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# SHEAR BEHAVIOUR OF PHYSICAL MODELS OF ROCK JOINTS UNDER RESTRICTED DILATION CONDITIONS

by

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## 1.0 Introduction

The investigation of frictional behaviour of rock joints has gained considerable interest due to increasing number of constructions in jointed rock masses. The stability analysis of jointed rock is often governed by the mechanical characteristics of joints of potential sliding. The direct shear test is a suitable experiment to determine these parameters. The normal load is maintained constant and moved latteraly to remain centered over the contact area during the testing.

The experimental boundary conditions corresponds insitu to a rock block slide at surface (Fig. 1.a), where normal load acting on the joint remains constant during the slide.

The direct shear test with constant normal load however, yields too low shear strength values for sliding of blocks constrained between two parallel dilatant joints corresponding to situations in underground constructions such as cavity constructions and tunnel constructions (Fig. 1.b) (Goodman, 1976). The stiffness of surounding rock leads to the activation of an additional normal load during shearing. This situation has been simulated by introducing a stiffness(k) to the normal loading via a computer where the measurements of the normal displacement gauge and the normal force are linked together (Leichnitz, 1985). The increase in normal force amounts to N = k.h where, h is the normal displacement.

The aim of this work is to investigate the influence of restrictions of the dilation on the frictional behaviour, by modifying the direct shear test machine to exert a stiffness to the normal loading during the test.

### 2.0 Models of rock joints

In order to avoid the difficulty of selecting identical rock joint surfaces to conduct shear tests under different conditions, it was necessary to cast several specimens using one and the same joint surface. Therefore replicas of the same joint surface were cast using cement mortar, whose properties resembled natural rock as closely as possible. On the basis of a literature review by Stimpson (1970) a suitable composition and curing time were decided.

### 2.1 Joint Surface

The artificial joint surfaces were introduced into turf cores while coring and were used as basic joints. Three joint surfaces with different roughness profiles were selected to study the dependancy of test results on the surface roughness. The roughness was recorded at seven lines along the joint surface and average roughness was determined.

| Profile | Roughness (JRC) |
|---|---|
| A | 7.6 |
| B | 12.2 |
| C | 9.5 |

### 2.2 Casting Procedure

Clay, Oil Clay, Parapin and Plaster of Paris were tested for making the mould of rock joints. It was found that the best results could be obtained by Plaster of Paris. The negative impressions of three selected joint surfaces, were obtained using Plaster of Paris and these impressions were used to cast test specimens from cement mortar, considered appropriate to represent rock material properties. The negative impressions were obtained from every pair of blocks separately and thus perfectly mated joints could be produced.

Cement, sand and water (1.5, 3.1, 1) were mixed

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thoroughly with a concrete mixer and then poured into the mould which was placed in a stainless steel cylinder. The steel cylinder had the exact internal diameter which could produce specimens with required diameter for the shear testing machine. To avoid the formation of air bubbles in the specimen and on the joint surface, cement mortar was pressed carefully using a wooden stick while the cylinder was externally tapped. The cast specimens were removed after 24 hours and left in water for 28 days for curing. The specimens for the determination of mechanical properties of model material were also cast in similar manner. The test specimens were cut and edges were ground to exact sizes and oven dried at 110°C for 8 hours.

### 2.3 Model Material Properties

The mechanical properties of the modelling material were obtained from standard uniaxial tests and Brazilian tests on 50mm diameter cylindrical specimens.

| | | |
|---|---|---|
| Uniaxial Compressive Strength ($\sigma_c$) | = | 336.5 kgf/cm² |
| Tensile Strength ($\sigma_t$) | = | 24.5 kgf/cm² |
| Basic Friction Angle ($\phi$) | = | 29° |

## 3.0 Experimental Procedure

The experiments were performed at the School of Civil Engineering of Kyoto University. The shear box can accommodate either 50mm diameter rock cores with joint surface normal to the core axis or 100 mm rock cores with joint surface parallel to the core axis.

The direct shear testing machine consists of a normal loading system to apply the load perpendicular to the shear plane and a shear loading system to cause one half of the specimen to slide over the other. To enable the top half of the specimen to slide freely, the normal load is applied through a roller bearing. The normal and shear forces were measured by electrical load cells while the normal and shear displacements were measured by electrical transducers. These four parameters sufficiently describe the frictional behaviour of rock joints.

