SHEAR DEFORMATION OF SIMULATED HEALED JOINTS FOR DESIGN OF STRUCTURES IN ROCK

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ABSTRACT

One of the most important deformation properties of rock mass discontinuities is its strenght under shearing stress. However, the shear strength of filled or healed joint will be the same as the shear strenght of joint filling material. The material filling the joints could be brought and deposited by groundwater, it may be crushed rock detritus produced during the formation of the joint itself, or it may be a crystalline material precipitated from groundwater solutions. Therefore, the shear strength of the infill material should be studied carefully together with the strength of rock mass itself.

The scale effect on shear strength of jointed rock, has led the authors to study the shear behaviour of granular metarial in the laboratory. Artificial materials were tested to simulate the behaviour of soft fill material found in discontinuities in field. As it was difficult to obtain the sample of joint fill material in the field it was decided to carry out tests on granular and artificial materials, and formulating, simulated filled joints.

ÖZET

Kaya kütlesi süreksizliklerinin en önemli deformasyon karakteristiklerinden biri makaslama kuvvetine karşı olan dayanımdır. Dolgulu ya da iyileştirilmiş eklemlerin makaslama dayanımı eklem doldu malzemesinin makaslama dayanımı ile aynı olacaktır. Eklemleri dolduran ya da iyileştirilmiş eklemlerin makaslama dayanımı eklem dolgu malzemesi yo *eklemlerin oluşumu sırasında kırılmış kaya parçaları ya da yeraltı suyunda bulunan çözelti halindeki minerallerin çökelmesiyle oluşmaktadır. Bu nedenle, dolgu malzemesinin makaslama dayanımı kaya kütlesinin dayanımı ile birlikte dikkatlice çalışmalıdır.*

Eklemli kayacın makaslama dayanımına etkisi, araştırmacıların laboratuvarda taneli malzemenin makaslama dayanımı üzerinde çalışmalara yönlendirmiştir. Sahadaki süreksizlikler içinde bulunan yumuşak dolgu malzemelerinin davranışını örneklemek amacıyla yapay malzemeler üzerinde bir seri seri deney yapılmıştır. Sahadaki eklemli dolgu malzemesinden örnek almanın zorluğu nedeniyle deneylerin taneli ve suni malzemeler üzerinde yapılması ue gerçek karakteristiklerin deney sonuçlarına göre formülleştirilmesi amaçlanmıştır.

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1. INTRODUCTION

From the engineering point of view joints can be classified according to the nature of fill material into clean, clay-filled or crystalline and detritus joints. The true shear strength of a filled joint will therefore depend to a large extent, on cohesive strength and internal angle of friction of the filling materials, and its moisture content. It has been shown that the shear displacement between two interlocked joint surface involves a significant degree of dilation under low normal loads and high degree of crushing of contact points on the joint surface under high normal load.

This paper presents the shear strength test results carried out on granular and artificial joint fill materials. This will provide basic understanding of the behaviour of the filled joints during rock slope failure.

2. SHEAR STRENGTH SIMULATED .DETRITUS MATERIAL

2.1. Sample Preparation and Testing of Simulated Betritus Materials

Four sets of tests were carried out on simulated granular type ma terial, namely limestone, sandstone and basalt. Materials were crushed using a jaw crusher, then sieved to give graded size fraction of granular particles. The specimens tested ranged in size from 0.8 mm upto 12.8 mm in four fractions. In order to enable comparison of the results, the same particle sizes were tested for all different rock materials. Each rock material test consists of four sets of specimens having sizes of 0 8-1.6 mm, 1.6-3-2 mm 3.2-6.4. mm and 6.4.-12.8 mm. Tests were performed under effective normal stress of 100, 200, 500, 1000, 2000 kPa A large direct shear machine was used (Figure 1) Shearing rate of 0 01 mm/min as suggested by ISRM for rock joints and granular material was used.

