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Evaluation of the effect of particle size in shear resistance study of an iron mine waste rock pile

Evaluation de l'effet de la taille des particules dans l'étude de résistance au cisaillement d'une mine de fer

Christ Jesus Barriga Paria, Eleonardo Lucas Pereira & Hernani Mota de Lima
Universidade Federal de Ouro Preto, Associação Brasileira de Mecânica dos Solos e Engenharia Geotécnica, Brasil, cjbarriga_87@hotmail.com

ABSTRACT: Generally, in the design phase the strength parameters obtained in the laboratory correspond to different particle sizes of those sterile disposed. The main objective of this dissertation is to study the waste rock behavior as a function of particle size scale effect and measure the variations in their geotechnical properties. In implementing the experimental program samples were used obtained from physical characterization tests appropriate to current standards. The methodology adopted was based on the behavior of a waste rock sample subjected to direct shear and its relation to the strength parameters obtained for various particle sizes. Based on this research were obtained from particle size correlations with relative compactness known empirically that highlight the influence of these parameters on the value of the friction angle of the waste rock. The concordance and the reproducibility of the results for the different specimen with different grain sizes attest and certify the quality of impressions and proposals made. The scale effect in determining the friction angle of the waste rock was evident the dependence between particle size of the waste rock specimen and waste rock shear resistance was realized by decreasing the tendency of the friction angle with the reduced diameter of its particles.

RÉSUMÉ: Les paramètres de résistance obtenus en laboratoire correspondent aux tailles de particules autres que les déchets miniers. L'objectif principal de cette dissertation est d'étudier le comportement des stériles en fonction de l'effet d'échelle de la taille des particules et de mesurer les variations de leurs propriétés géotechniques. Dans le programme expérimental, des échantillons ont été utilisés à partir de tests de caractérisation physique adaptés aux normes en vigueur. La méthodologie adoptée repose sur le comportement d'un échantillon de roche stérile soumis au cisaillement direct et sa relation avec les paramètres de résistance obtenus pour différentes granulométries. Sur la base de cette recherche ont été obtenus à partir de corrélations de taille de particules avec une compacité relative connue empiriquement qui mettent en évidence l'influence de ces paramètres sur la valeur de l'angle de frottement de la roche stérile. Le bon accord et la reproductibilité des résultats ont montré la qualité de la recherche. L'effet d'échelle dans la détermination de l'angle de friction de la roche résiduelle était évident que la dépendance entre la granulométrie de l'éprouvette de roche perdue et la résistance au cisaillement de roche résiduelle a été réalisée en diminuant la tendance de l'angle de friction avec le diamètre réduit de ses particules.

KEYWORDS: Shear Strength, Mine waste rock, Particle size.

1 INTRODUCTION

Waste rock dumps in a mining can be evaluated from the analysis of the behavior of sandy soils. This approach is based on the matches that take place in the properties of these materials. The lowest concentration of thin plastics, and the effect of compactness in both materials have justified the adoption of evaluation techniques, methods similar to the assays used to properly sandy soils. However, it should be noted that beyond the waste rock have a similarity with the grain size of the sand, their behavior can not be estimated exactly the same of sand, mainly due to mineralogical characteristics that differentiate it and the predominant presence of iron particles (in if the waste iron ore object of this study), thus justifying a more careful analysis.

Normally the granular soils consist of arrangements with irregular shapes formed by randomly varied granulometry particles. Thus, the most important factors influencing the shear strength of a granular soil mass are the type of particle forming this ground, the arrangement of particles and density index (DI), known as the relative density (CR). The behavior of granular soils as dependent on external forces is governed by the individual forces and displacements that occur at each point of contact. As the stresses transmitted in very large contact points, can be said that the shear strength of these soils is due basically to the horizontal component of the force between its particles. To mobilize the resistance to shear deformations should occur in the soil, and the related movement between grains main agent of this action.

Waste rock dumps often are large structures, formed by large amounts of waste rock named frank or marginal ore. In the case of opencast mines, procedures to achieve the ore with substantial economic value, can generate large amounts of waste rock, which, when arranged without control may be likely sources of landslides in frightening scale as occurred in 1966 in the city of Aberfan, Wales, Britain.

