DRA-48. THE ROLE OF OVERSIZE PARTICLES ON THE MEASURED SHEAR STRENGTH OF QUESTA ROCK PILE MATERIAL

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1. STATEMENT OF THE PROBLEM

What is the effect of oversize particles on the measured shear strength of the rock pile materials? Large rock fragments were encountered during the in-situ shear testing on the Questa mine rock pile materials. In order to evaluate the effect of these oversize particles on the friction angle and cohesion intercept of the rock pile materials, several laboratory and numerical shear tests were conducted. The friction angle and cohesion intercept are important parameters in controlling the gravitational stability of the rock piles.

2. PREVIOUS WORK

To eliminate or reduce the effect of oversize particles on the shear strength, ASTM standard D3080-98 (2003) recommends that the maximum particle size in a shear test specimen must be no larger than one tenth of the shear box width and one sixth of the specimen height. The SOP for the in situ shear testing (SOP-82) limits the maximum particle size to one seventh of the box width.

The literature survey reported by Fakhimi and Hosseinpour (2008a) indicates that there is no general agreement on the effect of oversize particles on the shear strength of soil; some researchers believe that oversize particles cause an increase in the measured friction angle while others report a reduction in friction angle in shear testing of the specimens with oversize particles (Fakhimi and Hosseinpour, 2008a, b). Note also that almost all the research work in this field has been concentrated on cohesionless materials. Furthermore, the authors are not aware of any research work that studied the effect of one oversize particle on the shear strength of rock pile materials from shear box measurements. All the previous studies reviewed are related to earth-fill rock dam or sandy-gravelly materials and the effect of scalping on their shear strength.

3. TECHNICAL APPROACH

In order to measure the shear strength of the near-surface material in some of the rock piles at the Questa mine, several in-situ shear tests were conducted using boxes of 30 cm × 30 cm and 60 cm × 60 cm in size. The details of the shear box apparatus and its accessories have been reported elsewhere (Fakhimi et al, 2008; Boakye, 2008). In a majority of the in- situ tests, one or two oversize particles that can modify the shear strength and deformational behavior of the material were encountered in the rock pile block along the shear plane. To address this issue, laboratory and numerical studies were performed on Questa rock pile material with oversize particles; these studies and results are summarized in this DRA.

Experimental studies were conducted on material collected from the Spring Gulch rock pile (sample no. SPR-VTM-0019). The material of minus No. 6 sieve was placed in

a 6 cm × 6 cm shear box for testing. The original and scalped gradation curves for the material using dry sieving are shown in Figure 1. To reduce the errors associated with material variations, the rock pile material retained on sieve numbers 10, 16, 30, 40, 50, 70, 100, and passing sieve No. 100 were collected in separate containers and mixed together according to the gradation curve of Figure 1 for direct shear testing. The air-dried material was mixed thoroughly with water to result in 6% water content. This water content is about the average value of the unsaturated rock pile materials that was measured in the field. Each sample was compacted in three layers in the shear box by tapping it carefully to result in a dry density of 1,670 kg/m^3. Note that in all shear tests, the dry density of the soil matrix was kept equal to 1,670 kg/m^3 irrespective of the size of the oversize particle. The normal stresses used for shear testing were 20.5 kPa, 42.3 kPa, and 68.2 kPa which are similar to those used for the in-situ shear testing. All the shear tests were conducted at a shear displacement rate of approximately 0.5 mm/min. The oversize particles were simulated by using stainless steel spheres or balls having diameters of 0.66 cm, 1.28 cm, and 1.90 cm. The reason for using spherical particles was to reduce the number of parameters involved in this study; non-spherical particles can have different degrees of sphericity and angularity that add to the complexity of the problem. The oversize particles were placed at the shear plane at the center, and on the left and right sides of the shear box to investigate whether the location of oversize particle modifies the shear strength. Figure 2 shows a photo of the shear box in which the left and right sides of the box have been depicted by letters L and R, respectively.

For the numerical analysis, the two dimensional hybrid discrete-finite element code CA2 was used (Fakhimi, 1998). The rock pile material was simulated with circular cylinders that can interact through the contact points. For the simple contact bond model (Itasca, 1999) implemented in this study, the micro-mechanical properties for interaction of two cylinders are normal and shear spring stiffnesses (k_n , k_s), normal and shear bonds (n_b, s_b) to "glue" the particles at the contact points, and a Coulomb friction coefficient (μ) which is activated when the bond between any two particles is broken. A contact is broken if the tensile normal contact force or shear contact force exceeds the contact bond strength. The two additional parameters in this model are the radius of the particles (R) and the genesis pressure (σ_0). The genesis pressure is used to create a small overlap of the particles. It has been shown that this small overlap of cylinders helps to more realistically simulate the tensile strength and friction angle of geomaterials (Fakhimi, 2004).

