Determination of shear strength parameters of dam body material using disturbed sampling

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ABSTRACT
The determination of shear strength parameters is the most important part of stability analysis of geotechnical structures. Cohesion and internal friction angle obtained from direct shear test are generally referred to as shear strength parameters of soil. Although there are numerous studies on shear testing of undisturbed samples, there are not many about determination of strength parameters from disturbed samples. In this study, shear strength parameters of soil material from a tailings dam, which was constructed without compaction, is evaluated. Because undisturbed sampling is impossible due to coarse grain size and looseness of the dam material, density of the direct shear test sample was determined according to standard compaction test results. Obtained results are compatible with the values given in the literature.

RÉSUMÉ
La détermination des paramètres de résistance au cisaillement est la partie la plus importante des analyses de stabilité des structures géotechniques. La cohésion et l'angle de friction interne obtenus lors d'un essai de cisaillement direct sont généralement appelés paramètres de résistance au cisaillement du sol. Même s'il y a de nombreuses études sur les essais de cisaillement réalisés sur des échantillons non-remaniés, il y a peu d'études sur la détermination des paramètres de résistance à partir d'échantillons remaniés. Dans cette étude, les paramètres de résistance au cisaillement du matériel d'un barrage de stérile, construit sans compactage du sol, sont évalués. Puisque l'échantillonnage non-remanié est impossible en raison de la taille des grains grossier et de la faible compaction du matériel du barrage, la densité de l'échantillon de l'essai de cisaillement direct a été déterminée selon les résultats des tests de compactage. Les résultats obtenus sont compatibles avec les valeurs données dans la littérature.

1 INTRODUCTION

In the construction stage of earth dams and other types of engineering structures, loose soils are compacted to a dense state by the reduction of air voids in order to improve the stability of the structure. Compaction increases the unit weight and strength properties of soils. The degree of compaction is quantified in terms of dry unit weight.

Figure 1. View of dam body material (from Tanriseven 2012)

In this study, strength properties of a tailings embankment, which was not compacted during construction stage, were determined by direct shear test with the help of soil compaction test. Figure 1 shows the embankment material containing large amount of gravels and cobbles, which makes it impossible to do undisturbed sampling.

2 MATERIAL PROPERTIES OF DAM MATERIAL

2.1 Moisture Content and Specific Gravity

Table 1 shows the moisture content and specific gravity values of the dam body material.

Table 1. Specific gravity and moisture content values of samples (from Tanriseven 2012)

	Specific gravity	Moisture content (%)
1.Sample	2.93	9.75
2.Sample	2.88	8.67
3.Sample	2.89	7.82
4.Sample	2.84	12.59
Average	2.88	9.71

Average moisture content of the samples was found as 9.71% (ranges from 7.82% to 12.59%). Moreover, specific gravity of the samples changes between 2.84 and

2.93, and the average specific gravity of the dam body was found as 2.88 (Tanriseven 2012).

2.2 Particle Size Analysis

Particle size distribution of the dam body was determined by sieving and sedimentation according to ASTM D422–63, 2007 standard.

Table 2 shows the particle size distribution of the dam body samples taken from different parts of the dam. It can be concluded that the average gravel content is 51%, sand content is 35% and clay content is 14%, approximately.

Table 2. Particle contents of samples (from Tanriseven 2012)

	Gravel (%)	Sand (%)	Clay (%)
1.Sample	49.10	36.30	14.57
2.Sample	52.10	34.90	12.95
3.Sample	53.00	35.90	11.06
4.Sample	49.90	32.70	17.42
Average	51.03	34.95	14.00

In line with the data given in Table 2 particle size distribution curves were obtained for the four samples. These curves are given in Figure 2.

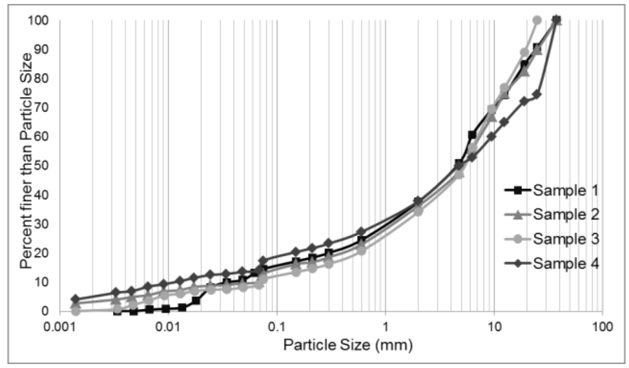

Figure 2. Particle size analysis of dam body samples (from Tanriseven 2012),

2.3 Atterberg Limits and Soil Classification

The Atterberg limits test was performed according to ASTM D4318–10 standards, and results are tabulated in Table 3.

