Investigation of Stability of Spoil Piles under Different Drainage Conditions

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Abstract

The stability of spoil piles extracted from open pit mines expresses critical significance in terms of environmental factors and human life. Spoil piles could reach high fine grain content as a result of a few environmental factors (weathering, external loading etc.). Different failures in the form of different drainage conditions can be developed for soils, which have high fine content, under several excavation, loading and external conditions. Which mechanical properties are critical during these failures can be differ for different materials. In this study, drained and undrained shear strength properties and corresponding slope stabilities were compared for spoil piles of Sekköy open pit mine in Muğla. Experimental results indicated that undrained shear strength properties were higher than drained shear strength properties. However, an undrained failure could be developed under the high pore water pressures.

Key words:, Drainage condition, pore water pressure, shear strength, stability.

1. Introduction

Surface mining causes a great number of environmental damage (air and water pollution, destruction of original topography, removal of surface vegetation etc.). To minimize the environmental damage, mine reclamation applications are performed for open pit mines. Reclamation is defined as that actions intended to return the land surface to an equivalent undisturbed condition, usually involving replacement of topsoil and vegetation on reconstructed land [8]. Most mine reclamation is focussed on creating landscapes that support wildlife habitat, forestry or agricultural uses with a focus on human safety, geotechnical and erosional stability, and good vegetative cover [9]. As stated above, an integral part of reclamation studies is geotechnical evaluation of spoil piles, which expresses the waste rock of surface mining.

Spoil piles generally have both fine and coarse soil grains due to weathering of rocks obtained by open pit mining. Stress relief, external loading, infiltration of rainwater processes are the main reasons for weathering of spoil piles. The remarkable content of fine grains expresses low permeability for spoil piles. Under the different excavation and loading conditions, various failures in the form of different drainage conditions may be developed for low permeability soils.

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Undrained failure can be developed for soils, which have high fine content, if failure velocity is higher than pore pressure dissipation velocity. Therefore the values of undrained shear strength parameters, which control undrained failures, are very important.

Up to now, comparison of drained and undrained shear strength properties for different soils has been performed by a number of investigators. Terzaghi [12] stated that an undrained failure can be developed for clay, silt and fine to coarse soils. Holtz and Kovacs [4] expressed that for a shearing failure, positive and negative pore pressure developments are valid for normal and over-consolidated clays, respectively. The authors also emphasize that Mohr-Coulomb failure envelope determined for total stresses is lower than determined for effective stresses for normal consolidated clays. On the other hand, for over-consolidated clays, Mohr-Coulomb failure envelope determined for total stresses is higher than determined for effective stresses. Existence of these trends for cohesive soils was verified by Jung et al. [6] and Bro et al. [2]. However up to the present the drained and undrained shear behaviours of spoil piles have not yet been studied detailed.

By considering of the previous studies and limitations emphasized above, this study aims to compare drained and undrained shear strength properties of spoil piles and to investigate critical failure type by assigning different pore pressure distribution for spoil pile slopes. In accordance with this purpose, shear strength properties were determined for spoil piles of Muğla-Milas under different drainage conditions. In the light of physical and mechanical data obtained in the laboratory slope stability analyses have been performed for spoil piles of Sekköy open pit mine in Muğla-Milas.

2. Theory

Mohr-Coulomb failure criterion is defined by Eq. (1). It expresses that two parameters (c and ϕ) and effective normal stress control to the shear strength of soil. But, the cohesion and internal friction angle of soil are varied by strain rate developed across the failure surface. Strain rate controls to pore pressure development in the soil. The critical question is which strain rate develops during the failure.

$$\tau = c + \sigma' \tan(\phi) \tag{1}$$

Where:
c: Cohesion
ϕ: Internal friction angle
σ': effective normal stress

Iverson [5] stated that velocity of a slope failure is varied and related a few parameters (time, rainfall duration, rainfall intensity, hydraulic conductivity etc.) and defines by equation given below.