Based on laboratory direct shear tests on the Spring Gulch material, an average friction angle (ϕ) of 41.2° and an average cohesion intercept (c) of 11.5 kPa were obtained. The elastic modulus and Poisson's ratio were assumed as E = 16.8 MPa and ν = 0.2, respectively. These macroscopic properties together with cylinders' radii (R) of 0.3 to 0.6 mm were used to obtain the corresponding micro-parameters (k_n, k_s, n_b, s_b, μ, and σ_0) through a calibration procedure (Fakhimi and Villegas, 2007) that suggested the following micro-properties: k_n = 33.06 MPa, k_s = 7.6 MPa, n_b = 18.5 N/m, s_b = 18.5 N/m, μ = 1.0, and σ_0/k_n=0.041. These micro-properties together with cylinder-wall contact properties of k_n = 10 GPa, k_s = 10 GPa, μ = 0.50, and n_b = s_b = 0 were used in simulations of a direct shear test and a biaxial test without any oversize cylinder. These simulations confirmed that the selected micro-parameters were in fact able to reproduce the correct macro-properties.

Note that the cylinders' diameters for simulation of soil particles were selected based on the particle size D_{50} of 0.9 mm in Figure 1; the cylinders diameters were allowed to have a random uniform distribution between D_{50}-0.3 mm and D_{50}+0.3 mm. Therefore, the cylinders' radii ranged from 0.3 mm to 0.6 mm in the numerical model.

While the laboratory results were used to validate the numerical model, the computational features of CA2 program provided a tool to investigate the influence of different parameters in the numerical model to help to interpret the laboratory findings.

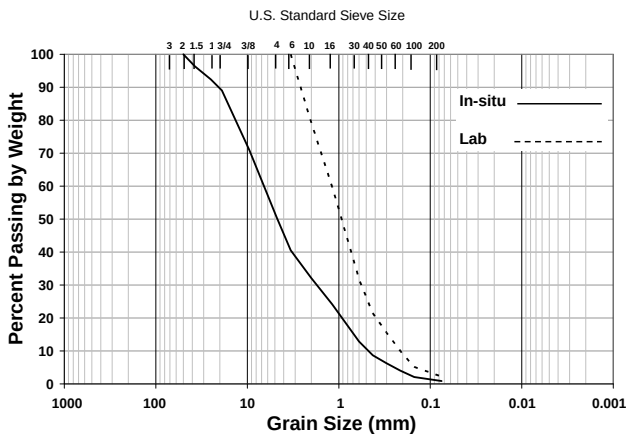


FIGURE 1. Gradation curves (in situ and lab) of the material used for experimental study.

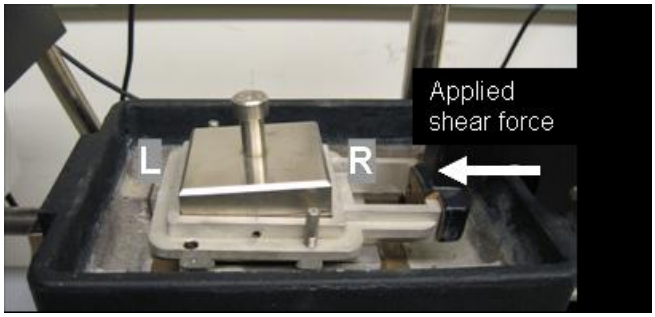


FIGURE 2. A photo of the shear box, showing tilting of the top plate, direction of applied shear force, and right (R) and left (L) sides of the box.

4. CONCEPTUAL MODEL

The shear box of this study was modeled using finite elements while a discrete element scheme was implemented to simulate the rock pile material within the box. Figure 3 shows a sketch of the shear box. The box is made of five pieces shown with letters A, B, C, D, and E in Figure 3. All these regions were discretized to finite elements that are not shown in the figure for the sake of clarity. Internal surfaces of the shear box were defined as "wall" in the CA2 program to interact with the discrete element domain. More details about the numerical model can be found in Hosseinpour (2008).

