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Performance of Soil Nails in Weathered Granite and Fill

Performance de renforcement par clouage du granite altéré et du remblai

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ABSTRACT: Soil nail is increasingly common in Malaysia for infrastructure works where high cut slope is often formed to accommodate road alignment, facilities, etc. In recent years, soil nailing has also proven to be a viable, cost-effective and environmental friendly alternative solution for deep excavation of basement to replace conventional solutions using vertical retaining wall such as contiguous bored pile, secant pile or diaphragm wall. Applications of soil nail for basement construction of up to 30m deep have been successfully designed and constructed where performance of the soil nailing works have been verified based on monitoring results. Design assumptions for the skin friction between the soil and grouted body of soil nail were also verified using instrumented preliminary and working pull-out tests on the soil nails. This paper discusses results of the pull-out tests on the soil nails and based on analysis of the test results, recommendations on the skin friction applicable for soil nail design are presented.

RÉSUMÉ : Les clous de sols sont de plus en plus communs en Malaisie pour les travaux d'infrastructure où une forte pente de talus est souvent créée pour le tracé de la route, pour accueillir les installations, etc. Ces dernières années, le clouage de sol s'est également avéré être une solution alternative viable, rentable et écologique pour remplacer les solutions classiques utilisant un mur de soutènement vertical tels que les pieux forés contigus, les pieux sécants ou les parois moulées pour les excavations profondes des travaux de fondations. Les applications du clouage de sol dans la construction d'excavations de plus de 30m de profondeur ont été correctement conçues et mises en œuvre et leurs performances ont également été vérifiées sur la base de mesures répétées. Les hypothèses de calcul des efforts d'adhérence entre le sol et les clous de sols avec injection ont également été vérifiées par des tests d'arrachement. Cet article présente les résultats des tests d'arrachement sur des clous de sol et sur la base de l'analyse de ces résultats, propose des recommandations sur la capacité en de scellement à prendre en compte lors de la conception des clous de sol.

KEYWORDS: Soil nail, skin friction, pull-out tests, deep excavation.

1 INTRODUCTION

Soil nails are increasingly common in Malaysia for infrastructure works where high cut slope is often formed to accommodate road alignment, facilities, etc. Soil nail is advantageous compared to other retaining wall system as the soil nails are installed directly onto the final slope/wall profile and as such, minimises earthworks compared to conventional retaining wall. Furthermore, soil nails installation also does not require heavy machineries compared to system such as contiguous bored pile (CBP), diaphragm wall/secant pile. Malaysia's experiences in soil nail design and construction have been discussed by Chow & Tan 2006 and Chow & Tan 2011.

In recent years, the use of soil nails as alternative solution to vertical retaining wall for basement excavation is also gaining popularity and has been successfully designed and constructed for basement excavation of up to 30m deep. This paper discusses the design and construction of a soil nailed slope for basement excavation of a commercial development in Mont' Kiara, Kuala Lumpur, Malaysia with excavation depth of up to 20m.

2 GENERAL GEOLOGY AND SUBSURFACE INFORMATION

The site is underlain by the Kuala Lumpur Granite formation. The granite rocks are generally whitish grey and dark grey in colour except certain parts with iron stained markings that gives orange and dark red colours to the rocks. The texture and composition of the granitic rock generally ranges from coarse to very coarse-grained.

A total of twenty nine boreholes were carried out at the site to facilitate retrieval of undisturbed soil samples for laboratory testing (e.g. Atterberg limits tests, Isotropically Consolidated Undrained Triaxial – CIU tests, etc.) and also in-situ tests such as Standard Penetration Tests (SPT). The interpreted borehole profiles relevant to the soil nail slope showing the SPT-N values, major/minor components of soil and Rock Quality Designation (RQD) for rock are shown in Figure 1. Some of the materials near to the surface, especially for materials with low SPT 'N' values (< 5) are filled materials.

Generally, the subsoil consists mainly silty SAND and sandy SILT with Liquid Limit (LL) ranging from 25% to 71% and Plastic Limit (PL) ranging from 15% to 42% and can be classified as low to high plasticity silty/clayey materials.

A total of eleven Isotropically Consolidated Undrained Triaxial (CIU) tests and four Direct Shear Box tests were carried out to determine the shear strength of the soil. The shear strength parameters of the subsoil adopted for design are $c'=3.5\text{kPa}$, $\phi'=30^\circ$.

3 DESIGN OF SOIL NAIL SLOPE FOR BASEMENT EXCAVATION

The soil nail slope with retained height of up to 20m is designed to ensure minimum long-term factor of safety of 1.4 as the soil nail slope will be permanent.

