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A NEW LABORATORY MODEL OF A SLAKING CHAMBER TO PREDICT THE STABILITY OF ON-SITE COAL MINE SPOILS

Chaminda Gallage[1], Golam Mostofa[2], David Vosolo[3] and Jay Rajapakse[4]

[1,2,3,4]Science and Engineering Faculty, Queensland University of Technology (QUT), Australia

ABSTRACT: Slope failures of spoil piles pose a significant safety risk in open-cut strip mining due to slaking over time due to overburden pressure and water saturation. Most spoil pile failures occur when the pit has been previously filled with water and then subsequently dewatered. It is important to understand how the mechanical properties of base spoil material are affected by slaking when designing safe spoil pile slope angles, heights, and dewatering rates. A new laboratory slaking chamber (360mm ID, 400mm high with 20mm wall thickness) has been designed and constructed to accommodate approximately 60 kg of spoil (unit weight, 18 kN/m3) and a simulated overburden pressure of 1000 kPa. Consolidation of the spoil can be measured through a linear variable differential transformer (LVDT) attached to the system. Using this apparatus, a fresh spoil material collected from a coal mine in Brown Basin Coalfield of Queensland, Australia was subjected to high overburden pressure (0 – 900 kPa) under saturated condition and maintained over a period of time (0 – 6 months) allowing the material to slake and successfully tested for classification, permeability, and strength properties. Results suggested that the slaking of saturated coal mine spoil increase with overburden pressure and the time duration over which the overburden pressure was maintained. Shear strength and permeability of spoil decreased with increase in spoil slaking.

Keywords: Coal Mine Spoil, Slaking Chamber, Overburden Pressure, Shear Strength, Permeability

1. INTRODUCTION

In open-cut strip mining, waste material is placed in-pit to minimise operational mine costs. Slope failures in these spoil piles pose a significant safety risk to personnel, along with a financial risk from loss of equipment and scheduling delays. It has been observed that most spoil pile failures occur when the pit has been previously filled with water and then subsequently dewatered. The failures are often initiated at the base of spoil piles where the material can undergo significant slaking (disintegration) over time due to overburden pressure and water saturation. The spoil materials are typically composed of blasted fragments of mudstone, siltstone and sandstone [1]. The mean particle size of spoil is highly, ranging from fines to particles of size 0.5 m to 1.0 m depending on in-situ properties of overburden, blasting technique and equipment used. Within the coal mine industry, spoil materials are categorised into four groups; Category 1 (Cat -1), Category 2 (Cat – 2), Category 3 (Cat-3),and Category 4 (Cat -4) [2].

In open-cut strip mining, waste materials are placed in-pit to minimise mine operational costs. It is common to observe blasted rock (Cat-3 or Cat -4) being placed by draglines to form the base for spoil piles and the weaker spoil materials such as soil (Cat-1) and highly weathered rocks (Cat-2) are placed by dump trucks on the top of base material to form the final spoil profile. To accommodate increasingly high volumes of spoil within a mine pit, spoil pile heights and slope angles are increased. In the Brown Basin Coalfield of Queensland in Australian, the typical height of spoil pile is ranging from 30 m – 70 m and the slope of the spoil pile varies between 26^0 to 40^0 [3]. As spoil pile heights are increased, the foundation material is subjected to a higher stress regime that may increase the rate of disintegration (slaking) of base spoil material due mechanical breakdown. The slaking of the base material is further increased with time when this high stress is maintained in saturated conditions. In open cut mining, it is common to observe a 10 – 15 m height of water in the pit when mining and pumping is stopped temporarily. Therefore, it is assumed that the base spoil material is saturated.

Slaking has been found to transform fresh or slightly weathered Permian (Cat -4 or Cat -3) at the base of spoil pile to weaker or/and weathered Permian [2]. This mechanical breakdown leads to a decrease in particle sizes, consequently reducing the shear strength and permeability of slake affected materials. This reduction in material properties of spoil base materials have been a root cause for the failures in spoil piles during dumping, and flooding/dewatering events. The failures of spoil piles can cause human casualties, damage to equipment, delay in miming, and an increase in mine operational costs.

