:- *Mohr circle plot from the triaxial test of the soil sample 3*

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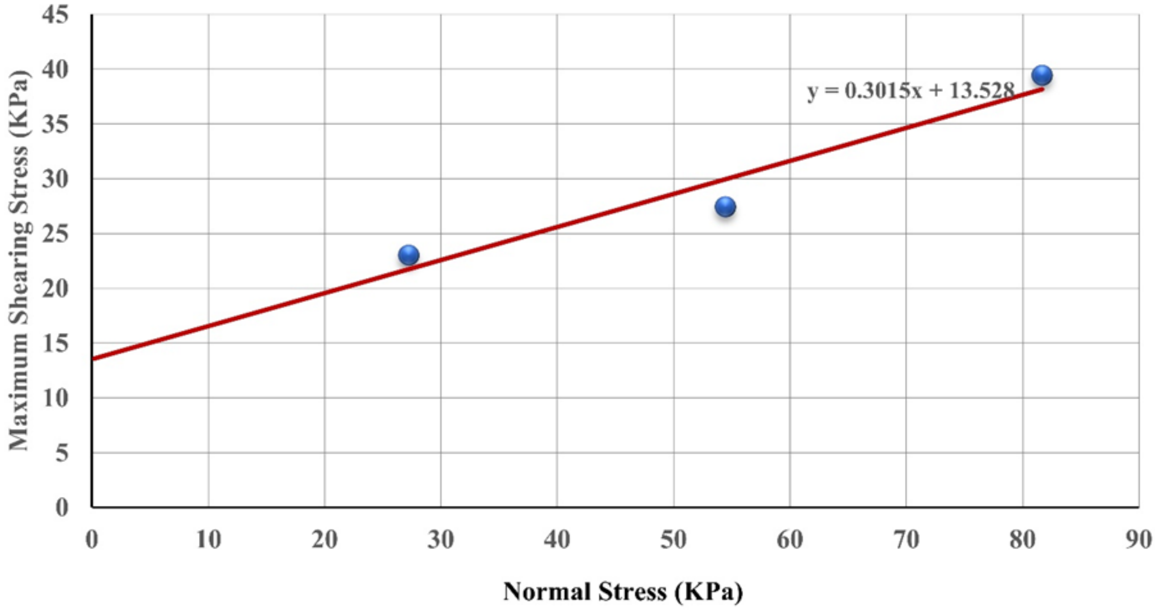

Fig.15:- *Normal stress vs. maximum shearing stress from the direct shear test of soil sample 4*

