

Deep Excavation for Basement via Soil Nailing Method

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ABSTRACT

Deep excavations for basement are common part of development to utilize underground space in densely populated areas. Protection of adjacent buildings and properties is a primary design concern nowadays for underground construction and thus, correct selection and design of suitable retaining wall system are critical for the success of the project. Common conventional retaining wall system used for deep excavation in Malaysia includes diaphragm wall, secant pile wall, contiguous bored pile wall, soldier pile wall or sheet pile wall supported either by internal strutting, temporary ground anchors, semi top-down or top-down, etc. The Authors had introduced soil nailing technique to replace the conventional retaining wall system for deep basement excavation in Malaysia. If the site condition is suitable for soil nailing technique, it will contribute to significant savings in cost and time of construction compared to conventional retaining wall system.

This paper presents two case histories on the use of soil nailing technique for deep basement excavation in Malaysia. The first case history presents an excavation of up to 30m deep for the construction of 7 levels of basement for a commercial development. The site is underlain by metasedimentary formation. The geotechnical challenge is to design and construct a deep basement of up to 30m deep with close proximity of low-rise structures (less than 5m) adjacent to the deep excavation. Experience learnt in characterizing the soil and weathered rock properties is also presented especially on determination of geotechnical parameters for weathered rock mass where proper sampling and testing of materials are difficult. Monitoring works on the completed soil nailed slope using settlement markers and inclinometers had demonstrated the effectiveness of the system where lateral movement and settlement are well within prediction. The case history demonstrates the effectiveness of soil nailing technique for deep basement construction even with close proximity of adjacent structures.

The second case history presents an excavation of up to 20m deep for the construction of 5 levels of basement in a mixed development underlain by granite formation. The site is adjacent to low-rise buildings at the boundary to the north and roads to the east and west sides of the site. This paper presents the detailed planning, coordination and interaction between geotechnical engineers and Architect to come out with the most cost effective and construction friendly solution that is at the same time fulfills the Architectural requirements. This case history demonstrates the importance of cooperation between Architect and geotechnical engineers in producing innovative solutions for the benefits of the project.

1 INTRODUCTION

1.1 Deep excavation for basement construction

Efficient use of space is a major design concern in urban development and as such, underground space is commonly utilized for basement parking, mechanical and electrical (M&E) rooms, etc. With high-rises, the depth of basement excavation is also significant in order to cater for the required numbers of carpark bays by local Authority. As such, like any major cities, the depth of basement excavation in Kuala Lumpur also increases as the country progresses and this continuously advances design concepts and capabilities of machineries to construct deeper basement. Some Malaysian experience in the design and construction of retaining wall and support systems for deep basement construction have been discussed by [Tan & Chow, 2008](#).

However, due to scarcity of land in Kuala Lumpur City Centre, major developments are increasingly being carried out in peripheral areas of Kuala Lumpur such as in Petaling Jaya, Mont' Kiara, Puchong and Shah Alam. These areas present unique challenges compared to conventional development in Kuala Lumpur City Centre as its land price and selling price are lower compared to Kuala Lumpur City Centre and the land available for development is bigger. This situation presented unique challenges and opportunities for innovative design as the selling price is not high enough for conventional basement excavation technique (e.g. diaphragm wall) to be economically feasible. However, with larger development area, some flexibility in basement layout and design allow techniques such as soil nail to be employed even for deep excavation with basement of up to 30m deep.

1.2 Soil nailing technique

Soil nail as stabilization measure for distressed slopes and for new very steep cut slopes has the distinct advantage of strengthening the slope without excessive earthworks to provide construction access and working space associated with commonly used retaining system such as reinforced concrete wall, reinforced soil wall, etc. In addition, due to its rather straightforward construction method and is relatively maintenance free, the method has gained popularity in Malaysia for highway and also hillside development projects.

In recent years, due to the advantages of soil nail which can be constructed in areas with difficult access and minimizes earthworks, soil nail system has also demonstrated its applicability for deep excavation works for basement construction. The use of soil nail system has resulted in cost savings to deep excavation project and also enables basement construction to be carried out in a relatively unobstructed working space.

The basic concept of soil nailing is to reinforce and strengthen the existing ground by installing closely-spaced steel bars, called 'nails', into a slope as construction proceeds from 'top-down'. This process creates a reinforced section that is in itself stable and able to retain the ground behind it. The reinforcements are passive and develop their reinforcing action through nail-ground interactions as the ground deforms during and following construction.

Various international codes of practice and design manuals such as listed below are available for design of soil nail:

- a) British Standard BS8006: 1995, Code of Practice for Strengthened/Reinforced Soils and Other Fills.
- b) HA 68/94, Design Methods for the Reinforcement of Highway Slopes by Reinforced Soil and Soil Nailing Techniques.
- c) U.S. Department of Transportation, Federal Highway Administration, Manual for Design and Construction Monitoring of Soil Nail Walls (FHWA, 1998).
- d) CIRIA C637: Soil nailing – best practice guidance.

A review of the various design methods for soil nail has been carried out by [Chow & Tan, 2006](#). In this paper, a brief discussion on the use of soil nail for deep excavation works is presented highlighting its relative advantages and also its limitations and how it can be overcome. Two case histories are also presented to illustrate the principles discussed.