$$\frac{1}{g}\frac{dv}{dt} = \sin\alpha\,[1 - FS\,(Z,t)] \quad (2)$$

Where:
FS (Z,t): factor of safety (function of material properties (c and ϕ) and pressure head in the slope).
ν: Velocity of failure
t: Time
α: slope angle

Numerical techniques are used to solve this equation and a solution obtained for a slope failure by Iverson [5]. Iverson [5] emphasized that theoretically 1-2 m/s velocities can be developed for the slope of loamy sand material by increasing time since rainfall onset. It means nearly 120000mm/min velocity which is higher than consolidated-drained strain rate values (less than 1 mm/min). As it can be seen from Eq. (2), pore pressure variation in time is most important parameter to determine failure velocity. So the development of positive pore pressures in soil is critical during the failure process.

Zhan and Charles [13] stated that infiltration of rainfall waters decreases negative pore pressure of soil and as time goes positive pore pressure can be developed with heavy rain in the soil during the infiltration process. Ling and Ling [7] investigated the pore pressure distribution on a sand-clay mixed slope model in laboratory scale. Ling and Ling [7] expressed that a positive pore pressure development, which is concentrated near the toe of slope, is present for different rainfall rates.

Consequently, pore pressure produced by external conditions as rapid and long duration rainfalls contribute to raise of failure acceleration. Therefore undrained failure mechanism can be valid for these situations. So consolidated-undrained shear strength parameters (c_u and ϕ_u) must be used to evaluate the undrained failure conditions for slopes.

3. Site Investigation

In this study, slope stability under the drained and undrained conditions has been investigated for the spoil piles of Sekköy open pit mine in Muğla (Figure 1). Field observations have demonstrated that spoil piles in the study area have been overlaid the marl and limestone of Sekköy formation. Spoil piles in the study area is largely composed of laminated marls. As a result of observation of the failures previously developed for spoil piles, it was inferred that failures are rotational type and independent of floor rocks. By using prismatic trenches created in study area, in situ unit weight of spoil piles was determined as13.8 kN/m^3.

To use in laboratory tests disturbed and undisturbed samples were collected from spoil piles. Disturbed samples were collected by using specimen bags. These samples were used in the laboratory experiments to determine physical properties of spoil piles. Undisturbed samples were obtained by thin wall tubes (20 cm in diameter and 45 cm in height) and specimen cutters and used in direct shear tests, which were performed under drained and undrained conditions.

Figure 1. A general view of spoil piles.

4. Laboratory Experiments

By using disturbed and undisturbed samples the physical and index properties (grain size distribution, unit weight, water content and Atterberg limits) and mechanical properties (shear strength properties) of spoil piles were determined by laboratory tests. ASTM [1] standards were used for laboratory experiments.

a) Shear strength characteristics

Shear strength properties of spoil material have been determined by direct shear tests under drained and undrained conditions. According to ASTM [1] standards, **0.21 mm/min** strain rate was ideal to allow pore pressure dissipation for consolidated-drained shear tests. On the other hand **1 mm/min** strain rate was used for consolidated-undrained shear tests. 7 and 3 test sets, which consist of at least 3 specimens, were used in consolidated-drained and consolidated-undrained shear tests, respectively. The test results and drained and undrained failure envelopes can be seen from Table 1 and Figure 2.

Table 1. Shear strength parameters determined by direct shear tests.