Five identical specimens from each of three different roughness profiles were tested in order to obtain the shear strength envelopes. The normal loading for tests were in the range of 5 to 40 kgf/cm².

The direct shear testing machine was modified to achieve the restricted dilation conditions by incorporating a spring in the normal loading path (Fig. 2). The shear tests under these conditions were performed in the range of 5 to 30 kgf/cm².

Test procedure was automatic and both loading systems were servo controlled. The shear displacement rate was maintained at 1mm/min for both loading types and the signals from measuring instruments were recorded at regular intervals of 2 seconds. The experimental procedure and data collection were performed by a NEC PC 9801 micro computer.

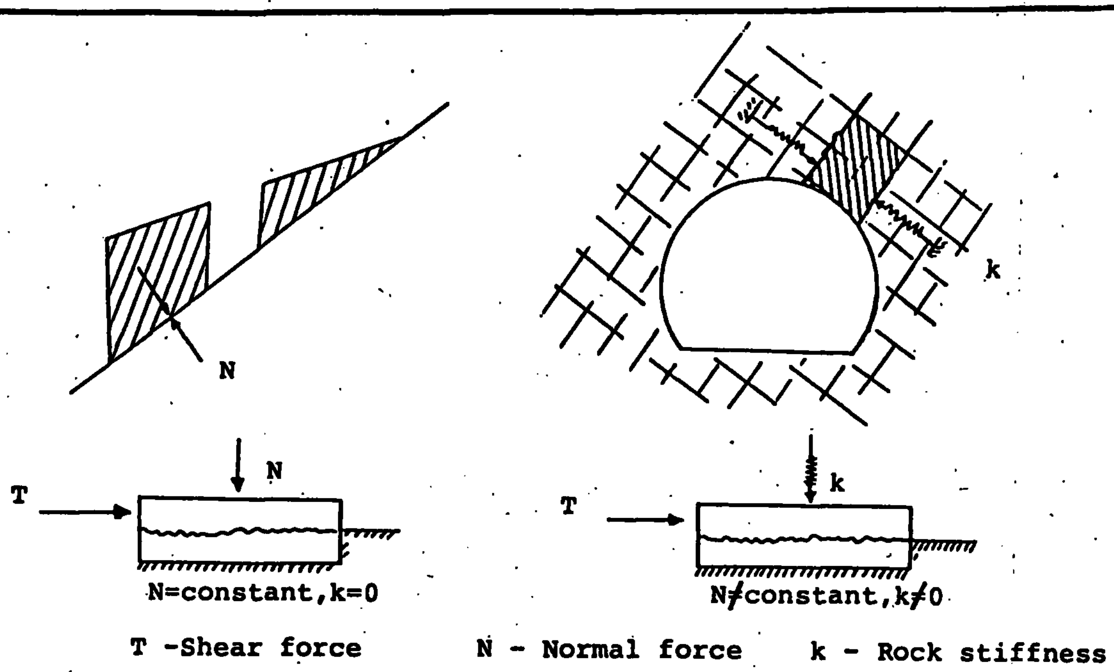


Fig.1. Simulation of in-situ boundary conditions in the shear test

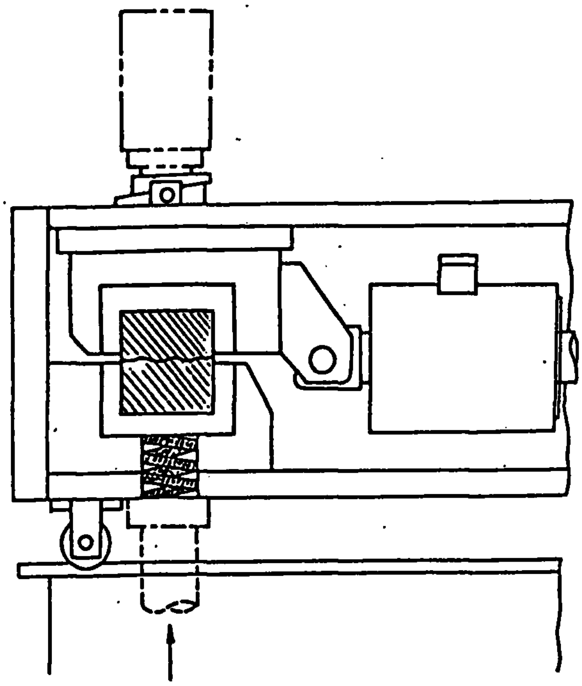

Fig.2. Modified shear testing machine to achieve restricted dilation conditions

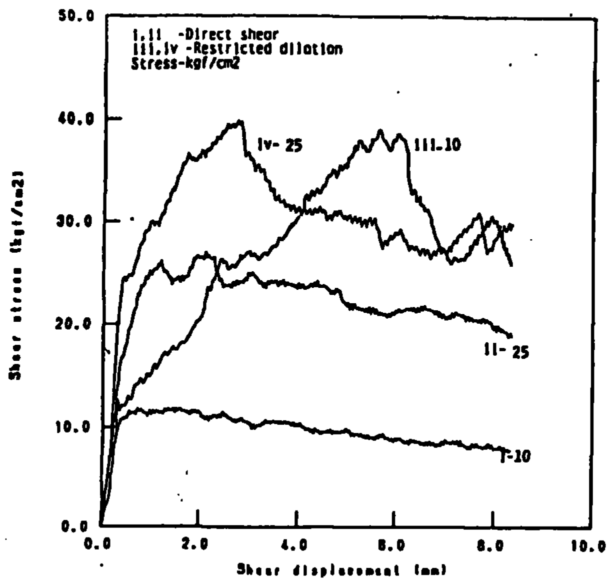


Fig.3. Shear stress Vs shear displacement for direct shear and restricted dilation (Roughness - A)

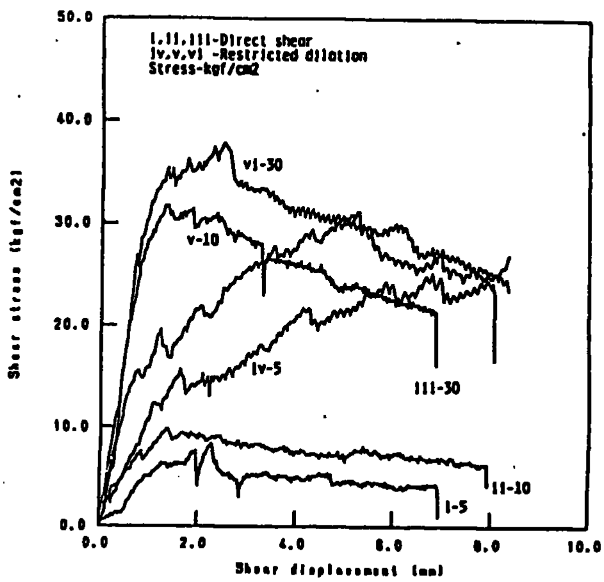


Fig.4. Shear stress Vs shear displacement for direct shear and restricted dilation (Roughness - B)

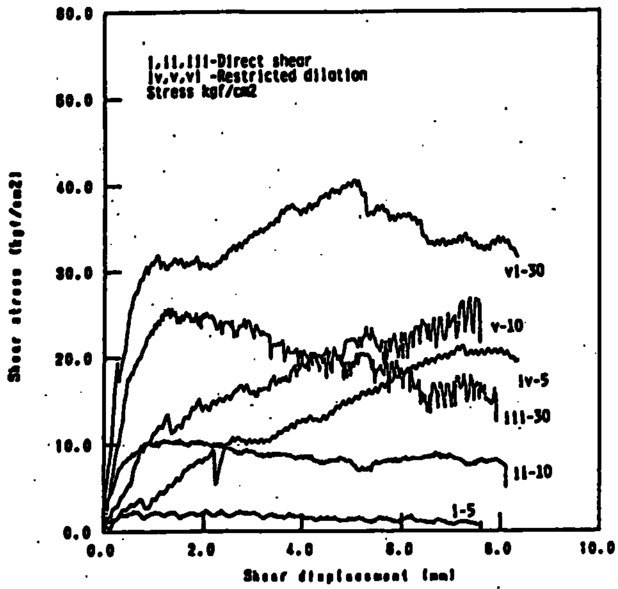


Fig.5. Shear stress Vs shear displacement for direct shear and restricted dilation (Roughness - C)