Table 3. Atterberg limits of samples taken from dam body (from Tanriseven 2012)

	Liquid limit	Plastic limit	Plasticity Index
1.Sample	30	19	11
2.Sample	26	18	8
3.Sample	28	18	10
4.Sample	30	18	12

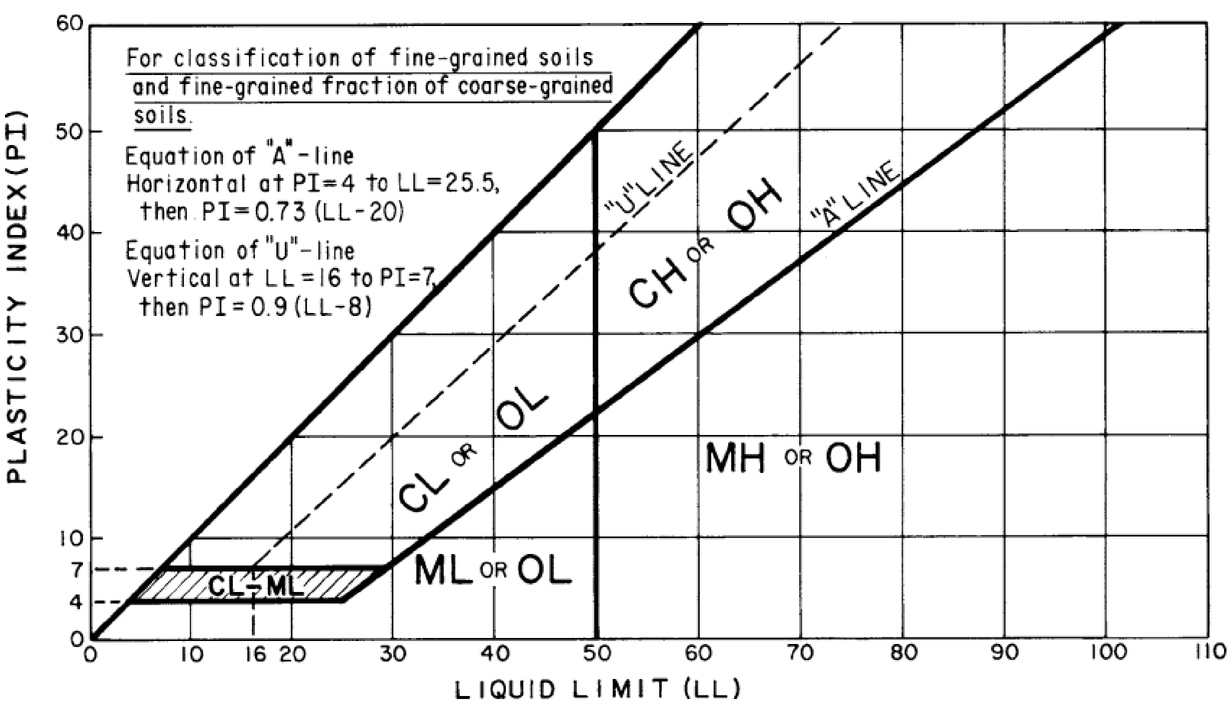

Figure 3. Plasticity chart (from ASTM D2487–11 2011)

Particle size distribution and Atterberg limits were evaluated according to the Unified Soil Classification System ASTM D 2487–11 in order to classify the soil. Dam body samples has coarse material fraction more than 50% and contains sand more than 15% and fine particles more than 12%.

In order to determine if fine particles are clay or silt, the LL and PI of the soil was inspected with the plasticity chart given in Figure Figure 3. Fine particles were found as clay, because the points of all samples fall above the “A line” and plasticity index is greater than 7. Therefore, the dam body material was classified as clayey gravel (GC) with sand and cobbles (Tanriseven 2012).

