SECTION 11

DIRECT SHEAR TEST

References

- ASTM D3080 – 11 – Standard Test Method for Direct Shear Test of Soils under Consolidation Drained Conditions.
- BS 1377: part 7 Soils for Civil Engineering purpose; Shear Strength Tests.
- Lambe, T.W., Soil Testing for Engineers.
- Bowles, Joseph E., Engineering Properties of Soils and Their Measurement (4th Edition)
- ASTM D 6026 - 06 – using Significant Digits in Geotechnical Data

General Discussion

This test is performed to determine the consolidated-drained shear strength of a sandy to silty soil. The shear strength is one of the most important engineering properties of a soil, because it is required whenever a structure is dependent on the soil's shearing resistance. The shear strength is needed for engineering situations such as determining the stability of slopes or cuts, finding the bearing capacity for foundations, and calculating the pressure exerted by a soil on a retaining wall.

The direct shear test is a strain-controlled test - the rate at which the soil will be strained is controlled. A specimen of soil will be placed into a *shear box*, and consolidated under an applied normal load. The shear box is made of two separate halves - an upper and a lower. After the application of the normal load, these two halves are moved relative to one another, shearing the soil specimen on the plane that is the separation of the two halves. The direct-shear test imposes stress conditions on the soil that force the failure plane to occur at a predetermined location (on the plane that separates the two halves of the box). On this plane there are two forces (or stresses) acting - a normal stress, σ_n, due to an applied vertical load P_v and a shearing stress, τ, due to the applied horizontal load P_h. These stresses are simply computed as:

$$\sigma_n = P_v/A$$

$$\tau = P_h/A$$

where A is the nominal area of the specimen (or of the shear box).

It is usually not corrected for the change in sample area caused by the lateral displacement of the sample under the shear load P_h. These stresses should satisfy Coulomb's equation:

$$\tau = c + \sigma_n \tan \varphi$$

As there are two unknown quantities (c and φ) in the above equation, two values, as a minimum, of normal stress and shear stress will be required to obtain a solution.

Since the shear stress and normal stress have the same significance as when used in a Mohr's circle construction, rather than solving a series of simultaneous equations for c and tan φ, one may plot on a set of coordinate axes the values of t versus σ_n from several tests (generally with τ on the ordinate), draw a line through the resulting locus of points, or the average locus of points, and establish the slope of the line as tan φ and the τ-axis intercept as the c parameter. This is commonly known as the *Mohr-Coulomb Failure Envelope*. For cohesion less soils, the intercept is usually negligible, and Coulomb's equation becomes

$$\tau = \sigma_n \tan\varphi$$

Test inaccuracies and surface-tension effects of damp cohesionless materials may give a small value of c, called the "apparent" cohesion. This should be neglected unless it is more than 1 or 2 psi. If the c value is large and the soil is a cohesionless material, the reason for the large value should be investigated.

The direct shear test was formerly quite popular, but with the development of the tri axial test which is much more flexible, it has become less popular in recent years. The advantages of the direct shear test are:

a. Cheap, fast and simple - especially for sands.
b. Failure occurs along a single surface, which approximates observed slips or shear type failures in natural soils.

Disadvantages of the test include:

a. Difficult or impossible to control drainage, especially for fine-grained soils.
b. Failure plane is forced--may not be the weakest or most critical plane in the field
c. Non-uniform stress conditions exist in the specimen.
d. The principal stresses rotate during shear, and the rotation cannot be controlled.

Principal stresses are not directly measured. Because the drainage conditions during all stages of the test markedly influence the shear strength of soils, the direct shear test is only applicable for relatively clean sands which are free draining during shear. For clay soils, some unknown amount of consolidation could occur during shear, which would give a larger shear strength than actual. Therefore the test is not generally recommended for cohesive soils.

Equipment

Special – Digital Direct Shear Machine The shear machine is designed to operate with lever arm assembly arranged to multiply a given normal load by 10.i.e. 1 kg on the load hanger applies a load of 10 kg to the sample. The lever arm should be balanced in the horizontal position by adjusting the position of the balance weight on the arm.

Figure 11-1 showing the machine used for direct shear test. The main components of this machine are as following:

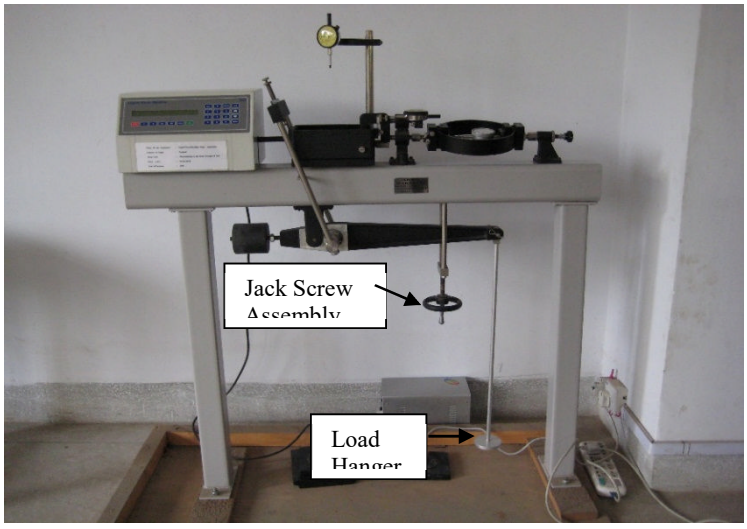


Figure 11-1: Digital Direct Shear Machine

a. **Shear Box**. Shear box is manufactured throughout in non ferrous metal. A range of shear boxes are available to suit the specimens of various sizes. It has two main part, upper and lower shear box, which slide over one another due to application of horizontal force. The floor of the box has retches for ease of drainage – it is lower pressure pad. The sample is placed within the box covered by upper and lower porous plates for draining out of water. At the top, upper pressure pad is placed. Figure 11-2 and 11-3 show shear box and its components

