STRESS-DILATANCY RELATIONSHIP FOR ROCKFILL MATERIAL

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ABSTRACT: Numerical simulation of rockfill behavior is of great importance in dam engineering and requires development of a constitutive model. It is thus proposed to examine the hardening/softening behavior of four different rockfill materials, namely Andesit-Basalt, Limestone, Sandstone and Diabase. The crushed stones tested here were obtained from quarries that are being used in the construction of Sabalan, Vanyar (two quarries) and Rudbar Lorestan dams respectively. Large tri-axial tests were carried out on compacted 30 by 60 cm samples under drained condition. In order to omit the effect of particle size distribution on the behavioral pattern, all samples had identical initial grading curves and were compacted to about 95% of its maximum dry densities. Point load and abrasion tests were also carried out to evaluate the basic strength and hardness of the aggregate. Therefore, it is proposed to establish an I_{S50}–dependent critical state, defining dilative/contractive behavior of rockfill. In other words, having the compressive strength, density and the mean confining pressure, it will be possible to estimate the hardening/softening behavior of the rockfill and thus the residual strength of the material.

INTRODUCTION

Optimized use of rockfill materials in all types of embankments is being sought through more accurate analysis by numerical software. In this respect the mechanical parameters in general and failure characteristics of rockfill materials in particular are of great interest in the field of dam engineering. However, since measuring the strength characteristics of this type of material requires special and very expensive equipment, many engineers rely on empirical relationships to evaluate the basic mechanical properties such as Young's modulus and angle of internal friction.

However, with the advent of new design software that employ sophisticated constitutive models, the need for further research on correlations of model parameters and the mechanical behavior of rockfills has intensified.

One of the parameters commonly referred to in the newer codes, is the angle of dilation or simply the rate of volumetric strain with respect to shear strain. The parameter is a part of hardening/softening law of geo-material constitutive laws.

Dilation is usually encountered in relatively dense (over-consolidated) particulate material after initial yield and affects the magnitude of residual strength (Charles and Watts 1980). At this point it must be re-iterated that density of the material is a parameter to be considered in conjunction with mean confining pressure. In other words, samples equally compacted show different behavior under various mean confining pressures. Dilative behavior is only encountered under relatively low mean pressures (Indraratna *et al*. 1993).

The behavior is also affected by other factors such as hardness and strength of the base rock. Asperities of crushed rock and the toughness have major bearing on the mechanical properties of the rockfill. During shearing of densely compacted rockfills, the hardness of asperities determines whether the material will undergo dilation or not.

In this paper, it is intended to evaluate the dilative behaviour of a number of rockfill

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materials using the results of large tri-axial tests under various confining pressures. These tests were carried out using the 30 cm diameter tri-axial apparatus of the Building and Housing Research Centre (BHRC) of Iran on four different rockfill materials from Rudbar-Lorestan, Vanyar (two quarries) and Sabalan dam projects. (Sadeghpour1998). The rock type in each project was Limestone, Sandstone, Diabase and Andesite-Basalt respectively.

SAMPLE PREPARATION

In order to eliminate any effect of particle size distribution on mechanical properties of samples, they were all prepared using crushed aggregate with a uniform grading curve (figure 1). The maximum particle size was chosen to be 30 mm to conform with the standard of 30 cm diameter tri-axial test sample. The shape of the grading curve was also obtained by parallel shifting of the typical rockfill. The samples were all compacted to 95% of its maximum dry density obtained from a modified Proctor compaction test.
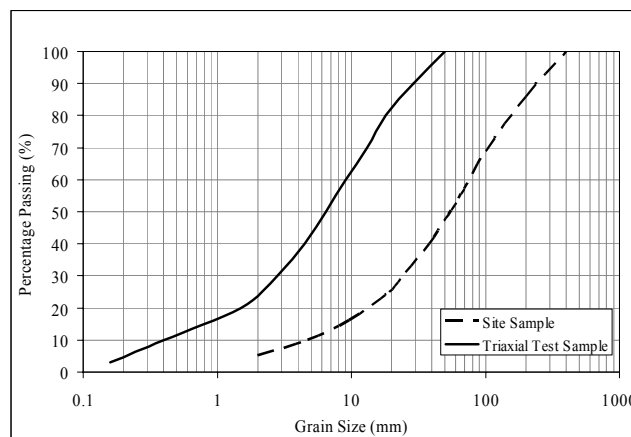

Figure 1.   Rockfill and sample particle distribution

Test Procedure

All tri-axial tests were carried out under consolidated-drained (CD) condition. The confining pressures under which the samples were consolidated ranged between 1 kg/cm^2 to 7 kg/cm^2, though some samples were tested under confining pressures of 9 kg/cm^2. The tests were carried out under static loading with a constant rate of prescribed displacement of 0.5 mm/min. The prepared samples were all subjected to partial vacuum to facilitate saturation. B values in excess of 0.95 were targeted as a standard of saturation.

