Investigation of the Rockfill Materials Properties Based on the Confining Pressure Effect and the Rock Type

M. Nemati¹, S. Jahangiri¹, F. Kalantary², M. A. H. Mehrdad³ and M. Veiskarami³*

¹- M.Sc. Student in Civil-Geotechnical Engineering, The University of Guilan,
   Email: m.nemati.civil@gmail.com
² -Faculty Member, School of Civil Engineering, K.N. Toosi University of Technology
   Email: fz_kalantary@kntu.ac.ir
³ -Faculty Member, Dept. of Civil Eng., Faculty of Engineering, The University of Guilan
   Email: mehrdad@guilan.ac.ir and mveiskarami@gmail.com
* Corresponding Author (Mehdi Veiskarami)

Abstract

Rockfill materials have been widely utilized in large structures as well as rockfill breakwaters and rockfill dams construction. Design procedure of such structures requires a rather precise estimation of geomechanical properties of such materials and hence, such properties are often evaluated with great difficulty. In this research, one of the important parameters commonly used in elasto-plastic constitutive model, namely dilation angle, is investigated by studying triaxial test results on five rockfill materials.

Keywords: Rockfill, Constitutive model, Dilation angle, Geomechanical properties.

1. INTRODUCTION

In general, the design of rockfill structures are affected by intrinsic properties of parent rock and this dependency distinguishes rockfill structures from other earth structures. The behaviour of the rockfill materials is affected by such factors as mineralogical composition, particles grading, size and shape of particles and stresses. Triaxial tests have been conducted on modeled rockfill materials [1-4], to study the stress strain behavior of rockfill materials and found that stress-strain characteristics of rockfill materials are non-linear, inelastic and stress dependent behaviour and increasing confining stress, maximum deviatoric stress, axial strain and volumetric strain at failure, increase.

In high confining stress, strength of material is dependent on particle breakage. Therefore, friction angle, particle sliding and particle breakage control material’s behaviour [5]. The friction angle of rockfills decreases with a declining rate, with the increase of confining pressure. Rate of dilation is dependent on the degree of breakage. At high confining pressure, the breakage increases, because expansion is restricted [6]. According to investigations of Marachi et al. (1972), axial strain is affected by particle shape and type of parent rock. However, particle shape is more influential. In addition, round shaped particles has greater friction angle.

Another factor, which influences the material’s behavior, is particle grading. Particle grading controls the friction angle of rockfills, by breakage process. Comparing uniformly graded materials, well-graded rockfill has lower particle breakage and greater friction angle. Uniformly graded materials have higher ratio of porosity [7].

Porosity is dependent on particle shape and gradation; the porosity increases with decreasing uniformity coefficient and increasing particle roundness. At low confining stresses, porosity and initial relative density affect the rockfill strength. [3]

In this paper, it is intended to perform a study on the dilative behaviour of rockfill samples under different test conditions. In addition, the stress-strain-volume change behaviour of the modeled rockfill materials has been investigated. The behaviour of various rockfill materials have been compared.

2. DILATION ANGLE

It is a well-known fact that “precompressed” granular samples show dilative behaviour during shear. The term “precompressed” indicates that the density is high with respect to surrounding pressure. Hence, it is expected that samples with equal density exhibit different dilative behaviour under different confining pressures. In other words, dense samples dilate during shearing under low confining pressure, whereas the same sample would contract under high confining pressures.
Granular material’s stress-strain behaviour (especially post failure) is affected by volumetric strain. There are two kinds of deformation in granular materials: [8]

1) Distortion (and crushing) of individual particles
2) Relative motion between particles as the result of sliding or rolling

In constitutive modeling, the angle between the incremental vector of the volumetric plastic strain and deviatoric plastic strain is known as dilation angle:

\[
\psi = \tan^{-1}\left(\frac{\frac{de_v^p}{de_d^p}}{\frac{de_v^p}{de_d^p} - \frac{de_i^p}{de_i^p}}\right) = \tan^{-1}\left(\frac{de_v^p}{de_d^p - de_i^p}\right)
\]

(1)

\[
\tan\psi = -\frac{2de_v^p}{3de_d^p - de_i^p}
\]

(2)

The negative sign arises from the convention that contractive volumetric strain and increasing deviatoric strain is taken as positive.

3. MATERIAL SPECIFICATION AND TEST RESULT

In this paper, experimental data from five large dams in the Azarbayjan Province, Iran, is used. Triaxial tests were carried out on rockfill samples in the Soil Mechanics Laboratory of the Building and Housing Research Centre (BHRC), which is equipped with a 30cm diameter triaxial apparatus [9].

The gradation curves of the rockfill samples are shown in Figure 1. Parallel scaling was used to limit the maximum particle size to 30mm. Details of the tests are summarized in Table 1 below.

<table>
<thead>
<tr>
<th>Group</th>
<th>Sample Specification</th>
<th>Index Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Origin</td>
<td>Name</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One</td>
<td>Aydoghmoush Dam Project</td>
<td>A-And-AV</td>
</tr>
<tr>
<td></td>
<td>A-And-AV-U</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sahalan Dam Project</td>
<td>A-Dio-SB</td>
</tr>
<tr>
<td></td>
<td>Saharan Dam Project</td>
<td>R-Dio-SH</td>
</tr>
<tr>
<td></td>
<td>Vanyar Dam Project</td>
<td>A-Dia-VN</td>
</tr>
<tr>
<td></td>
<td>Yamechi Dam Project</td>
<td>R-And-YM</td>
</tr>
</tbody>
</table>

It has been attempted to compact all samples equally with optimum water content and the samples were all compacted to 95% of its maximum dry density, obtained by a compaction test carried out in accordance with the modified effort (ASTM D1557).