2 SOIL NAIL FOR DEEP EXCAVATION

Soil nail offers significant advantage for deep excavation works especially in areas outside of major city centre which requires deep basement in order to maximize land use. Development features which are most suited for the use of soil nail to replace conventional system such as diaphragm wall are as follows:

- a) Areas just outside of major city centre where land price and selling price is not at the top most tier.
- b) Sizeable land for development with typical land area exceeding 6 acres. Larger land area will give more flexibility in terms of layout and carpark planning in order to optimize basement construction.
- c) Best suited for areas with different elevations across the site where conventional retaining wall such as top-down construction may induce unbalanced forces onto the permanent structures. Typical land profile is illustrated in Figure 1. Nevertheless, soil nail system can also be adopted for relatively flat land and in Malaysia, it is significantly cheaper compared to conventional system such as diaphragm wall with top-down construction and is also faster as the area will be relatively free for subsequent basement construction.

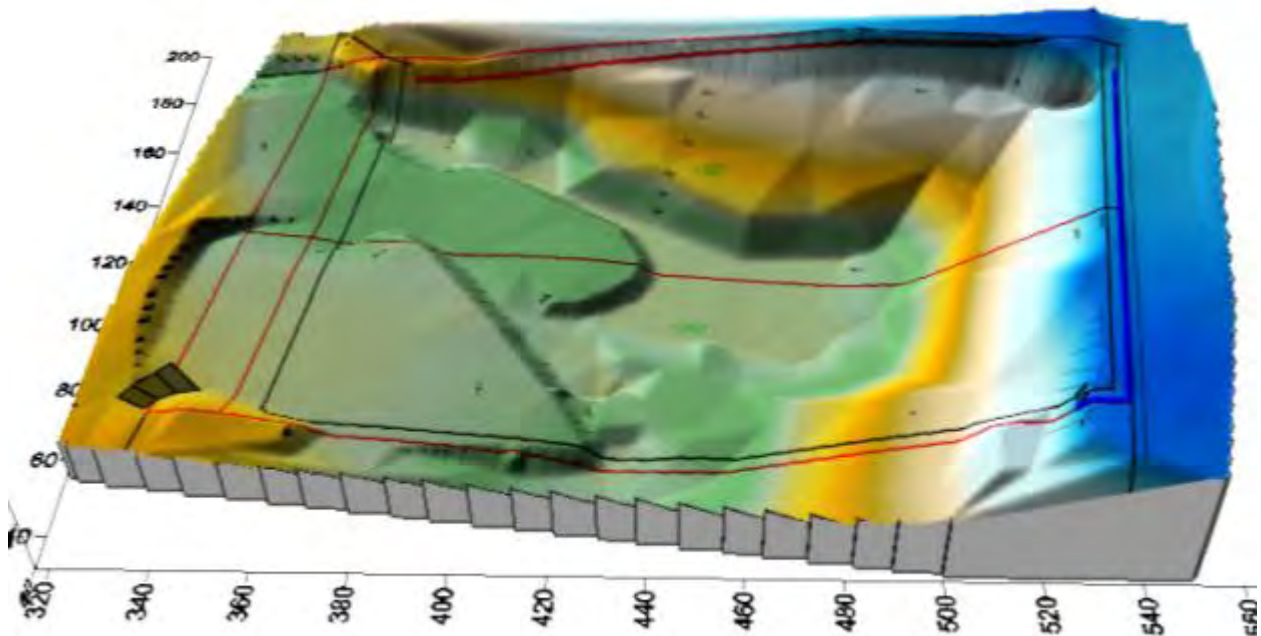


Figure 1: Land profile suitable for soil nail system due to different ground elevations surrounding the site.

Some of the advantages of soil nail system compared to conventional retaining wall system associated with deep basement are:

- a) Does not require large working space for the works. For example, diaphragm wall would require area for large machineries, storage for bentonite and recycling of bentonite fluid.
- b) Relatively cheaper.
- c) Relatively cleaner site as disposal of drilled/excavated materials will be less.
- d) Straightforward construction as it does not involve other trades. For example, top-down construction would involve concreting and structural works, installation and prestressing of temporary ground anchors for anchored wall system, etc.

Similar to any system, there are limitations to the system as follows:

- a) Requires close coordination and cooperation between Architect, Structural Engineer and Geotechnical Engineer. The system is generally different compared to conventional design where basement walls

are usually located at the edge of the boundary, right up to the statutory building setback requirements. As such, Architect and Engineers would have to work together in order to optimize the basement layout to suit the ground profile and the design. This would result in an optimized solution for the development which is a compromised solution between ideal Architectural, Structural and Geotechnical considerations. As such, **involvement of geotechnical engineer should start from early development planning stage.**

- b) May require interfacing with foundation works as the system works best by not disrupting the superstructure design (changes to accommodate soil nail system to suit the ground profile are confined to basement carpark only). Some columns for superstructures would be situated at berms within the soil nail system in order to support the superstructure.
- c) Requires considerable design effort as the design needs to integrate with Architectural, Structural and Earthworks requirements while at the same time fulfilling safety and serviceability of adjacent structures affected by the excavation works.

The above limitations can be overcome if proper planning is carried out and would result in significant savings in terms of cost and time to the project as demonstrated in the two case histories discussed in the following sections.

3 CASE HISTORY 1: 30m DEEP EXCAVATION FOR MIXED COMMERCIAL DEVELOPMENT (SOLARIS DUTAMAS)

3.1 Description of project

The proposed development, Solaris Dutamas, consists of 3-5 storey commercial units, office blocks of up to 42 storey high and 33-storey service apartments with 6 levels of basement on an 18-acre land. [Figure 2](#) shows picture of the proposed development while [Figure 3](#) shows completed view of the basement works taken recently (superstructure works completed).



Figure 2: Overall perspective of proposed Solaris Dutamas.



Figure 3: Completed basement and superstructure works.