The shear stress-shear displacement results were obtained from the experimental and numerical direct shear tests (Hosseinpour, 2008). Both the experimental and numerical test results were interpreted using the Mohr-Coulomb failure criterion. The best fit line through the pairs of normal and peak shear stresses was used to obtain the cohesion and friction angle of each series of tests.

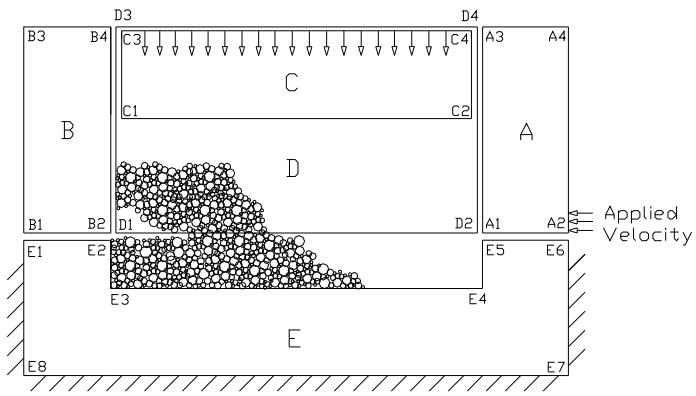


FIGURE 3. A sketch of the shear box used for the numerical simulation.

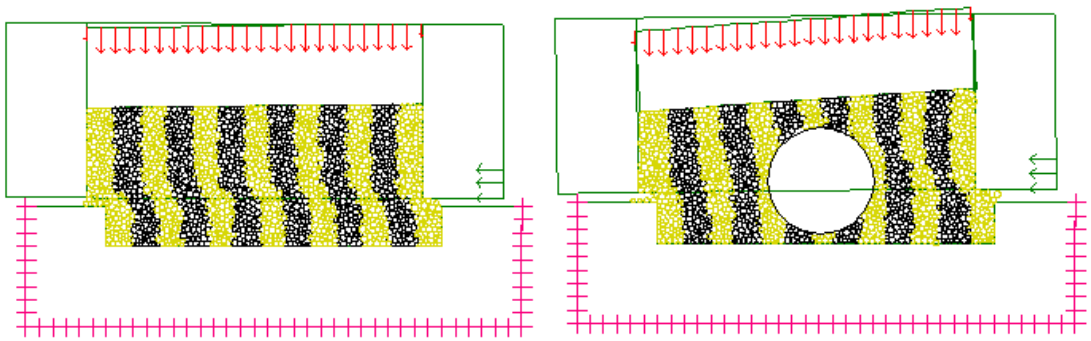
5. STATUS OF COMPONENT INVESTIGATION

The shear stress-shear displacement behavior, Mohr-Coulomb failure envelopes, and deformation of the shear box in the numerical and experimental tests were obtained and studied in detail (Hosseinpour, 2008; Fakhimi and Hosseinpour, 2008a, b). In addition to the numerical simulation of the laboratory shear box, the in-situ shear box was simulated as well. The results of in-situ shear box modeling are presented in Hosseinpour (2008).

In total, 68 laboratory direct shear tests were conducted. To assure the consistency and repeatability of the shear tests results, normally more than one physical test was performed for a fixed ball size, ball location, and applied normal stress.

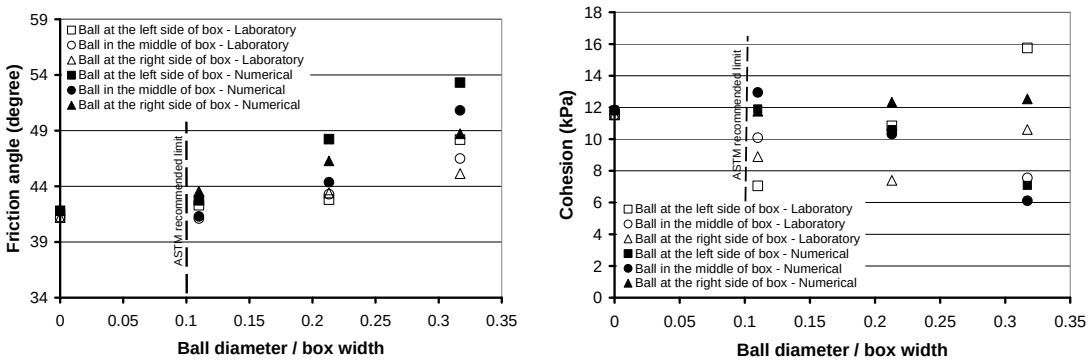
The deformed shapes of the numerical specimens at a normal stress of 68.2 kPa and after 3.5 mm shear displacement are shown in Figure 4. Figure 4a is the deformed specimen without the oversize cylinder while in Figure 4b the deformed specimen with the largest oversize cylinder placed at the box center is shown. The dark and light bands in the specimens were initially vertical before any shear displacement was applied. Therefore, the deformed bands in Figures 4a and 4b illustrate the concentration of shear deformation along the shear band. Note that in the situation without the oversize ball, all the deformed bands are approximately showing the same amount of shear distortion. On the other hand, the shear distortion is not uniform along the shear band when the largest oversize particle is placed in the shear box. In fact in this latter case, the second dark band from the left does not show much noticeable shear distortion. Therefore, the presence of an oversize particle can prevent uniform shear distortion of the specimen along a straight shear band. Note also the presence of oversize particle in Figures 4b causes excessive tilting of the top platen. Excessive dilation of the simulated material (compare Figs. 4a and 4b), tilting of the top platen, and the deformation along a curved shear band need more energy to develop. These observations explain why the measured friction angles and cohesions are affected by the presence of the oversize particle.