In order to obtain an evaluation of the aggregate hardness, "Los-Angles" abrasion test and "Point Load" index tests were carried out on samples of each three rockfill material, with equal specifications.

Test Results

The results of tri-axial tests including diagrams of "deviatoric stress"-"axial strain" and "volumetric strain"-"axial strain" are presented in Figure 2. Limestone and Sandstone samples were tested under 1, 3, 5 and 7 kg/cm^2 confining stress and the Andesit-Basalt samples were tested under 3, 6 and 9 kg/cm^2 confining stress. The Diabase Samples were tested under 1, 2, 4 and 7 kg/cm^2 confining stress.
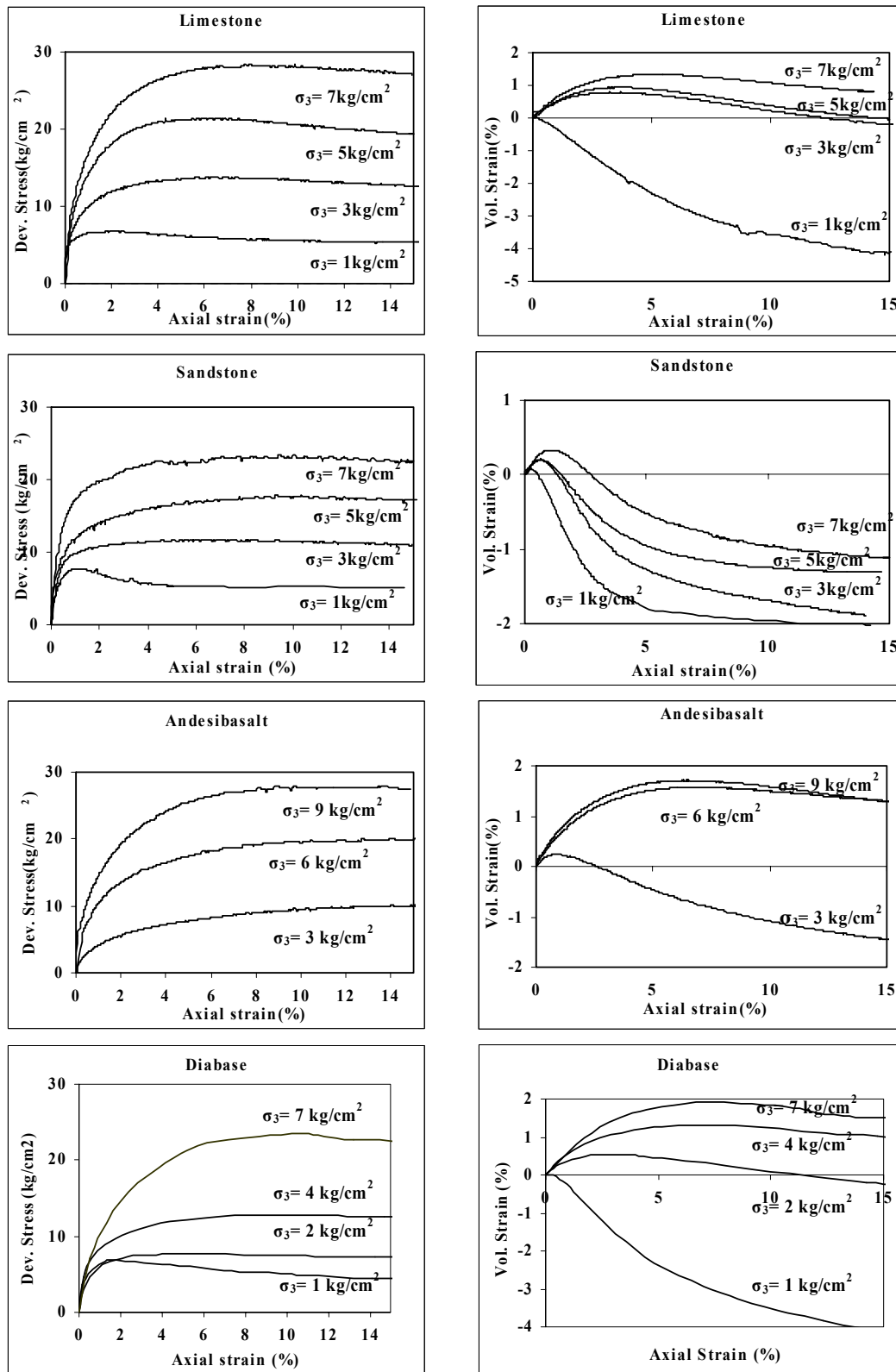
Figure 2.   Variation of "Deviatoric stress" and "Volumetric Strain" versus "Axial Strain"