To avoid accidents of this magnitude and secure chemical and physical stability of waste rock dumps, many studies and tests are conducted to obtain material properties. In this context, the study of waste rock behavior depending on their particle size associated with strength parameters proves interesting, mainly through analysis to quantify the influence of the size of the particles in the friction angle of the waste rock material.

2. MATERIALS AND METHODS

2.1 Study Location

The study consisted of characterization tests and direct shear made in the Technology Center of Applied Geotechnics (CTGA) Geotechnical Center (NUGEO) of the Federal University of Ouro Preto (UFOP). The trial of this research program was developed from the use of a sample originating from an iron mine located in the Iron Quadrangle, have been collected randomly from a representative point of the sterile pile. To determine the physical and chemical characteristics of the sterile was adopted methodically regulatory procedures according to the Brazilian Association of Technical Standards (ABNT) and when the absence of these, international procedures, such as the American Testing Company and Materials (ASTM).

2.2 Experimental Program

Sterile characterization tests were carefully performed to determine the grain size, grain density, maximum and minimum of voids and direct shear test. The latter aimed to obtain the strength parameters. The direct shear test was chosen by the characteristics of the material under study. The ease of direct shear access and manipulation contribute to the choice of the test.

2.2.1 Comminution of sterile sample, identify and build siz e distribution curves

The evaluation of the sterile grain size is of fundamental importance in waste piles project, due to condition various geotechnical properties of granular materials, such as arrangement of grains, permeability and shear strength, the latter object of study of this work. Thus, it becomes necessary to obtain the initial particle size distribution of the obtained sterile sample for subsequent construction of curve prepared for an analysis of the influence of the particle size in sterile strength parameters used in the study.

Granulometric classification of the sample obtained in the field based on the ASTM D422-36 was established. First there was the screening to determine the coarser fractions of the sample and sizes of similar grains to the gravel and sand, with the use of traditional screens available in the laboratory with a maximum opening of 75 mm and the minimum aperture of 38μm. To obtain the percentages of fines, represented by silts and clays did not take place the conventional sedimentation procedure. We opted for particle size by laser diffraction, measuring the grain size distributions by measuring the angular variation in the intensity of scattered light as a laser beam interacts with the sample dispersed particles. large particles scatter light at small angles to the beam, and smaller particles scatter light at large angles. The particle size of the sterile curve is shown in Figure 1.

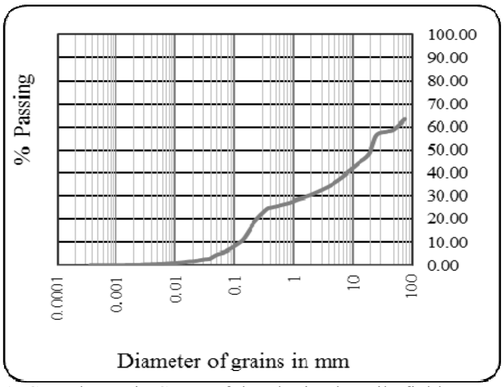

Figure 1. Granulometric Curve of the obtained sterile field.

Since the purpose of this research incorporates especially an evaluation of scale effect, sterile was then brought to the crusher for reducing the particle size so as to achieve the endurance tests in smaller particle size samples.

The jaw crusher with an approximate opening of 18 mm was used for primary crushing. After passing through the primary crushing, then part of the material was again crushed by a roll crusher, adjusted to an approximate opening of approximately 7 mm. As a final process step, a part of the comminuted material on the roll crusher was brought to grinding by a ball mill with load for obtaining fine particle size fraction.

The reproduction of gradation curves had the principle to maintain the proportion of graduation sterile, for smaller particle size materials, adapting them for testing in large, conventional shear boxes. In the case of large equipment (described in this chapter), its shear box has dimensions of 200 mm x 200 mm and 50 mm sample height. In order to obtain a behavior in which burst itself is characterized by the formation of a continuous shear surface in the mass of material, avoiding the sterile shear grain, only the material in the sieve bolt 3/4 " was used. Thus, the greater equivalent diameter of the particle brought to shear box was 19 mm.