3 LABORATORY TESTING

3.1 Standard Compaction Test

In the construction stage of earth dams or other types of engineering structures, loose soils are compacted to a denser state. Compaction increases the unit weight and strength properties of soils. Moreover, compaction increases stability of embankment slopes. The degree of compaction is measured in terms of dry unit weight.

In this study, laboratory compaction method was used to determine the correlation between moisture content and dry density of soils taken from different parts of the dam. According to ASTM D698-07 standards, this method can only be applied to soils that have 30% or less by mass of soil retained on the 3/4–in. (19.0 mm) sieve and have not been previously compacted.

Among three types of compaction test methods (method A,B,C), method C is the most suitable one for the material specification. A mold with 6 in. (152.4 mm) diameter was used, thus soil material passing through 3/4 in. (19.0 mm) sieve was prepared at selected water content and placed in three layers into the mold; each layer was compacted by applying 56 blows. The procedure was repeated for a sufficient number of specified water contents to achieve a relationship between dry density and moisture content.

3.2 Direct Shear Test

The shear strength is the resistance of the soil to interparticle movement. This resistance is derived from cohesion and internal friction. Cohesion is the attraction of one particle to another, while internal friction is the resistance to movement. The shear strength of a granular soil is defined by equation 1. This equation is referred to as the Mohr-Coulomb failure criterion. For saturated soils, the stress carried by the soil solids is the effective stress and equation 1 is modified to equation 2.

$$\tau = c + \sigma \tan \phi \qquad [1]$$

$$\tau = c + (\sigma - u) \tan \phi = c' + \sigma' \tan \phi' \qquad [2]$$

Where u is pore water pressure, τ is shear stress, c' is effective cohesion, and σ' is effective normal stress on the failure plane at the failure. The cohesion (c) and angle of internal friction (ϕ) depends on the stress history of the soil, current stress state, and the type of test. Among two types of shear strength tests; drained and undrained; drained shear strength is more suitable for dam stability analysis. The drained shear strength represents the long-term condition where there is no increase in pore water pressure due to the applied load. The undrained shear strength represents the short-term conditions, or construction, where the water pressure does not have time to dissipate.

Coarse granular soils are generally used as fill material for earth-retaining structures and embankments due to their good drainage and compaction properties and high strength. Bauer and Zhao (1993) stated that the shear strength testing of coarse granular soils can be a problem because most testing equipment is of small size with respect to the particle size in the soil. A 60 mm x 60 mm direct shear box is not suitable for testing of coarse granular materials. Nakao and Fityus (2008) stated that in order to obtain reasonable shear strength parameters for coarse granular soils, the size of the shear box must be many times larger than the largest particle size within the soil.

For the determination of effective cohesion and effective internal friction angle belonging to the dam body, direct shear tests were performed on disturbed samples, according to ASTM D3080M–11 standard. The consolidated-drained test was conducted to represent the long-term loading and drainage conditions existing in the field. Complete drainage was allowed during axial loading and shearing stages. The soil was sheared slow enough, to drain the soil completely and to inhibit excess pore water pressures. The shear load was applied to the lower part of the box, while the upper part is restrained against horizontal movement.

As previously mentioned, undisturbed sampling was impossible for the embankment material and the soil did not have a special particle arrangement. In this case, the behavior of the material of a certain composition is primarily ruled by its density, which can be reconstituted in laboratory (Simoni and Houlsby, 2006). For direct shear test, soil specimen was reconstituted in the laboratory with a specified compaction value obtained from standard compaction test.

The required compaction for earth structures is generally denoted between 90% and 95%. Das (2006) stated that in most specifications for earthwork, it is desirable to achieve a compacted field dry unit weight of 90-95% of the maximum dry unit weight obtained in the laboratory by either modified or standard compaction test. Rolston and Lade (2009) indicated the compaction requirement as 90% of the standard density.

In the stated case, compaction effort was not applied to the dam material at the construction stage. Therefore, a systematic approach was developed for specimen preparation. Initially constructed part of the dam has the maximum compaction under the weight of the upper layers. In this sense, the compaction of the dam material decreases towards the upper part of the dam.