2.2. Shear Testing Results on Granular Materials

A series of tests were carried out on different rock materials in four fractions in order to compare the results. The shear strenght parameters were represented by shear displacement diagrams for smallest size material 0.8-1.6 mm, for sandstone, limestone and basalt respectively, Figures 2, 3 and 4. It has been concluded that the shear behaviour of all curves is similar; the peak shear strength increases with an increase in displacement. As the normal stress increases the peak strength reaches its maximum value then tend to keep constant with an increase in displacement. It has been noticed that the shear strength of basalt samples is sligthly higher than that of limestone. In addition the shear strength of limestone samples is greater than that of the shear strength

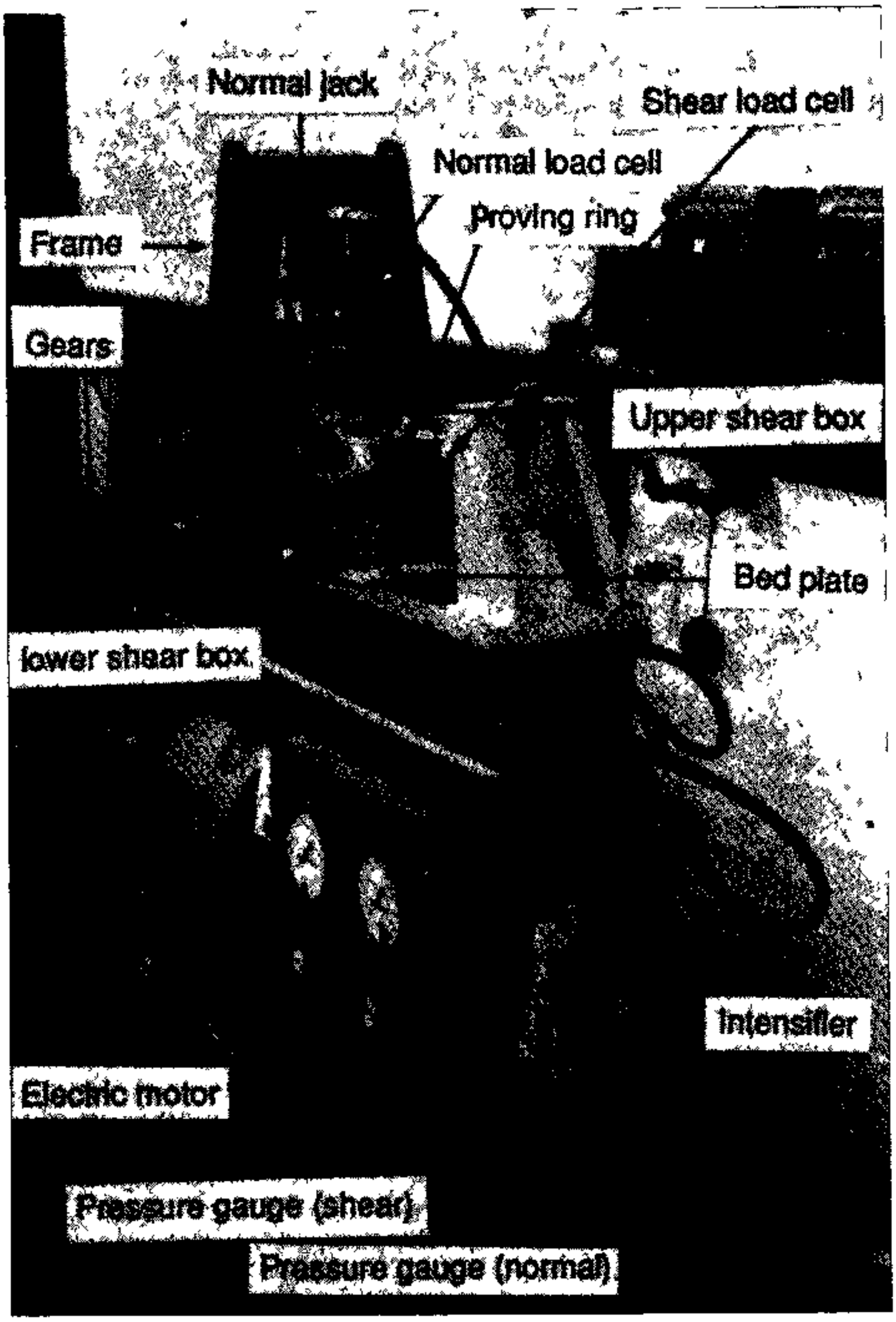

Figure 1 — The large direct shear machine

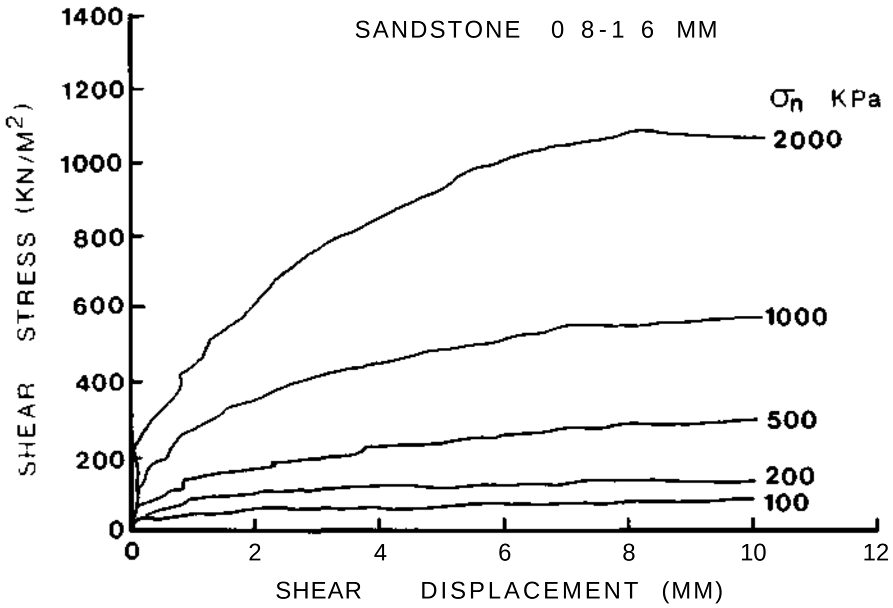

Figure 2 — Shear stress-displacement diagram for the series of tests on sandstone specimen

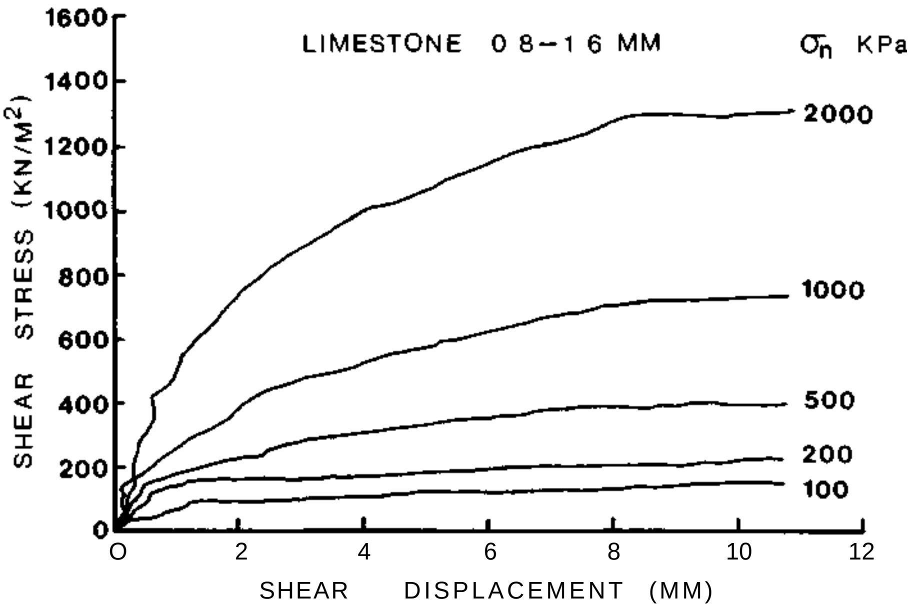

Figure 3 — Shear stress displacement diagram for the series of tests on limestone specimen