In order to determine safe height and slope angles for spoil piles and their appropriate dewatering rates, it is important to understand how the shear strength and permeability of saturated spoil foundation materials decrease with overburden pressure and time. Research has been conducted [4] to determine the shear strength and other properties of relatively fresh coal mine spoil under high overburden stress. However, no research has been conducted to investigate the degradation of properties of saturated spoil material due to slaking under overburden pressure and time. This paper presents the results of laboratory testing carried out to investigate the effects of slaking on classification, strength, and permeability properties of coal mine spoil (Category -3).

2. DESIGN AND CONSTRUCTION OF THE SLAKING CHAMBER

The chamber consists of an acrylic cylinder with internal diameter and height of 360 mm and 400 mm, respectively, and a wall thickness of 20 mm. The top and the bottom stainless steel plates are fastened by eight bolts to seal the chamber. The chamber can accommodate approximately 60 kg of spoil (assume initial unit weight of 18 kN/m3) allowing space for the piston plate. This mass is expected to be sufficient to yield results for different tests such as classification, shear strength, and permeability of slaked spoil materials. Simulated overburden pressure is achieved by means of applying air pressure to compartment above the piston which then compresses the spoil in the lower compartment with the applied pressure. A rubber seal is attached to the piston to prevent air leak through the space between the piston and the inner wall of the acrylic cylinder. A pressure of 20 kPa is needed to overcome the friction between the piston and the inner wall of the cylinder.

Two porous stones (Bronze) were embedded in the base plate and in the piston where the material is in contact. The sample can be saturated by sending water from the bottom and allowing water to freely flow through the sample and to exit from the top. Water pressure in the sample is maintained at atmospheric conditions. It is important to make sure that the water in the chamber is under atmospheric conditions so that the applied pressure on the spoil from the piston is equal to the effective stress. The consolidation of the spoil over the period of time under the applied constant overburden pressure can be measured directly from the linear variable differential transformer (LVDT) attached to the piston shaft.

Fig. 1 shows a schematic diagram and a photo of a pressure chambers used. Four such chambers were employed in this experimental program.

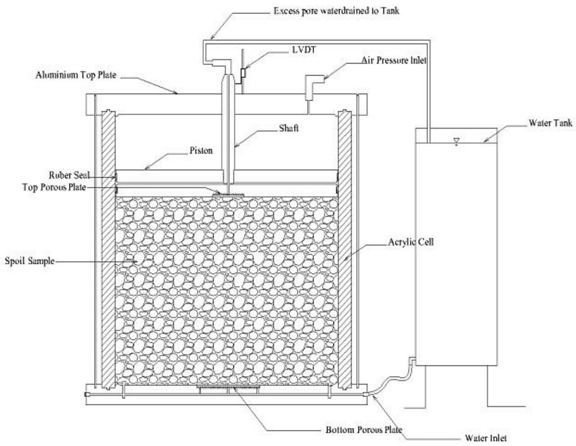

Fig. 1. (a) Schematic diagram, (b) Photo of a pressure chamber used in the experimental program

3. TEST MATERIAL

Fresh coal mine spoil (Category -3) was collected from an open-cut mine in Brown basin coalfield in Queensland, Australia. The particle size distribution of the collected spoil material is shown in Fig. 2. According to Australian standard AS 1289.3.9, Liquid Limit, Plastic Limit, and Linear

Shrinkage were determined as 34.1%, 22.0% and 4.9%, respectively. Further, the material was analysed for its mineral composition using X- ray diffraction with the results are shown in Table 1.