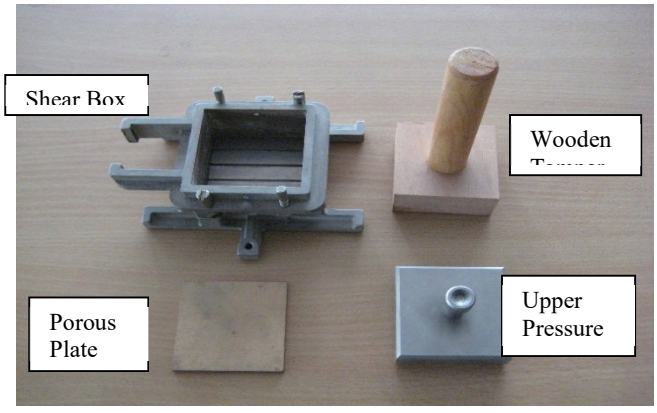


Figure 11-2: Components of Shear Box.

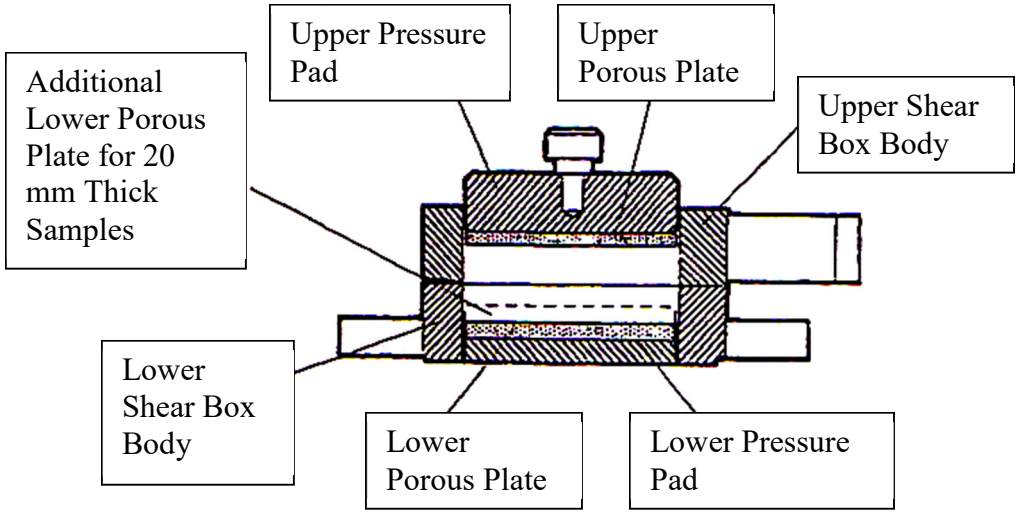


Figure 11-3: Schematic Diagram of Shear Box.

b. **Dial Gauges** There are three dial gauges fitted with the machine for taking various readings. Vertical dial gauge is attached directly to the up stand arm and shows the vertical displacement due to shearing. This reading indicates the volume change of sample due to application of stress. Horizontal dial gauge displays the displacement in sample due to shearing. This reading is used to measure the strain in the sample. Proving ring dial gauge displays the displacement in proving ring due to application of horizontal force. This reading is multiplied by a factor to determine the applied load. Figures 11-4 and 11-5 show different types of dial gauges.

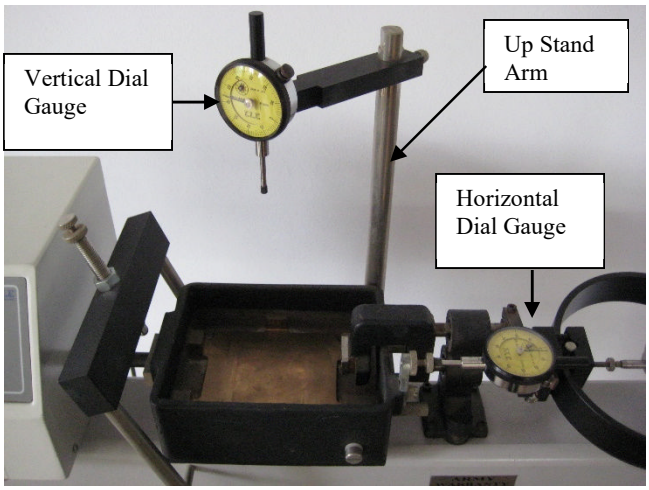


Figure 11-4: Vertical and Horizontal Dial Gauge.

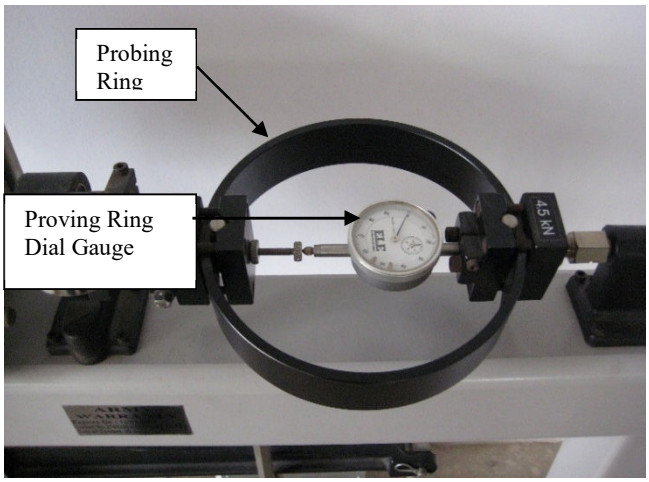


Figure 11-5: Probing Ring Dial Gauge.

c. **Shear Apparatus** It is a digital machine fitted with motor to control the strain. Figure 11-6 shows the apparatus.