In this study, the dam was divided into three main zones according to its elevation from ground surface. It was assumed that each zone respectively had a dry density of 70%, 80%, and 90% of the maximum dry density value obtained from standard compaction test results. Samples with natural moisture contents were placed in three layers within the 300 mm x 300 mm shear box, so that each layer compacted equally. A total of 6 specimens were tested and tests were performed on soil samples having 70%, 80% and 90% compaction, respectively.

A 300 mm x 300 mm direct shear box (Figure 4) was used and the sample was reconstituted in the laboratory with 15 cm depth and with a compaction obtained from proctor compaction test.

Figure 4. Direct shear box (300 mm x 300 mm) (from Tanriseven 2012)

In ASTM D3080M–11 standard, it is stated that the minimum specimen width for square specimens must not be more than 10 times the maximum particle size and the minimum initial specimen thickness must be more than 6 times the maximum particle diameter. According to these information, maximum particle size was determined as 15/6=2.5 cm. Therefore, before testing commenced, the sample was screened to remove all particles greater than 2.5 cm.

Based on discussions of Jewell and Wroth (1987), Bauer and Zhao (1993), Mowafy (1986) and Bauer et al. (1990), it is generally accepted that a shearing rate of around 1 mm/min is appropriate for the shearing of granular backfills. The samples were sheared at a constant rate of 0.8 mm/min, which is suitable for the described material and shearing rate obtained from consolidation curves.

The samples were tested under 345, 580 and 830 kPa normal stresses, respectively. Normal stresses required for testing were estimated by dividing the applied load by the area of the shear box. Specified stresses represent the height of the overburden in relation to depth of the sample in the embankment.

Tests were performed in a water bath and the sample was completely submerged in water to make sure that the samples had no cohesion. In order to measure drained strength parameters, the sample is firstly consolidated under normal load for 20 hours, before shearing it at a rate that is slow enough to ensure that significant excess pore pressures are not created within the sample.

In order to inspect the effect of compaction on shear strength, the samples with different compactions were tested under the same normal stress (580 kPa) and shearing rate.

4 RESULTS

In this study two-stage testing was performed; standard compaction test and direct shear test. Standard compaction test was conducted on four samples. The results of standard compaction test, which gives the maximum dry density and the optimum moisture content, are given in Table 4. Optimum water content is 9.32% and maximum dry density is 2.23 g/cm^3, on average. Maximum dry density values are used for the reconstitution of direct shear test samples.

Table 4. Optimum water content and maximum dry density values (from Tanriseven 2012)

	Optimum water content (%)	Maximum dry density (g/cm^3)
1.Sample	9.84	2.19
2.Sample	8.45	2.28
3.Sample	9.54	2.25
4.Sample	9.43	2.18
Average	9.32	2.23

Compaction curves for the four samples are given in Figure 5.

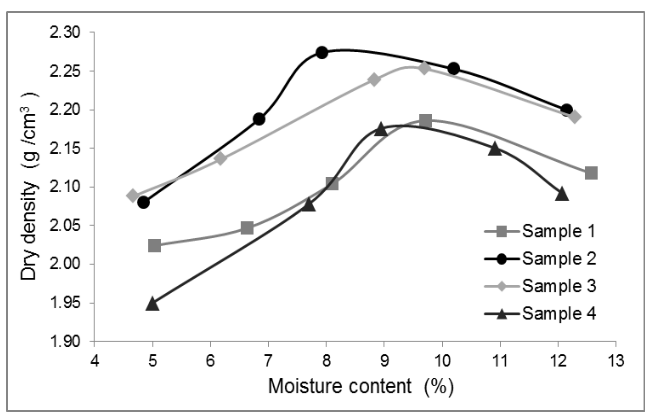

Figure 5. Standard proctor compaction curves for all samples (Tanriseven 2012)

The relationship between compaction and shear strength is given in Figure 6. The sample was compacted at a dry density 80% of maximum dry density obtained from proctor compaction test was failed at 466.7 kPa, whereas the sample with 90% dry density was broken down at 470.2 kPa. In conclusion, 10% difference in sample compaction does not have a great effect on the shear strength of soil.

