Pull Out and Creep Behaviour of Soil Nailing – A Case Study

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ABSTRACT

The use of soil nails for slope strengthening is one of the popular methods since 1980s due to the attractive benefits of simple and fast installation method to reinforce cut slope. Proper assessment of the soil nail behavior between the nails and the surrounding soil will contribute to the safe and economical design of the reinforced soil structure. At present, the safety factor is adapted to soil nailing design and analysis, however, some soil nailed slope, which are designed, in compliance to the slope guidelines end up with failure. For the current knowledge, there is limited information on the loss of the shaft friction in soil nailing due to creep and the research on the behavior of the soil nail is also limited. Hence, in order to provide additional information on the behavior of the conventional soil nailing system, the bore holes and pull out test data were collected from the various projects: 1) Cheras, Kuala Lumpur, 2) Penang Hill, Penang, and 3) Kajang, Selangor. This study is focused on the behavior of the soil nail under pull out test at various types of soils and different soil nails characteristics. The parameters measured are soil nail pull out resistance and displacement of soil nails under different loading. In addition, the creep behavior of the soil nail was a study based on the displacement under maintain period at maximum test load during the pullout test. The creep behavior of soil nail is causing the loss of tension in the soil nail and that affecting the performance of the engineered slope. For the study and result presented, it is clear that soil nail under certain types of soil, especially dry, poorly graded cohesionless soils or soil with high water table is creep susceptible and had a lower pull out resistance. Pull out test on soil nail installed in medium stiff clayey Silt and sandy Silt and socketed in rock is performing up to design expectation

Keywords: *soil nail, pull out test, creep, pull out resistance, slope strengthening*

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Introduction

Soil nailing technique was developed in the early 1960s, partly from the technique for rock bolting and multi anchorage

Soil Nailing System

The soil nailing technique was designed to improve the stability of slopes, retaining walls and excavations principally through the mobilization of tensions in the soil nails. A main component of the soil nail is shown in Figure 1. The steel bars used are typically ranging from 25mm to 40mm in diameter, with yield strength of 460 to 500 N/mm^2 [19]. The steel bar will be installed in the drill holes having a diameter in the range of 100mm to 300mm and at spacing between 1m to 2m. The nail head comprises two main components which are the bearing-plate, hex nut, and washers, the headed-stud. Grout for soil nails is commonly a neat cement grout, which fills the annular space between the nail bar and the surrounding ground. The water/cement ratio for grout used in soil nailing applications typically ranges from 0.4 to 0.5. The characteristics of the grout have a strong influence on the ultimate bond strength at grout- ground interface. Grout is pumped shortly after the nail bar is placed in the drill hole to reduce the potential for hole squeezing or caving. In solid nail bar applications, the grout is injected by trauma methods through a grout pipe, which is previously inserted to the bottom of the drill hole, until the grout completely fills the drill hole.

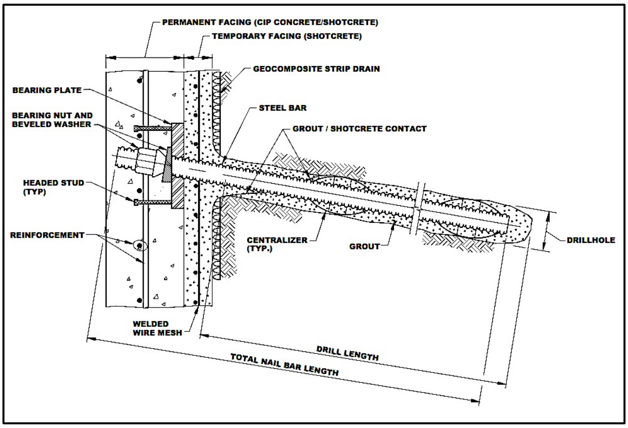

Figure 1: Main components of the soil nail [2]

As shown in Figure 2, the frictional friction between the soil nails and soils as well as the reactions provided by soil-nail head/facing, the tensile forces will be developed. The tensile forces in the soil nails reinforced the ground by directly supporting some of the applied shear loadings by increasing the normal stress in the soil on the potential failure surface. Thereby, the soil nail will allow the higher shearing resistance to be mobilized. The structural facing and soil nail head will provide the confinement effect to the active zone. Therefore, this will increase the mean effective stress and the shearing resistance of the soil. The resistance against pull out failure of the soil nails is provided by part of soil nail that is embedded into the ground behind the potential failure surface.

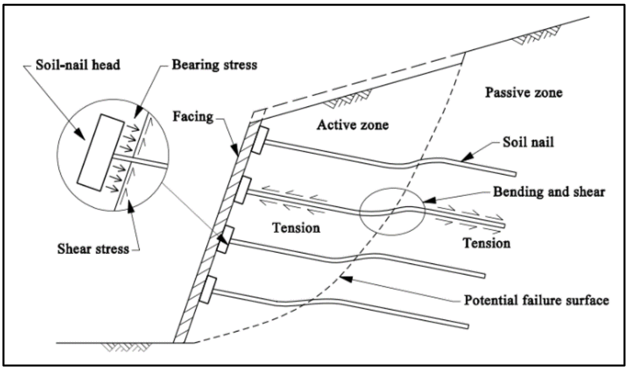

Figure 2: Two zone model of a soil nail system [14]

The internal stability of the soil-nailed system is usually assessed using a two-zone models, namely the active zone and the resistance zone, which are separated by a potential failure surface as shown in Figure 2. The active zone is the region in front of the potential failure surface, where it has a tendency to detach from the soil-nailed system. The resistant zone is the region behind the potential failure surface, where it remains more or less intact. The soil nails act to tie the active zone to the passive zone.

In the active zone, forces are developed in soil nails through interaction between the ground, the soil nails, the soil-nail heads and the slope facing. There are two fundamental mechanisms of nail-ground interaction, namely, the nail-ground friction that leads to the development of axial tension or compression in the soil nails, and the soil bearing stress on the soil nails and the nail-ground friction on the sides of soil nails that lead to the development of shear and bending moments in the soil nails. The soil nails and soil-nail heads/facing act together to tie the active zone to the resistance zone. The interaction between soil-nail heads and the ground, particularly the bearing mechanism, gives rise to tensile loads at the heads of soil nails. The tensile loads at the soil-nail heads are taken up by the soil-nail reinforcement. The resistant zone behind the potential failure surface contains the distal end of the soil nails with enough bond length to prevent the soil nails from being pulled out. When there is ground deformation in the active zone, pullout forces are induced in the soil nails in the resistance zone.

