Physical Filling Shear Box Test

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Abstract: The paper presents the influence of joint infilling clay, using a small direct shear box. The rock mass used in this experiment was Woodkirk Sandstone which is upper coal measure sandstone from Morley, south Leeds. The tests were carried out with fresh, damaged and polished joint blocks, with and without filling material. The ratios of filling thickness to the highest asperity (T/A) are 0.5 and 1 in the tests. The shear box tests were also carried out with two different filling materials, one consisting of fine particles, crush-sieved Woodkirk Sandstone, and the other of coarse particles, mud-produced Woodkirk Sandstone from core-drilling, for the determination of the shear strength of the filling material. The factors affecting the filled joint such as filling thickness, joint surface conditions and the physical properties of the filling material, and the relationship between these factors in the filled joint are reported in this paper. The shear box tests also define the physical shear strength characteristics in clean and filled joints.

Key Words: direct shear box test, filled joint, filling material, shear strength

Introduction

Rock masses usually contain such features as bedding planes, faults, fractures, joints and other mechanical defects which, although formed from a wide range of geological processes, possess the common characteristics of low shear strength, negligible tensile strength and high fluid conductivity compared with the surrounding rock material (Patton (1968), Ladanyi and Archambault (1970) Barton (1974) Goodman (1974)). These features, which do not occur in other materials such as steel or concrete, have a significant influence on the strength and deformability of rock masses in underground structures. Thus the determination of strength and load bearing capacities of discontinuities is essential when an underground structure is designed.

In recognising the central role of discontinuities in rock engineering, there are, however, difficulties in obtaining representative parameter values on an engineering scale due to the anisotropy created by discontinuities. Furthermore if filling material in various thicknesses between the joints’ surfaces exists, the joint behaviour may be more anisotropic. A complete understanding of jointed and infilled rock mass is therefore required for engineering design purposes.

In a geological structure which includes discontinuities and faults filled with weak material, these discontinuities would give rise to critical problems for the stability of an underground structure due to the concentration of stress or deformation. Therefore direct filling shear box tests were carried out for the verification of the filling
mechanism. This paper describes the basic infilled joint mechanism and defines characteristics of infilled material and joint which affect joint mechanism.

**Experiment method**

Jointed blocks, which were 5.6 x 5.6cm, were tested in a direct shear box test under constant normal load. This shear box test was carried out both with and without filling material and under low normal and shear loads because the filling material was squeezed out. The direct shear box apparatus used was a Wykeham Farrance Direct Shear Box. The machine is basically a large version of a conventional direct shear apparatus, and its design was based on the simple principle of applying a shear force at constant rate under constant normal load. A range of simple adjustable clamping devices consisting of two rectangular plates of metal connected by threaded rods was prepared. The thickness of those metal plates was from 16 to 25mm to allow for the variation in thickness of the joint halves or filling material. The plates were firmly positioned against the front and back vertical walls of each joint half.

The shear load was measured up to 1.766kN through a proving ring. Shear load and displacement were monitored by an X-Y plotter through a LVDT for conversion into an analogue signal. Vertical displacement was monitored through a 0.01mm dial gauge resting on the normal load pin.

The shear motions were transmitted by a horizontal shaft powered by an electric motor via a worm and wheel arrangement; the shear force (T) was applied through a proving ring. The sliding table rests on low-friction ball bearings and has a free movement of approximately 30mm. The normal load is applied at the centre of the specimen via a pin directly connected to a vertical hanger. The rate of shearing loading was standardised to approximately 0.82mm/min.

Vertical displacements were recorded at 0.15mm ‘gross’ shear displacement intervals until a constant residual strength had been reached. The ‘gross’ shear displacements were afterwards corrected for proving ring deflection to obtain the true relative displacement between the joint halves. This experimental apparatus is illustrated in Figure-1.

The ratios of filling-thickness to asperity (T/A) in the fresh and the damaged jointed block are 0.5 and 1.0 respectively for the prediction of the influence of the T/A. The filling thickness of the polished jointed block is the same as that of the fresh rock at T/A=1 because there were no asperities in the polished rock. The effective normal stresses applied were 40, 75, 106, 140 and 200kPa. The test programme was as follows:

I. Direct shear tests on the discontinuities without filling to determine their shear strength characteristics.

II. Direct shear tests to determine the strength of the filling material alone.

III. Direct shear tests to determine the shear strength along the interface between the joint surface and the filling material in T/A = 0.5 and 1.
Figure-1. Schematic of the direct shear box test apparatus.