Direct shear test results			
Consolidated-Drained Test		**Consolidated-Undrained Test**	
c (kPa)	ϕ (°)	c (kPa)	ϕ (°)
8.6	30.6	13	33.2

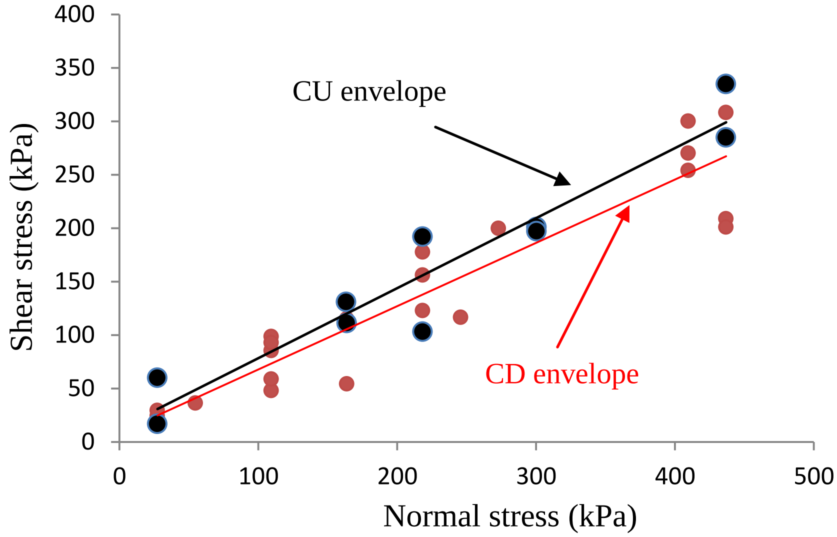

Figure 2. Failure envelopes obtained for drained and undrained shear tests.

b) Phsical and Index Properties

Physical and index properties (Grain size distribution, Atterberg limits and water content) of spoil material were determined by laboratory tests. Grain size analyses were performed on 5 disturbed samples. According to the results of grain size analyses, fine and coarse grains in the spoil material is nearly equal. It can be seen from Table 2 that spoil material has averagely %47 fine and %53 coarse content. Atterberg limits and water content of spoil material were summarized in Table 3.

Table 2. The results of grain size analyses.

	Grain size			
	Clay(%)	**Silt(%)**	**Sand (%)**	**Gravel (%)**
Range (%)	5-21	20-58	9-43	15-33
Average (%)	11.8	35.2	29	24

Table 3. The water content and Atterberg limits of spoil material.

Water content (%)	**Liquid limit (%)**	**Plastic limit (%)**	**Plasticity index (%)**
21	41.1	25.6	15.6

5. Comparision of Drained and Undrained Slope Stabilities for Spoil Piles

Terzaghi [12], Iversen [5] and Ling and Ling [7] expressed that undrained failure could be developed for soils which have considerable fine content. In this study spoil material has nearly 50 percent fine content so it can be said that undrained failure could be developed under suitable conditions. Excessive pore pressure generation is a major reason to create a undrained failure for a soil slope. Iversen [5] and Zhan and Charles [13] stated that positive pore pressures can be developed during infiltration process with severe rainfall. In addition that high failure velocities could be reached with time since rainfall onset emphasized by [5].

In this study slope stabilities under different drainage conditions were compared for spoil piles, which have 10, 20 and 30 meter slope heights. For three different slope profiles, which have factor of safety higher than 1, pore pressures concentrated across the toe part of failure surface were assigned to reach limit equilibrium accordance with distribution of laboratory findings of Ling and Ling [7] and Zhan and Charles [13]. In analyses, two different factors of safety (F=1.05 and F=1.10) were used. 20 m slope profile and assigned pore water pressure values across to failure surface to reach limit equilibrium were given in Figure 3 and 4. In analyses SLOPE/W [11] software was used and the results of Morgensten-Price [10] method were based on. Slope stability analysis results were summarized in Table 4.

Table 4. Maximum pore pressures needed to create drained and undrained failures for different slope heights.