The pullout resistance is an internal failure mode, it occurs when the bond resistance in the soil and nail interface is inadequate and it can slip out if the pullout force is allowed to increase beyond the limiting capacity of the soil shear strength. There are two theoretical methods that are adopted in solving the equation linking the bearing stress, shear and bending forces. The first solution is based on the theory of elasticity and the second is the method of limiting stresses acting on a laterally loaded rigid pile. The tension forces in the nail tend to start from zero at the tip of the nail, increasing to the maximum value and then decrease to a value at the facing that is a fraction of the maximum tensile value [20].

There are two types of soil nail system in use, i.e. passive soil nail system and active soil nail system. Where, passive soil nail system is more commonly used. Chase [3] stated that it was considered passive soil nail when it does not mechanically pre-tensioned after installation and become fused in tension when the supporting soil deforms laterally or having a mass soil movement. Nail remains in a passive state if there is no soil improvement. For active system, the stress is applied into soil nail and the surrounding soil is compressed. This is a fundamental difference between soil nail passive and active system.

Bond Strength

The bond strength is rarely measured in the laboratory and there is no standard laboratory testing procedure that can be used to evaluate bond strength. Therefore, designs are typically based on conservative estimates of the bond strength obtained from field correlation studies and local experience in similar conditions [2]. In Malaysia, the Ultimate Bond Stress is usually obtained based on correlation with SPT “N” values and typically ranges from 3N to 5N. The estimated bond strength to be used as estimation in the design stage recommended by FHWA (2003) [2] is as stated in Table 1. However, this figure may not be accurate, therefore pull out test is necessary to be verified the ultimate bond strength used.

The geotechnical capacity or pull out strength of the soil nail can be calculated using the Equation 1.

$$Q_{ult} = q_{u\ ult}\, x\, A_B \tag{1}$$

Where, Q_{ult} = Ultimate Pull Out Strength (kN), $q_{u\ ult}$ = ultimate bond stress (kN/m^2) can be obtained from Table 1 and As = Nail Bonded Area (m^2).

This estimated pull out strength is to be used during the design stage and to be verified by pullout test. Meanwhile, the structural capacity of the soil nail reinforcement can be calculated using Equation 2.

$$Qs = 0.87\ Fy\ As\ (kN) = 0.87 \times Fy \times (\pi D^2/4) \tag{2}$$

Where, Q_s = Structural Capacity of the steel reinforcement (kN), F_y = Yield Strength of the steel reinforcement (kN/m^2) and As = cross sectional area of the steel reinforcement (m^2).

Table 1: Estimated Bond Strength of Soil Nail in soils and rock (FHWA, 2003) [2]

Material	Construction Method	Soil/Rock Type	Ultimate Bond Strength, q_u (kPA)
Rock	Rotary Drilled	Marl/limestone	300 – 400
		Phyllite	100 – 300
		Chalk	500 – 600
		Soft dolomite	400 – 600
		Fissured dolomite	600 – 1000
		Weathered sandstone	200 – 300
		Weathered shale	100 – 150
		Weathered schist	100 – 175
		Basalt	500 – 600
		Slate/Hard shale	300 - 400
Cohesionless Soils	Rotary Drilled	Sand/gravel	100 – 180
		Silty sand	100 – 150
		Silt	60 – 75
		Piedmont residual	40 – 120
		Fine colluvium	75 – 150
	Driven Casing	Sand/gravel	
		low overburden	190 – 240
		high overburden	280 – 430
		Dense Moraine	380 – 480
		Colluvium	100 – 180
	Augered	Silty sand fill	20 – 40
		Silty fine sand	55 – 90
		Silty clayey sand	60 – 140
	Jet Grouted	Sand	380
		Sand/gravel	700
Fine-Grained Soils	Rotary Drilled	Silty clay	35 – 50
	Driven Casing	Clayey silt	90 – 140
	Augered	Loess	25 – 75
		Soft clay	20 – 30
		Stiff clay	40 – 60
		Stiff clayey silt	40 – 100
		Calcareous sandy clay	90 – 140

Note: Convert values in kPa to psi by multiplying by 0.145 and 1kPa = 1 kN/m^2.

The pullout capacity of a soil nail installed in a grouted nail hole is affected by the size of the nail (i.e., perimeter and length) and the ultimate bond strength, q_S. The bond strength is the mobilized shear resistance along the soil-grout interface. In current practices, pullout test has been conducted to determine the soil nail pullout resistance (skin friction on the interface between soil nail and soil) and soil nail movement. The pullout resistance (q_s) of the nail was obtained by dividing the peak pullout force by the active surface area of the nail using the equation below:

$$q_s = \frac{P}{\pi DL} \tag{3}$$

Where P = peak pullout force interpreted from the pullout force-displacement curve (kN); D = diameter of the nail (m); and L = length of the nail in contact with the soil (m). Displacement was measured using the dial gauges at the soil nail head during the pullout test.

Potential Failure Mode of a Soil Nailed Slope

The failure modes of soil nails can be classified broadly as external and internal failure mechanisms. External failure refers to the development of potential failure surfaces essentially outside the soil-nailed ground mass. The failure can be in the form of bearing, rotation, sliding, or other forms of loss of overall stability. Internal failure refers to failures within the soil-nailed ground mass. Facing failures are due to flexural failure of the structure facing, punching shear failure and headed-stud failure of the soil nail head.

Internal failures can occur in the resistance zone, active zone or in both two zones of a soil-nailed system. An engineering assessment shall be carried out for all four potential failure modes (pullout failure, nail tendon failure, face failure and overall failure) for the design soil nailed slopes [4]. The design of the facing is often neglected by designers thinking that its sole purpose of the facing is to protect against surface erosion only. The facing should be designed to resist the earth pressures, bending moment and punching shear force from the pulling of soil nail under the earth pressure.

