Application of Bentonite Grout in AKARPILES

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ABSTRACT

AKARPILES is an innovative solution for slope stabilization with less environmental footprint. Grout is one of the key components in AKARPILES. This study focused on stabilizing surficial slope failure, which commonly occurred in Malaysia. There are many methods help to improve slope stability of slopes. The idea of AKARPILES was innovated from the function of the tree root system in slope stabilization. Grout was pumped in and discharged through the outlets on the piles, after the piles are installed on the slope and intercepting the slip plane. The grout had then filled the voids within the soil with random pattern. SKW mixture was used to simulate the soil slope. Trial mix of the grout was carried out to obtain the optimum mixing ratio of bentonite: cement: water. Cone penetration test (CPT) and vane shear test (VST) were conducted on the grout mixture in a different mix ratio to obtain the strength gained. Grout dispersion area by two different designs of AKARPILES were recorded and compared. The results were affected by the design of piles.

Keywords: *Slope stabilization, surficial slope, soil nailing, bentonite grouting*

Introduction

Landslide becomes a very common issue in Malaysia and usually happened in hilly areas. Many factors might contribute to slope failure, including uncontrolled logging activities in slopes and rapid development in hilly areas. Logging activities will increase the surface runoff causing surface erosion and fasten the slope failure. The idea of AKARPILES was generated from the tree root system in slope stabilization. After the piles are installed on the slope and intercepting the slip plane, grout was pumped in and discharged through holes on the piles. One of the key elements in AKARPILE for slope stabilization is the grout filling the voids and holding the soil from failure. The objectives of this paper are to characterize the grout and determine the strength of grout.

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This study is based on application of AKARPILES in surfacial slope stabilization, which refers to slope failure with a depth of less than 4 m.

The results of this paper provided an optimum bentonite grout mix ratio to be applied in AKARPILES. Moreover, the grout for AKARPILES was designed to be mixed on site and this might reduce the transportation cost. Less man power and machineries are required by construction industries for development. The time required for the slope stabilization process is also reduced due to simple installation mechanisms for AKARPILES. This methodology believed to enhance the safety of slopes and minimize the risk of slope failure.

Literature Review

Slope material have a tendency to slide due to shearing stress created in the soil by gravitational and other forces, such as seismic activity and water flow [1]. Factor of safety (FOS) is the ratio between the resistance forces and gravity pull, it is important in order to determine slope stability. JKR/Malaysia (2010) had outlined that the minimum global FOS for treated slopes shall be 1.5. Most cases in Malaysia, the slope fails when the rainfall intensity is larger than the soil infiltration rate, consequently raising pore water pressure that trigger slope failure [3].

The concept of AKARPILES includes soil nailing and grouting. Grouting is the action that placing grout material under pressure to seal or stabilize joints and pores of subsoil. There are various types of grouting, such as fill grouting, compaction grouting, jet grouting and fracture grouting [4]. Pressured grouting is one of the grouting techniques in soil stabilizing in soil nailing. Grout can be placed under pressures ranging from 0.5 to 8 MPa or gravity force [5].

There are few common materials for grouting suspensions, i.e. cement, bentonite, additives, clay, water, sand and fillers. Bentonite has a significant effect on the compressive strength, rheological properties and fluidity of grout [6]. Sodium bentonite absorbs more water than calcium bentonite and it expands to a volume 12-15 times its original dry size when fully saturated with water. A small amount of cement is therefore introduced into the grout to reduce the expansive properties of bentonite [7]. There are some basic considerations of grouting, i.e. applied pressure of grouting, flow behaviour of grouting material, ageing behaviour of grouting material and strength of grout [8].

Methodology

The concept was based on the function of vegetation that prevent soil slope from sliding. Figure 1 shows the schematic diagram of AKARPILES in slope. Grout is pumped out through the outlets in the piles. In this study, a mixture of sand, kaolin and water (SKW) with a ratio of 8: 2: 1 was used to simulate soil in the test. Two designs of AKARPILE were produced by the scale 1:10. Table 1 summarizes the differences between Piles design A and design B.