3.2 General geology and subsoil profile

The site is underlain by metasedimentary rock formation known as Kenny Hill Formation. The bedrock consists of sandstone/siltstone with quartzite and phyllite. The weathered soils are generally characterized by the presence of sandy SILT/CLAY.

Typical simplified borelog profiles at the site are shown in [Figure 4](#) for relevant boreholes at the Northern boundary of the site where the highest soil nail of up to 30m is constructed. In general, the residual soil layer is very thin (generally less than 10m) before deep weathered metasedimentary materials with SPT-N > 50 is encountered. The significant thickness of the weathered metasedimentary materials presented challenges in characterizing its behavior due to sampling difficulties and its variability. For design purposes, soil properties were carried out using equivalent Mohr-Coulomb (c' , ϕ') parameters based on Hoek-Brown failure criterion. The soil nail slope is continuously re-assessed during construction as the slope surface is exposed and rock mass characterization was carried out by experienced geologist/geotechnical engineer.

[Figures 5 and 6](#) show typical weathered metasedimentary materials exposed during soil nail construction.

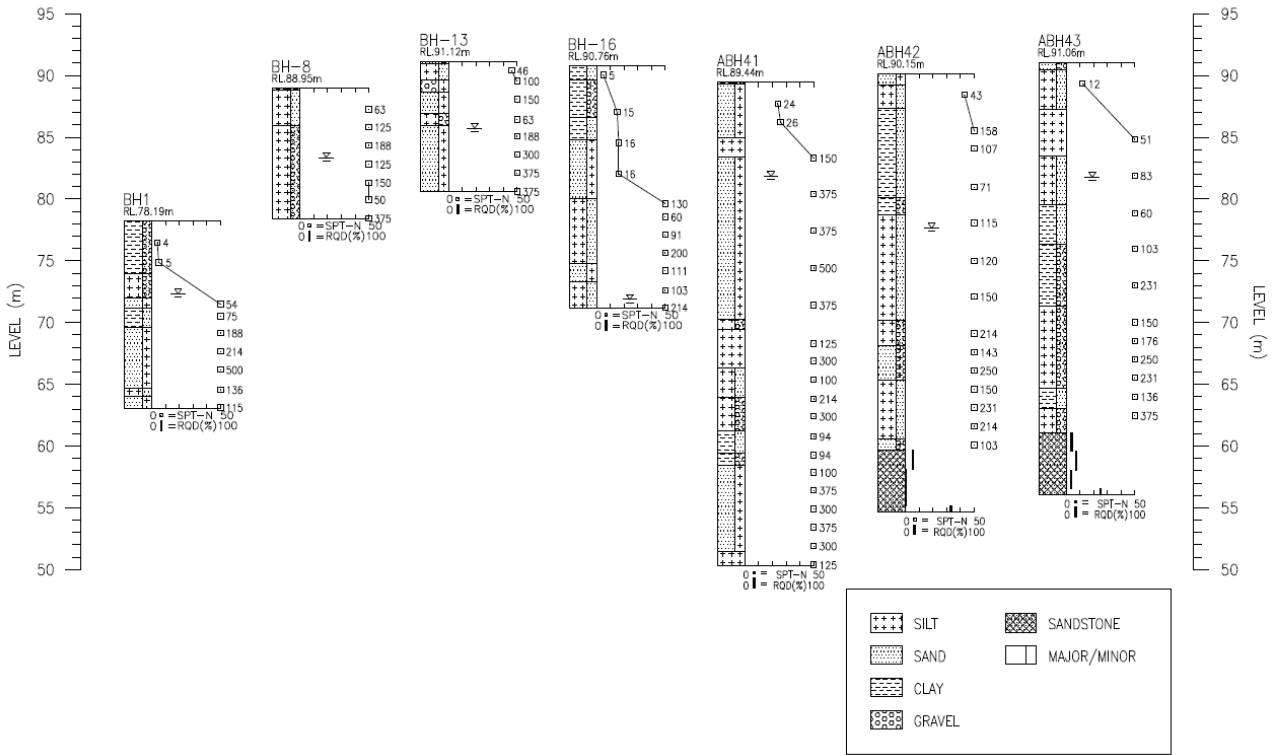


Figure 4: Typical simplified borelog profiles at Northern part of the site with soil nail wall up to 30m high.



Figure 5: Typical weathered metasedimentary materials exposed during soil nail construction (Grade V/VI).



Figure 6: Typical weathered metasedimentary materials exposed during soil nail construction (Grade III/IV).

3.3 Design of soil nail system for deep excavation

The original retaining wall system consists of $\phi 600\text{mm}$ contiguous bored pile (CBP) wall with temporary ground anchors as shown in [Figure 7](#). However, review of the contiguous bored pile system shows that the cost of the CBP wall will be high as it needs to drill through the Grade III/IV material in order to form the CBP. The weathered material cannot be left unsupported as it is highly fractured and is susceptible to degradation with time. As such, soil nail system is introduced as alternative to CBP wall and it is believed that the use of soil nail system for basement construction with such high retained height of up to 30m is being introduced for the first time in Malaysia.

[Figure 8](#) shows the alternative soil nail system which was successfully constructed. The alternative soil nail system requires some minor modifications to the basement layout and also proper planning of construction sequence and foundation system to support the superstructure. [Figures 9 and 10](#) show pictures taken during soil nail construction where the close proximity of existing buildings (less than 5m) to the soil nail slope can be observed. Completed bored piles (with protruding starter bars) within the soil nail slope can also be seen. [Figure 11](#) shows picture taken when basement construction has been completed.