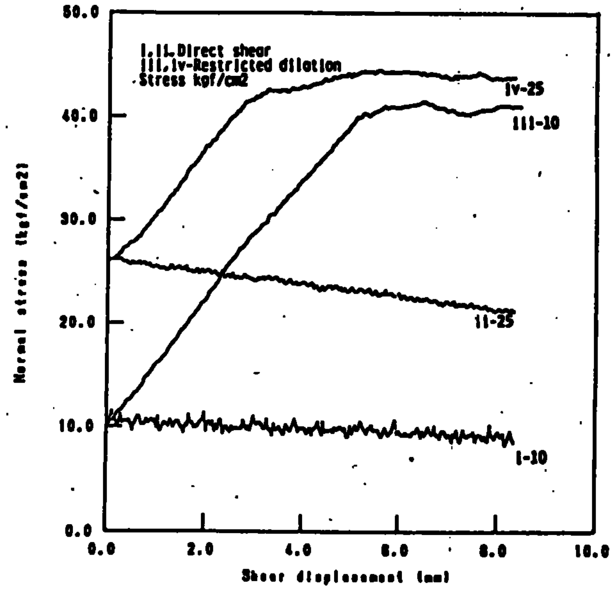


Fig.6. Normal stress Vs shear displacement for direct shear and restricted dilation (Roughness - A)

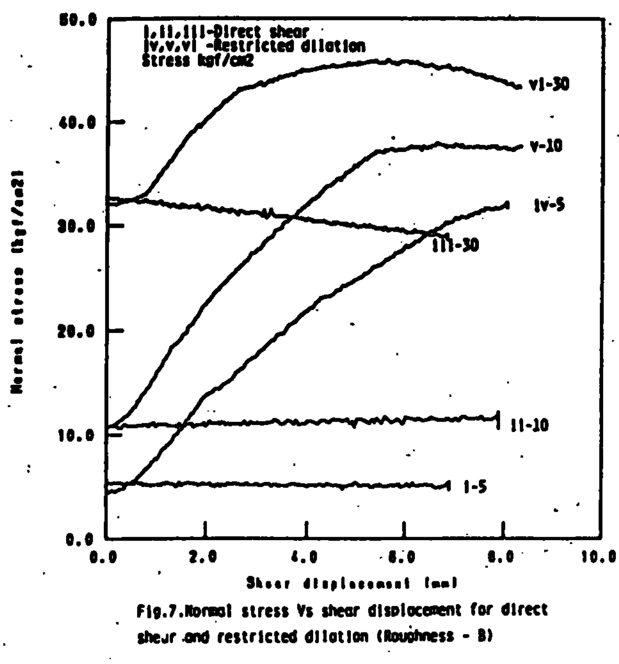


Fig.7.Normal stress Vs shear displacement for direct shear and restricted dilation (Roughness - B)

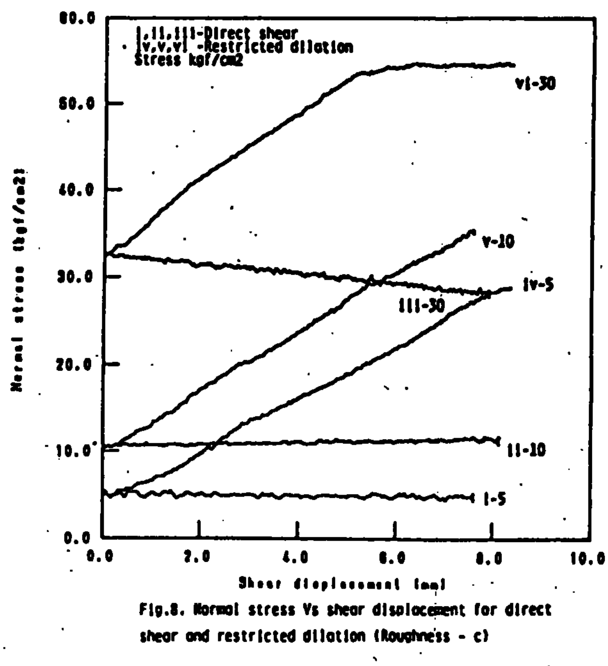


Fig.8. Normal stress Vs shear displacement for direct shear and restricted dilation (Roughness - c)