Therefore, we used the original material as a reference for obtaining the other curves, considering only part of the curve corresponding to the representation of grains smaller than 19 mm. The other curves were constructed considering the same feature of the original curve, graphically obtained through parallelization. They longitudinally distributed with equal spacing, and then through the analytical method to obtain the through-held weights and percentages for each of the different grain size ranges. Figure 2 shows four curves, with the latter, called EMF-03, with particle size of premeditated material so stay 50% retained on # 200 sieve (75 micron opening). Thus, all samples were to behave like granular most keenly.

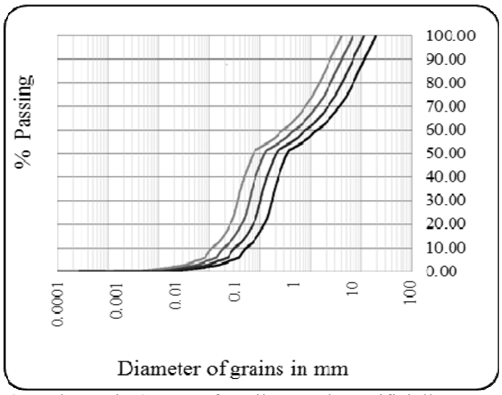

Figure 2. Granulometric Curves of sterile samples artificially structured.

The samples were artificially and structures were identified by 3 letters followed by two numbers. The three letters refer to the Iron Ore Barren, and subsequent algorithms correspond to variation in particle size of the sterile. Held an opposite procedure of particle size analysis, as graphically, critically, it managed to get the values of the cumulative percentages, then get analytically those of retained percentages values accumulated and partial, reaching at the end, the necessary weights the plots. The percentage represented by the curves presented above, are shown in Table 1 (ABNT). Table 2 shows, from the granulometric analyzes of samples, the values of the characteristic diameters D10, D30, D50 and D90 and the value of the non-uniformity coefficient (CNU) and curvature (CC). These values were obtained in order to verify how the grain size of the samples, based on the characteristic diameters, interferes with the friction angle.

Table 1: Particle size distribution according to ASTM

	Scale	EMF-00 %	EMF-01 %	EMF-02 %	EMF-03 %
Grave		26.63	-	-	-
	G	10.27	31.15	23.93	14.38
Sand	M	11.07	13.82	16.71	22.51
	F	39.22	34.44	22.16	12.89
Silt		11.55	18.60	34.42	45.74
Clay		1.12	1.67	2.23	3.38
Colloid		0.14	0.32	0.55	1.10

It is observed that non-uniformity coefficient (CNU) for all samples is above 15, characterizing materials and slaughtered granulometric curves, occupying a larger region, with different diameters, which is typical non-uniform materials.
Although classical classification attribute granular soils as possessing curvature coefficient (CC) between 1 and 3, the sterile studied show a reasonable degree. Despite the D30 value approaches regarding D10, there is a growing when evaluating D50. After all, we tried to work with a well-distributed particle size, to produce a distribution proportionally equivalent to the original sample, as already highlighted in the chapter of the experimental program.

2.2.2 Density and Voids Ratio

The tests were conducted in accordance with auditing standards: ASTM D854-14: Standard test methods for Specific Gravity of Soil Solids by Water Pycnometer.
The procedures of NBR 12004 standards (ABNT, 1990), "Solo - Determination of the maximum void ratio of non-cohesive soils" and NBR 12051 (ABNT, 1991), "Solo - Determination of minimum soil voids non-cohesive "out to obtain the maximum specific mass and a minimum of granular materials, knowing the density of the material grains, to obtain the minimum and maximum void ratios, respectively.
In theory, it calculated the value of the void ratio to a relative compactness (CR) of 50%. Each sample had a different void ratio since their maximum and minimum void ratios are also different. So it is not possible to establish a correlation due to the void ratio, but the relative compactness.
The summary of the values obtained for these samples are shown in Table 3.