H (m)	Pore pressure (kPa)	F=1.05	F=1.10
30	u_{cd}	16.4	25
	u_{cu}	59.2	76.3
20	u_{cd}	10.9	21
	u_{cu}	12.1	27.5
10	u_{cd}	9.3	14.6
	u_{cu}	10.2	22.5

It can be seen from Table 4 that 9.3, 10.9 and 16.4 kPa maximum pore pressures are required to create consolidated-drained failures for 10, 20 and 30 m slope heights, respectively. On the other hand undrained failures could be developed after exceeding 10.2, 12.1 and 59.2 kPa maximum pore pressures for 10, 20 and 30 m slope heights, respectively. It means that when induced pore pressure by infiltration of rain water exceeds a threshold value for slope profiles, which have factor of safety higher than 1, the factor of safety of slope will reach to limit value (F=1) and consolidated-drained failure will start. If the heavy rainfall continues then the factor of safety will decrease dramatically. So the velocity of failure will increase [5] and undrained failure will develop.

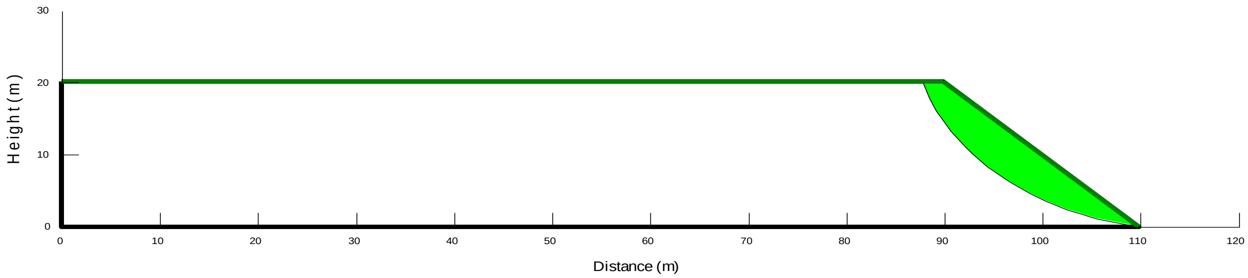

Figure 3. Slope geometry and failure surface obtained for a 20 m high slope.

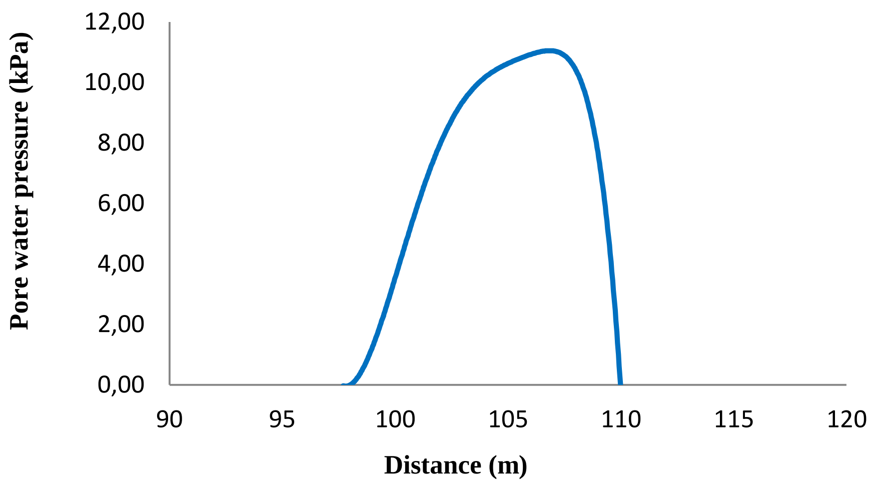

Figure 4. Pore pressure distribution assigned across the failure surface needed to reach limit equilibrium to start a consolidated-drained failure for a 20 m slope.

4. Conclusions

In this study it was aimed to compare drained and undrained shear strength properties of spoil piles of Muğla-Milas. The results of laboratory experiments indicated that consolidated-drained shear strength properties of spoil material is higher than consolidated-undrained properties. According to results of slope stability analyses performed for three different slope heights (10, 20 and 30 m), the pore pressure requirement to start consolidated-drained failures increases by slope height increment. After the beginning of drained failures, if heavy rainfall continues then consolidated-undrained failures will develop by increasing velocity of failure.

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