Pullout failure results from insufficient embedded length into the resistance zone to resist the destabilizing force as shown in Figure 4. Some factors governed the pullout capacity of the soil nails, such as, the location of the critical slip plane of the slope, the size (diameter) of the grouted hole for soil nail and the ground-grout bond stress (soil skin friction). The diameter of the grouted hole for soil nail is usually in the range of 75mm to 150mm for commonly available drilling rigs by using a time method, filling from the bottom up and non-shrink grout [5]. The ultimate pull-out resistance between the nail and soil/rock should be checked to ensure that the FOS against slope failure is adequate.

Therefore, the determination of appropriate pull out resistance/ ground-grout bond stress and pullout capacity, which is based on a critical slip plane is needed to stabilize the slope against pullout failure. It is usually verified by a pull-out test.

Soil Nail Creep

The failure in pull out also can be contributed by the soil nail creeps. The active soil nail suffers the gradual movement of the shaft towards the frontal bearing plate due to the tensile pull [6]. The creep is due to the gradual shearing at the point of soil–nail interaction. Creep occurs because the tension and the shear force are acting in the same longitudinal plane, but opposite in direction as shown in Figure 5. The passive pressure behind the bearing plate is providing the reaction to the pull. Creep occurs due to the resisting shear force giving way to the tensile pull.

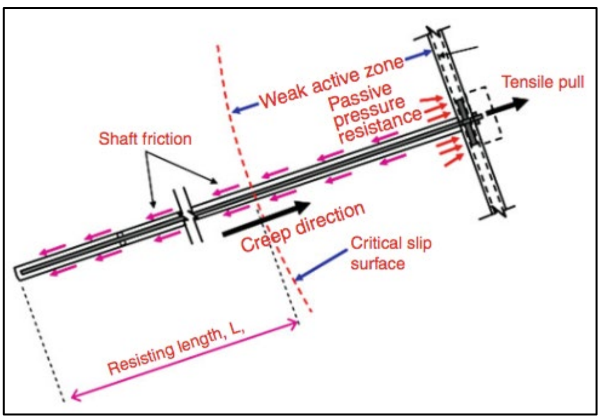

Figure 3: Conceptual model of the active soil nail system indicating the creep direction [6].

Sustained, long-term loading of fine-grained soils surrounding soil nails may cause creep deformation. Creep takes place under constant effective stresses in the soil and may cause deformations that adversely affect the lateral deflection of soil nail walls. There are no specific criteria that can be used to establish whether a soil exhibits unfavorable creep potential. However, practice has shown that soils with potential for creep include [2]:

1. Fine-grained soils with a liquid limit (LL) ≥ 50;
2. Fine-grained soils with plasticity index (PI) ≥ 20;
3. Fine-grained soils with undrained shear strengths ≤ 50 kPa (1,000 psf);
4. A liquidity index (LI) ≥ 0.2; and
5. Organic soils.

Pull Out Test

In general, field in-situ pull out test and laboratory pullout tests and direct shear box tests was used by some researchers to investigate the behavior of soil nails for example, Heymann et. al., [8], Franzen, [9] and Feijo and Erhlich, [10]. Researchers have shown that the results are greatly influenced by the testing methods and soil conditions [11]. Most studies were mainly focused on the ultimate pullout strength by carrying out the pullout tests in a force-controlled manner.

The primary method for soil nail testing is in-situ pulling out the soil nail at the nails head. There are 3 ways in which soil nails can fail due to internal stability: 1) Tensile failure of the soil nail bar, 2) Failure between the grout and bar 3) Failure between the grout and soil [12]. The first two failure mechanisms are generally well defined but the capacity of the grout / soil interface is difficult to predict. Drilling technique, grouting method and ground condition is the factors affecting grout/soil interface capacity.

There are two basic types of soil nail test, namely, Sacrificial Test and Production Nail Test. Sacrificial test is carried out mainly to investigate the ultimate bond stress of the soil. This test can be carried out before design start or during the construction to confirm the ultimate bond stress used in the design as shown in Table 1. Test load usually based on Design Load or Working Load. Meanwhile, the Production nail test is for acceptance of the working nails. This is to confirm satisfactory performance of the production nails. Minimum 2-3% of the soil nails to be tested or minimum 3-5 numbers and 1 number for each type of soil and 1 number per excavation stage [13].

Soil nails are pulled out tested in the field to verify that the nail design loads can be carried out without excessive movements and with an adequate factor of safety. Testing is also to verify the adequacy of the contractor's drilling, installation, and grouting operations prior to and during construction of the soil nail. The period of monitoring should be sufficient to ensure that pre stress or creep fluctuations stabilize within tolerable limits. A proper comparison of the short-term result with those of the on-site suitability tests provides a guide to long-term behavior [16].

Zhao et.al [17] is also using the similar setup to study the Pullout Mechanism and Failure Characteristics of Soil Anchor. Meanwhile, Pradhan et.al., [18] is studying the behaviour, soil–nail pullout interaction with loose fill materials in the laboratory by adapting the concept of in situ pull out test. It is due to the safety reasons and high cost, it is not possible to carry out a large number of field tests, especially when the slopes are saturated or nearly saturated. Therefore, a large-scale test box with a loading frame and pulling device was fabricated so that pullout tests can be carried out in the laboratory. Details procedure was presented by Pradhan et. al [18] and will not be discussed here as this study will focus on field pull out test.

Creep potential can be directly evaluated during the field testing of individual soil nail load tests [2]. In these tests, a load is applied to the nail in various load increments, and at selected load increments, a creep test is conducted. The creep test consists of holding the load applied to the soil nail during a period of up to an hour and measuring the cumulative nail head displacement at increasingly longer intervals. By relating the increment of nail head displacement over a certain time, a creep rate can be obtained. Creep rates exceeding 2 mm (0.08 in.) in a time period between 6 and 60 minutes in logarithmic scale indicate substantial creep potential. If excessive creep is calculated, it is necessary to modify the design by reducing nail spacing or increasing the nail length.

Pull Out Test Procedures

This study will be focusing on comparison of soil nail resistance in different soil types, structural capacity and under different loading.