4. TRIAXIAL TEST’S RESULT

Triaxial tests had been carried out on all the samples. The triaxial test apparatus could accommodate samples with a diameter of 30cm. All tests were performed under static consolidated-drained condition. Axial loading was imposed with constant rates of prescribed displacement of 0.5 mm/min. Triaxial tests had been done under different confining pressures. The results are shown in Figure (2) to (8). In all these figures, the compressive
volume changes are considered positive and expansive volume changes have negative values. In $\frac{d\varepsilon_v}{d\varepsilon_d}$ - axial strain curves the dilation has positive value.
5. THE EFFECT OF CONFINING PRESSURE ON SHEAR STRENGTH OF ROCKFILL

As it is presented in figure (9), increasing confining pressure the angle of friction decreases. Considering the stress factor, \( \beta = \frac{\sigma_v - \sigma_h}{2\sigma_h} \), variation of the friction angle versus stress factor is linear in a logarithmic scale. As it is presented in figure (10), this relationship is represented in equation (3).
6. THE EFFECT OF CONFINING PRESSURE ON DILATION ANGLE

As confining pressure increases, particle breakage increases and correspondingly, the dilation angle decreases. The results show the same trend in this research. Figure (11) shows the variation boundary of dilation angle in all samples. While increasing the confining pressure, this boundary decreases. The type of parent rock, shape of particles, grading and density effects are the main reasons of the expanded boundary at low confining pressures. As it can be seen in Figure (11), the maximum dilation angle in confining stress of 100KPa varies from 10 to 37.5 degrees and from zero to 15 degrees at confining pressure of 500KPa. The same comparison about strain corresponding to maximum dilation angle in figure (12) shows that axial strain corresponding to maximum dilation angle varies from 1 to 5 percent in confining pressure of 100KPa in confining stress of 500KPa.

7. THE EFFECT OF PARTICLE SIZE DISTRIBUTION ON VARIATION OF THE FRICTION AND DILATION ANGLE
The particle breakage induced hardening behavior of rockfill materials has intensified the effect of particle breakage on overall behavior of rockfills and its significant feature appears in materials dilative behavior. Rockfills with bigger particles has more breakage. In addition, uniformly graded material has more breakage and lower strength in comparison with well-graded materials.

8. THE EFFECT OF PARENT ROCK TYPE ON VARIATION OF FRICTION AND DILATION ANGLE

Hard rocks are expected to provide particles with hard asperities, which exhibit greater dilation. A similar trend is observed in A-And-AY sample with 19% and A-Dia-VN sample with 30% weight loss in Los Angeles abrasion test. However, at lower confining pressures R-Dia-SH with 46.25% weight loss in Los Angeles abrasion test has greater dilation in comparison with the R-And-YM sample with 32.5% weight loss. This trend is converse at confining stress of 700KPa. Because particle breakage in round shaped particles at low confining pressures is not as effective as in angular shaped particles. On the other hand, at high confining pressures, the effect of breakage is intensified even in round shaped particles and it affects the whole behaviour of the sample. Figure (13) represents the variation of dilation angle versus loss weight in Los-Angeles abrasion test at confining pressure of 300KPa for A-Dio-SB, A-Dia-VN and A-And-AY samples. It shows that the dilation angle at failure decreases while abrasive strength decreases.

![Figure 13. Variation of dilation angle versus loss weight in LA abrasion test at conf. stress of 300KPa.](image)

9. VARIATION OF DILATION ANGLE VERSUS FRICTION ANGLE

Researches of Vaid and Sasitharan (1992), Yang & Li (2004) and Veiskarami (2010) about dilative behaviour of sands showed that there is a unique relationship between the maximum dilation angle and the maximum friction angle. Samples with angular shaped particles have achieved this agreement. These samples have approximately the same grading specifications. Figure (15) shows this trend and Equation (4) expresses the relationship.

\[ \psi = 1.356 \phi - 49.95 \quad (4) \]

It is concluded that the relationship between the friction and dilation angles is affected by many other factors such as compactness, sample size, fine percentage and parent rock type.
10. CONCLUSIONS

In this study, consolidated drained triaxial tests have been conducted on rockfill materials. The results obtained are summarized as follows:

Dilation is directly related to the abrasive strength of angular shaped particles in rockfill mass. In rockfills with round shaped particles, breakage induced behaviour is intensified at high confining stress. Thus, at high confining pressures, variation of the dilation angle is related to abrasive strength of materials.

Rockfill materials show increase in axial strain and volumetric strain with the increase in confining pressure.

The materials show increase breakage factor with the increase in confining pressure.

Uniformly graded material has more particle breakage.

Angle of friction in well-graded sample is about 4 degrees greater than that of the uniformly graded sample. It conforms to the results of Marsal’s tests in 1973. Uniform samples undergo greater axial strain at failure at high confining pressures. The difference between the shear strength of well-graded samples with uniformly graded samples exceeds, increasing high confining pressure up to certain stress level because of multiplied effect of breakage at high stresses.

By increasing the particle breakage, the dilation angle decreases. This effect can be resulted from the particle breakage, which tends to a hardening behaviour.

About the effect of particles dimensions it is concluded that materials with greater $d_{50}$, have more breakage. Well-graded materials have lower breakage and greater dilation in order to existence of average sized particles.

There is a unique relationship between the maximum friction angle and the stress factor $\beta$.

11. REFERENCES