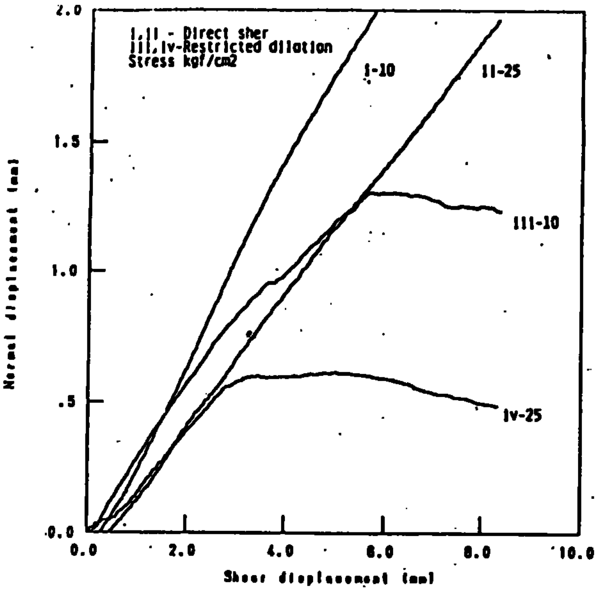


Fig.9. Normal displacement Vs shear displacement for direct shear and restricted dilation (Roughness - A)

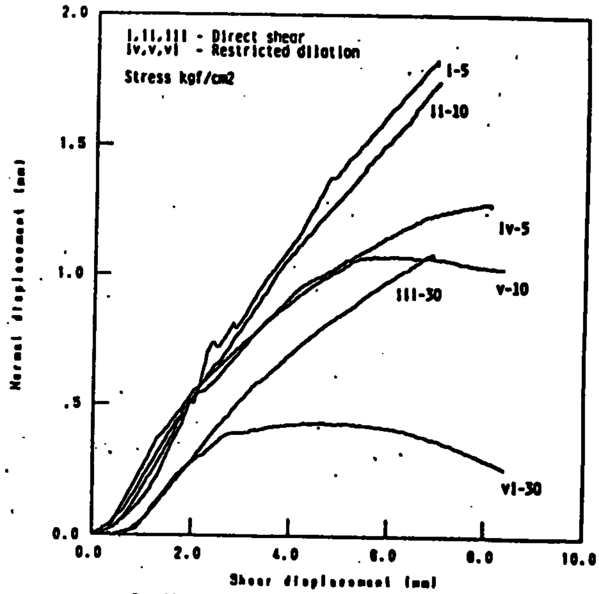


Fig.10. Normal displacement Vs shear displacement for direct shear and restricted dilation (Roughness - B)

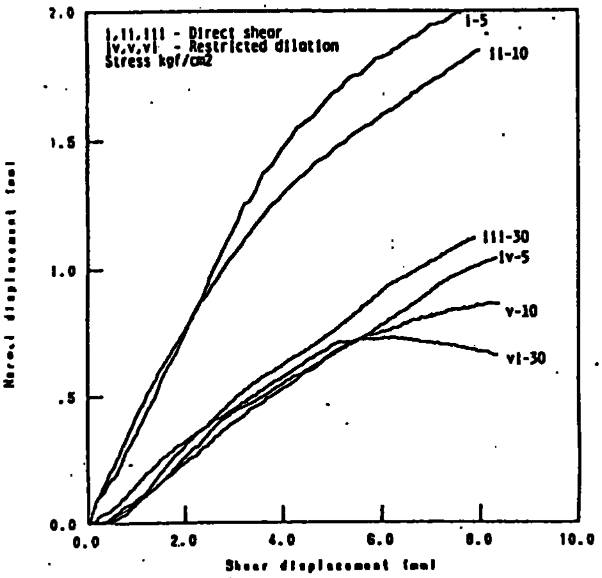


Fig.11. Normal displacement Vs shear displacement for direct shear and restricted dilation (Roughness - C)