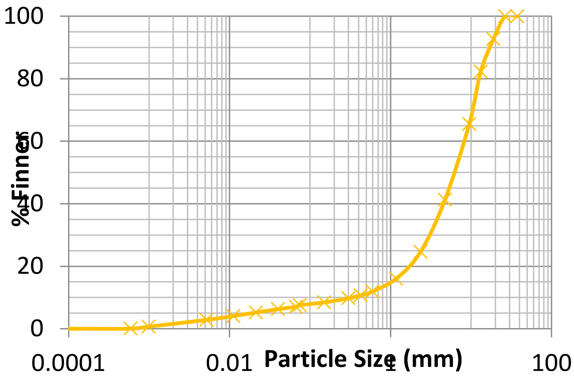

Fig. 2 Particle size distribution of test material

Table 1: Mineral composition of test material

Minerals	Amount (%)
Quartz	34.00
Albite	28.80
Kaolin	2.30
Mixed layer illite	9.20
Mica, 2M1	16.40
Anatase	8.90

4. TEST PROGRAM AND METHODOLOGY

The saturated spoil material was subjected to slaking under different overburden pressures, which represent the height of the spoil pile, and time over which the overburden pressured were maintained. To achieve the objectives of this research, classification, shear strength, and permeability properties of spoil that would be subjected to slaking under the conditions given in Table 2 will be measured in the laboratory using standard laboratory test methods. Sample 1 is the reference material which is fresh spoil and not subjected to overburden pressure in the chamber.

Table 2: Slaking condition of spoil samples

Duration of slaking	Overburden pressure (kPa)		
	300	600	900
Zero (2 days)	Sample 2	Sample 3	Sample 4
3 Months	Sample 5	Sample 6	Sample 7
6 Months	Sample 8	Sample 9	Sample 10

To obtain each spoil sample given in Table 2, the following methodology was followed:

- 320 mm height of the pressure chamber was divided into 10 equal layers as shown in Figure 3a
- The water content of the spoil was measured. Bulk mass of spoil required for each layer to achieve dry unit weight of 18 kN/m^3 was calculated. Dry unit weight of 18 kN/m^3 was chosen as it was the average unit weight of spoil pile measured in the field.
- Bulk mass of spoil required for each layer to achieve the dry unit weight of 18 kN/m^3 was poured into the chamber and tamped using the weight shown in Fig. 3a until the required height was achieved. This procedure was repeated for all 10 layers to achieve the spoil height of 320 mm.
- The piston and the top plate were mounted and LVDT was set to measure the vertical displacement of the piston. The vacuum was connected to the top port coming through the piston and air in the compacted spoil was sucked for about 2 hours.
- As shown in Fig. 3b, the water tank was then connected to the bottom of the chamber and the system was left for 1 day (24 hours) for saturation.
- After saturation, air pressure equivalent to overburden pressure of (e.g: 300, 600,800(900) kPa) was applied in to the upper chamber and maintained for a period of 2 days, 3 months, 6 months, and 12 months.

Fig. 3. (a) Compacting spoil into the pressure chamber, (b) Saturation of spoil compacted into the pressure chamber

- After the saturated spoil has been subjected to slaking over a predetermined period of time under a certain overburden pressure, the spoil was taken out from the chamber after releasing pressure and removing the top plate and the piston.
- Each sample slaked under different pressures over different time periods was tested for

particle size distribution following Australian standards

- To obtain particle size distribution down to 75 microns, wet sieving was conducted. Particle size distribution for particles smaller than 75 microns was obtained using a Malvern particle size analyser.
- To measure the permeability, the spoil was compacted into the mould measuring 150 mm diameter (see Fig. 4) to achieve the dry unit weight of 18 kN/m^3 and the constant head permeability was performed.
- To measure the shear strength parameters, the specimen with 100 mm diameter and 200 mm in height compacted to achieve the dry unit weight of 18 kN/m^3 was tested in triaxial apparatus under undrained consolidation test conditions (with pore-water pressure measurement) following multi-stage test procedures. Fig. 5 depicts the triaxial system used for this experimental program.