Equipment

The main testing equipment to perform pull out test is arranged as per the procedure stated in FHWA [2]. The equipment used is one unit of 60 tonnes or 120 tonnes hollow plunger hydraulic jack, two units of calibrated dial gauges with minimum 50 mm travel, one unit of load cell and one unit of calibrated pressure gauge with a maximum 10,000 psi reading. All the test equipment must be calibrated. The pressure gauge and load cell were used to measure the applied load. The hydraulic jack then independently supported and centered over the nail so that the nail does not carry the weight of the jack. Loading on the nails was monitor through pressure gauge and load cell. The stressing equipment then, placed over the nail in such a manner that the jack, bearing plates, and stressing anchorage are in alignment as shown in Figure 4.

Soil Nails Pullout

The soil nails were installed at three different project sites. Then the testing carried out to 1.5 times of the Design Working Load to the selected nails. The arrangement of the pull out test setup is shown in Figure 4. Pull out failure is defined as movement in excess of 1mm between the 1 minute and 10 minute reading or 2mm per log cycle of time over a minimum holding period of 60 minutes. The soil nail was tested for the full grouted length as detail in the Table 2 for Cheras, Table 3 for Kajang and Table 4 for Penang Hill. After the construction of the soil nail, the nail was grouted in place. After grouting, the nails were loaded until the primary grout has attained a crushing strength of at least 30 MPa, as verified from the test on 150mm cubes. Reaction frame was arranged to be at a slope face within 1m radius from the center of the drilled hole and free from any possible movement due to any construction activities, weather condition or the testing itself. The soil nail pull out test was made by incrementally loaded the nails. The nails movement was measured and recorded to the nearest 0.01mm with respect to an independent fixed reference point at each increment load. The test load was monitored with a load cell and pressure gauge as a primary and secondary device respectively. The load holding period was started as soon as the test load is applied. Movement was recorded in 0,1,2,3,4,5,6 and 10 minutes.

Figure 4: Setup for Pull Out Test

For creep test, the loading period is extended and the nail movement was recorded in 15, 25, 30, 45 and 60 minutes. Each increment of load must not be greater than 25 percent of the design load of the nail tested. The loading was terminated for failure or at 1.5 or 2.0 times design working load. As for safety reason, all the nails tested must not be stressed beyond 0.8 times the characteristic strength of the nail reinforcement.

Acceptance Criteria

General practice, the soil nail test is deemed accepted if the unit bond stress at a failure load or test termination is equal to or greater than twice of the design unit bond stress. The acceptance Criteria for the Pull Out Test according to BS 8006 (2011) [7] is (1) Creep rate shall not be more than 2mm per log cycle of time as the test load and (2) Total nail head displacement at the test load shall not be more than the theoretical elastic deformation of the free length. According to Geo (2008) [14], acceptance criteria is (1) Plot of nail head displacement with a log time shall be displayed a decreasing rate of creep (at creep test only) and (2) Creep rate shall not be more than 2mm per log cycle of time at the test load or 0.1% of bonded length. Meanwhile, according to VicRoads (2002)[15] the acceptance criteria for Pull Out Test is (1) Plot of nail head displacement with log time shall be linear or display decreasing rate of creep, (2) Creep rate shall be less than 2mm, (3) The movement of the steel bar head under the test load shall be less than 0.2% of the bonded soil nail length and (4) Total nail head displacement at the design load shall not exceed 12mm beyond the theoretical elastic deformation of the free length plus one half of the bonded length.

Pull Out Behaviour Of Soil Nail – Case Studies For Cheras, Kajang And Penang Hill

Pull out test was carried out to determine the pull out resistance and the displacement of the soil nail. Total 15 numbers of soil nail were tested in full scale from three (3) selected sites including five (5) numbers from site in Cheras, Kuala Lumpur, five (5) numbers from Penang Hill, Penang, and five (5) numbers from Kajang, Selangor. According to the borehole data, the soil properties of these three sites are differs from each other, where Cheras site is dominated by silty Sand with average SPT of 3-10. Meanwhile, Kajang site consist of medium stiff clayey Silt with average SPT value between 3-15. Penang site consist of sandy Silt and Granite with recorded SPT value between 3 - 50. Therefore, the design of soil nail is also different in terms of length, diameter of drilled holes, diameter of reinforcement and working load.

Soil Nail Behavior for Cheras site

Result from site in Cheras, Kuala Lumpur was presented in Table 2 and load against displacement result plotted as shown in Fig. 8. From Site Investigation study, soil properties for this site is mainly fill silty Sand with SPT "N" value between 3 to 10. Although ground water table is low during the construction, the soil was observed to be wet. Some loose sand with some mix of backfill material also encountered during the drilling of the bore holes. Summary of the data collected from the project site in Cheras, Kuala Lumpur is as stated in Table 2. The soil nails tested is selected randomly from various location and slope height within the same slope. The drilled holes of the soil nails is 100mm and using reinforcement with a diameter of 25mm. Soil nails A24 and B22 are 18m long, C15 and A17 is 15m long and finally B25 is 12m long. The tensile strength of the steel reinforcement used was 460 N/mm^2 with Modulus Young of 200GPa. The structural strength/capacity of the soil nail using the above steel reinforcement is 196 kN calculated using Equation 2. Both soil nails at point A24 and B22 was designed with the same length of 18 m at 99 kN design working load, while another 2 soil nails at point C15 and A17 was designed with 15m length with 82 kN design working load and another soil nail, B25 with 12m length with 66 kN design working load. The result from the pullout test at point A24 and B22 obtained the pullout force of 148.5 kN which was 1.5 times of the design working load. The soil nails displacement in these points was observed 1.795 mm and 3.267 mm which reveals lower than 0.2% of the bonded soil nail length (less than 36 mm). Using equation 3, the calculated pull out resistance of soil nails point A24 and B22 is 26 kN/m^2.