Rock mass properties
The rock mass used in this experiment was Woodkirk Sandstone which is upper coal measure sandstone from Morley, south Leeds. The rock mass consists of coarse and medium size particles and the ranges of compressive and tensile strengths of the rock are 50–60MPa and 3–4MPa respectively.

Filling material properties
The filling materials used were of two different types, coarse and fine. The coarse material was crush-sieved Woodkirk Sandstone, while the fine material was mud-produced Woodkirk Sandstone from core-drilling. Particle size of the fine filling material is 0.71mm or less and particle size of the coarse filling material is in the range 0.09–1.4mm. Table-1 shows more detailed data about the range of particle sizes.

<table>
<thead>
<tr>
<th>Particle size (mm)</th>
<th>0.01</th>
<th>0.053</th>
<th>0.18</th>
<th>0.24</th>
<th>0.35</th>
<th>0.49</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse material (%)</td>
<td>21.45</td>
<td>17.65</td>
<td>12.04</td>
<td>10.23</td>
<td>25.34</td>
<td>3.71</td>
</tr>
<tr>
<td>Fine material (%)</td>
<td>0.49</td>
<td>0.24</td>
<td>0.49</td>
<td>5.1</td>
<td>13.11</td>
<td>80.58</td>
</tr>
</tbody>
</table>

Table-1. Filling material size.

Joint characteristics
The conditions of the joint surfaces for the direct shear box tests were an artificially produced uneven joint, a damaged and a polished surface for the analysis of the influence of the joint surface. An artificially produced uneven joint illustrates the surface conditions in Figure-2. The range of their joint roughness coefficients (JRC) is
approximately 5-6. The polished jointed block was hand polished on emery paper after diamond saw-cutting. The damaged jointed block was a fresh rock block which was used for the direct shear box test at least 5-8 times. The interspaces which existed between the two asperities were filled with fine particles which were crushed from the joint surface by the shearing action. The joint roughness of the damaged joint block is the same as that of the fresh rock block, however, in the case of the former the tips of the asperity would be severely damaged which cannot be illustrated in the diagram.

Figure-2. Schematic of the joint wall geometry used in the direct shear box tests.

Results
The shear strength envelopes for clean fresh, damaged and polished joint blocks are illustrated in Figure-3. The polished rock block can be considered as planar joints, therefore, the friction angle of a polished joint block is the same as the basic or residual friction angle (φb or φr). The friction angle of a clean fresh jointed block may involve both the basic friction angle (φb) and the asperity angle (i). It may also have cohesion (c) without an effective normal load due to the asperity strength. The characteristics of the damaged jointed block are between that of the fresh joint and that of the polished joint because the effect of its asperities may reduce due to the abrasion of the asperity. The damaged jointed block therefore also involves an asperity angle but less than that of the fresh joint block (see Figure-3).

Figure-4 illustrates the variable joint behaviour without filling material for the influence on the joint surface. The fresh joint block reaches the residual strength without an obvious peak strength. This is because the JRC and the JCS are low. The shear strength of the damaged sandstone constantly increases and then reaches the peak/residual strength and in the polished sandstone after the peak strength, the shear strength reduces due to slip occurring on the polished surface. The shear strengths of the damaged and the polished jointed blocks are 63% and 32% of that of fresh joint block respectively. The shear stiffness of the fresh joint block is much higher than those of the damaged and the polished jointed blocks. The joint surface is therefore a critical factor in the determination of the shear strength of the entire rock mass.
Figure-3. Shear strength envelopes for a clean fresh joint, damaged and polished joint blocks.

Figure-4. Comparison between shear stress-displacement for a clean fresh, damaged and polished joint blocks.

The shear box tests were also carried out with two different filling materials, one consisting of fine particles and the other of coarse particles, which were mentioned above, for the determination of the shear strength of the filling material (see Figure-5). These fillings were consolidated over 24 hours before the experiments were carried out. The shear strength of the fine material is approximately 10% higher than that of the coarse filling because the fine filling is consolidated much more than the coarse filling and the fine particles are aligned along the shear direction in the test. These strengths are higher than that of the polished rock block as illustrated in Figure-3.
Figure-5. Comparison between shear stress-shear displacement of fine and coarse filling material.

Figure-6. Representative shear stress-displacement graphs for different normal stresses in the clean fresh joint block.