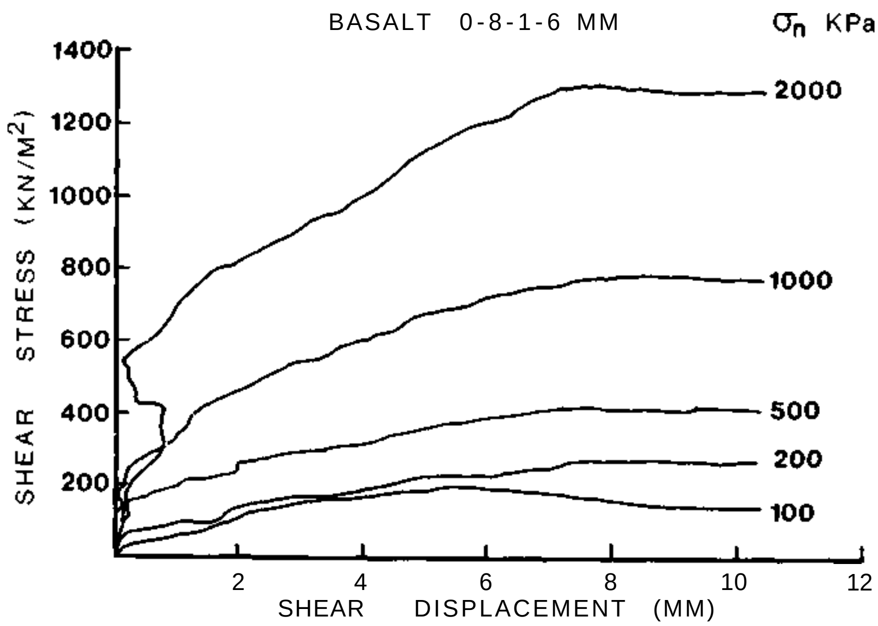

Figure 4 — Shear stress-displacement diagram for the series of tests basalt specimen

of sandstone samples which may be related to the rock material lithology and composition. Tests carried out on the largest size fraction between 6.4-12 8 mm revealed that, the peak shear strenghths are accompanied by large displacement.

Table 1 summarizes the results of direct shear testing, showing that the shear strength of granular material increases with decrease in particle size The friction angle decreases with increase in particle size. This may be attributed to the particle re-orientation and the progressive nature of multi-particle failure as the test advances. The affect of particle size on the angle of internal friction, 0 is plotted against the particle size in Figure 5. It can be clearly seen that the friction angle for all materials at a given normal loads is greatest for the small specimens and least for the large specimens. The friction angle for the maximum particle size 12.8 mm was in general 7 to 10 degrees less than the material size 1.6 mm. These results resemble closely to the results previously obtained by other investigators, (7) Tabte 2.

Table 1 — Results of direct shear testing on granular materials

Table 1_ Results of direct shear testing on granular materials

Rock type	Particle size (mm)	Linear regression (C) kpa	(deg.)	Corr. coeff. R	Geometric regression A	B	Corr.coeff. R
Sandstone	0.8- 1.6	19.5	27	0.9993	1.1174	0.8906	0.9964
	1.6- 3.2	56.60	23	0.9945	1.5458	0.8373	0.9962
	3.2- 6.4	88.3	22	0.9813	6.3424	0.6319	0.9792
	6.4-12.8	115	20	0.9896	7.5915	0.6100	0.9792
Limestone	0.8- 1.6	69.4	30	0.9986	3.379	0.762	0.9956
	1.6- 3.2	130.97	28	0.9953	5.086	0.713	0.9963
	3.2- 6.4	166.93	27	0.9810	6.065	0.695	0.9554
	6.4-12.8	224	20	0.9987	31.86	0.430	0.9678
Basalt	0.8- 1.6	52	30	0.9968	4.539	0.7148	0.9779
	1.6- 3.2	46	26	0.9951	4.177	0.7020	0.9770
	3.2- 6.4	50	21	0.9952	1.797	0.8054	0.9959
	6.4-12.8	100	18	0.9590	3.336	0.7134	0.9782

