SHEAR STRENGTH CHARACTERISTICS OF A ROCKFILL MATERIAL

Brijesh Kumar¹, Nitish Puri², Saurabh Jaglan³

¹(Associate Professor, Department of Civil Engineering, SIET, Ambala, Haryana, India)
²(Research Scholar, Department of Civil Engineering, NIT, Kurukshetra, Haryana, India)
³(Assistant Professor, Department of Civil Engineering, GGGI, Ambala, Haryana, India)

ABSTRACT

In last five decades, direct shear test has emerged out as an effective method for determining shear strength of soils and various other materials, because of its simplicity and reliable results. It is a common practice to perform direct shear box tests on granular soils to determine the shear strength for engineering purposes. However, same shear box cannot be used for all types of materials, as particle size of rockfill varies from very small (less than equal to 4.75 mm) to very large (more than 4.75 mm). Hence larger particles are tested in moderate or large shear boxes. The shear strength is required whenever a structure’s stability and serviceability is dependent upon shearing resistance of soils. The shear strength is required for various engineering purposes such as determination of stability of slopes or cuts, bearing capacity calculations for foundations and for the calculation of earth pressure exerted by a soil on a retaining structure. A moderate sized direct shear box test was used to determine the shear strength characteristics of Beas river rockfill of varying sizes. Shear stress, void ratio, angle of shearing resistance (Φ) and shear strength over the range of normal pressure varying from 1.0 to 2.0 kg/cm² for various grain sizes of rockfill were determined. It has been observed that the angle of shearing resistance increases with decrease in particle size at a particular void ratio. However, a general decrease in shear stress is observed with increasing values of grain size.

Keywords: Direct shear test, Grain size, Shear box, Shearing resistance, Void ratio.

1. INTRODUCTION

Direct shear test is a standard method for determining shear strength characteristics of soils of almost all sizes. It is possible to test soil samples with large grain sizes (>4.75 mm), which is an important advantage of this test. Methods for carrying out direct shear tests for geotechnical engineering purposes are well established in practice [14]. Shear strength parameters are used in design of earthen dams and embankments, calculation of bearing capacity of soil-foundation
systems, estimation of earth pressure behind the retaining walls and to check the stability of natural slopes, cuts and fills. Shear strength of soil has its maximum resistance to shearing stress at failure on the failure envelope. Shear strength is composed of two parameters, firstly, angle internal friction ($\Phi$) which is the resistance due to friction between individual particles at their contact points and interlocking of particles and second, is cohesion ($C$) which is resistance due to inter-particle forces which tend to hold the particles together in a soil mass. The second parameter is almost negligible when coarse grained particles are concerned [11].

The relation of these two parameters ($C$, $\Phi$) with shear strength ($\tau$) of soil has been given by equation 1 proposed by Coulomb:

$$\tau = C + \sigma \tan \Phi$$

For coarser materials the cohesion between particles is almost zero so equation 1 will change to equation 2 shown below:

$$\tau = \sigma \tan \Phi$$

A few decades back, direct shear tests were only carried out for finer particles (< 4.75 mm) due to unavailability of bigger shear boxes. But in the present scenario, with advancement in technology and vision things have become possible. Now a day’s larger shear boxes are available and can be incorporated in determining shear characteristics of larger grain sizes of specimens. Also engineering properties of coarser material have to be investigated as these materials are being used in railway tracks, earth dams, earth canal embankments, earth canal lining and pavement construction. It is a common practice to use gravelly soils if locally available because of their high stability and strength characteristics. A series of direct shear tests was conducted in order to determine shear strength characteristics of rockfill with respect to variation in these two parameters:

1. Void ratio
2. Average particle size

These parameters are of great importance to highway engineers and geotechnical engineers involved in construction of various earth and earth retaining structures.

2. MATERIALS & METHODOLOGY

2.1 Rockfill material

The rounded, sub angular, angular crushed and coarse grained rockfill from the banks of Beas River were used as the base materials in the tests. Rockfill was collected from Bharat Stone Crushing Co, Stone Crushers and Stone Metal Suppliers, Dalhousie Road, Pathankot-145001. They are available on the basis of size and shape. The material is classified as GW (well graded gravels) and grayish in colour as per the specifications of IS codes. The specific gravity of Beas river rockfill was calculated and found to be 2.67. The absorption value for the rockfill has been observed as 1.84%. Brazilian test was performed in order to determine tensile strength of rockfill, it was found to be 16.77 kg/cm$^2$. This ensures that specimen is medium strong and can resist normal wear and tear. Various types of rockfill materials collected are tabulated below in Table1.
Table 1. Particle sizes of various rockfill