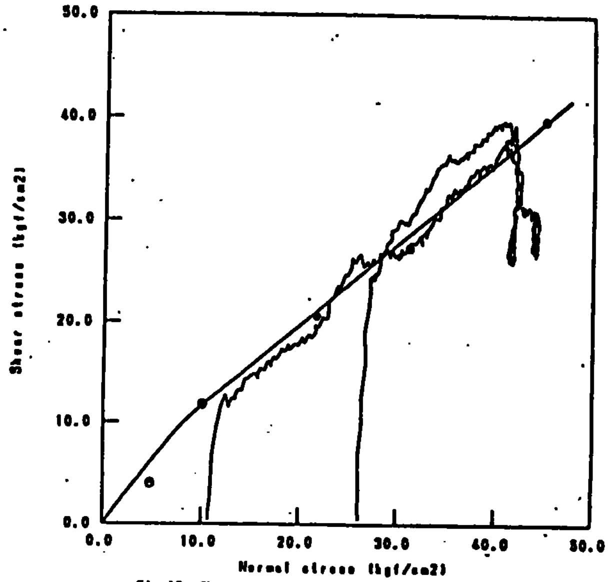


Fig.12. Shear stress Vs Normal stress for direct shear and restricted dilation (Roughness - A)

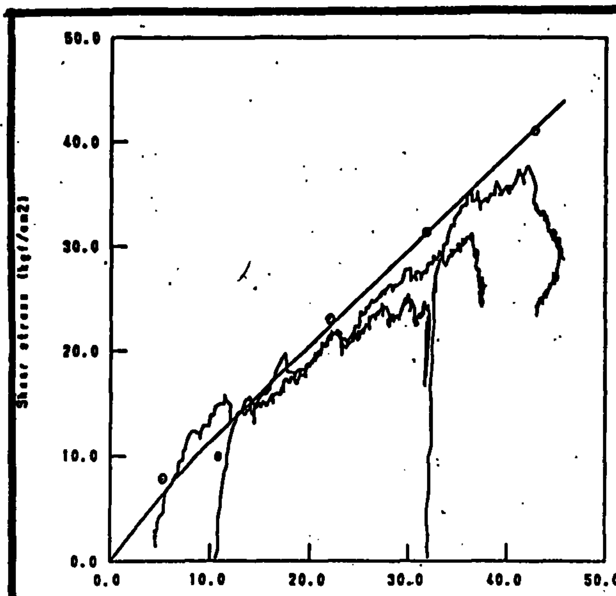


Fig.13. Shear stress Vs Normal stress for direct shear and restricted dilation (Roughness - B)

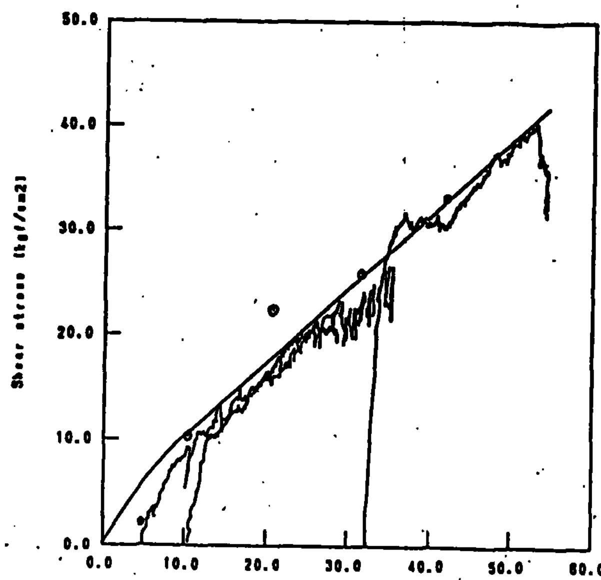


Fig.14. Shear stress Vs Normal stress for direct shear and restricted dilation (Roughness - C)

# 4.0 Experimental Results

## 4.1 Shear stress versus shear displacement

Figs. 3, 4, 5 illustrate the results of the direct shear tests and tests with restricted dilation on joint roughness profiles A, B and C. In the direct shear tests, after a small shear displacement, the maximum stress is mobilised. But with the restricted dilation conditions, shear stress increases gradually and reaches a maximum value after a large shear displacement. It is however noticeable that curves for both loading types become qualitatively similar with the increasing initial normal stress (eg. Fig. 4, 5 curves iii & vi). It appears that at still higher initial normal stresses curves iii and vi may become identical.

## 4.2 Normal stress versus Shear displacement

Figs. 6, 7, 8 illustrate the variation of normal stress with the shear displacement on roughness profiles A, B and C. Tests under the restricted dilation conditions (eg. Fig. 7 curves iv-v) show gradual increase in normal stress, however the test vi initiated at 30 kgf/cm$^2$ behave in a different manner where after a short shear displacement, normal stress becomes constant.

As the initial normal stress becomes higher, they show a supression of the dilation so that normal stress does not increase very much after achieving a certain value.