Figure 11-6: Digital Shear Apparatus.

General.

- Tamper for compacting soil
- Balance (0.1 g sensitivity)
- Drying oven
- Calipers
- Straight edge
- Large evaporating dish
- Spoons, etc.
- Timer

Test Procedure.

First It must be needed to be familiar with the apparatus including the direction of travel of all parts of the apparatus, electric motor (on/off switch, forward/reverse, speed) etc. One can take help from laboratory technicians. First time users should also know - how to apply normal loads, function of each screw in the shear box, measurement of the dial indicators including the units. After that the following procedure should be continued:

a. The volume of the specimen to be constructed should be determined. The cross-sectional area of the interior of the shear box should be measured. The depth of the shear box should be measured. The thickness of the bottom frictional plate and the top porous stone should be determined.

b. When the specimen is setup, the top of the porous stone should be flush with the top of the shear box. Knowing this, and with the above dimensions measured, the volume of the prepared specimen may be calculated.

c. Knowing the density desired and the volume of the specimen, the mass of sand required to set up the specimen can be calculated. The required mass of the sample should be obtained.

d. **Setting up the Specimen**.

(1) The shear box should be placed in the direct shear device. It should be made sure the fixing screws (screws that locks the shear box together) are locked in place and the set screws (screws that adjust the gap space between the shear box halves) are at the bottom of their travel.

(2) The bottom frictional plate should be placed into the bottom of the shear box with the rough side up. The lower porous stone and a filter paper above it should be placed. See Figure 11-7.

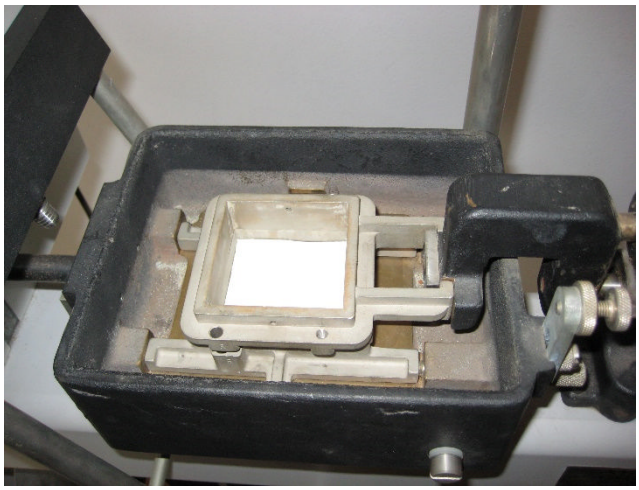


Figure 11-7: Placement of Lower Porous Plate and Filter Paper.

(3) The cutter above the soil sample should be placed and with a push; the cutter into the soil should be inserted to collect the specimen. In case of sandy sample, the sand should be poured in rather loosely.

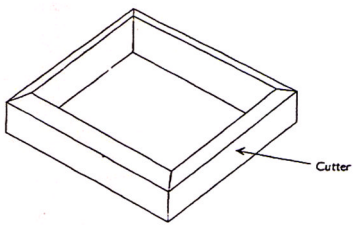


Figure 11-8: Cutter for Sample

(4) The cutter filled sample on the shear box should be placed and with the help of wooden tamper, the sample into the shear box should be inserted. See Figures 11-9 and 11-10 for the schematic diagram and placement of sample into the shear box.

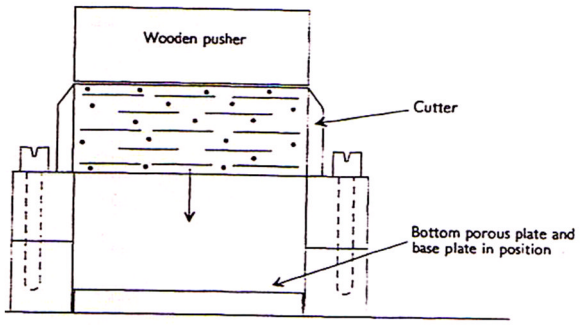


Figure 11-9: Schematic Diagram of Placement of Sample into the

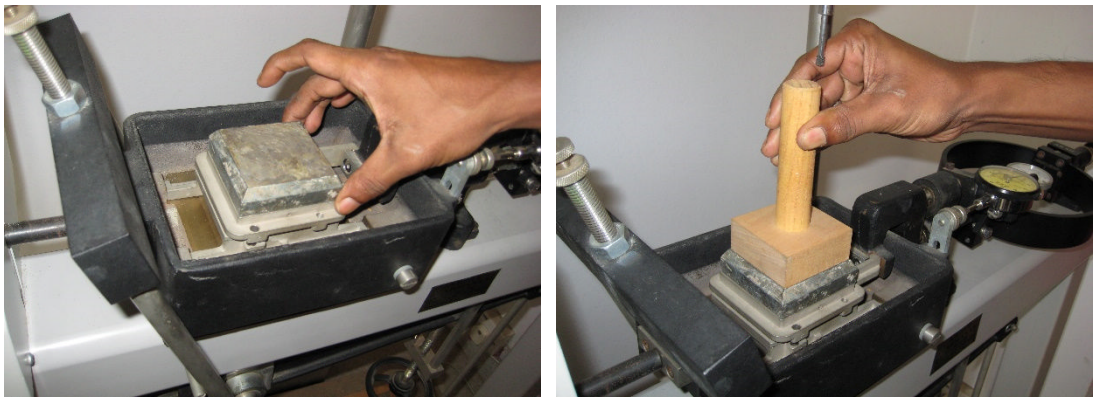


Figure 11-10: Placement of Sample into the Shear Box.