In Figures 5a and 5b the friction angle and cohesion versus the normalized ball diameter are shown. Note that not only the size of the oversize ball, but also its location affects the shear behavior of the material (Fakhimi and Hosseinpour, 2008b). In general, both numerical and experimental results show increase in friction and decrease in cohesion. An exception is for the situation that the largest ball was placed on the left side of the box that resulted in an increase in the cohesion. The reason for this experimental observation is not clear but could be due to the nature of cohesion intercept values that in general show more scatter in the measured data compared to the friction angle values (Baecher and Christian, 2003). In Figures 5a and 5b, the recommended limit of the maximum particle size to the box width of 0.10 by ASTM (2003) is shown as well. Experimental results in Figures 5a and 5b suggest that the average error in friction angle and cohesion intercept measurement for a maximum particle size to box width of 0.2 are about 2 to 3 degrees and 10% to 15%, respectively. Similar observations were obtained from the numerical simulation of the in situ shear box (Hosseinpour, 2008).



(a) (b)

FIGURE 4. Deformed specimens with applied normal stress of 68.2 kPa after 3.5 mm shear displacement in the numerical tests a) without the oversize cylinder b) with the largest oversize cylinder in the middle of the box.



(a) (b)

FIGURE 5. Friction angle (a) and cohesion (b) vs. the normalized oversize ball diameter. The allowable maximum particle size / box width of 0.1 recommended by ASTM is shown with the dashed lines.

6. RELIABILITY ANALYSIS

The reliability with which the numerical and laboratory shear tests can be applied to in-situ shear box tests is dependent on the density of soil matrix. The main assumption in

this study is that the density of soil matrix in the field is not affected by the presence of large particles. This assumption needs to be verified by careful field measurement of soil density at a distance from and in the vicinity of large rock fragments.

The friction angles from the numerical model are in general greater than those from laboratory tests especially for the situations where larger oversize particles are used. This could be due to the fact that the numerical model is two dimensional and the oversize particle is a cylinder covering the whole width of the shear box model compared to the spherical ball used in the physical tests.

In general the following conclusions of the DRA are considered reliable considering the overall consistency between the results of experimental and numerical direct shear tests.

7. CURRENT CONCLUSION OF THE COMPONENT

Laboratory and numerical tests were conducted to investigate the role of oversize particles on the measured shear strength of Questa rock pile material. The oversize particles were simulated by placing stainless steel spheres with different diameters along the shear plane. The two dimensional numerical tests used a hybrid discrete-finite element model to mimic the shear behavior of the rock pile material. In general, both the physical and numerical tests suggest an increase in the friction angle and a decrease in the cohesion due to the presence of the oversize particle. The error in physical measurements of friction angle and cohesion intercept in a direct shear test with an oversize particle seems to be limited to approximately 2 to 3 degrees and 10% to 15%, respectively, if the ratio of the maximum particle size to the box width is less than 0.2. This limit of 0.2 is greater than that of 0.1 recommended by ASTM standard and the value of one seventh in the SOP-82. Therefore, it appears that the ASTM requirement is too conservative for the case under study. It is concluded that a limit of 0.2 of the ratio of maximum particle size to box width for the Questa rock pile material could be used in measuring the cohesion intercept and friction angle with an error of at most about 2 to 3 degrees in friction angle and 10% to 15% in cohesion intercept measurement, respectively..

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9. TECHNICAL APPENDICES

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