As is evident from these results in spite of some dilation in most samples no significant softening was encountered (excluding Sandstone and Diabase sample consolidated under 1 kg/cm^2 pressure).

The angle of internal friction of the four rockfill materials (namely Limestone, Sandstone, Diabase and Andesit-Basalt) was evaluated to be 39°, 36°, 39° and 39° respectively. Applying the rule of thumb that the angle of dilation is in the order of $\frac{1}{3} - \frac{1}{2}$ the angle of internal friction, would give this parameter for each rockfill type to be (13°-20°), (12°-18°), (13°-20°) and (13°-20°) respectively.

The variation of slope of volumetric strain with respect to axial strain during shearing for all samples is shown in Figure 3.

DILATION ANGLE

Going back to the theoretical basis, we have by definition:

$$\tan \psi = \frac{d\varepsilon_v}{d\varepsilon_d}$$

$$\varepsilon_v = \varepsilon_a + 2\varepsilon_r$$

$$\varepsilon_v = \varepsilon_a - \varepsilon_r$$

$$\frac{\varepsilon_v}{\varepsilon_a} = \frac{3\tan \psi}{2 + \tan \psi}$$

where
ψ is the angle of dilation,
ε_v is the volumetric strain,
ε_d is the deviatoric strain,
ε_a is the axial strain,
and ε_r is the radial strain. Since through laboratory measurements, only ε_v and ε_a have been obtained, their ratio may be defined in terms of dilation angle, as is shown below:

$$\tan \psi = -\frac{2d\varepsilon_v^p}{3d\varepsilon_a^p - d\varepsilon_v^p}$$

Since the confining pressure of 3 kg/cm^2 was common between three rockfill types (excluding Diabase), it was chosen as a basis of comparison and behavior of Diabase is compared for the confining pressure of 2 kg/cm^2. Thus, the variation of function $\frac{3\tan \psi}{2 + \tan \psi}$ along the test for the confining pressure of 3 and 2 kg/cm^2 is plotted for the four samples in Figure 4. The peak values of ψ function for all samples are determined and the
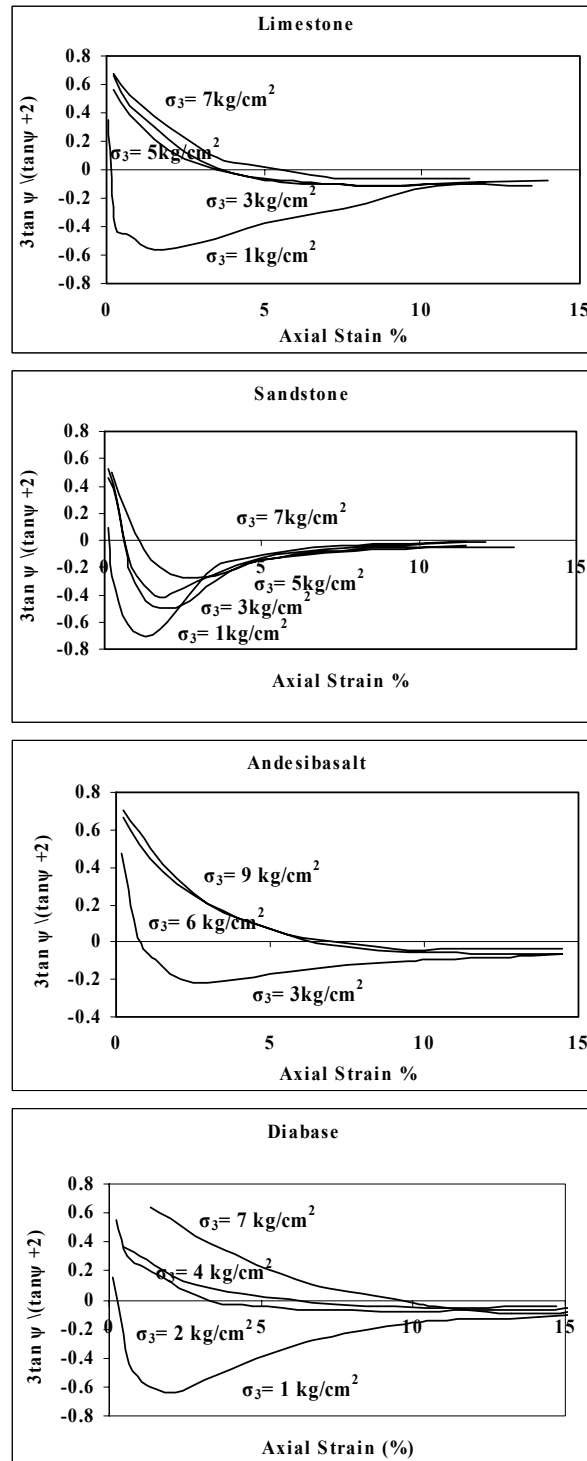