Figure-7. Representative shear stress-displacement graphs for different normal stresses in the clean damaged joint block.
Figures 6 and 7 show the relationships between the shear stress-displacement in the clean fresh and damaged jointed block under various normal loadings. According to the increase of the normal loads, the shear strength increases at a more or less a constant rate and all curves show the constant shear stiffness values.

Figures 8, 9 and 10 illustrate the shear-normal stress relationship in fresh, damaged and polished jointed blocks with and without filling. The ratio of the filling thickness to the asperity (T/A) is 1 in these filling shear tests. The size effects of filling material particles exert a slight influence on the shear strength of the filling joint according to the joint surface conditions and the normal loading conditions (see Figure-8). The difference between the total friction angles (gradients) in the jointed blocks with and without filling in the fresh rock block is larger than that of the damaged rock block because the asperities of the damaged jointed block were worn away and their influence was reduced. The friction angle of the polished joint block with or without filling are almost the same. However, with increasing normal load the friction angle of the fine filled joint block is slightly higher than that of the other rock blocks due to the strength of the filling material alone (see Figure-10). These diagrams illustrate the joint surface effect in a filling joint test.

Figure 11 gives curves which show the relationship between the ratio of the filling thickness to the asperity ratio (T/A) and the shear strength of the jointed block according to the contact rock conditions and filling material types. The shear strength of the filled fresh joint is approximately 20~30% higher than that of the filling alone, even if the filling thickness is equal to the asperity ratio (T/A=1). The rock contacts between the upper and the bottom blocks may occur at the highest asperity ratio because the filling material may be squeezed out due to the concentration of stress.

![Figure-8. Comparison the shear-normal stress for clean, fine filling and coarse filling in a fresh rock joint.](image)
Figure-9. Comparison the shear-normal stress for clean, fine filling and coarse filling in a damaged rock joint.

Figure-10. Comparison the shear-normal stress for clean, fine filling and coarse filling in a polished rock joint.

Goodman (1970) stated that when the ratio of T/A ratio is over 1.25 the joint surface effect disappears. However, differing from the case of the fresh rock block to which Goodman’s model applied, the shear strength of the damaged rock is almost the same as or a little higher than that of the filler alone, because there were only small contacts occurring. The damaged rock can be considered to have a low asperity angle because the tips of the asperities may be worn off or broken away. These results are therefore similar to those presented by Ladanyi and Archambault (1977) regarding the relationship between asperity angle and shear strength of the jointed block.

The shear strength of the clean polished jointed block is less than the filler strength alone. This differs from that of the other joint types as the shear strength reduces if filling is placed in the joint, therefore, the shear strength of the polished joint with filling increases. It shows that the function of the joint surface may disappear and its
strength is almost the same as the filling strength alone. The vertical displacement failed to register in the shear test due to the influence of the joint geometry.

In this investigation which was carried out on the shear strength of the filled joints, the thickness of the filling and the joint surface is shown to have a great influence on the shear strength of the filled joint.

![Figure-11. Comparison between shear stress and ratio of the filling thickness to the asperity height (T/A).](image)

**Conclusions**

The conclusions obtained from the physical filling shear box tests are as follows:

1. The friction angle of a polished joint block is the same as the basic/residual friction angle, whereas, the friction angle of a clean fresh joint block may involve both the basic friction angle and the asperity angle. Therefore, the shear strength of damaged joint block is between that of fresh and that of polished joint block due to the removal of some of the joints asperities.

2. The main factors exerting an influence on the filling shear strength may be classified into the physical properties of the rock mass and filling material, filling thickness, joint surface condition/geometry, the degree of consolidation for the filling and loading conditions.

3. The shear strengths of the damaged and the polished joint blocks were approximately 63% and 32% respectively of that of the fresh joint block without filling material. The shear strength of the fine filling material is higher than that of coarse filling material because of an increase in fine particle friction due to the consolidation of the fine filling material and the low strength of the coarse particles.

4. At a T/A ratio of 0.5 the joint roughness still considerably affects the rock mass strength because the rock contacts occur at the highest asperity. However, when
the ratio of the filling thickness to the highest asperities is over 1.0, the physical properties of filling may determine the rock mass’s shear strength with no influence from the contact surface conditions. The joint roughness effect on shear strength was also found to be affected by the filling particle size.

5. This experiment was limited because it was carried out with a homogeneous and isotropic filling material which is non-cohesive and fine-grained materials and has been tested under very low normal loads with no confining pressure and very thin filling thicknesses. These tests are considered to be initial experiments and further testing is required to overcome these limitations.

References