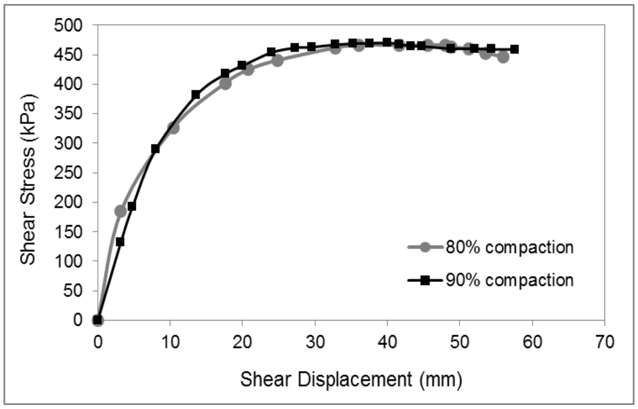

Figure 6. Shear Displacement vs. Shear Stress relationship of a sample with different compaction (from Tanriseven 2012)

Direct shear tests were conducted on six samples (2 sets). Because of insufficient sample amount, sample 1 and 4; and sample 2 and 3 were combined for direct shear testing. This combination was performed according to standard proctor compaction curves, which shows similar compaction characteristics. Peak shear strength and residual shear strength were obtained from shear stress versus shear strain plots. Effective internal friction angle and effective cohesion were determined by plotting the shear stresses at failure from consolidated-drained tests, linear trendlines were drawn both for peak and residual strengths (Figure 7).

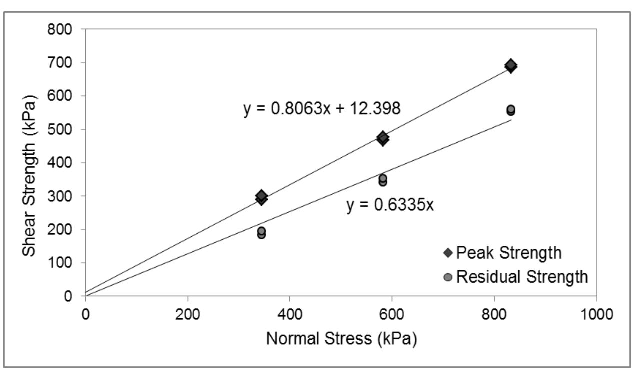

Figure 7. Failure envelopes for embankment material (from Tanriseven 2012)

Mohr Coulomb failure criteria was used to represent the behaviour of the dam body material. In deterministic approach a single value should be selected for design from the scatter of test results (Wolff, 1985). Table 5 shows peak and ultimate cohesion and internal friction angle values for dam body.

Table 5. Peak and ultimate strength parameters of embankment material (from Tanriseven 2012)

	Effective internal friction angle, ϕ' (^{o})	Effective cohesion, c' (kPa)
Peak	38.88	12.40
Ultimate	32.35	0

5 CONCLUSION

In this study, it was intended to determine shear strength parameters of a tailings dam body with unknown compaction.

At first standard compaction test was conducted on soil samples to approximate the compaction and in place density of the dam material.

The experiments and calculations were conducted according to the depth where the soil was lying at the dam body. For this purpose, the dam body was divided into three layers, these layers are approximately under the effect of 345 kPa, 580 kPa and 830 kPa normal stresses, respectively.

A total of 6 specimens were tested and tests were performed on soil samples having 70%, 80% and 90% compaction which represents the three layers of dam. Standard direct shear box (60 mm x 60 mm) is not suitable for testing of coarse granular soils. A large scale direct shear box (300 mm x 300 mm) was used for testing because dam body material was classified as clayey gravel (GC) with sand and cobbles.

In order to check the performance of the study, it was compared to the values given in literature. Typical internal friction angle values for medium-dense sand is given in the range of 32° to 38°, while typical internal friction angle values for medium-dense sandy gravel can range from 34° to 48° (Das, 2006).

Moreover, for sand-sized material typical values of peak and ultimate internal friction angles are 28° to 60° (Holtz and Kovacs, 2003) and 26° to 35° (Das, 2006), respectively. The lower values are applied to rounded particles and loose sand, while the higher values are for angular particles and dense sand. Obtained results are within the range of values given in the literature. Therefore, this approach may be used whenever undisturbed sampling is impossible.

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