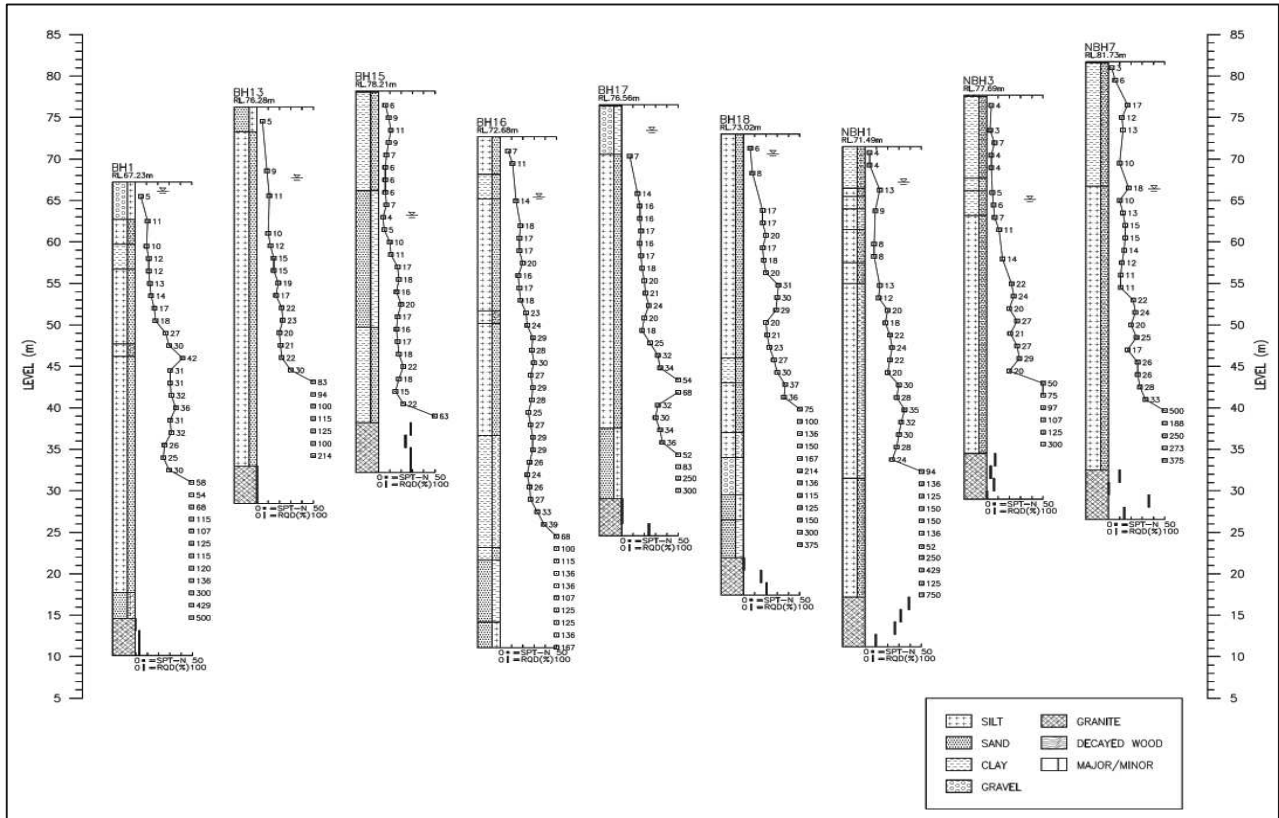


Figure 1. Borehole profiles relevant to soil nail slope.

Critical to the design of the soil nail slope is the assumptions on the skin friction between the ground and the grouted body of soil nail and as such, a series of instrumented pull-out tests on preliminary soil nails (non-working soil nails) were carried out at site to verify the design assumptions. The soil nails adopted at site generally consists of 4m to 18m length soil nails with 16mm to 32mm diameter galvanized high yield reinforcement (yield strength = 460N/mm²) slotted inside a 150mm diameter hole formed by open hole construction (without temporary casing) and filled with Grade 30 non-shrink grout.

3.1 Soil nail pull-out tests

A total of six numbers of instrumented pull-out tests on preliminary soil nails (non-working soil nails) were completed at the time this paper is prepared and the details of the pull-out tests are summarized in Table 1. All the soil nails are 6m length with 5m grouted length and 1m ungrouted length (free length) at the top. Typical set-up for the pull-out tests is shown in Figure 2 while details of the instrumented preliminary soil nails are shown in Figure 3.



Figure 2. Typical set-up for pull-out tests.

tests on preliminary soil nails (non-working soil nails).