Table 2: Summary of Soil Nail and Pull Out Test at Cheras, Kuala Lumpur

Ref No.	A 24	B 22	C 15	A 17	B 25
Soil Type and Hardness	Silty SAND	Silty SAND	Silty SAND	Silty SAND	Silty SAND
Reinforcement Size (mm)	25	25	25	25	25
Length (m)	18.0	18.0	15.0	12.0	12.0
Working Load (kN)	99	99	82	82	66
Max Test Load (kN)	148.5	148.5	123.0	123.0	99.0
Displacement (mm)	1.795	3.267	Failed to Maintain Load at 59.8 kN	Failed to Maintain Load at 41.0 kN	Failed to Maintain Load at 33.0 kN
Creeps at maintain load (mm)	0.1125	0.1025			

Another 3 soil nails tested is C15 and A17 with 15m length and B25 with 12m length. All three soil nails fail to achieve the Design working Load of 82 kN for 15m length and 66 in for 12m length. The Fig.8 also shows that the soil nails continue moving after reaching the maximum loading that it can sustain. Soil nail C15 failed at 59.8 kN, A17 failed at 41 kN and B25 failed at 33kN. The failure of these soil nail points was expected due to the insufficient embedded length into the resistance zone that resist the destabilizing force as discussed in section 1.3. This is because the 18m length soil nail (A24 and A22) was capable of sustaining the load. Using equation 3 above; the pull out resistance for soil nail C15, A17 and B25 is 12.69 kN/m^2, 10.876 kN/m^2 and 8.75kN/m^2 respectively. This low value of pull out resistance is due to the soil nails installed in soil consist of filling sandy Silt. Pull out resistance obtained in this pull out test, revealed the result is comparable to the ultimate bond stress in Table 1 which is falling under the category of cohessionless soil, augered and silty sand filled. The value given in Table 1 is 20 – 40 kN/m^2. Meanwhile, the value of pull out resistance calculated was lower. This is attributed by the presence of water in the soil during the construction of the soil nail. The trend line of the pull out behavior was plotted as shown in Fig. 5. Soil nails A24 and B22 shows a complete plot of two cycle test and had reached the maximum test load of 148.5 kN. However, residual displacement for A24 recorded as 4.6mm. This residual displacement is where, the soil nail is permanently displaced. The reason for this is because of the loss of friction between the soil nail-ground. Meanwhile, three other nails are loosing the friction at their ultimate bond strength (before it failed) as discussed previously and proved by the straight lines towards the end of the graph.

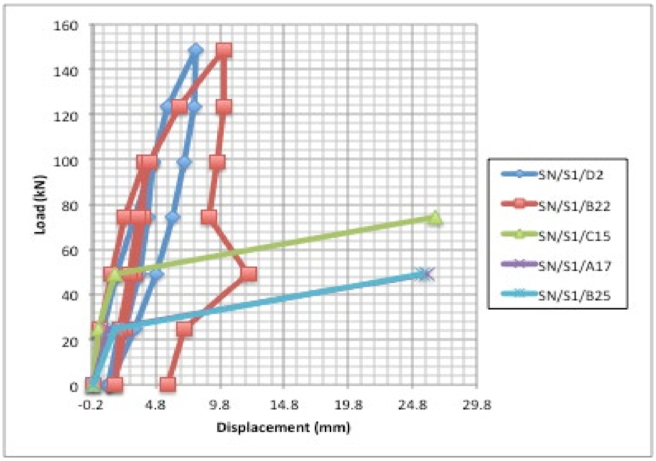

Figure 5: Load vs Displacement plot for Soil Nail at Cheras, Kuala Lumpur

Soil Nail Behavior for Kajang site

The soil nails tested is selected randomly from various location and slope height within the same slope. From the bore hole data on this site shows that the soil description is medium stiff clayey Silt with a little of Sand and the SPT "N" value ranges from 3-15 (refer Table 3). The drilled holes of the soil nails is 100mm and using reinforcement with a diameter of 32mm. The Tensile Strength of the steel reinforcement is 460 N/mm^2 with Modulus Young of 200GPa. The structural strength/capacity of the soil nail using the above steel reinforcement is 322 kN. It can be calculated using Equation 2. Meanwhile, the bearing plate used is 200x200x20mm. Soil nail inclination is 10-15 degree downward for tremie grout purposes. All tested soil nails, namely; D33, C21, D26, C27 and B583 are having the same length of 18m.

The maximum test load is 285kN which is lower than the structural capacity of the steel reinforcement. At maximum load of 285 kN, the displacement recorded was 11.14mm for D33, 10.43mm for C21, 12.77mm for D26, 8.73mm for C27 and 9.56mm for B58. The soil nails displacement in all these test points was observed to be lower than 0.2% of the bonded soil nail length (less than 36 mm) as specified by VicRoads (2002) [15]. Using Equation 3, the calculated pull out resistance of soil nails tested is 50.40 kN/m^2. From Table 1, stiff clayey Silt has an estimated ultimate bond stress of 40 – 100 kN/m^2. This revealed the result of the pull out resistance obtained from the field study is within the ranges and soil nail are demonstrated sufficient pull out resistance to resist the pull out load up to 285 kN. Soil nail displacement against load was plotted and presented in Fig.6. The trend line is considered consistent for all five nails tested. This is due to the soil nail installed in a competent soil stratum.

Table 3: Summary of Soil Nail and Pull Out Test at Kajang, Selangor

Ref No.	D 33	C 21	D 26	C 27	B 58
Soil Type and Hardness	Medium stiff Clayey Silt	Medium stiff Clayey Silt	Medium stiff Clayey Silt	Medium stiff Clayey Silt	Medium stiff Clayey Silt
Reinforcement Size (mm)	32	32	32	32	32
Length (m)	18.0	18.0	18.0	18.0	18.0
Working Load (kN)	190	190	190	190	190
Max Test Load (kN)	285	285	285	285	285
Displacement (mm)	11.14	10.43	12.77	8.73	9.56
Creeps at maintain load (mm)	0.03	0.04	0.04	0.03	0.01

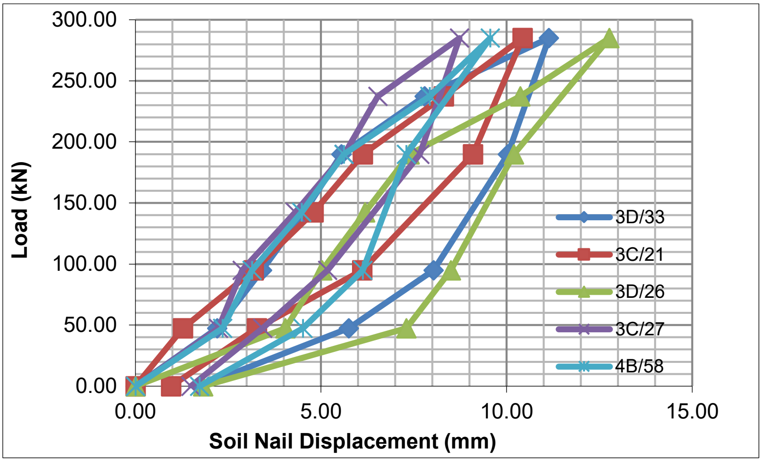

Figure 6: Load vs Displacement plot for Soil Nail at Kajang, Selangor

All nails tested to maximum test load of 285 kN and tested for 2 cycles. The creep was also measured during the pull out test in second cycle and the result will be discussed in section 4. Residual displacement is minimal, proved the nails and the reinforcement was not affected by the creep.