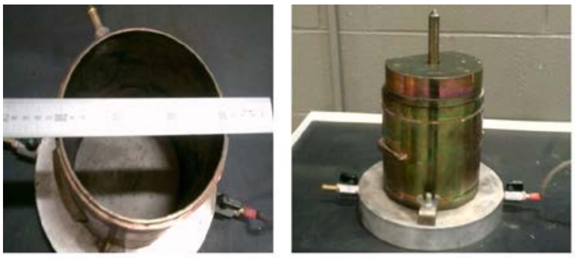

Fig. 4. Permeability cell used for measuring permeability using constant head method

Fig. 5. Triaxial system used for measuring shear strength properties of spoil

5. RESULTS AND DISCUSSION

Results of soil classification tests (particle size distribution), permeability, and shear strength tests of sample 2 - 10 are compared with those of Sample 1. Sample 1 is considered as the reference material as it is unslaked (fresh) spoil which was directly collected from an open-cut coal mine in Brown basin coalfield in Queensland, Australia. These results can be used to discuss overburden pressure and time effects on spoil slaking.

5.1 Grain Size Distribution

The effect of slaking on particles size distribution of spoil samples was determined from combined results of wet sieve analysis and laser diffraction analysis (Malvern apparatus). The Fig. 6 represents particles size distribution of nine slaked and one fresh spoil sample.

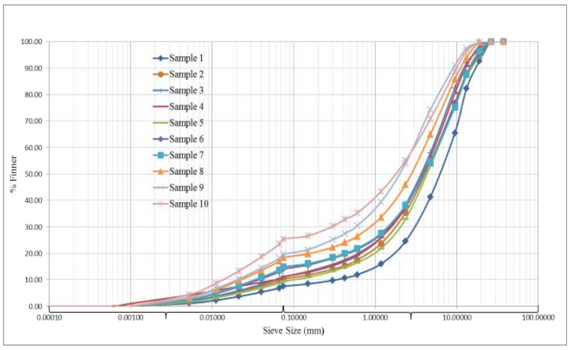

Fig. 6. Particle size distribution of slaked spoil samples

As seen in Figure 6, the amount of fine particles increased with the increment of slaking time and overburden pressure. For spoil Sample 1, the amount of material finer than 75µm was approximately 8% which grew with increasing time and pressure to about 25% for spoil Sample 10 after 180 days under 900kPa overburden pressure. However, there was no significant increment of clay particles (particle size less than 0.002mm) due to slaking but had a significant increment of silt particles. The increase in the amount of fine particles in spoil samples with saturation time and pressure is an indication of more material disintegration or slaking

5.2 Hydraulic Conductivity

The influence of slaking on hydraulic conductivity was determined by the constant head permeability test. Fig. 7 portrays the influence of overburden pressure and slaking time on permeability. It can be seen that the permeability decreases with an increase in overburden pressure as well as an increase in slaking time. Overburden pressure has a significant impact on permeability when it is slaked over a longer duration (e.g. 180 days). When the spoil is subjected to slaking over a long period for example, after 180 days of slaking, the permeability decreased from 0.884×10^{-06} m/sec to 0.017×10^{-06} m/sec (about 1/44), when the overburden pressure was increased from 300 to 900 kPa. For shorter slaking periods (e.g. two days), the permeability decreases from 2.1×10^{-06} m/sec to 0.96×10^{-06} m/sec (about ½) when the overburden pressure increases from 300kPa to 900kPa.