Figure 11-11: Placement of Sample is Completed and Cutter Removed.

(5) A filter paper on the top of the sample and the upper porous stone above it should be placed. It should be sticking up out of the shear box at this point, see Figure 11-12.

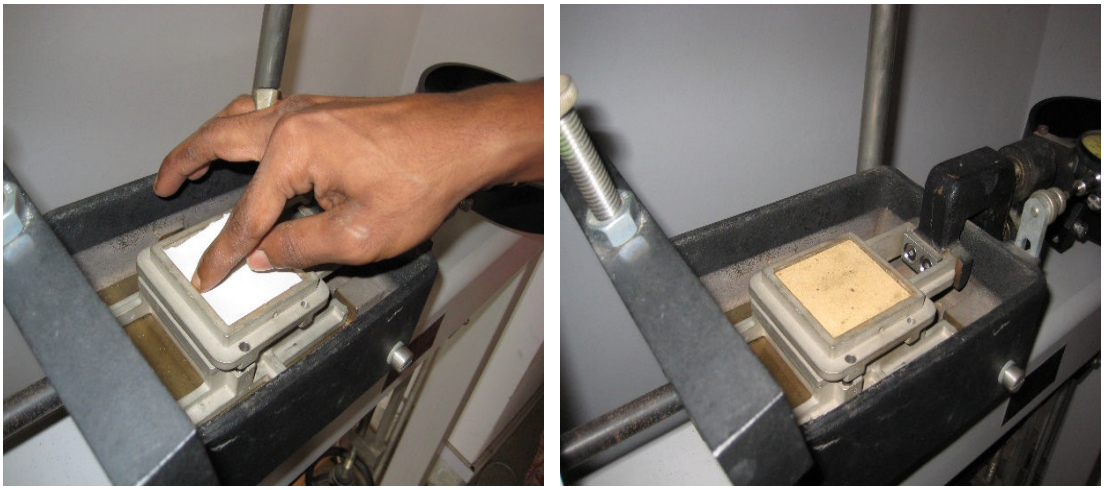


Figure 11-12: Placement of Filter Paper and Upper Porous Plate.

(6) The loading cap and ball bearing should be placed on top of the porous stone. The reaction bar of the loading frame should be lowered until it just touches the ball bearing. The nuts should be used to lock the reaction bar into place. Finally, the fixing screws should be removed. See Figure 11-13.



Figure 11-13: Placement of Loading Cap and Ball Bearing.

e. The extensometers should be attached which measure shear and normal displacements. The dial should be adjusted which measures normal displacement to read either expansions or contractions. The initial readings should be recorded on all dials. Before proceeding with the test, It should be checked carefully to see that there is no connection between the two parts of the soil container except the soil.

f. The new vertical displacement dial reading should be recorded. It will have moved, and the specimen will thus have densified. This combined with the initial dial reading that already obtained will allow to calculate the actual density of the specimen (it will be slightly denser than planned).

g. The desired normal load should be applied. In direct shear test, the test procedure is repeated using at least three identical specimens with variable normal stresses. It is sometimes convenient to interpret the results, if the normal stresses are so chosen one is closer to the existing overburden and one of each of the other two on the either side of the overburden.

(1) The normal stress required on the specimen must be related to a mass comprising the load yoke and set weights W.

(2) $W=(\sigma_n * L^2/9810)$kg, Where L represents length of box in mm and σ_n stress kN/m^2.

(3) The shear machine is fitted with a balanced lever loading device, fine adjustment of which is achieved by the balance weight.

(4) The initial position of lever loading device and hence loading yoke can be achieved by adjusting the jacking handle and load pin.

(5) To apply the load to the sample the weights may either be added to the weight hanger with the jacking handle fully down, or with the jacking handle supporting the lever loading arm then slowing winding the jacking handle down to transfer the load to the sample.

h. **Pre-Test Check**.

(1) Ring of required capacity/sensitivity should be loaded and should be set correctly.

(2) The 'train' of components are all in contact from load ring adjuster to strain lead screw.

(3) Shear box is set tight in carriage.

(4) Loading yoke correctly positioned with vertical displacement measuring device set.

(5) Alignment screws are removed. Shear box separator screws screwed in to just lift the upper box away from the lower box then retracted.

(6) Strain rate is set (0.00001 to 9.99999 mm/min).

i. **Shearing the Specimen**.

(1) The horizontal (shear) loading should be started and readings of the load, shear displacement, and vertical displacement dials should be taken. Readings should be taken every 0.01 inches of shear (horizontal) deflection—this corresponds to every 10 units on the dial.

(2) For a strain- controlled test, a set of readings should be taken every 15 seconds for the first 2 minutes, and then a set every 0.03 in. of horizontal displacement. The test should be continued to a horizontal displacement of approximately 15 % of the length of the specimen unless a constant shear force is obtained first.

(3) For a stress- controlled test a set of readings should be taken before each new load is added. The test should be continued to failure.

(4) The shearing is complete when load is determined to be dropping (the residual strength of the soil has been reached).

j. The applied normal pressure should be backed off, dismantled and the shear box should be cleaned.