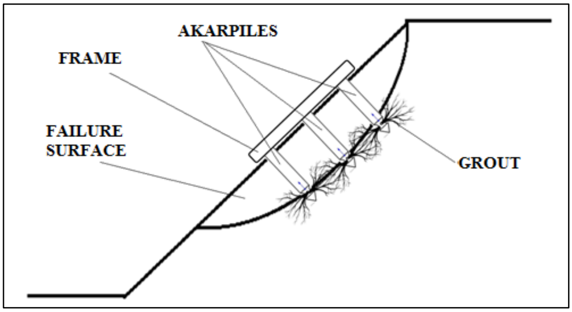


Figure 1: Schematic diagram of AKARPILES in slope stabilization.

Table 1: Design specifications for Design A and Design B of AKARPILE

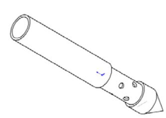
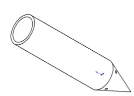
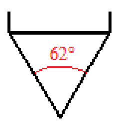
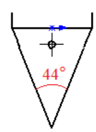
Specification	Design A	Design B
3D view		
Angle of pile tip		

Table 1: Design specifications for Design A and Design B of AKARPILE (cont.)

Specification	Design A	Design B
Length	175 mm	110 mm
Penetration depth in slope	120 mm	100 mm
Diameter of outlets	4 mm	2 mm
Number of grout outlets	8	4

Flowability test, cone penetration test (CPT) and vane shear test (VST) were carried out to obtain the behavior of grout. Grout with water/bentonite (w/b) ratio of 2, 4 and 6 were produced with mixer. The lift method was used to test the flowability of grout. The spread diameters for every test were recorded. Figure 2 shows the schematic diagram of lift method to test the consistency of grout [9].

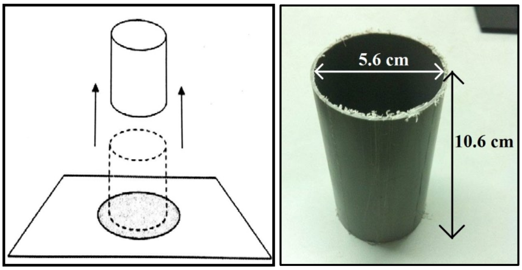


Figure 2: Schematic diagrams in lift method

CPT was carried out to estimate the effect of the w/b ratio on the material's strength. After the mixing process, three containers were filled with different w/b ratios of grout layer by layer up to three layers. The dimensions of the containers were 9.3 cm (width) × 13 cm (length) × 4 cm (height), as shown in Figure. 3. 2-5 times of tapping of the container for each layer was done to remove air in the grout and the surface was smoothened by a scraper. The mass of grout was measured to calculate the density of grout.

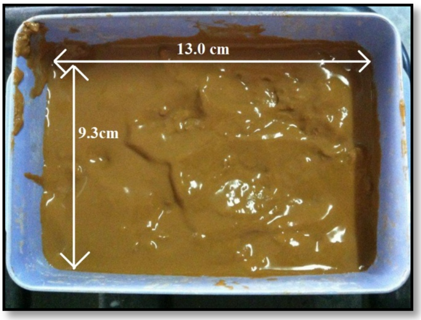


Figure 3: Container used to fill with grout

The 30 % and 50 % mass of bentonite was replaced by cement the in grout w/b = 6 to carry out CPT and VCT. The CPT was carried out by referring to BS1377: Part 2: 1990 with standard cone penetrometer (see Figure 4). The cone was released from the surface of the soil sample and left to penetrate by its self-weight for 5 seconds, followed by measuring of the penetration depth. The penetration measurements were taken at different time intervals of 30 min, 60 min, 90 min and 120 min, 180 min, followed by 24 hours, 48 hours and 72 hours to monitor the strength gained of the bentonite grout.

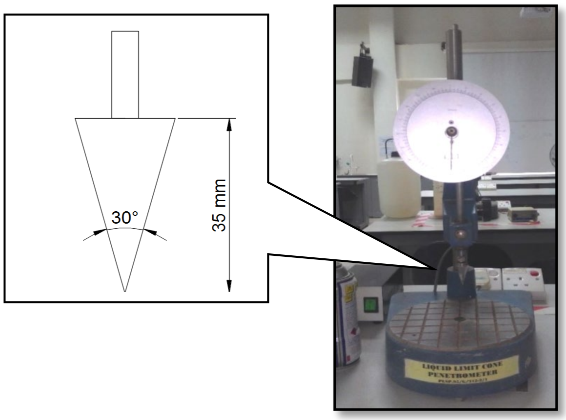


Figure 4: Standard cone penetrometer.