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Type of Rockfill</th>
<th>Size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Rounded Beas River Rockfill</td>
<td>10 – 12.5</td>
</tr>
<tr>
<td>2.</td>
<td>Sub angular crushed Beas Rockfill</td>
<td>6.3 - 10</td>
</tr>
<tr>
<td>3.</td>
<td>Angular Crushed Beas Rockfill</td>
<td>(a) 4.75 - 6.3, (b) 2.36 - 6.3</td>
</tr>
<tr>
<td>4.</td>
<td>Coarse Grained Beas Rockfill</td>
<td>1 - 2.36</td>
</tr>
</tbody>
</table>

2.2. Test Apparatus

Direct Box shear tests have been performed on rounded and crushed rockfill of different size. The natural river rockfill were rounded or sub rounded whereas the crushed rockfill were angular or sub angular in shape. The shear box used for the testing had the internal dimensions 30 x 30 x 12 cm, made of thick steel plates to hold the sample. The moderate sized shear box is ideal for testing geosynthetics and also soil and other materials that contain large particles of up to 20 mm. The sample is consolidated by the application of the vertical load. The horizontal displacement is driven by a high resolution stepper motor. The machine is entirely managed manually and the technical assistant reads the processes of force, axial pressure and displacements, manages the motor, the vertical hydraulic loading system. Using a large sample is possible to gain a more representative indication of shear strength. Furthermore, the large shear box can be used to obtain the angle of friction between many materials. Particular applications include the construction of earth dams and other embankment work. The machine includes 100 kN load cell, three dial gauges, mounting brackets and shear box.

![Fig.1. Direct shear test apparatus with moderate sized shear box](image)

2.3 Methodology

The test is carried out on a soil sample confined in a metal box of square cross-section which is split horizontally at mid-height. A small clearance is maintained between the two halves of the box. The soil is sheared along a predetermined plane by moving the top half of the box relative to the bottom half. A typical shear box is shown below:
If the soil sample is fully or partially saturated, perforated metal plates and porous stones are placed below and above the sample to allow free drainage. If the sample is dry, solid metal plates are used. A load normal to the plane of shearing can be applied to the soil sample through the lid of the box. Tests on sands and rockfill can be performed quickly, and are usually performed dry as it is found that water does not significantly affect the drained strength. For clays, the rate of shearing must be chosen to prevent excess pore pressures building up. As a vertical normal load is applied to the sample, shear stress is gradually applied horizontally, by causing the two halves of the box to move relative to each other. The shear load is measured together with the corresponding shear displacement. The change of thickness of the sample is also measured. A number of samples of the soil are tested each under different vertical loads and the value of shear stress at failure is plotted against the normal stress for each test. Provided there is no excess pore water pressure in the soil, the total and effective stresses will be identical. From the stresses at failure, the failure envelope can be obtained. The above explained methodology is as per the specifications of ASTM: D3080-98 and IS. 2720 (Part XIII), (1986) [1][3]. The main advantage of this test is that it is easy to test sands and rockfill. Large samples can be tested in large shear boxes, as small samples can give misleading results due to imperfections such as fractures and fissures, or may not be truly representative. Also samples can be sheared along predetermined planes, when the shear strength along fissures or other selected planes are needed [15].

There are some disadvantages as well and the major demerit is that the failure plane is always horizontal in the test, and this may not be the weakest plane in the sample. Failure of the soil occurs progressively from the edges towards the centre of the sample. Also, there is no provision for measuring pore water pressure in the shear box and so it is not possible to determine effective stresses from undrained tests. Moreover, the shear box apparatus cannot give reliable undrained strengths because it is impossible to prevent localised drainage away from the shear plane [13].

3. EXPERIMENTAL INVESTIGATIONS

A series of tests were conducted on rockfill and the samples were subjected to normal stresses ranging from about 1.0 Kg/cm² to 2.0 Kg/cm². The shear strength values corresponding to different normal loads for Beas river rockfill are presented in Table.2 below.
### Table 2. Strength characteristics of various rockfill