Data Analysis

1. The shear stress can be computed as $\tau = Ph / A$, where P_h is the horizontal load and A is the area of specimen in the shear box.
2. The normal stress can be computed as $\sigma n = Pv / A$, P_v is the vertical load.
3. The angle of internal friction, φ, can be computed from

$$\varphi = \tan^{-1}\frac{\tau}{\sigma}$$

where,

τ = shear stress = {(Proving ring reading - initial proving ring reading) × ring calibration factor}/ area

σ = normal stress = Normal force / area.

However, since τ/σ is a ratio of stresses on the same surface, it can be determined by dividing the shear force by the normal force.

Results

Method of Presentation.

a. The results of a direct shear test on a cohesionless/cohesive soil can be presented in a summary table and/or by a stress-strain curve (or stress ratio-strain curve).

b. A stress- strain curve usually consists of a plot of τ/σ and normal displacement versus shear displacement. The two plots should be on the same page using the same scale of shear displacement.

A stress- strain curve usually consists of a plot of shear stress versus shear displacement (cohesive soil).

c. Normal stress and peak/maximum shear stress thus estimated and plotted in a peak shear stress-normal stress curve. A best possible straight line is fitted to the observed point to represent the failure envelope. The shear strength parameters c and φ is thus obtained from the plot. It is to be noted that usually we get the drained strength parameters from direct shear test. For granular soil as the cohesion is zero and the available strength parameter would be only φ. At least three test are carried out at different normal stresses and a straight line passing through origin and the respective points defines the failure envelope for sand soil (as c=0). The slope of the line gives the value of φ.

Significant Figures

1. The angle of shear resistance should be expressed to the nearest 0.1.
2. The axial strain should be expressed to 3 significant digits.
3. The value of stress or pressure should be expressed to 3 significant digits

Typical Values

1. Peak friction angles in dense, well- graded, coarse sand usually range from 37º to 60º for dense, uniform, fine sand they are usually between 33º and 45º.
2. There is less variation in the values of ultimate friction angle; a typical value is 30º.
3. The volume changes that occur during shear depend too much on the initial void ratio to give any typical values. Normally, only the loosest of sands tend to show a net negative volume change, or contraction, at failure.

Table 11-1: Typical Values of Effective Angle of Friction for Granular Soil (After Terzaghi and Peck, 1967)

Soil type	**Effective angle of internal friction, φ (Degrees)**	
	Loose	**Dense**
Nonplastic silt	27-30	30-34
Silty sand	27-33	30-35
Uniform sand	28	34
Well graded sand	33	45
Sandy gravel	35	50

WORKED OUT EXAMPLE

Direct Shear Test

Test Serial No. : 11

Date Tested: October 15, 2008

Tested By:

Project Name: Airport Road – Rokeya Sharoni Link Road Project

Sample Number: U-1, 3.0 m

Visual Classification of Soil: Gray silty clay, trace fine sand, low plasticity, moist, CL

Initial Data

Shear Box Length = 60 mm

Shear Box Width = 60 mm

Shear Box Area = 60 x 60 = 3600 mm^2

For Normal Stress, σ_1 = 0.0028 Kg/mm² (Load on hanger= 1 Kg)

(Shear and Normal Displacement Dial: 1 unit = 0.01 mm and Proving Ring Dial: 1 unit = 0.31 Kg)

Elapsed Time (sec)	Shear Displacement Dial Reading	Shear Displacement (mm)	Normal Displacement Dial Reading	Normal Displacement (mm)	Proving Ring Dial Reading	Shear Force (Kg)	Shear Stress (Kg/mm)
0	0	0	0	0	0	0	0
15	48	0.48	-8	-0.08	31	9.61	0.0027
30	98	0.98	-6	-0.06	45	13.95	0.0038
45	142	1.42	-3	-0.03	55	17.05	0.0047
60	205	2.05	4	0.04	62	19.22	0.0053
75	266	2.66	8	0.08	66	20.46	0.0057
90	330	3.30	15	0.15	67.5	20.92	0.0058
105	389	3.89	22	0.22	69.5	21.55	0.006
120	453	4.53	28	0.28	72	22.32	0.0062
135	513	5.13	32	0.32	73	22.63	0.0063
150	579	5.79	36	0.36	73.5	22.78	0.0063
165	638	6.38	38	0.38	73.5	22.78	0.0063
180	740	7.40	41	0.41	72	22.32	0.0062
195	770	7.70	44	0.44	68	21.08	0.0059

Sample Calculations (For last data)