Soil Nail Behavior for Penang site

Soil on Penang Hill site consists of sandy Silt and rock (Granite) with SPT "N" Value of soil ranges from 3 to more than 50. Five numbers of soil nail tested in Penang Hill. The soil nail length is 24m and socketed into rock with varies depth ranges from 7.5m to 18.0m with the drilled hole size of 125mm. Reinforcement used is high tensile 40mm steel bar with Fy of 1,030 MPa and Modulus Young of 170 GPa. Using equation 2, the structural capacity of the soil nails is 1,126kN. Bearing plate used is 220x220x40mm thick mild steel plate. Soil nails were installed at a high inclination downward of 45 degrees in order to reach rock layer. Working load of the soil nails is 600kN. Creep measured at 15 minute maintains load test is ranges from 0.2 mm to 0.86 mm as stated in Table 4.

Table 4: Summary of Soil Nail and Pull Out Test at Penang Hill, Penang

Ref No.	A1	A3	A5	A13	A15
Soil Type and Hardness	Sandy SILT & Granite	Sandy SILT & Granite	Sandy SILT & Granite	Sandy SILT & Granite	Sandy SILT & Granite
Reinforcement Size (mm)	40	40	40	40	40
Length (m)	24	24	24	24	24
Length in rock (m)	7.5	18.0	15.0	16.5	8.0
Working Load (kN)	600	600	600	600	600
Max Test Load (kN)	900	900	900	900	900
Displacement (mm)	46.05	36.46	32.32	45.68	44.68
Creeps at maintain load (mm)	0.65	0.40	0.20	0.56	0.86

Recorded maximum displacement for A1 is 46.0mm, A3 is 36.4mm, A5 is 32.3mm, A13 is 45.6mm and A15 recorded 44.6mm. The soil nails displacement in all these test points were observed to be lower than 0.2% of the bonded soil nail length (less than 48 mm) as specified by VicRoads (2002) [15]. Therefore, the soil nails can be concluded as achieving the desired strength and allowable displacement. Soil nails in Penang site are in the high strength category which fully utilized the bond strength in rock which is estimated to be around 400 N/mm^2 (FHWA, 2003). Using Equation 3, the pull out resistance of the soil nails can be calculated. However, due to the bonded length in rock, soils bond stress was negligible. Therefore, the calculation of pull out resistance was only taking into account of the bonded length inside rock. The pull out resistance calculated for soil nails; A1 – 305.60 kN/m^2, A3

– 127.32 kN/m^2, A5 – 152.80 kN/m^2, A13 – 138.90 kN/m^2 and A15 – 286.50 kN/m^2. This revealed the result of the pull out resistance obtained from the field study is within the ranges and soil nail are demonstrating sufficient pull out resistance to resist the pull out load up to 900 kN.

Figure 7 shows the plot of test load against displacement. For all 5 numbers of nails tested. All soil nails are pulled out tested to 900 kN with highest displacement of 46.05mm. Soil nails selected for testing are showing the same behaviour in terms of total displacement. The trend line is considered consistent for all five nails tested. This is due to the soil nail installed in a competent soil stratum and anchored into rock layer. The contribution of the bond stress in rock allowed for the utilization of high strength structural reinforcement.

Soil nail A15 was undergone 3 cycles of the creep test to study the behaviour or pattern of creep under different loading and maintain load period. First creep test was conducted at loading of 600kN for 15 minutes. The creep recorded is minimal i.e., 0.03mm. Then the loading was increased to 1,030 kN and creep for soil nail A15 was monitored for 40 minutes. The creep result recorded is substantially as shown in Fig. 11 i.e., 2.8mm. To further verify the creep test result for soil nail A15, another creep test was carried out at 1,030 kN and loading was maintain for 120 minutes and result plotted as shown in Fig.12.

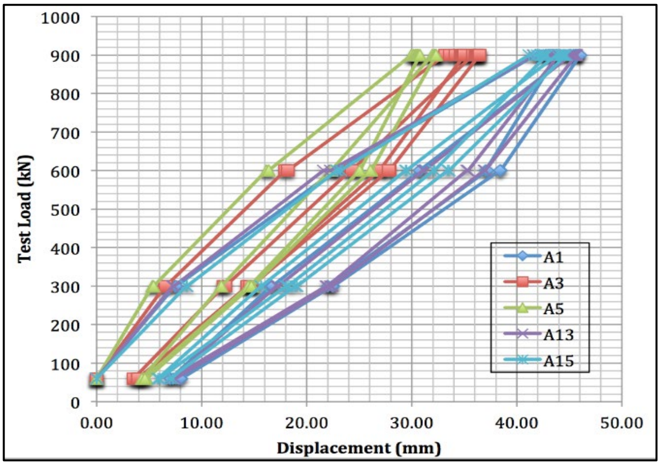

Figure 7: Load vs Displacement plot for Soil Nail at Penang Hill, Penang

From the result of the field pull out test discussed above, obviously not all soil types are suitable for the installation of the soil nail system. In Penang Hill and Kajang for example, the soil nail demonstrated higher pull out resistance due to the competent soil encountered. Meanwhile, for Cheras site, the pull out resistance is low and cannot even achieve the initial design working load. Soil nails is best suited to be used in residuals soils and weathered rock without unfavorably oriented, low strength structure. Besides that, stiff cohesive soils such as clayey silts and low plasticity clays are not prone to creep. Soil nail also suitable to be used in naturally cemented or dense sand and gravels with some cohesion. Also, the soil nails usage must be above the ground water table as the cohesion of the soils will be diminishes when the soils are saturated.