Table 3: Dry Densities of each sample for CR = 50%

Sample	e_{max}	e_{min}	e	γ_s g/cm^3	γ_d g/cm^3
EMF-0	0,83	0,24	0,53	3,938	2,568
EMF-1	0,9	0,25	0,57	3,960	2,516
EMF-2	0,86	0,24	0,55	3,952	2,549
EMF-3	1,00	0,32	0,66	4,096	2,467

Obtaining these values was essential for molding sample, as highlighted in the previous chapter, therefore, from the knowledge of the value of the dry density and the mold volume, it was calculated the value of the mass used in each mold to the different samples.

2.2.3 Shear Strength Tests

To evaluate the behavior of artificially structured samples, conventional direct shear tests were performed and large, in compact servo-controlled equipment. The experimental procedures involved series of test samples under different confining tensions following the D3080 / D3080M-11 ASTM standards. The obtained friction angles are showed in Table 4.

Table 4: Effective Friction Angle values (φ')

SAMPLE	Friction (º) Great Port	Angle (φ') Convencional
EMF-00	42,83	-
EMF-01	42,38	41,93
EMF-02	41,95	41,53
EMF-03	40,36	41,37

3 ANALYSIS OF RESULTS

The increase of the EMF-00 sample resistance in large test can also be attributed to the higher iron content present. Thus, both the granulometry and the high iron content (shown on the high value of the specific mass of grains) contributed to the increased value of the friction angle of the original sample
It must be further noted that the samples EMF-01, EMF-02 and EMF-03 were obtained and built considering the same feature of the original curve, graphically obtained through parallelization. Therefore, as already highlighted in this paper, the original sample was comminuted by crushing. The crushing operation produces abrasion between the grains of the material, which can influence the shape and roughness of the grains. The process may generate less rough and angular grains, thereby contributing to the reduction of surface friction, which leads consequently to a reduction of the friction angle. Materials consisting of angular grains tend to have greater than compounds meshing soil rounded particles. Thus, angular grains tend to have higher friction angles.

The linearity expressed in the test with conventional equipment can be related to the unique behavior experienced during shearing for all samples. It is noteworthy that even with the exclusion of the EMF-00 sample the finest sample (EMF-03) has grains with a maximum diameter of 4 mm, corresponding to one fifth of the CP time. The dilatant performance was observed for all samples tested. In the large scale test, whereas the amount of CP should be at least 6 times the diameter of the largest grain of the material to be tested, the EMF-sample 03 is perfectly aligned with the North American standard procedures. It is observed that only for this sample when comparing the two devices, the obtained friction angle was greater for the conventional assay (41,37º) than for large ones (40,36º).

4 CONCLUSIONS

Two automated direct shear equipment, a large and a conventional, were used during the research. Tools were consistent with the data acquisition system and insertion consistent data, and the software used was judged very friendly. These are tools that contribute to precision in data collection and reduction potential reading error sources. Technological advances implemented in the large equipment, to improve the operation were significant, according to the specifications of the American Society for Testing and Materials.

The execution of shear tests at large especially for determining the resistance of sterile parameters proved to be a consistent tool when applied to granular sterile. The agreement and the reproducibility of the results for the different samples with different grain sizes, attested and measured the quality of impressions and proposals made.

The results of trials conducted in conventional equipment were more conservative when compared to the results of the extensive equipment. It was perceived friction angles keep a smaller amplitude difference between the equivalent angles to each reduction in particle size of the waste material studied.

However, it is clear that a reassessment of the maximum grain diameter to be used for a given height of the CP. The effect of grain size during the shear was observed, particularly in conventional equipment, whose samples showed shear during expansion.

The effect of working range in determining the friction angle of the sterile object of this research, it became evident, both in the conventional test as the large test. The dependence between particle size of the samples sterile and the sterile shear resistance was realized by decreasing the tendency of the friction angle with the reduced diameter of its particles.

Finally, it is emphasized that for a proper assessment of the project, with regard to the geotechnical behavior of sterile, are relevant studies of this nature, since many structures are scaled from trials with reduced particle sizes compared to those present in field. In general, when this is done, the outcome of the project is moving in the sense of security, because if conservative design parameters based structures. However, although evaluated, looking for a study of the effect of scale, structures that require smaller disposition areas may be proposed, generating as a result, significantly less environmental impact.

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