Shear displacement = Shear displacement dial reading x 0.01

= 770 x 0.01 = 7.70 mm

Normal displacement = Normal displacement dial reading x 0.01

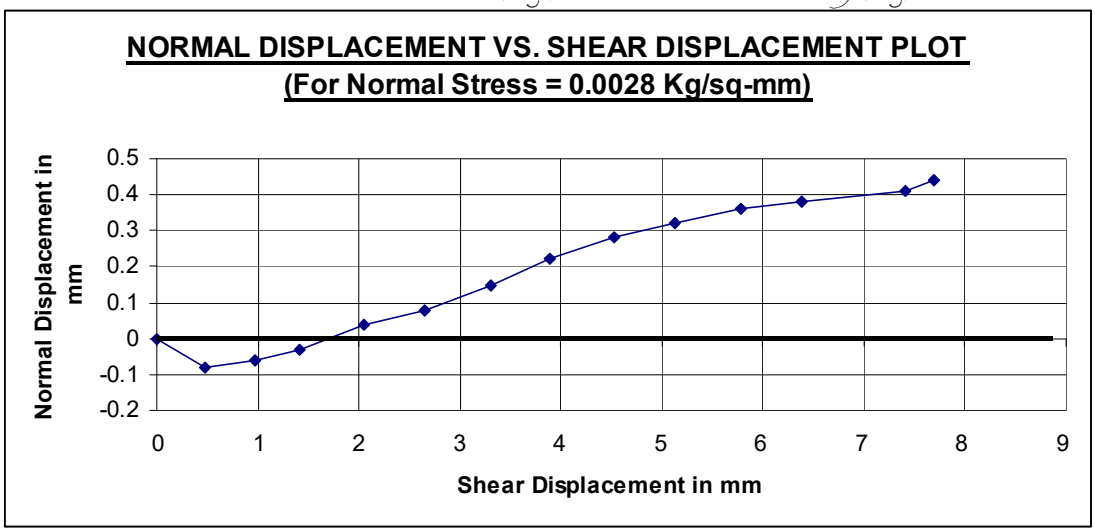
= 44 x 0.01 = 0.44 mm

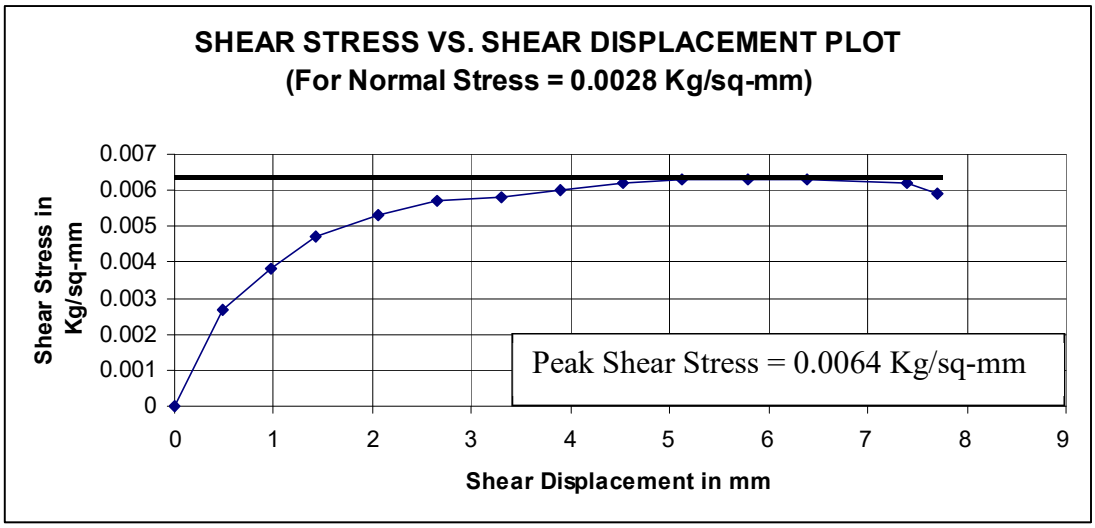
Shear force = Proving dial reading x 0.31 (load factor)