## 4.3 Normal displacement versus Shear displacement

Fig. 9, 10, 11 illustrate the variations of normal displacement with the shear displacement where the curves for restricted dilation show a much lower dilation as compared to the direct shear tests at identical normal stresses. It can be further seen that normal displacement achieves a peak after some shear displacement under restricted dilation conditions. The amount of dilation may depend on the stiffness of the spring attachment. With a spring of low stiffness, dilation can be further reduced.

## 4.4 Shear stress versus Normal stress

Figs. 12, 13, 14 illustrate the plots of shear strength results of direct shear tests at five different normal stresses along with the shear stress variations of tests under restricted dilation conditions at different initial normal stresses. It is clearly seen in all three cases that the increase in shear stress due to restricted dilations, follow the shear strength envelope very closely. However, the maximum shear stress depends on the initial normal stress level.

# 5.0 Discussion

The physical modelling procedure adopted in this study gives satisfactory results. The use of stainless steel cylinders of specific diameter for casting, provide test specimens directly and avoid the need of coring. Plaster of Paris proved to be the most suitable material for obtaining the mould of rock joints.

The peak shear displacement in direct shear tests occurs at an early stage of shearing and it does not change significantly with the increase in normal stress. The peak shear displacement was less than 1% of the length of the specimen (As shown by Barton, 1977)

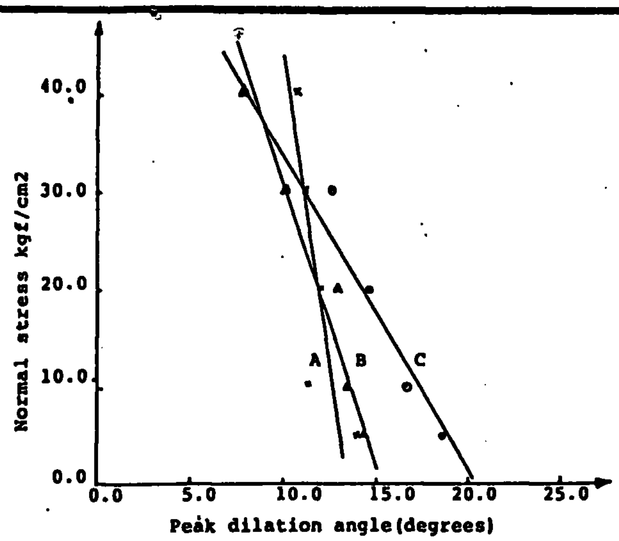


Fig.15. Effect of Normal stress on the peak dilation angle (Roughness-A,B,C)

with in the range of normal stresses concerned. In contrast, the shear tests under restricted dilation yields considerably higher peak shear displacements (Fig. 3, 4, 5). However, it reduces with the increase in normal stress.

At higher normal stresses, the shear displacement curves in direct shear and shear under restricted dilation become qualitatively similar with identical peak shear displacement. It appears that at still higher normal stresses than used in this investigation, both curves may become identical in every respect, viz; peak shear stress and peak shear displacement.

In contrast to the observations made by Hedocia (1985), peak dilation angle which was calculated from the portion of the dilation curve corresponding to peak shear displacement in direct shear tests, decreases sharply with the increasing normal stress (Fig. 15). This behaviour is in agreement with the work of Bandis et al. (1981).

It is interesting to note the behaviour of shear stress against the normal stress under restricted dilation conditions (Fig. 12-14). The increase in shear strength due to restricted dilation conditions coincide with the shear strength envelope obtained from direct shear tests on identical joints. Particularly the test conducted at initial normal stress of 10 $kgf/cm^2$ under restricted dilation conditions yields a stress path which almost covers the whole length of the shear strength envelope. It appears that with a suitable spring attachment to restrict the dilation, shear strength envelope can be derived from a single shear test.

## 6.0 Conclusions

Shear tests under restricted dilation conditions yield a stress path identical to the shear strength envelope of the particular joint roughness. The results were in agreement with three different roughness profiles. Similar work on this aspect is not found elsewhere and therefore further work should be carried out with springs of different stiffness on identical rock joints so that the influence of spring stiffness on the shear behaviour can be investigated. The use of physical models of natural rock joints is appropriate since identical joint surfaces are reproducible.

## 7.0 Acknowledgements

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