At the same time intervals, the three samples were used to carry out VST to relate the shear strength of grout. The test was carried out with a standard vane shear apparatus according to the BS1377: Part 7: 1990 (Figure. 5). A vane with dimensions 12.7 by 12.7 mm was used in the test. The spring used is ELE international lab vane spring set EL26-2275/10, with serial no. 1103-5-107.

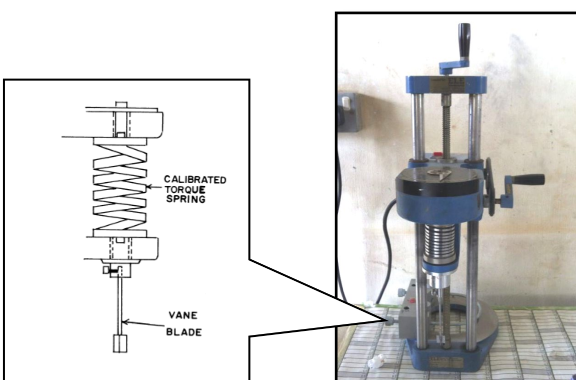


Figure 5: Standard vane shear apparatus.

The softest spring (Spring 4) was used for the VST. The grout was prepared as for CPT. Figure 6 shows the calibration curve for the spring was used to obtain the torque. The shear strength, c_u was derived from the vane shear test using Equation (1).

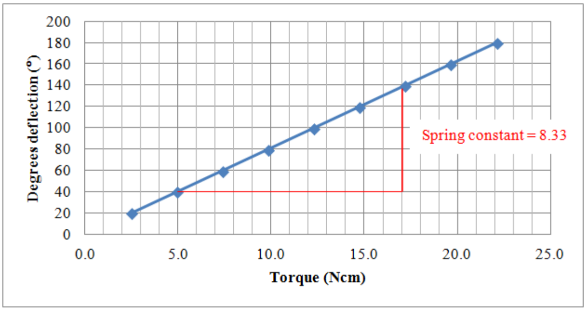


Figure 6: Calibration curve for torsion spring 4.

$$c_u = 2T/\pi D^2 [H+(D/3)] \quad (1)$$

Where, T = torque applied (Nmm)
D = overall width of the vane (mm)
H = the length of the vane (mm)

The grout was then mixed with SKW and used to carry out CPT and VST. 0 %, 30 %, and 50 % of bentonite in grout were replaced by cement and SKW was added with same mass into the grout and mixed. Three samples were tested with the same interval for the grout tests.

Results and Discussions

Figure 7 shows the spread diameter for the grout using the flowability test. Meanwhile, Figure 8 shows the relationship between spread diameter with water bentonite ratio. It can be seen that as the spread diameter increases with the water bentonite ratio. The grout which produced the largest spread diameter of 13.5 cm was selected to be used in AKARPILES due to its low consistency. Besides that the grout with low consistency is easier to be pumped as compared to the lower values. The plot shows that grout with w/b=6 have the highest consistency among the others. Therefore, grout with w/b=6 was chosen to be used and cement addition was made to increase the strength of grout.

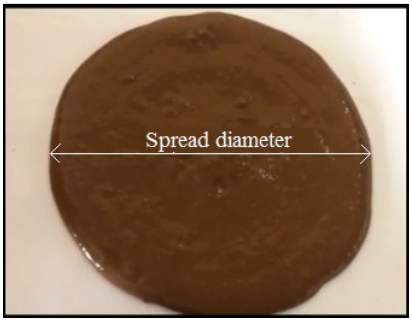


Figure 7: Spread diameter of grout.