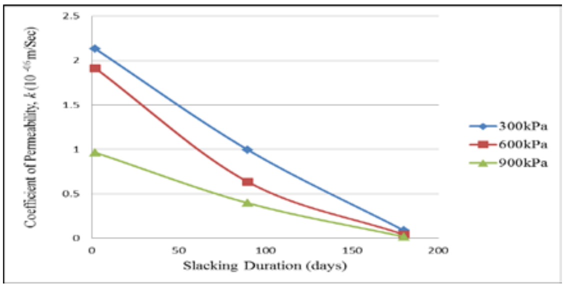

Fig. 7. Effect of slaking time and overburden pressure on hydraulic conductivity

When the overburden pressure is increased, particles are crushed and compacted to decrease the volume of voids. The overburden pressure was maintained over a period of time. Spoil particles are further degraded and broken down in smaller fragments. As a result of the degradation of particle size the porosity decreased and the unit weight increased with time and overburden pressure. Permeability or flow through any sample is a function of unit weight, porosity and effective particle size and shape. Therefore, permeability decreases with increasing overburden pressure and slaking time. In brief, due to slaking over 180 days under different overburden pressures, spoil materials become low permeable gravel type materials from medium permeable.

5.3 Shear Strength

The multistage consolidated undrained triaxial tests were performed on cylindrical spoil samples. Each test specimen of 100mm diameter and 200mm height was prepared to achieve a dry density of $18kN/m^3$ by wet compaction with initial moisture content of 10%. Once a specimen was enclosed in a 0.8 mm thick latex membrane, it was saturated to achieve B-value of above 0.95. Multistage triaxial tests were conducted in three stages with three different cell confining pressures of 500kPa, 600kPa and 700kPa and at the beginning of each stage back pressure was maintained at 300kPa. The effective confining pressures at the beginning of each stage were 200, 300 and 400kPa.

After consolidating the specimen for about two hours under drained conditions and stage one stress conditions (cell pressure 500kPa and backpressure 300kPa), it was sheared by applying monotonic vertical stress with a vertical strain rate of 0.05% per minute. The failure for each stage was assumed when maximum deviator stress (σ_d) was reached peak or 2% vertical strain (from the beginning of each loading stage) was achieved. Once the failure was reached for stage one, the applied vertical stress (deviator stress) was released and stage two stress conditions were applied (cell pressure, $\sigma 3 = 700$ kPa and backpressure = 300 kPa). The specimen was then consolidated under drained conditions for about two hours before shearing it under undrained conditions until above mentioned failure criteria was achieved. Then, following the same steps, stage three of the test was completed. Fig. 8 illustrates the observed axial strain (ε_a) versus deviator stress behavior of a multi-stage triaxial testing of the spoil specimen prepared using Sample 9. Using these values and confining pressures for each stage, total and effective major principal stresses (σ_1 and σ_1') and total and effective minor principal stresses (σ_3 and σ_3') were computed. Using effective major (σ_1') and minor (σ_3') principal stresses at failures the Mohr-Coulomb failures envelop was then drawn to obtain effective shear strength parameters: effective cohesion (c') and effective friction angle (ϕ'). Table 3 summarizes the shear strength properties of spoil samples obtained from multi-stage triaxial testing.

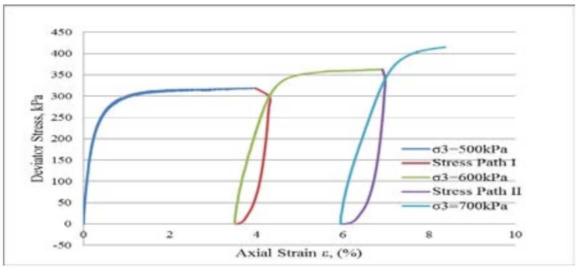

Fig. 8. Deviator stress vs axial strain obtained from multi-stage triaxial test on Sample 9