Nail No.	Bar Diameter (mm)	Maximum test load achieved (kN)	Nearest borehole
Y-7 (RL 75.19)	25	175.0	BH-15
W/X-16 (RL 71.40)	25	140.0	BH-13
Y-10* (RL 73.24)	25	131.2	BH-15, NBH-3
Y-13* (RL 74.50)	25	148.8	NBH-3
Y-7* (RL 73.24)	25	78.8	BH-15
Y-1/2 (RL 74.00)	32	286.0	NBH-7

Note:

1. Different maximum test load is achieved primarily due to various site issues such as improper test set-up where the dial gauge has reached its maximum travel distance, malfunctioning of the load cell, etc. and not due to inadequate bond strength of the soil.
2. * - Results ignored due to improper preparation of free length at the soil nail head which interferes with instrumentation results.

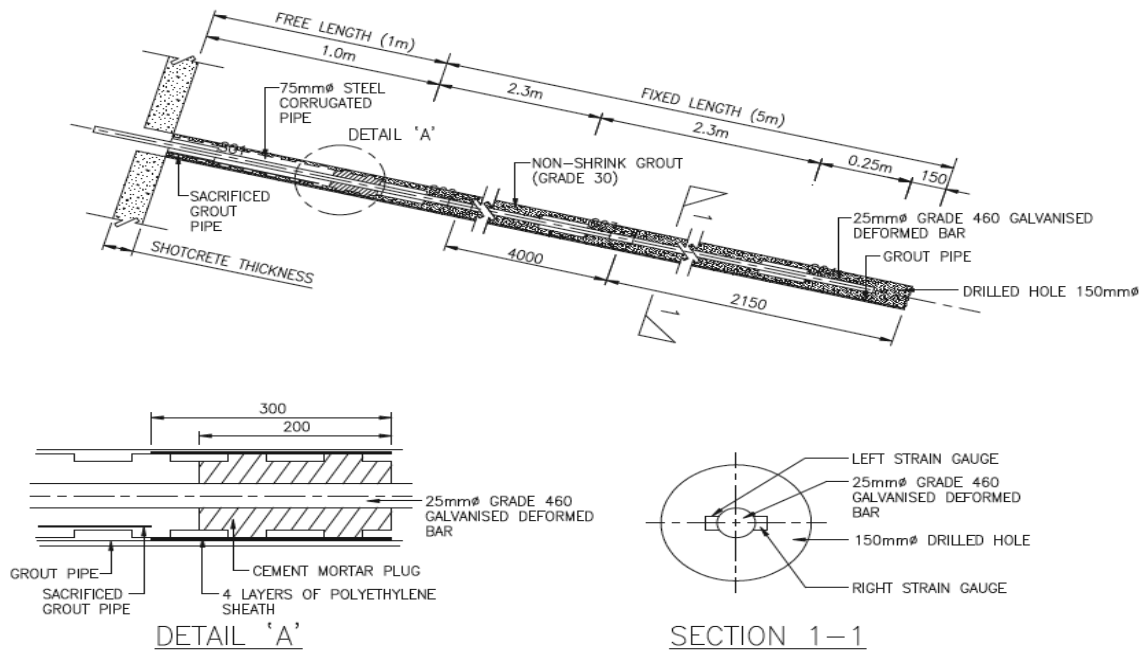


Figure 3. Typical details of instrumented preliminary soil nail.

4 RESULTS OF INSTRUMENTED PULL-OUT TESTS

The test procedures and testing sequence of the soil nails are in accordance with FHWA 1998 and the loading schedule is summarised in Table 2. The pull-out test results showing the mobilised skin friction vs nail movement are shown in Figures 4 to 6.

Table 2. Pull-out tests loading schedule (FHWA 1998).

Load	Hold Time (minutes)
0.25 DTL	10
0.50 DTL	10
0.75 DTL	10
1.00 DTL	10
1.25 DTL	10
1.50 DTL (Creep Test)	60
1.75 DTL	10
2.00 DTL	60
Repeat cycle if test load increased to 3.00 DTL	

Note:

1. DTL – Design test load
2. Test load limited to maximum 80% yield strength of nail reinforcement

The longer holding time of 60 minutes at 1.50 DTL and 2.00 DTL is to monitor creep movement. The acceptance criteria is total creep movement of less than 2mm per log cycle of time between the 6 and 60 minute readings and the creep rate is linear or decreasing throughout the creep test load hold period.

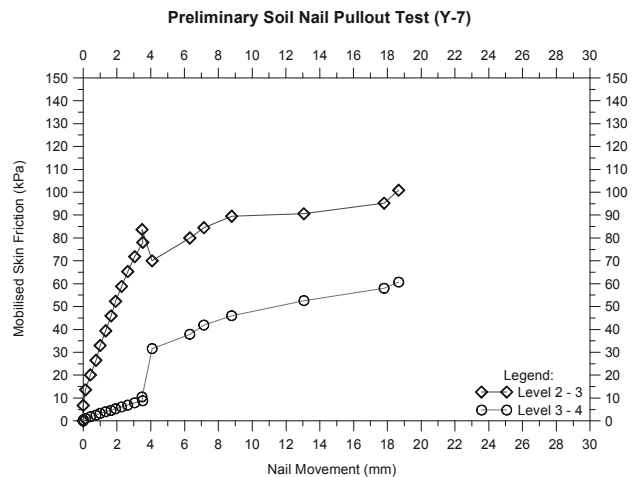


Figure 4. Pull-out test results for nail Y-7.