Table 2 — Summary of previous investigations on particle size effect (2)

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Source	Maximum particle size and type of test	Conclusions
Bishop (1)	25-6 mm Direct shear	Particle size does not affect angle of internal friction.
Lewis	6 mm Direct shear	Angle of internal friction increases as particle size increases.
Vailorga et al	4 mm Triaxial shear	Particle size does not affect angle of internal friction.
Rowe	1 mm Sliding friction	0 increases as particle size
Losite	75 mm Triaxial shear	Angle of internal friction increases as particle size decreases.
Kirkatrick (3)	2 mm Triaxial shear	Angle of internal friction increases as particle size decreases.
Marsal (8)	200 mm Triaxial shear	Angle of internal friction increases as particle size decreases.
Lee et al (4{	18 mm Triaxial compression	Compression increases as the particle size increases.
Fumagllt	260 mm Triaxial compression	Compression increases as the particle s^ze increases.

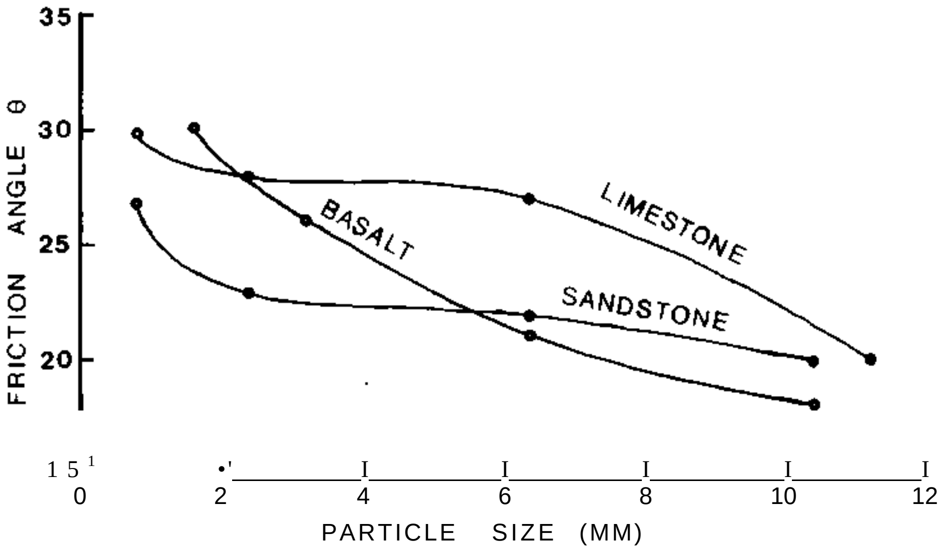

Figure 5 — Angle of internal friction vs particle sizes of limestone, basalt and sandstone samples

3. SHEAR STRENGTH TESTING OF ARTIFICIAL FILLING MATERIALS

In order to study the shear strenght of soft filling material, simulated artificial material, were prepared using commercially available quickset cement, sandstone and water in five different proportions. The mixture percentages comprising 20% quickset cement with filler, 16% sandstone and 64% water were carefully mixed together in a rotary mixer. All the samp[1] es were kept in plastic bags to preserve the moisture content.

3.1. Shear Testing Equipment

All shear tests were performed in a small commercially available shea- [4]•[3]sting rig (Figure 6). The maximum size of specimens accepted by this machine were square specimens (60X60X10 mm). Normal load was applied by a dead weight system through a lever arrangement with an arm ratio of 10:1. The rate of shearing was controlled by an electric motor, gearbox and a feed arrangement. The shear rate could be varied from a rate of strain of 0 33x10 mm/min to 4.23 mm/min In order to