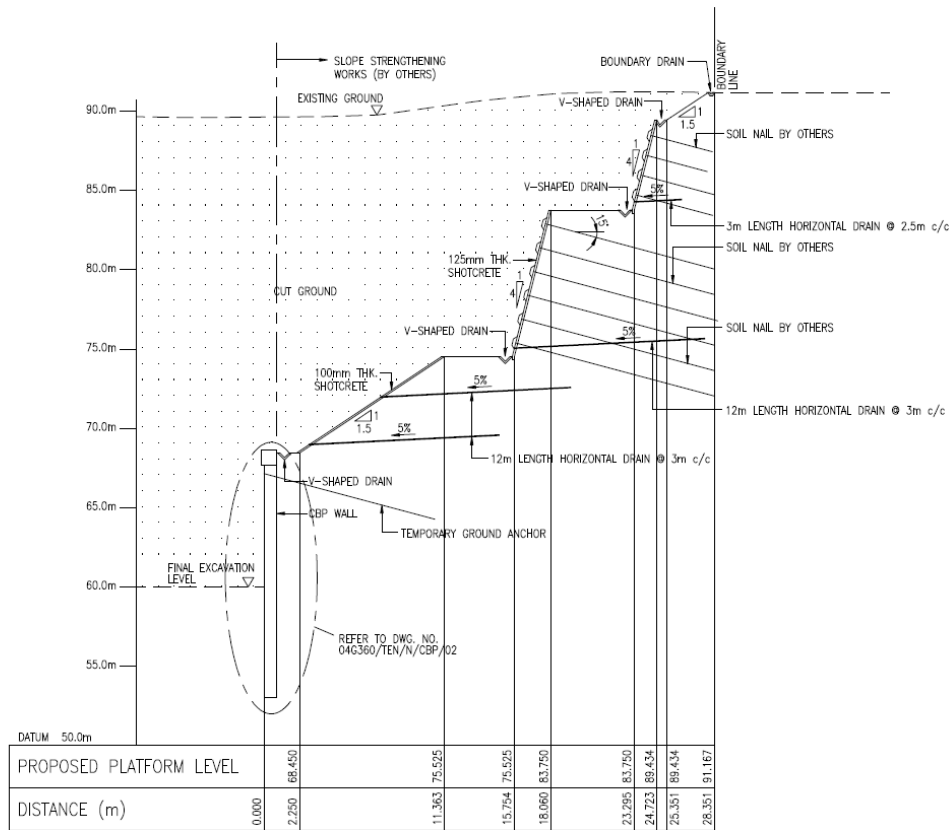


Figure 7: Original design of retaining wall system using conventional CBP wall with temporary ground anchors.

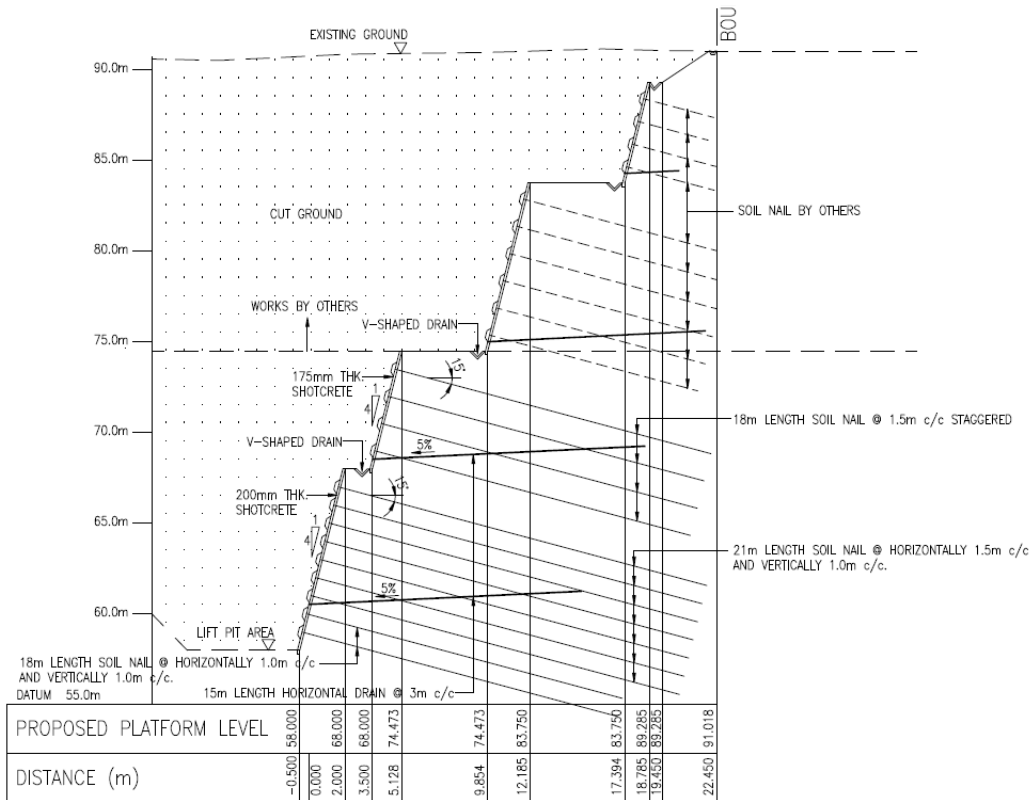


Figure 8: Alternative soil nail system to replace conventional CBP wall with temporary ground anchors.



Figure 9: Picture taken after completion of soil nailing works and basement construction on-going.





Figure 11: Picture taken after completion of basement construction.