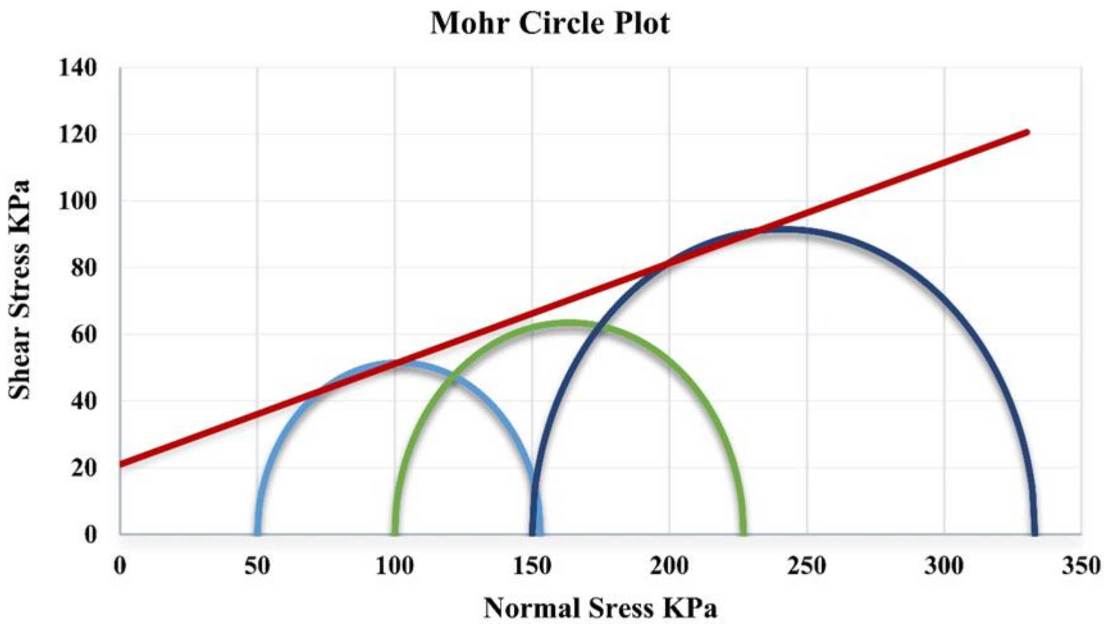

Fig.16:- *Mohr circle plot from the triaxial test of the soil sample 4*

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In this instance, for both soil samples, the variation between the triaxial test and the direct shear test is less than 1. By looking at the soil's structure, it is possible to explain why the direct shear test result is lower than the triaxial test result for the undisturbed material. Two factors may be used to identify the soil structure. The soil profile and soil horizon are those. A layer of soil or soil-like material that is roughly parallel to the ground surface is referred to as a soil horizon. The soil profile, on the other hand, is described as a vertical segment of the soil that passes across all of its strata. The consequence of dirt being layered horizontally is a soil horizon. Some soils are accumulated over a long period of time, generating a horizontal layer. The plane also happens to be weaker than the others, along with the layer interface. The soil horizon in the Khulna area has extensive layering since it is part of the Gangetic alluvial soil track. A sample of the undisturbed specimen is collected, and it is oven-dried for 24 hours to better display the layers.In a direct shear test, the soil is restrained on a shear box and torn apart at around the midpoint of the specimen's height. Along with the soil sample, the top half of the box is torn apart by the bottom half. As a result, in a direct shear test, the failure plane is pressed. The shear strength recorded will be significantly less if the direct shear test failure plane is at the soil layering interface. The failure plane in the triaxial test is not pre-set, though. The soil sample is supplied triaxially together with the pressure. Therefore, there is a lower likelihood that the soil's horizontal stacking will intersect the failure plane. As a result, the triaxial test's shear strength result is higher. This discovery also supports the findings of tests conducted on remoulded specimens. The reconstruction of remoulded specimens makes them suitable for testing. The procedure modifies the soil's original structure. The soil's horizontal stratification is thus reduced to a certain amount at the time of remoulding. Therefore, when employing a remoulded specimen in the direct shear test, the shear strength is enhanced. Similar to this, a part of the remoulded specimen is oven dried for 24 hours and studied to better see the soil structure after remoulding. In conclusion, the triaxial test may provide more trustworthy results than the direct shear test when an undisturbed specimen is employed. But because the horizontal soil layering is lessened when the remoulded specimen is employed, the test's results are less significant. Figures 17 and 18 offer a summary of the comparison of the shear strength characteristics for the undisturbed specimen and the remoulded specimen, respectively.

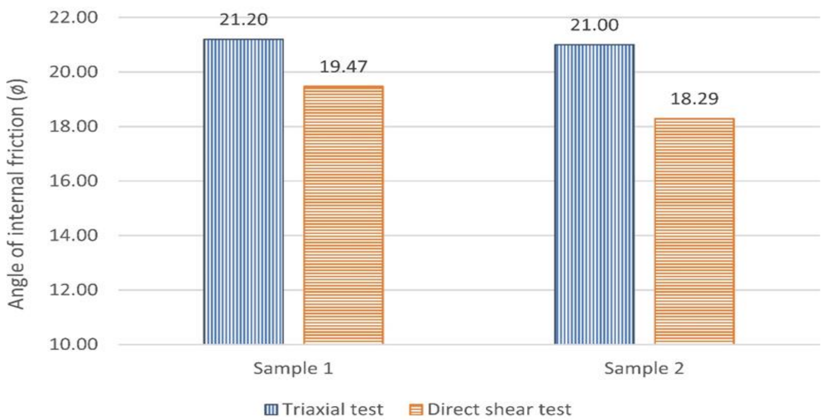

Fig.17:- *Angle of internal friction of soil sample 1 and 2 obtained from direct shear test and triaxial test from the undisturbed specimen*