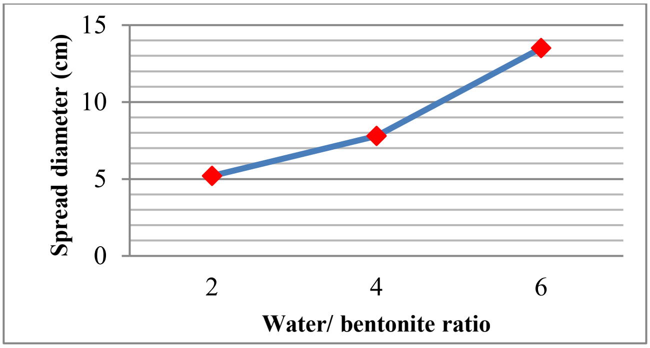


Figure 8: The plot of spread diameter of grout with different w/b ratio

CPT was carried out by referring to mix ratio as stated earlier in this study. Equation 2 is used to determine the ratio of penetration depth, D_r. Figure 9 shows the penetration of the cone into the sample of grout.

$$D_r = \Delta D / D \quad (2)$$

Where, ΔD = change of depth
D = original depth

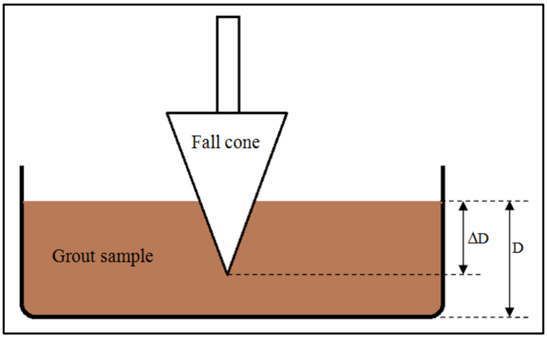


Figure 9: Schematic diagram for CPT

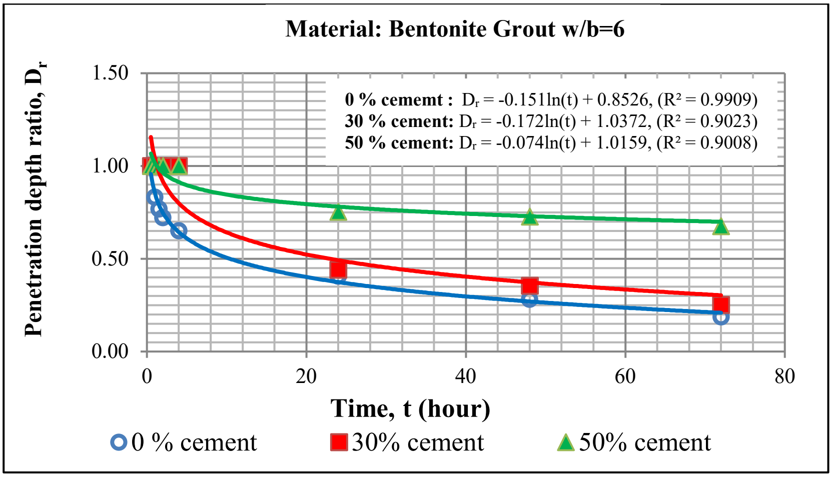


Figure 10: Relationship between D_r versus time for grout

As shown in Figure 10, it was observed that penetration did not change during the first 4 hours after the mixing with water for grout with cementation. The control sample with 0 % cement started to harden in the first hour and the D_r decreased exponentially with time. After 24 hours, the samples with cementation started to harden and the D_r decreased with time. The plot for control grout has the smallest gradient followed by 30 % and 50 % cement replacement. This indicates that the aging rate of grout decreases with the increment of cement replacement in grout. For sample with 50 % cement, it was also observed that, a water layer appears on the surface of the slurry. This phenomenon is known as instantaneous bleeding [10].

The shear strength, c_u of bentonite grout with w/b= 6 with replacement of cement by 0 %, 30 %, and 50 % mass remains constant in the first 24 hours. By referring the calibration curve in Figure 6, the grout mixture does not meet the minimum c_u to be captured in VST (degree deflection < 20°). This indicates the c_u to be less than 6 kPa.

Note that the VST seems not to be applicable to investigate the ageing behavior of grout mixture as no reading was captured during the test. Therefore, results in CPT are more applicable to test the ageing behavior for grout.