Figure 3. Variation of the ratio of Volumetric Strain-Axial Strain versus Axial Strain

angle of dilation is calculated and plotted against confining pressure in Figure 5.
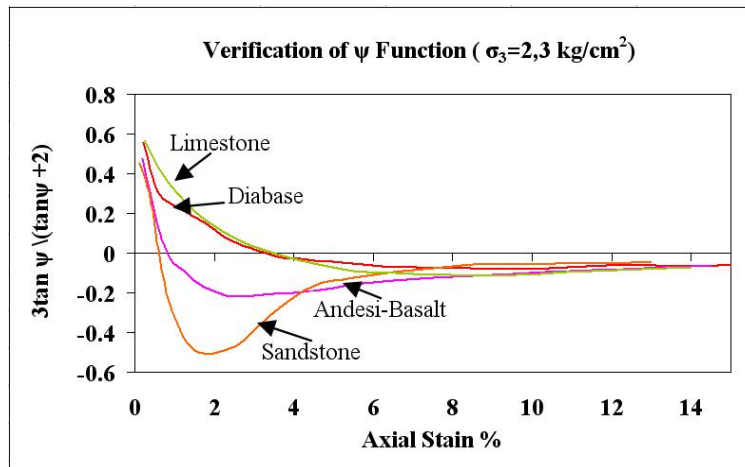

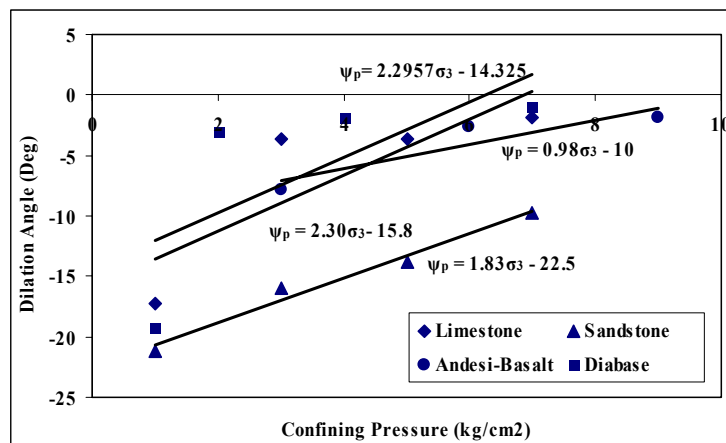Figure 4.   Variation of $d\varepsilon_v/d\varepsilon_a$ during shearing

Figure 5.   Variation of peak values of ψ against confining pressure

Looking at the results of Point Load Test, which is a measure of hardness of rock and the percentage loss during Los Angles abrasion test (Table 1), which can be viewed as a measure of the rock toughness, one can see some correlations between these measures and the angle of dilation. The variation of L.A. abrasion and point load test results versus the coefficients of linear regressions obtained from Figure 5, are shown in Figures 6 and 7.