The design of the soil nail slope was carried out based on the recommendations of FHWA, 1998. Broadly, the design needs to ensure:

- a) Internal failure
 - i. Face failure
 - ii. Pullout failure
 - iii. Nail tendon failure
- b) External failure – Global failure surface
- c) Serviceability to prevent distresses to adjacent existing buildings

FHWA, 1998 provides a rational and detailed approach for the design of soil nail system which ensures safety with respect to internal failure and external failure. Particular attention was paid to design of adequate thickness of shotcrete due to the significant height of the soil nail slope with steep angle (4V:1H) and also in deriving correct parameters especially on nail load diagram for stability analysis. The importance of nail load diagram is briefly discussed below.

In [Figure 12](#), it can be seen that the nail load diagram consists of three zones, A, B and C. Zone A is governed by the strength of the facing, T_F and also the ground-grout bond stress, Q . If the facing of soil nails is designed to take full tensile capacity of the nail, then the full tensile capacity of the nail can be mobilized even if the critical slip circle passes through Zone A. However, to design the facing with full tensile capacity of nails instead of lower T_F is not economical for high slope (e.g. more than 15m). Zone B is governed by nail tendon strength, T_N and Zone C is governed by ground-grout bond stress, Q . From the diagram, it is clear that the mobilized nail resistance should not exceed the nail load envelope developed from the three failure criteria discussed above. Therefore, the nail resistance as input for slope stability analysis should refer to the nail load diagram ([Figure 12](#)) corresponding to the available bond length for the critical slip plane ([Figure 13](#)).

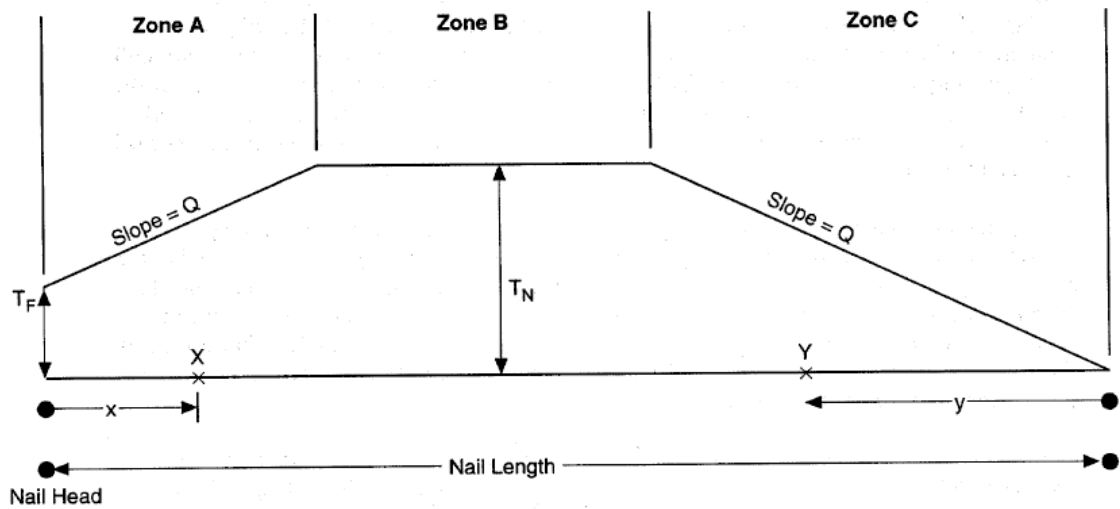


Figure 12: Nail load diagram (FHWA, 1998).

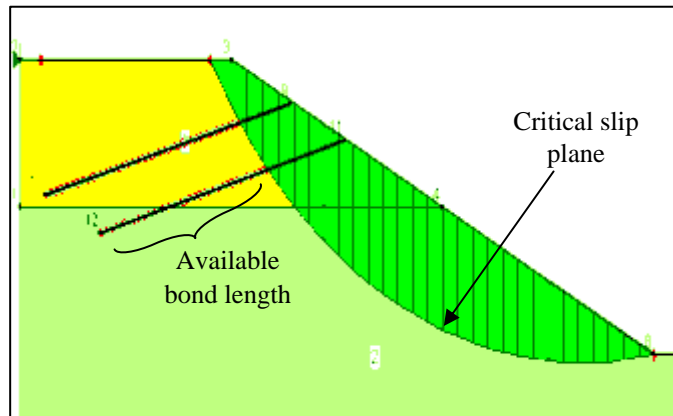


Figure 13: Available bond length from slope stability analysis.

Some slope stability analysis software may have the capabilities to automatically adjust the nail resistance based on the ground-grout bond stress and nail tendon strength. However, extra caution needs to be exercised as some of the software does not cater for the reduction of nail load at Zone A and assumes strength of T_N . As illustrated in Figure 14, failure to cater for the reduction of soil nail resistance in Zone A may lead to overestimation of the available nail resistance in slope stability analysis for critical slip circle that passes through this zone.

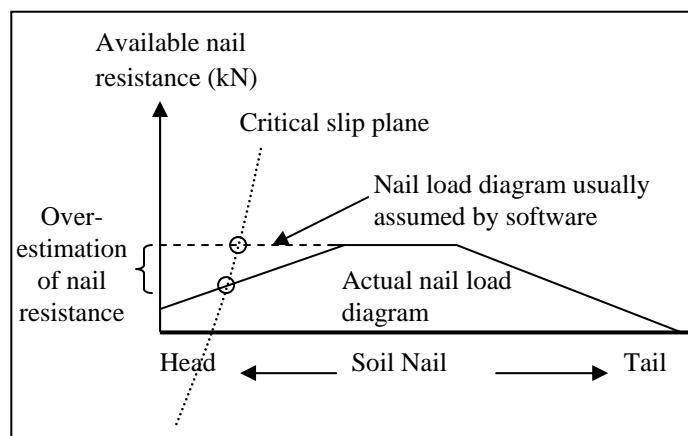


Figure 14: Overestimation of nail resistance if shotcrete facing strength not taken into consideration.