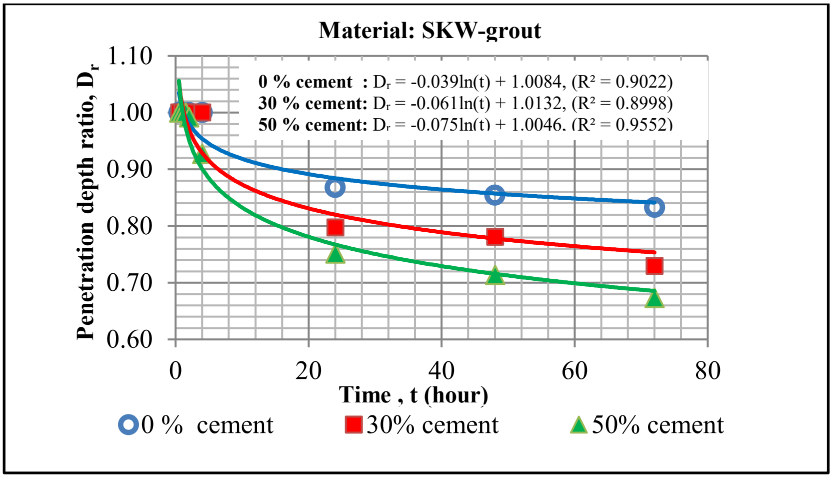


Figure 11: Plot of D_r against time for SKW-grout

Figure 11 shows the result for CPT of SKW-grout. During the first 90 minutes, it was observed that the penetration did not change for all three samples. All three plots show significant changes after 24 hours, where D_r decreases rather linearly with time. Plot of grout with 50% cement replacement has the smallest D_r. This indicates that with the increment of cement dosage in the grout, the stiffness of the SKW increases. A graph of c_u against time for grout-SKW mixture is plotted in Figure 12.

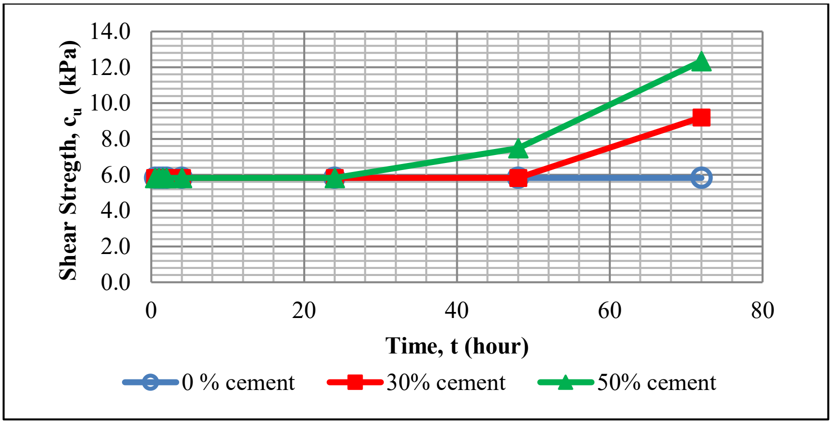


Figure 12: Plot of c_u against time for grout-SKW mixture.

The grout without cementation (0%) did not gain any strength throughout the period. From Figure 12, the plot for mixture with 50% replacement of cement in grout gained the highest shear strength in 72 hours which is 12.34 kPa, followed by 30% replacement of cement which is 9.20 kPa. It was obvious that with the increasing replacement of cement in the grout, the shear strength increases within the same time interval.