= 68 x 0.31 = 21.08 Kg

Shear stress = Shear force / sample area

= 21.08 Kg / 3600 mm^2 = 0.0059 Kg/mm^2

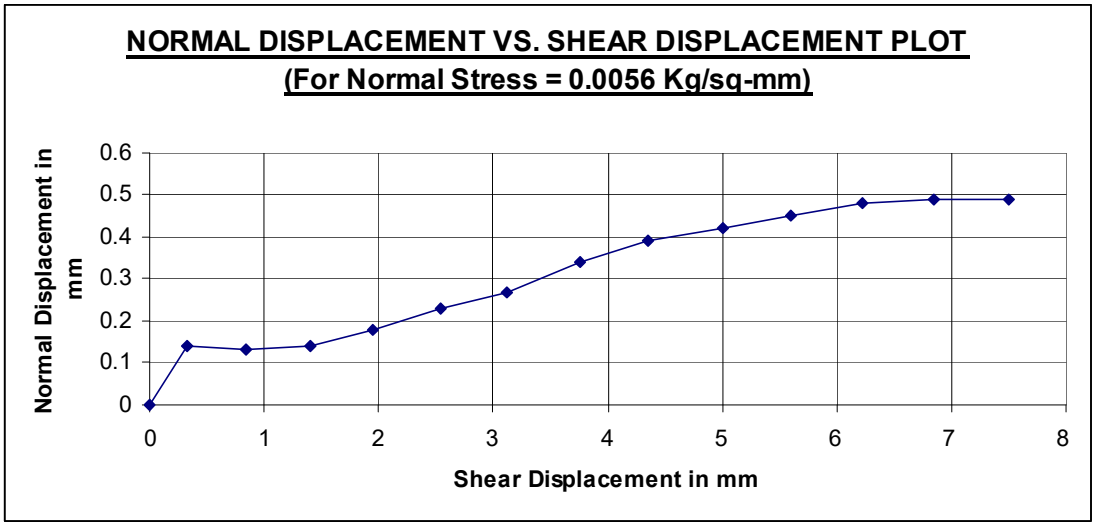


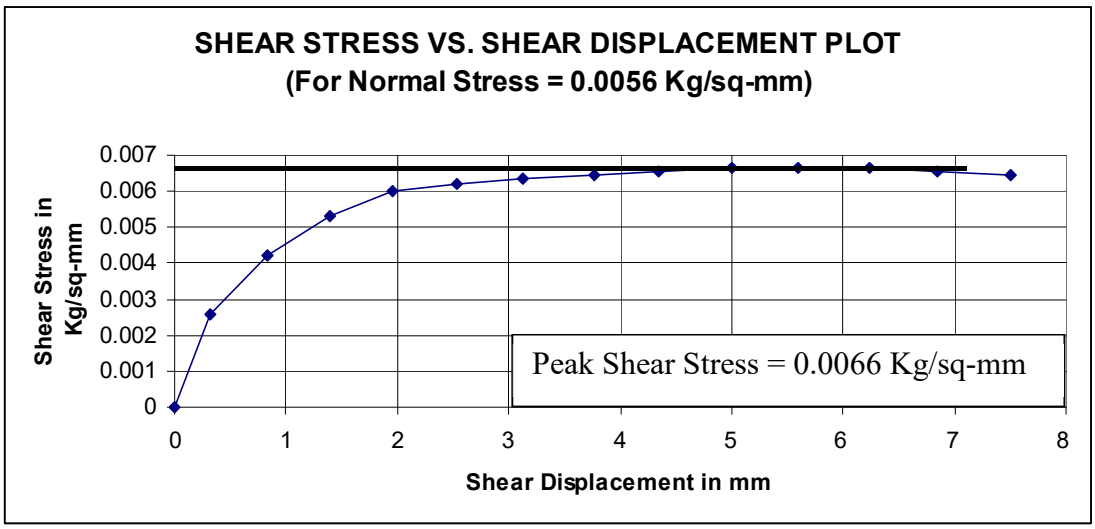


For Normal Stress, σ_2 = 0.0056 Kg/mm² (Load on hanger= 2 Kg)

(Shear and Normal Displacement Dial: 1 unit = 0.01 mm and Proving Ring Dial: 1 unit = 0.31 Kg)

Elapsed Time (sec)	Shear Displacement Dial Reading	Shear Displacement (mm)	Normal Displacement Dial Reading	Normal Displacement (mm)	Proving Ring Dial Reading	Shear Force (Kg)	Shear Stress (Kg/mm)
0	0	0	0	0	0	0	0
15	32	0.32	14	0.14	30	9.3	0.00258
30	84	0.84	13	0.13	49	15.19	0.00422
45	140	1.40	14	0.14	61.5	19.065	0.0053
60	195	1.95	18	0.18	70	21.7	0.00603
75	254	2.54	23	0.23	72	22.32	0.0062
90	312	3.12	27	0.27	74	22.94	0.00637
105	376	3.76	34	0.34	75	23.25	0.00646
120	435	4.35	39	0.39	76	23.56	0.00654
135	500	5.00	42	0.42	77	23.87	0.00663
150	560	5.60	45	0.45	77	23.87	0.00663
165	623	6.23	48	0.48	77	23.87	0.00663
180	684	6.84	49	0.49	76	23.56	0.00654
195	750	7.50	49	0.49	75	23.25	0.00646

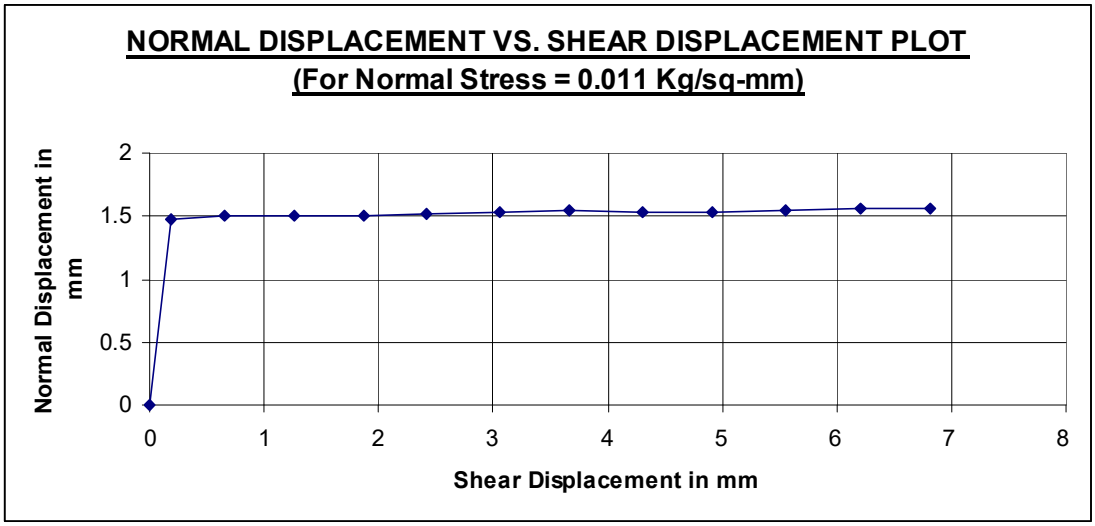

NORMAL DISPLACEMENT VS. SHEAR DISPLACEMENT PLOT
(For Normal Stress = 0.0056 Kg/sq-mm)
Normal Displacement in mm
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
Shear Displacement in mm