As the soil nailed wall will be left exposed and is part of the permanent structure, the minimum factor of safety (FOS) required is 1.4. The details of the soil nail satisfying ultimate limit state requirements are:

- a) Nail diameter of 25mm to 32mm (Yield strength of nail = 460 N/mm²)
- b) Grout hole diameter = 125mm.
- c) Nail length from 4m to 21m.
- d) Shotcrete thickness of 100mm to 200mm.

During the design process, one of the major challenges in designing the soil nail system is characterization of the highly fractured/weathered rock mass (Figure 6). Based on reported range of basic friction angles (Barton & Choubey, 1977) for rock materials which is reproduced in Table 1 below, the effective stress shear strength parameters adopted for the weathered sandstone is $\phi' = 35^\circ$ and $c' = 15\text{kPa}$. The basic friction angle is not adjusted for roughness and surface irregularities as site observation has confirmed the surfaces of the weathered rock is quite smooth. A relatively low effective cohesion, $c' = 15\text{kPa}$ is adopted as it is imprudent to adopt high c' value especially for long-term stability considerations.

Table 1: Basic friction angles for a range of rock materials (Barton & Choubey, 1977).

Rock type	ϕ_b dry Degrees	ϕ_b wet Degrees
Sandstone	26 – 35	25 – 34
Siltstone	31 – 33	27 – 31
Limestone	31 – 37	27 – 35
Basalt	35 – 38	31 – 36
Fine granite	31 – 35	29 – 31
Coarse granite	31 – 35	31 – 33
Gneiss	26 – 29	23 – 26
Slate	25 – 30	21

As the soil nail work progresses, review of the weathered rock mass parameters were also carried out based on site observations by geotechnical engineer/geologist using Hoek-Brown criterion as shown in Figure 15. Results from Figure 15 indicate the adopted shear strength parameters for the weathered rock is appropriate. It is noted that the equivalent Mohr-Coulomb parameters obtained from Hoek-Brown criterion are $\phi' = 35^\circ$ and $c' = 77\text{kPa}$ but as explained above, the use of lower c' for long-term slope stability is recommended.

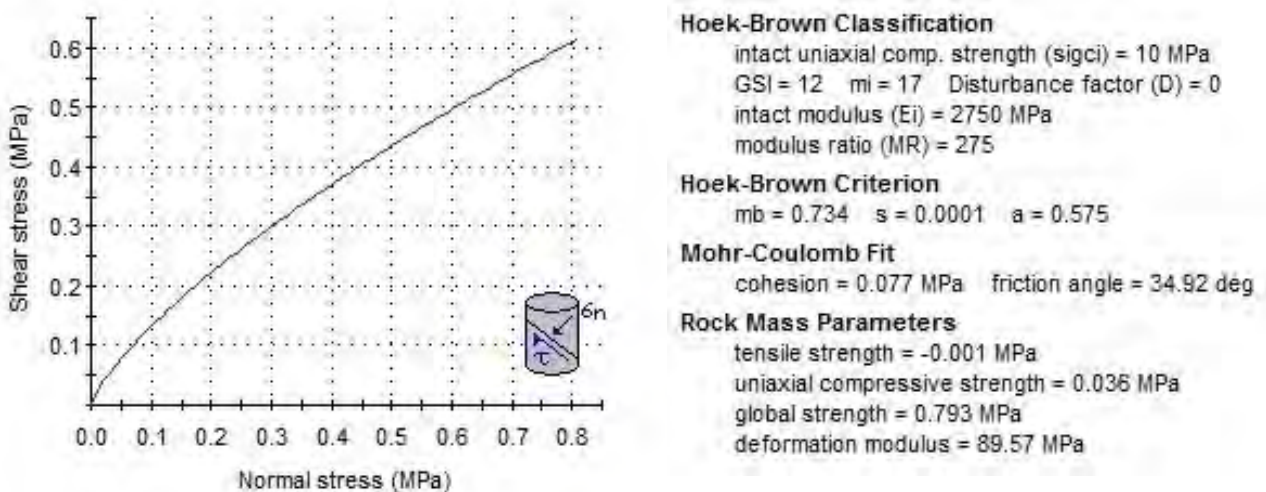


Figure 15: Rock mass parameters for weathered sandstone based on Hoek-Brown criterion (Output from Roclab software).

Due to the close proximity of adjacent low-rise structures, serviceability limit states were also checked using finite element method. The analysis was carried out using the commercial software, PLAXIS. Typical model set-up in PLAXIS is shown in Figure 16.