<table>
<thead>
<tr>
<th>Type of Particles</th>
<th>Particle size (in mm)</th>
<th>Shear force at Failure (Kg)</th>
<th>Normal stress (Kg/cm²)</th>
<th>Shear stress at failure (Kg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rounded rockfill</td>
<td>10 – 12.5</td>
<td>882</td>
<td>1.0</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1285</td>
<td>1.5</td>
<td>1.428</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1836</td>
<td>2.0</td>
<td>2.04</td>
</tr>
<tr>
<td>Sub Angular Crushed Gravel</td>
<td>6.3 - 10</td>
<td>975</td>
<td>1.0</td>
<td>1.083</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1489</td>
<td>1.5</td>
<td>1.654</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1840</td>
<td>2.0</td>
<td>2.044</td>
</tr>
<tr>
<td>Angular Crushed Gravel</td>
<td>4.75-6.3</td>
<td>1033</td>
<td>1.0</td>
<td>1.148</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1515</td>
<td>1.5</td>
<td>1.683</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1951</td>
<td>2.0</td>
<td>2.168</td>
</tr>
<tr>
<td>Angular Crushed Gravel</td>
<td>2.3 - 6.3</td>
<td>1080</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1552</td>
<td>1.5</td>
<td>1.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2003</td>
<td>2.0</td>
<td>2.226</td>
</tr>
<tr>
<td>Coarse Grained Gravel</td>
<td>1 – 2.36</td>
<td>1314</td>
<td>1.0</td>
<td>1.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1575</td>
<td>1.5</td>
<td>1.750</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2002</td>
<td>2.0</td>
<td>2.244</td>
</tr>
</tbody>
</table>

The variation of shear stress with normal stress is plotted for various rockfill materials and the results are shown in Fig.3 to Fig.7.

**Fig.3. Variation of shear stress vs. normal stress for rounded river rockfill of size range 10 – 12.5 mm**
Fig. 4. Variation of shear stress vs. normal stress for sub angular crushed river rockfill of size range 6.3 – 10 mm

Fig. 5. Variation of shear stress vs. normal stress for angular crushed river rockfill of size range 4.75 - 6.3 mm
Fig. 6. Variation of shear stress vs. normal stress for angular crushed river rockfill of size range 2.36 - 6.3 mm

Fig. 7. Variation of shear stress vs. normal stress for coarse grained river rockfill of size range 1 - 2.36 mm
The Angle of shearing resistance ($\phi$) corresponding to void ratio was calculated at failure shear stress for Beas river rockfill and are reported in Fig.8 to Fig.12.

**Fig.8. Variation of Angle of Shearing Resistance vs. Void Ratio for rounded river rockfill of size range 10 – 12.5 mm**

**Fig.9. Variation of Angle of Shearing Resistance vs. Void Ratio for sub angular crushed river rockfill of size range 6.3 – 10 mm**
Fig. 10. Variation of Angle of Shearing Resistance vs. Void Ratio for Angular crushed river rockfill of size range 4.75 – 6.3 mm

Fig. 11. Variation of Angle of Shearing Resistance vs. Void Ratio for Angular crushed river rockfill of size range 2.36 – 6.3 mm
4. RESULTS AND DISCUSSIONS

The shear strength of rockfill material depends on shearing resistance offered by its grains due to interparticle friction and locking. It has been observed that the angle of shearing resistance (Φ) increases with decrease in size of shear box. However, size of shear box was not a deciding parameter in our study. But authors suggest this criterion for further research. It also depends on the particle size, gradation of material and the size of shear box used. Following results have been observed in context with:

4.1. Angle of shearing resistance

It has been observed that the angle of shearing resistance increases with decrease in particle size at a particular void ratio. It has been observed that the angle of internal friction reduced from 42.5° to 48.5° with decrease in particle size from 12.5 mm to 1 mm for Beas river rockfill. However, the angle of internal friction decreases with increase in normal stress at a particular void ratio. Also Angle of shearing resistance decreases with increase in void ratio at a particular normal stress. These results are clearly verified in Fig.8 to Fig.12.

4.2 Shear stress

From Fig.3 to Fig.7 it can be observed that shear stress increases with increase in normal stress for a particular grain size. However, a general decrease in shear stress is observed with increasing values of grain size. All the results of this study are in accordance with many other investigators [2][4-9][12].
CONCLUSIONS

Direct shear tests were conducted on rockfill obtained from Beas River, Pathankot over the range of normal stress from 1.0 to 2.0 kg/cm². The following conclusions have been drawn on the basis of test results analyzed:

1. The angle of internal friction reduced from 48.5° to 42.5° with increasing particle sizes of rockfill. Moreover, the current values of $\Phi$ were found suitable for designing rockfill dams (as a slope of 1.4:1 or 1.3:1 can be obtained easily by using these gravels or rockfill).
2. Also an average shear strength 2.0 kg/cm² has been observed, which is quite suitable if gravels are to be used in sub-grade design and construction.
3. Also specific gravity of the rockfill material has been observed to be 2.67 while its absorption limit and tensile strength values are 1.84% (must be less than 2%) and 16.77 kg/cm² respectively. This assures the durability of our rockfill material.

ACKNOWLEDGEMENTS

Authors acknowledge the support provided by Department of Civil Engineering, Shivalik Institute of Engineering and Technology (SIET), Ambala and Department of Civil Engineering, Galaxy Global Group of Institutes (GGGI), Ambala.

REFERENCES

15. Website:– http://nptel.iitm.ac.in/