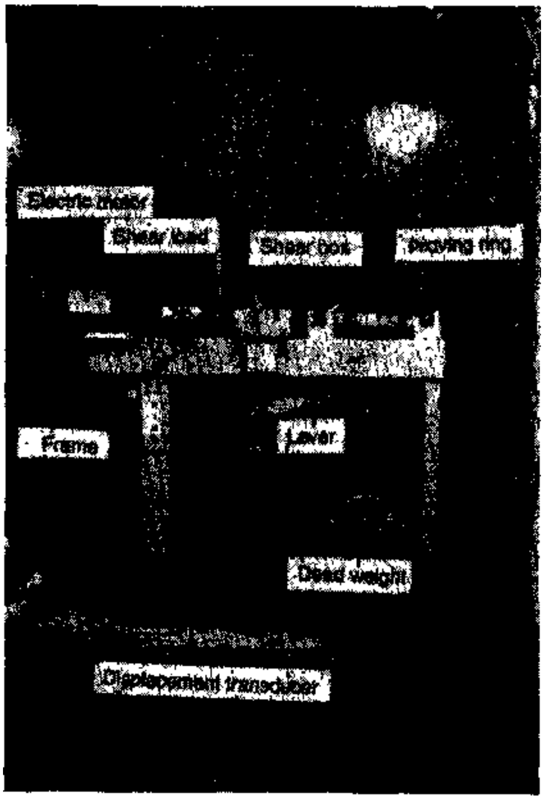

Figure 6 — The small shear testing rig.

investigate the effect of shear rate, four shear rates were used in a preliminary experiment namely 0.024, 0.12. 0.59 and 2.96 mm/min and the optimum shear rate of 0.12 mm/min was selected for the tests, (11). The shear force developed by the constant rate of strain was monitored through a proving ring and load cells. The shear box was interfaced with a microcomputer which permitted complete monitoring of shear test at various normal load value until a residual stress value was obtained. Various normal stresses used for the tests were 55, 77, 160, 350 and 640 kPa respectively.

3.2. Shear Tests Results on Artificial Soft Fill Material

Results of shear tests for various curing times are given in Figure 7. Both linear and curvilinear shear strength envelope curves have been obtained and the results are summarized in Table 3.