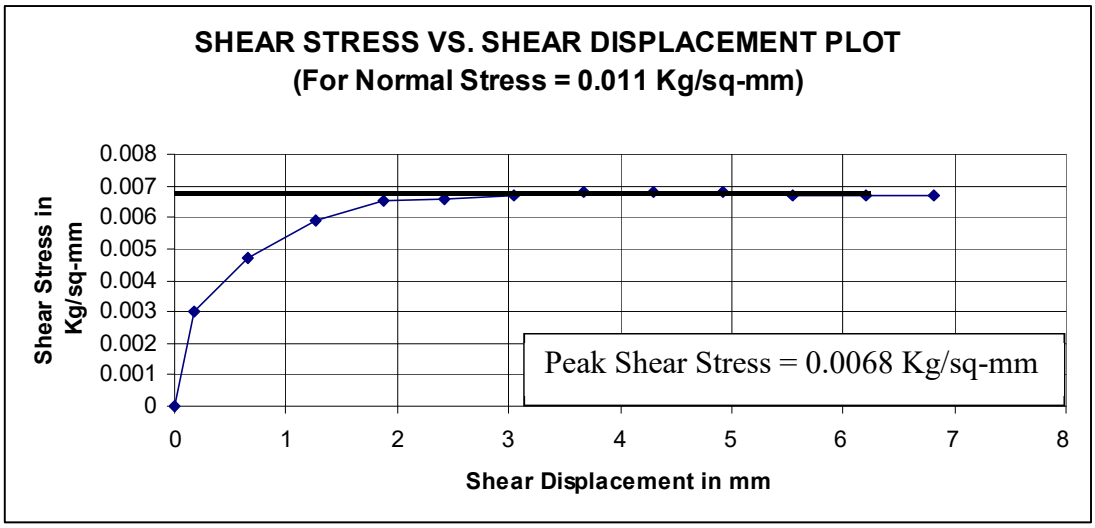

SHEAR STRESS VS. SHEAR DISPLACEMENT PLOT
(For Normal Stress = 0.0056 Kg/sq-mm)
Shear Stress in Kg/sq-mm
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
0
1
2
3
4
5
6
7
8
Peak Shear Stress = 0.0066 Kg/sq-mm
Shear Displacement in mm

For Normal Stress, σ_3 = 0.011 Kg/mm² (Load on hanger= 4 Kg)

(Shear and Normal Displacement Dial: 1 unit = 0.01 mm and Proving Ring Dial: 1 unit = 0.31 Kg)

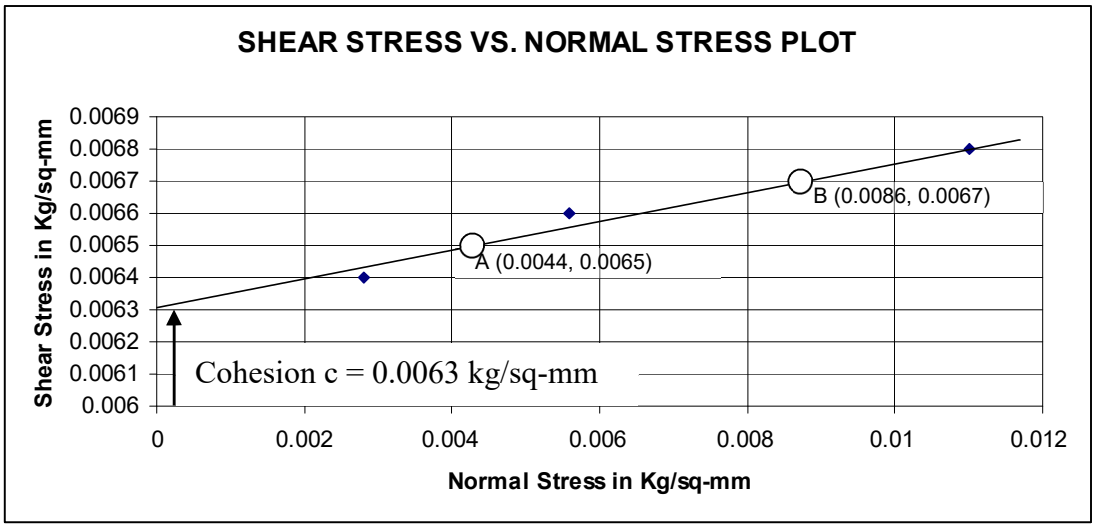
Elapsed Time (sec)	Shear Displacement Dial Reading	Shear Displacement (mm)	Normal Displacement Dial Reading	Normal Displacement (mm)	Proving Ring Dial Reading	Shear Force (Kg)	Shear Stress (Kg/mm)
0	0	0	0	0	0	0	0
15	18	0.18	148	1.48	35	10.85	0.003
30	65	0.65	150	1.50	55	17.05	0.0047
45	127	1.27	150.5	1.505	69	21.39	0.0059
60	187	1.87	151	1.51	76	23.56	0.0065
75	242	2.42	151.5	1.515	77	23.87	0.0066
90	305	3.05	153	1.53	78	24.18	0.0067
105	367	3.67	154	1.54	78.5	24.335	0.0068
120	430	4.30	152.5	1.525	78.5	24.335	0.0068
135	492	4.92	153	1.53	78.5	24.335	0.0068
150	555	5.55	154	1.54	78	24.18	0.0067
165	620	6.20	155.5	1.555	78	24.18	0.0067
180	682	6.82	156	1.56	78	24.18	0.0067





At different applied normal stress corresponding peak or maximum shear stress are:

Observation	Normal Stress in kg/mm^2	Shear Stress in kg/mm^2
1.	0.0028	0.0064
2.	0.0056	0.0066
3.	0.011	0.0068



RESULT

From graph,

Cohesion c of the soil sample = 0.0063 kg/sq-mm

Again, taking two points on the line A (0.0044, 0.0065) and B (0.0086, 0.0067), the slope angle of the line or angle of internal friction,

$$\begin{aligned}\phi &= \tan^{-1}\left(\frac{0.0067-0.0065}{0.0086-0.0044}\right)\\ &= \tan^{-1}\left(\frac{0.0002}{0.0042}\right)\\ &= 2.73^0\end{aligned}$$

Comment

The determined value of angle of internal friction φ is very less than expected.

Most probably, the readings of third observation are misleading.