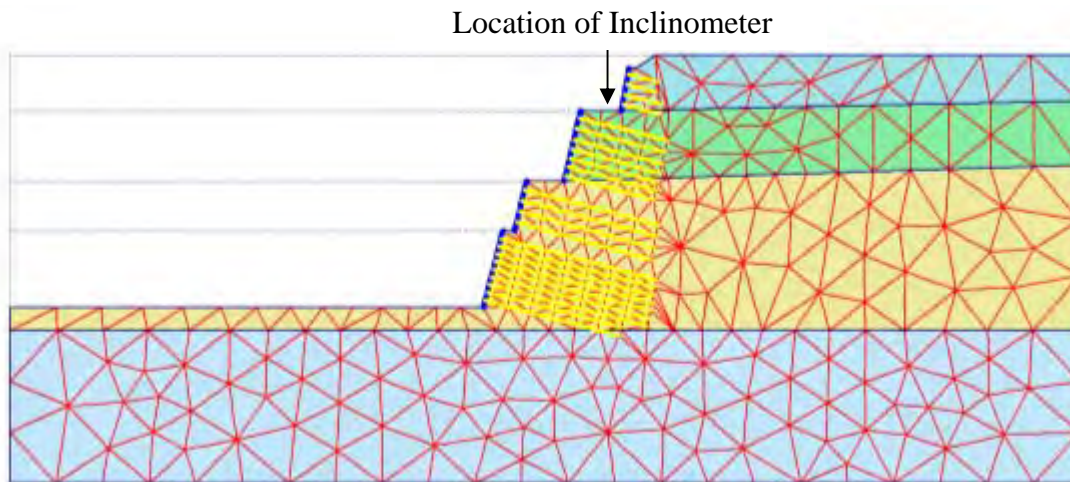


Figure 16: Typical finite element model in PLAXIS for soil nail system.

Figure 17 shows the measured ground movement using inclinometer together with the predicted ground movement from PLAXIS. It can be observed that the ground movement measured at site generally agrees with the prediction although the predicted movement is larger which is expected as slightly conservative deformation parameters were adopted during design. Based on the prediction, the soil nail slope is not expected to cause any significant distress to the adjacent structures and this is subsequently confirmed by monitoring results and visual assessment on the adjacent structures.

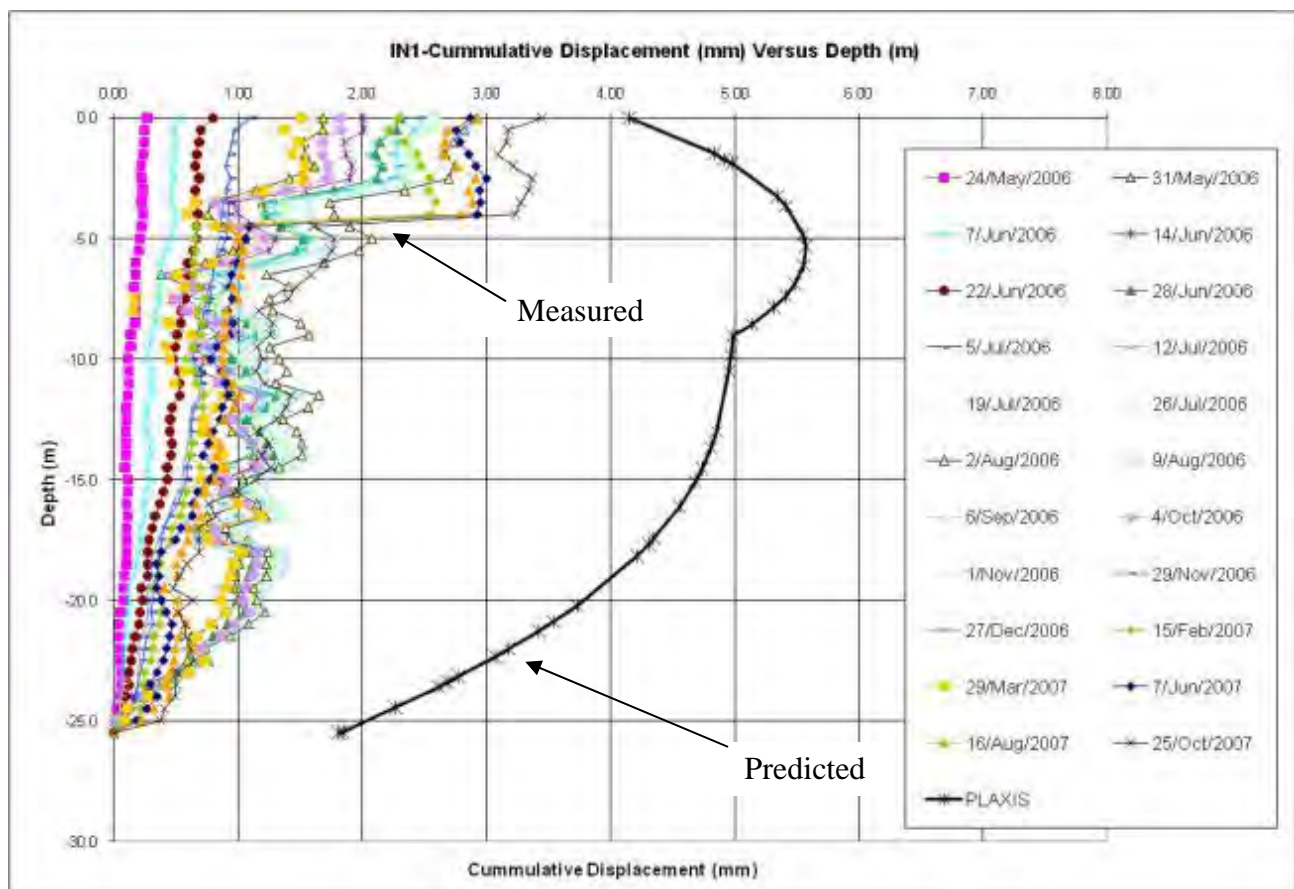


Figure 17: Predicted and measured ground movement of soil nail slope.