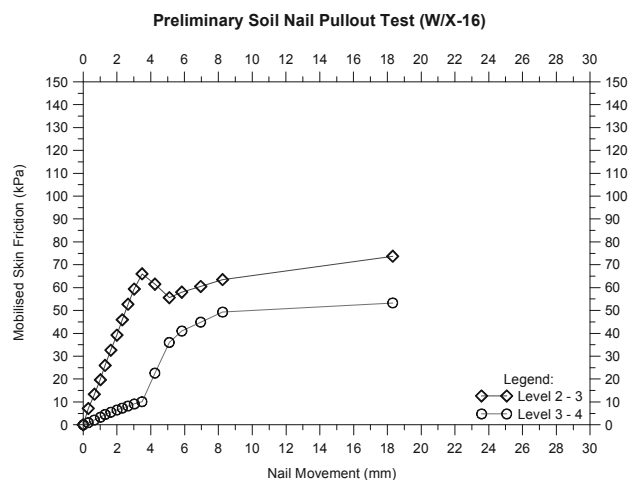


Figure 5. Pull-out test results for nail W/X-16.

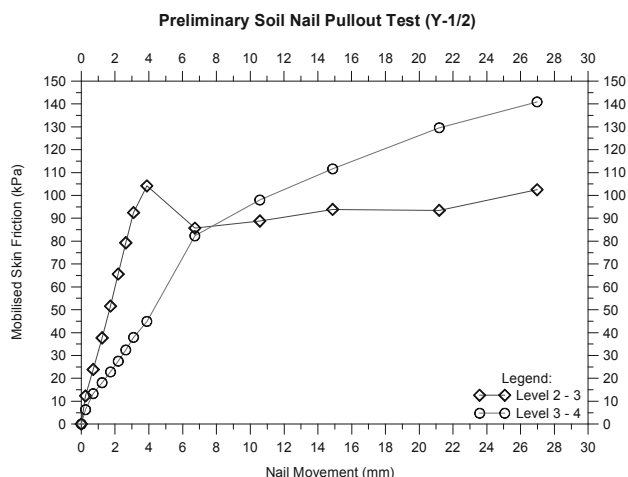


Figure 6. Pull-out test results for nail Y-1/2.

From the pull-out tests, the following observations could be made:

- The ultimate skin friction is mobilised at relatively small nail movement of approximately 4 to 6mm which is about 3-4% of the diameter of the drilled hole.
- Only nail Y-1/2 demonstrates the expected behaviour where initially, more load is transferred to the upper part of the nail until the upper part reaches the ultimate skin friction and thereafter, more load is transferred to the lower part of the nail.
- Other nails (Y-7 and W/X-16) also demonstrated behaviour where initially, more load is transferred to the upper part of the nail. However, the mobilised skin friction for the upper part of the nail has rather unexpectedly continued to increase after the initial drop. This is unexpected and is possibly due to interference from the shotcreted slope surface where the pull-out tests were conducted. It is possible that the shotcreted slope surface restricts the expansion of the soil particles during testing and contributed to the increase in mobilised skin friction for the upper part of the nail.
- The SPT-N values at the level of the tested soil nails typically range from 5 to 13 (average about 10) and the mobilised skin friction recorded range from 50 to 140kPa. This indicate a conservative correlation of skin friction can be 5x SPT-N for soil nail design in weathered granite or fill.
- Results of the pull-out tests also indicate the equation proposed by HA 68/94 (see Eq. 1) underpredicts the mobilised skin friction considerably.

$$Q = \sigma'_n \tan \phi' + c' \text{ (kN/m}^2\text{)} \quad (1)$$

where

σ'_n = average radial effective stress
 ϕ', c' = soil shear strength parameters

5 CONCLUSIONS

A series of instrumented pull-out tests were carried out for a proposed basement with excavation up to 20m deep supported using soil nailed slope. The pull-out test results indicate a conservative preliminary correlation for skin friction between the ground and the grouted soil nail of 5x SPT-N can be adopted for soil nail design in weathered granite or fill.

Further pull-out tests at deeper layers of the subsoil are currently being carried out at site and the results will be presented in the future. Some improvement to the current test procedures will also be carried out such as hacking a larger area of the shotcreted surface surrounding the test nail in order to ensure the results are not affected by the shotcreted slope surface.

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