Creep Behaviour of Soil Nail

Creep test is conducted as part of the verification or proof test to assess the time-dependant elongation of the test nail under constant load. Creep test is commonly performed to verify that design load are resisted without excessive deformation occurring in the soils. In creep test, the movement of soil nail head is measured over a period of time of usually 10-60 minutes while the applied load is held constant. In this study, the creep was observed in 10 minutes for Cheras and Kajang sites. For Penang Hil, the creep was observed for 15 minutes, 40 minutes and 120 minutes.

The soil nail creep was observed at Cheras site has revealed that at maintaining load test of 148.5 on giving the value of 0.1125mm for Soil Nail A24 and 0.1025 mm for Soil Nail B22. This result indicates soil nail tensile strength and the bond stress is sufficient (less than 1 mm for 10 minutes maintain load) to withstand the tensile pull from the expected shear force of the slope.

The pull out test result at Kajang, Selangor project also indicated creep movement when tested to 1.5 times of working load and maintain for 10 minutes. For 18.0 meter length soil nail, the creep movement from 0.01mm and 0.05mm when tested until 285kN maximum load. Comparison of the Creep result for Penang Hill was presented in Fig. 8. Overall, soil nails creeps are showing the similar pattern of linear and decreasing over log-time (minute). However, the creeps seem to be influenced by the soil nail free length as shows in Table 4. Creep for soil nails A3, A5 and A13, is 0.40mm, 0.2mm and 0.56mm, respectively where the soil nails are socketed into rock of 18.0m, 15.0m and 16.5m. Meanwhile, for soil nails with shorter socket length into rock. The creeps recorded is higher which is 0.65mm for A1 and 0.86mm for A17 where the socket length is 7.5m and 8.0m, respectively.

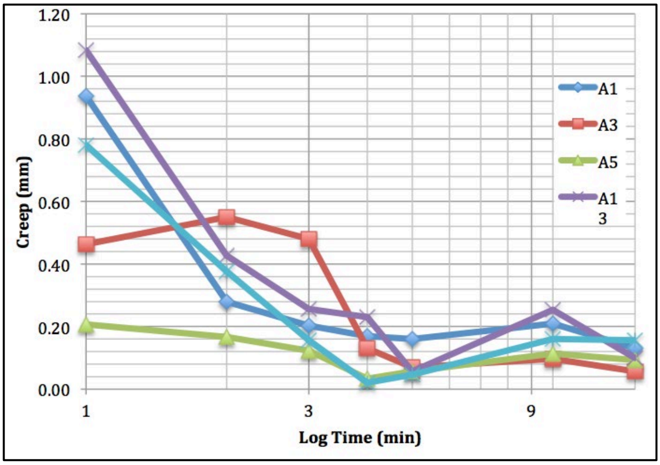

Figure 8: Creep vs Log Time at Penang Hill

The highest creep recorded (displacement against time) during maintained load is 0.86mm recorded for soil nail A15 and lowest creep was recorded for soil nail A5.

From the estimated bond strength in Table 1, the assumption can be made that pull out resistance of the soil nails is increased linearly with the length of soil nails socketed into hard stratum/ rock as the pull out resistance were contributed by the friction between nails-rock. The maximum creeps for all five numbers of the soil nail was plotted against it assumed free length, i.e., length of soil nails inside the soil. The result is interesting, as it is clear that the rock socket for the soil nail contributed to the pull out resistance and subsequently reduces the soil nail creep. Therefore, for Penang Hill site, further study was carried out to investigate the creep behavior of the soil nails. As it is obviously can be seen from the Load versus the Displacement plot in Fig. 7 and Table 4, total displacement is substantial as compared to the result from Cheras and Kajang sites.

Three (3) creep test carried out for soil nail A15 is at 600kN maintain for 15 minute, at 1,030 kN maintain for 40 minutes and at 1,030 kN maintain for 120 minutes. The result shown in Figure 10, 11 and 12, respectively. Before that, soil nail was pulled out tested for full 2 cycle at maximum test load of 1,030 kN and result shown in Figure 9. The pull out test was limited to 80% of the steel bar tensile capacity due to safety reason.

The creep was measured at the maximum test load as indicate in Figure 9. Soil Nail A15 which is having a total length of 24m with a diameter of 125mm and design capacity of 600kN was pull out tested at 1,030 in. The maximum displacement recorded is 28.290mm. As compared to the first test in Figure 10 above where soil nail A15 recorded a maximum displacement of

44.68mm. Lower displacement recorded was expected as the bond stress between the nail and soil had been mobilized due to the previous test conducted. FHWA (1998) [19] concluded only very small displacements between the nails and the adjacent ground are required to mobilize the ultimate bond stress. Numerous pull out test have established that relative displacements in order of 1 to 2 mm are often all that's required to achieve the ultimate pull out resistance.

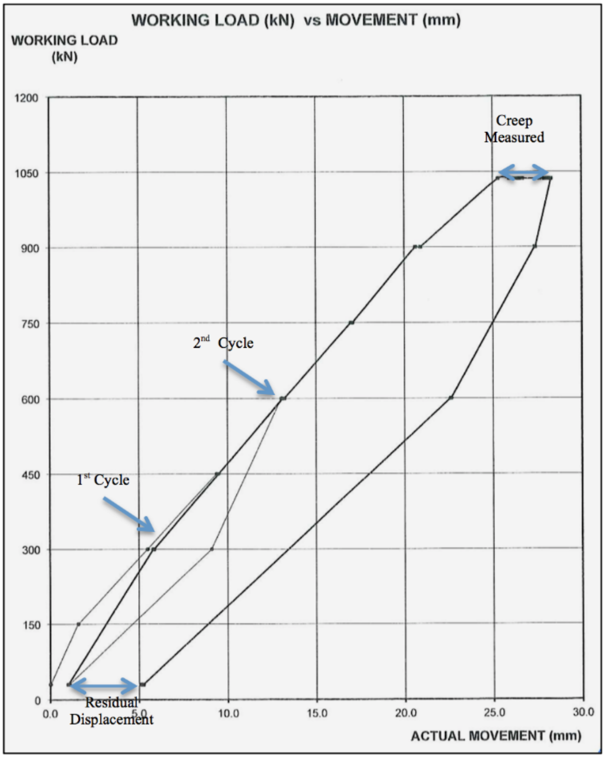

Figure 9: Load vs Displacement plot for Soil Nail A15 (Load test up to 80% Fy Steel Bar, i.e 1,030 kN)