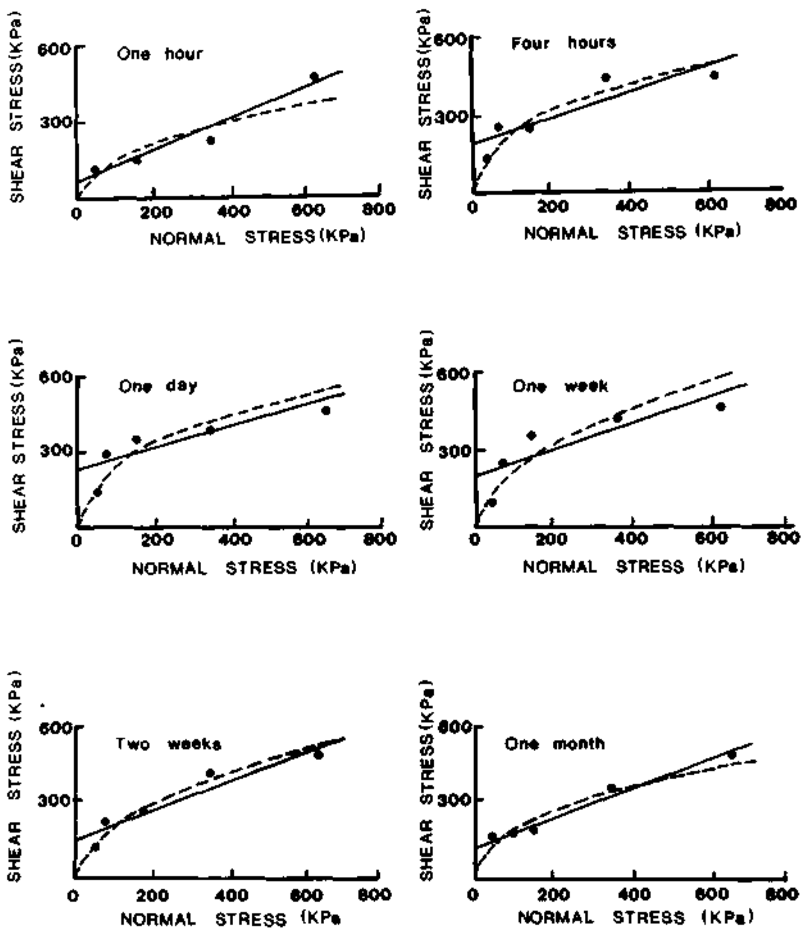

Figure 7 — Shear test results for various curing time

Table 3 — Direct shear test results of artificial mixtures.

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Curing time	Linear regression (kPa)	(deg.)	Correlation coefficient	Geometric regression A	B	Correlation coefficient
One hour	59.419	31	0.9670	12.8357	0.5173	0.9238
Pour hours	181.895	26	0.8817	27.87	0.4494	0.9337
One day	228.893	22	0.7802	39.802	0.3976	0.8443
One week	184.118	28	0.8320	14.832	0.5691	0.8804
TMo weeks	248.137	42	0.9504	32.950	0.5030	0.9685
One month	268.066	55	0.9903	50.895	0.4688	0.9459

Figure 8 presents the increase in the angle of friction of the mixtures with time from curing, 1 hour to 800 hours. The results indicate that the internal friction angle increased from 22 to 55 degrees, a percentage increase of 210%. Figure 9 shows an increase in shear strength of mixtures with time for various normal loads. These results again show a percentage increase in the cohesive strength of 50%.

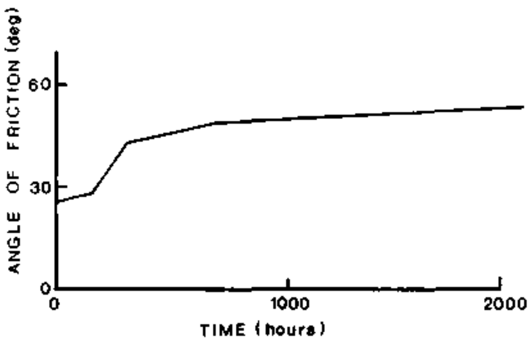

Figure 8 — Increase of friction angle with curing time

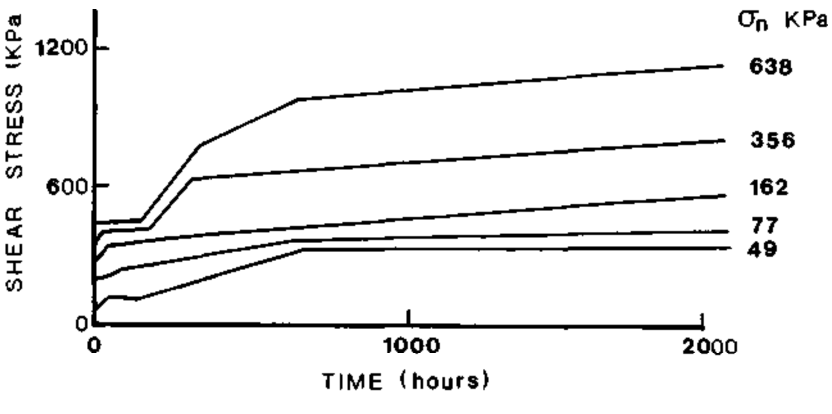

Figure 9 — Increase of strength with time for various normal loads

4 DISCUSSION AND CONCLUSIONS

Tests on granular and artificial materials proved that it is not possible to rely on the shear strength of open rock joints as determined in the laboratory for the evaluating of the stability of hard rock slopes. The shear strength of filling material of rock joints varies considerably with type, size and origin of various filling materials. For instance the size of filling material affects the shear strength of joint as shown by the test results. Also for artificial material which in this case, represents the detritus and/or precipitated filling materials, the shear strenght varies with joint moisture content. In any stability assessment the shear strenght of both actual rock joint and the material that filling the joints should be tested and the results should be analysed before a design décision is taken.

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