The effective shear strength parameters cohesion and friction, varied from 1kPa to 40kPa and 38.62° to 33.22° due to slaking under different conditions (Table 2.4). As can be seen from Table 3, effective friction angle of spoil materials dropped due to slaking approximately 5.4° from the initial fresh condition. Furthermore, effective cohesions were exhibited by gradual increment up to 90 days and after 180 days; it dramatically increased to 40kPa. For reduction of friction angle, both slaking time and overburden pressure played similar roles whereas for effective cohesion the increment slaking time played a dominate role. The undrained friction angle and cohesion presented in Table 3 indicated a similar conclusion. Due to slaking, the undrained friction angle for sample 2 was dropped to 18.47° from 26.98° (Sample 1). The friction angle gradually decreased with minor exemptions, with slaking time and overburden pressure which finally reached to 15.78° for spoil Sample 10. The undrained cohesion gradually increased from 10kPa, Sample 1 to 30kPa for Sample 7. Then, it increased dramatically to 190kPa. In fact, undrained cohesion was influenced dominantly by slaking duration

Table 3: Shear strength properties of spoil samples

Samples	Effective Cohesion, C' (kPa)	Effective friction angel, φ' (°)	Total Cohesion, C (kPa)	Total friction angel, φ (°)
Sample 1	1.00	38.62	12.00	26.98
Sample 2	2.00	34.75	12.00	18.47
Sample 3	2.00	33.29	10.00	15.83
Sample 4	2.00	34.59	15.00	18.75
Sample 5	2.00	34.74	20.00	17.05
Sample 6	3.20	33.30	19.00	16.30
Sample 7	4.00	33.83	30.00	16.90
Sample 8	10.00	33.75	40.00	17.37
Sample 9	20.00	33.52	50.00	15.68
Sample 10	40.00	33.22	190.00	15.78

6. CONCLUSION

The grain size distributions of spoil samples(slaked samples) suggest that this category 3 soil material is not a highly slakable material. The amount of fines (particle smaller than 0.075 mm) in the fresh soil sample (Sample 1) was about 8%. It increased to the maximum of 25% in sample 10 which was slaked over 180 days under 900 kPa overburden pressure. No significant increase in clay particles (particles smaller than 0.002 mm) were observed in sample 10 compared to sample 1 (fresh spoil).

The shear strength properties of spoil samples were obtained from consolidated undrained triaxial tests with pore-water pressure measurement. The undrained shear strength parameters from triaxial tests revealed that the material strength of spoil materials, category type 3 was medium to low with small cohesion.

Triaxial tests on fresh spoil gave effective friction angle of 38.6^0, undrained friction angle of 27^0, effective cohesion of 1 kPa, and undrained cohesion of 12 kPa. Due to slaking of spoil material over six months under 900 kPa overburden pressure, the effective friction and undrained friction angles decreased by 5.4° and 11.2°, respectively. The effective and total cohesion increased by 40 kPa and 170 kPa, respectively.

The constant head permeability test results indicated a reduction in hydraulic conductivity due to slaking. The permeability property for fresh spoil was 6.99×10^{-6} m/sec and dropped rapidly for short termed slaked spoil samples with pressure. After six months of slaking, the effect of overburden pressure became insignificant and the permeability coefficient dropped to approximately 1.70×10^{-8} m/sec

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8. REFERENCES

[1] Kalinski ME, Karem WA and Little LM, "Estimating hydrocompression potential of mine spoils from a site in eastern Kentucky using dry unit weight and moisture content", International Journal of Mining, Reclamation and Environment, Vol.24(4), 2010, pp. 350–362.

[2] Simmons J, and McManus D, (2004). "Shear strength framework for design of dumped spoil slopes for open pit coal mines", Proceedings of Advances in Geotechnical Engineering, Vol.2, 2004, pp. 981-991.

[3] Williams DJ, Zou JS and Graham J, "Reliability index versus safety factor for coal mine slope pipe stability", Proc. of the International Conference on Slope Stability, Isle of Wight, England, 1991, pp. 71-77,

[4] Hendrychova M, Salek M, Tajovsky K and Rechor M, "Soil Properties and Species Richness of Invertebratesons on Afforested Sites after Brown Coal Mining", Restoration Ecology, Vol. 20(5), 2012, pp. 561–567.

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Corresponding Author: Chaminda Gallage