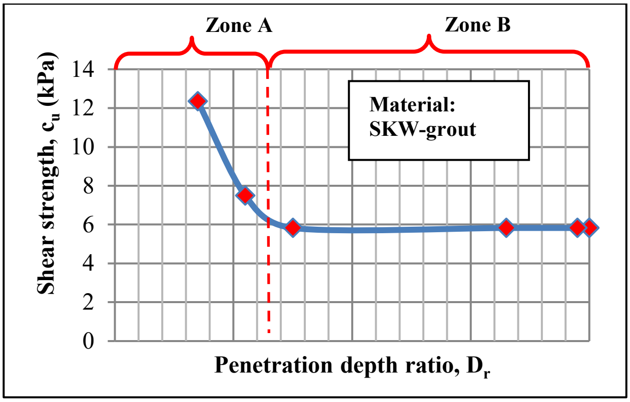


Figure 13: Relationship between D_r and c_u for SKW-grout

From Figure 13, Zone A and Zone B are identified to differentiate the relationship between D_r and c_u for SKW-grout at different strength range. Zone A is when D_r is less than 0.73 and c_u increase while D_r decreases. However, c_u maintains at 6 kPa in Zone B ($0.73 \leq D_r \leq 1$). This condition happened due to the c_u for the samples did not reach the minimum c_u which could be captured by the vane shear apparatus. If $D_r = 1$, it indicates that the cone is fully penetrated into the grout where the grout was not found to be adequately hardened to resist even 6 kPa of shearing force. Overall, the strength gain pattern is similar to that demonstrated by the cone penetration results, i.e. an increase in c_u corresponding with a decrease in D_r.

Therefore, the bentonite grout with mix ratio for bentonite: cement: water is 2:2:6 was chosen as the optimum result for AKARPILES.

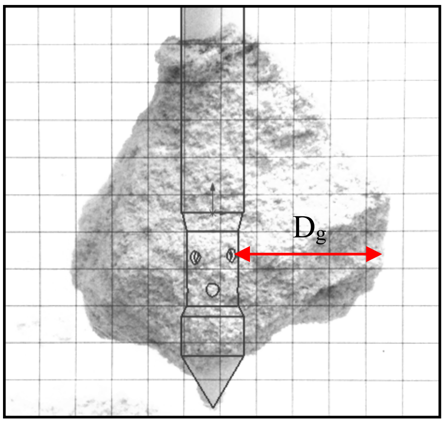


Figure 14(a): 2D-grout dispersion for Pile A

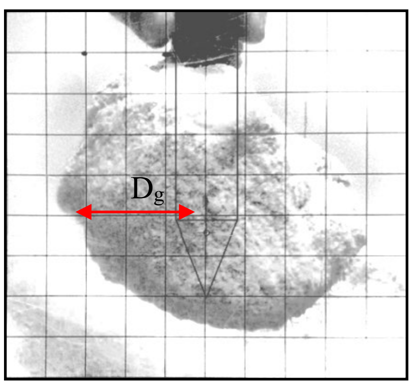


Figure 14(b): 2D-grout dispersion for Pile B.

The two dimensional grout dispersion for AKARPILE design A and B are shown in Figure 14(a) and (b) where D_g is the effective grouting distance. The grout dispersion area, A_g in AKARPILE Design A and B are 53 cm^2 and 38 cm^2, respectively. The difference between both of them might be caused by the diameter of grout outlet, the position of outlets and number of outlets (refer to Table 1). The diameter of the outlets in design A (∅=5 mm) is larger than design B (∅=2 mm), i.e. 3 mm different. In pile design B, the outlets are located at the cone tip, therefore the grout might be resisted by the soil and required more pressure to be pumped out through the outlets. Besides, the higher number of grout outlets allows more efficient grout dispersion from the piles.

Conclusions

AKARPILES were designed with a hollow body and grout outlets to allow grout-pumping into weak zone of the slope. Two designs for AKARPILES were presented in this study, with difference in several aspects: the length, angle of cone tip, number of grout outlets, and diameter of outlets, the penetration depth and position of the grout outlets. The designs were produced using SolidWorks and the prototypes were produced by 3D-printing.

As conclusion, introduction of cement into bentonite grout is able to reduce the expandability of bentonite grout and increase the shear strength. The bentonite: cement: water = 2:2:6 is the optimum mix ratio for grout in AKARPILES. The grout was easy to be pumped at this mix consistency. The highest shear strength gained from the grout-SKW mixture in 3 days is 12.34 kPa. With high pressure (≈100 kPa) applied, grout was pumped out and to fill the fissures in the slip plane of the slope and hold the soil like tree roots do.

With the same grout mixture, Pile A has a larger grout dispersion radius and area compared with pile B. At the end, this study is considered as succeed and the objectives are achieved. A more detailed research and analysis on the design of AKARPILE need to be carried out to make this solution more applicable in our real life.

Acknowledgement

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