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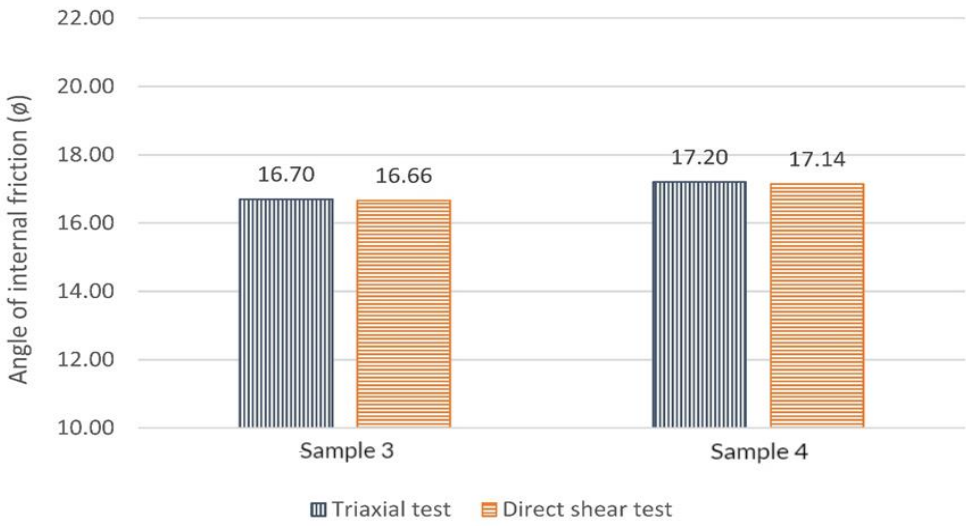

Fig.18:- *Angle of internal friction of soil sample 3 and 4 obtained from direct shear test and triaxial test from the remolded specimen*

The anisotropy of clay theory can be used to better explain this phenomenon. The clay particles orient perpendicular to the direction of the main primary stress as a result of consolidation, which is predominantly induced by anisotropy in cohesive soils. The parallel arrangement of the clay particles results in directional differences in clay strength. Remoulding eliminates the anisotropic condition, which reduces a significant disparity in the outcomes. However, the skill of the individual doing the operation will determine how accurately the specimen is remoulded.

Overall, the findings will be lower than the initial value when we test alluvial soil using a direct shear test in an undisturbed environment. Thus, it is preferable to do the triaxial test. The outcomes of the direct and triaxial tests performed on the remoulded specimen are comparable.

CONCLUSIONS

The goal of the study is to conduct an experimental analysis of the shear strength test findings of alluvial soil under direct shear test and triaxial test on undisturbed and remoulded specimens. Although the research is not focused on the link between internal friction and plasticity index, the observed findings of the direct shear test and triaxial test demonstrate a rise in the internal friction angle's values with an increase in plasticity index. The internal friction angle in the direct shear test is 1.73 to 2.71 lower than the internal friction angle discovered via triaxial testing on the undisturbed material. The triaxial test's angle of internal friction is larger than the direct shear test when tests are performed on remoulded specimens.

Due to the design of the direct shear box, the plane of failure in direct shear strength is halfway up the height of the soil specimen. The dirt is layered horizontally, and each layer's interface is weaker than the remainder of the plane. The shear strength value is occasionally lower than the triaxial test because the failure plane occasionally coincides with the layers interface.

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There is no possibility of such an occurrence during the triaxial test. Since the triaxial specimen's failure plane is not specified, it is not expected that the specimen's horizontal planes of weakness will affect the shear strength measurement. In the triaxial test, the angle of internal friction in the remoulded specimen is larger than the angle in the undisturbed specimen, which corresponds to the direct shear test.

Due to the horizontal stacking having no effect on the shear strength, the change in the angle of internal friction as it relates to triaxial testing is quite little. Remoulding the specimen results in a more uniform and isotropic soil structure. As a consequence, horizontal stacking has no impact on the findings of the direct shear test. When evaluating alluvial soil, the results of a direct shear test conducted in an undisturbed environment will be lower than the initial value. Therefore, it is preferable to adopt for this triaxial test. The direct and triaxial test findings are comparable when utilising the remoulded specimen. So, for this, triaxial testing as well as direct shear testing is possible.

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