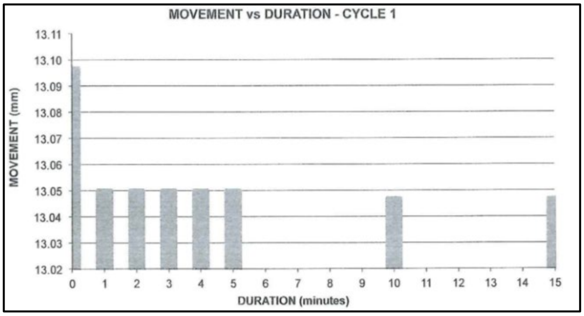

Figure 10: Creep Test Result at 600kN (Maintain Load 15 Minutes)

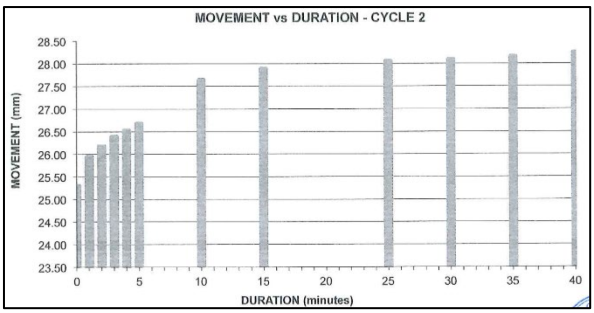

Figure 11: Creep Test Result at 1,030 kN (Maintain Load 40 Minutes)

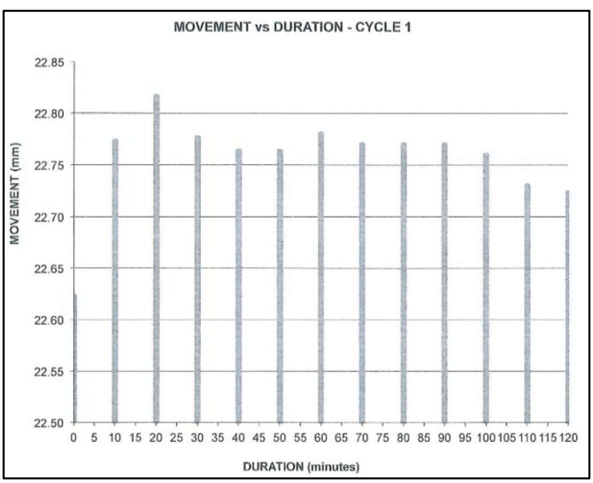

Figure 12: Creep Test Result at 1,030 kN (Maintain Load 120 Minutes)

With initial reading at 22.63mm, after 10 minutes the reading recorded is 22.83mm i.e. 0.2mm increment. The reading was taken every 10 minutes. Final reading taken at 120 minutes is 22.73mm. This gave a total creep result of 0.1mm after 120 minutes maintain load. The creep recorded for all soil nails tested are within the allowable 1mm for maintaining period less than 15 minutes and 2mm for maintaining a period of up to 60 minutes as specified by various guidelines explain in section 2.3.

Apparently, due to creep problem there are certain ground condition which is not well suited for the use of soil nails. Organics soils or clay soils with Liquidity Index greater than 02 and undrained shear strength less than 50 kN/m are reported susceptible to soil nail creep [19]. This soil may continue to creep significantly over the long term and may also exhibit a significant decrease in the soil-grouts adhesion and nails pull out resistance if saturated following the construction.

Although creep tests may provide some indication that a failure condition is imminent when the measured nail head movement rate accelerate, this test does not allow for easy interpretation that the maximum nominal bond resistance is achieved.

Conclusions

The conclusions can be made from this research area:

1. Pull out strength varies based on bond stress between the soil nail and surrounding soil or rock. Silty sand fill material, gives a lower value of pull out resistance, i.e. in the ranges of 8.75 – 26.00 kN/m2. Medium stiff clayey silt give values pull out resistance of 50.40 kN/m2. Meanwhile, soil nail installed in sandy silt rock socketed gives the highest value of pull out resistance in the range of 127.32 kN/m^{2} - 305.60 kN/m^{2}.
2. Pull out displacement varies depending on soil types and length of soil nail. In silty sand fill material (Cheras site) the displacement is in the ranges of 1.795 – 3.267 mm at maximum test load of 148.5 kN for 18m long soil nail. Meanwhile, in medium stiff clayey Silt the recorded displacement is in the ranges of 8.73mm – 12.77mm fat maximum pull out load of 285kN for 18m long soil nail. As for Penang Hill site, which is consist of sandy Silt & Granite, the displacement recorded is in the ranges of 32.32 mm – 46.05 mm at 600kN for 24m soil nails.
3. The creep behavior of soil nail was a study based on the displacement at maintaining test load for 10, 15 ,40, and 120 minutes. For Cheras site (silty sand), creep measured in the ranges of 0.1125 mm – 0.1025 mm (10 minutes). For Kajang site (Stiff clay), creep recorded was in the ranges of

0.01 mm – 0.04 mm (10 minutes). Meanwhile creep recorded at Penang Hill (sandy silt) is in the ranges of 0.20 mm – 0.86 mm.

4. For soil nail with certain length socketed into rock, the working capacity is higher and creep behavior within the tolerable limit. Soil nail without rock socket are expected to developed creep over time. The creep movement is suspected to increase under longer maintain period and this can cause the loss of tension in the soil nail system and will affect the performance of the engineered slope.
5. Soil nailing is well suited for Stiff to hard fine-grained soils, which includes stiff to hard clays, clayey silts, silty clays, sandy clays, sandy silts, and combinations of theses. It is also applicable for dense to very dense granular soils with some apparent cohesion. Soil nail is not suitable for dry, poorly graded cohesionless soils, soft to very soft fine- grained soils, and organic soil (very low bond stress or soil nail interaction force leading to excess nail length). Soil nailing is also not recommended for soils with high ground water table.
6. The reinforcements need to be sufficiently strong to prevent nail tendon tensile failure and the ground-nail ultimate pull out resistance must be sufficiently high to prevent pull out of the reinforcements. Besides, the nails and the nails-grout ground interface must be sufficiently stiff to ensure that the reinforcing loads can be developed without undergoing excessive deformations.

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