Table 1.   Result of L.A. abrasion tests and point load tests

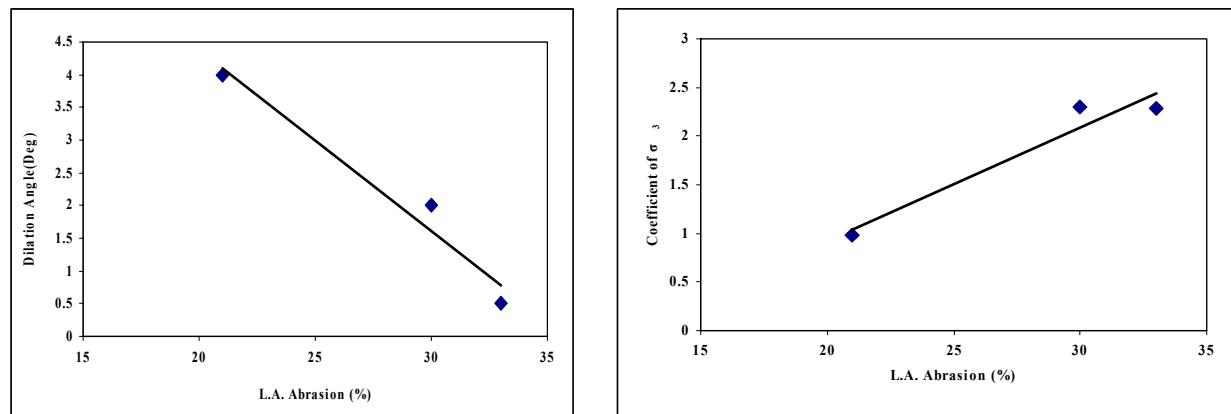| Rock Type	L. A. Abrasion Loss (%)	Point Load Index I_{S50}
Limestone	30	2.11
Sandstone	32	2.75
Andesibasalt	21	5.45
Diabase	33	1.90

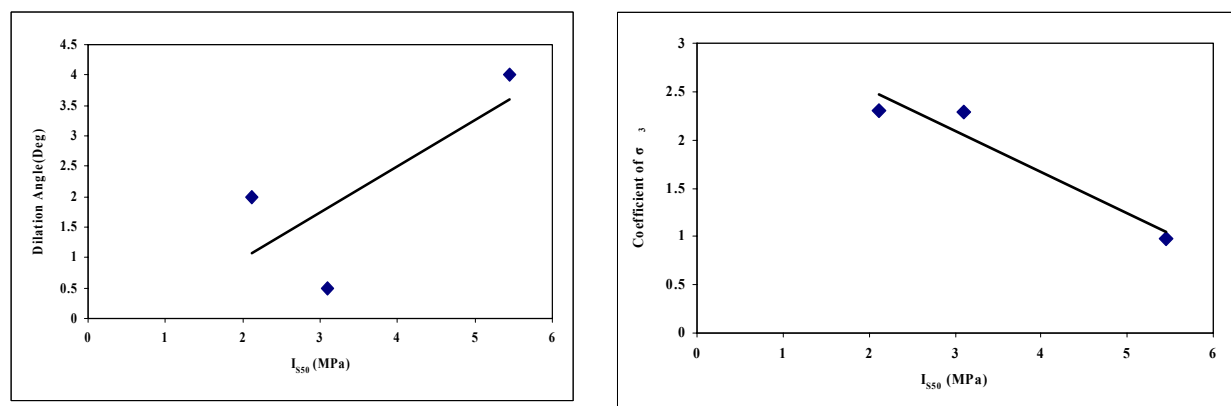Figure 6.   Correlations of Dilation parameters with L.A. Abrasion

Figure 7.   Correlations of Dilation parameters with I_{S50}

CONCLUSION

It can be seen the Andesit-Basalt sample exhibited greater dilation at a smaller axial strain then the others.

Another conclusion that can be arrived at is the fact that dilative behavior reaches a peak at pre-yield stage. The amount of this peak value and the percentage axial strain that it occurs in, is dependent on the material parameters and characteristics, as well as confining pressure, gradation of soil mass and resistance of particle edges to breaking. These may be determined by the potential of weight loss in Los-Angeles abrasion test.

REFRENCES

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