The soil nails were also subjected to verification and proof test based on the following acceptance criteria in accordance with FHWA, 1998:

- a) For verification tests, a total creep movement of less than 2mm per log cycle of time between the 6 and 60 minute readings is measured during creep testing and the creep rate is linear or decreasing throughout the creep test load hold period. (Note: The creep criterion has been established to ensure that the nail design load can be safely carried throughout the structures' service life (up to 100 years) without causing movement that could damage the structures)
- b) For proof tests, a total creep movement of less than 1mm is measured between the 1 and 10 minute readings or a total creep movement of less than 2mm is measured between the 6 and 60 minute readings and creep rate is linear or decreasing throughout the creep test load hold period.
- c) The total measured movement at the maximum test load exceeds 80 percent of the theoretical elastic elongation of the test nail unbonded length.
- d) A pullout failure does not occur at the maximum test load. Pullout failure is defined as the load at which attempts to further increase the test load simply result in continued pullout movement of the test nail.

Based on verification tests carried out on preliminary soil nails, the ultimate capacity of the ground-grout bond ranges from 3 to 5 times SPT-N (in kPa). As such, the 3*SPT-N correlation was routinely adopted for preliminary design in Malaysia and optimization to 5*SPT-N will be carried out if pull-out test results justify higher values.

Typical result of a pull-out test is shown in [Figure 18](#).

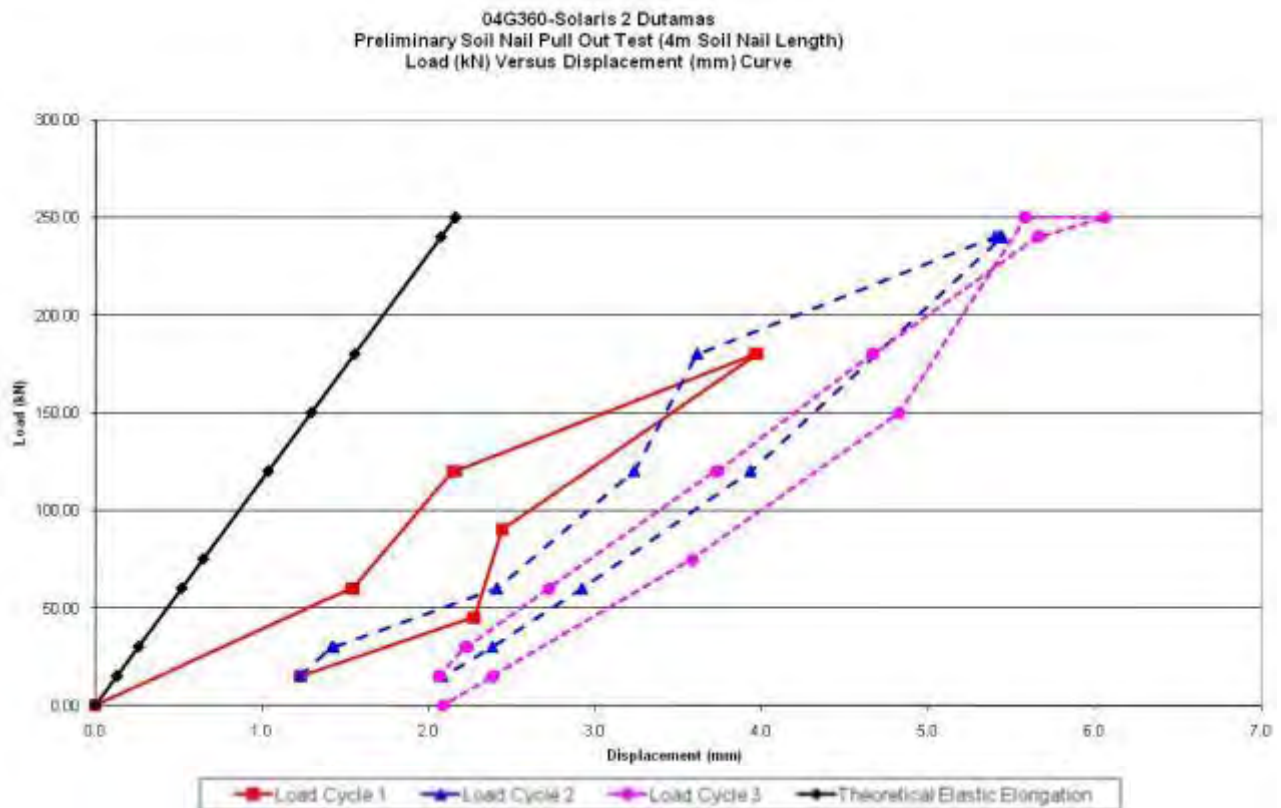


Figure 18: Typical verification pull-out test results.

In summary, the performance of the soil nail system is satisfactory and is superior compared to conventional retaining wall system for this particular project site resulting in significant time and cost saving. The cost savings resulting from the soil nails system is approximately RM5 Million.

4 CASE HISTORY 2: 20m DEEP EXCAVATION FOR MIXED COMMERCIAL DEVELOPMENT AT MONT' KIARA

4.1 Description of project

The proposed development consists of 1 block of 37 storey Hotel and SOHO and 1 block of 19 storey serviced apartments with 5 levels of basement which requires excavation using soil nail of up to 20m deep.

4.2 General geology and subsoil profile

The site is underlain by the Kuala Lumpur Granite formation and the granite bedrock has been detected during the soil investigation works. The texture and composition of the granitic rock generally ranges from coarse to very coarse-grained. The overburden materials consist mainly of completely weathered residual soils, which are derived from the weathering of granitic rock. Loose fill is also detected at certain parts of the site which is reflected in the low SPT-N blow count (SPT-N < 10). Typical borelog profiles are shown in Figure 19.

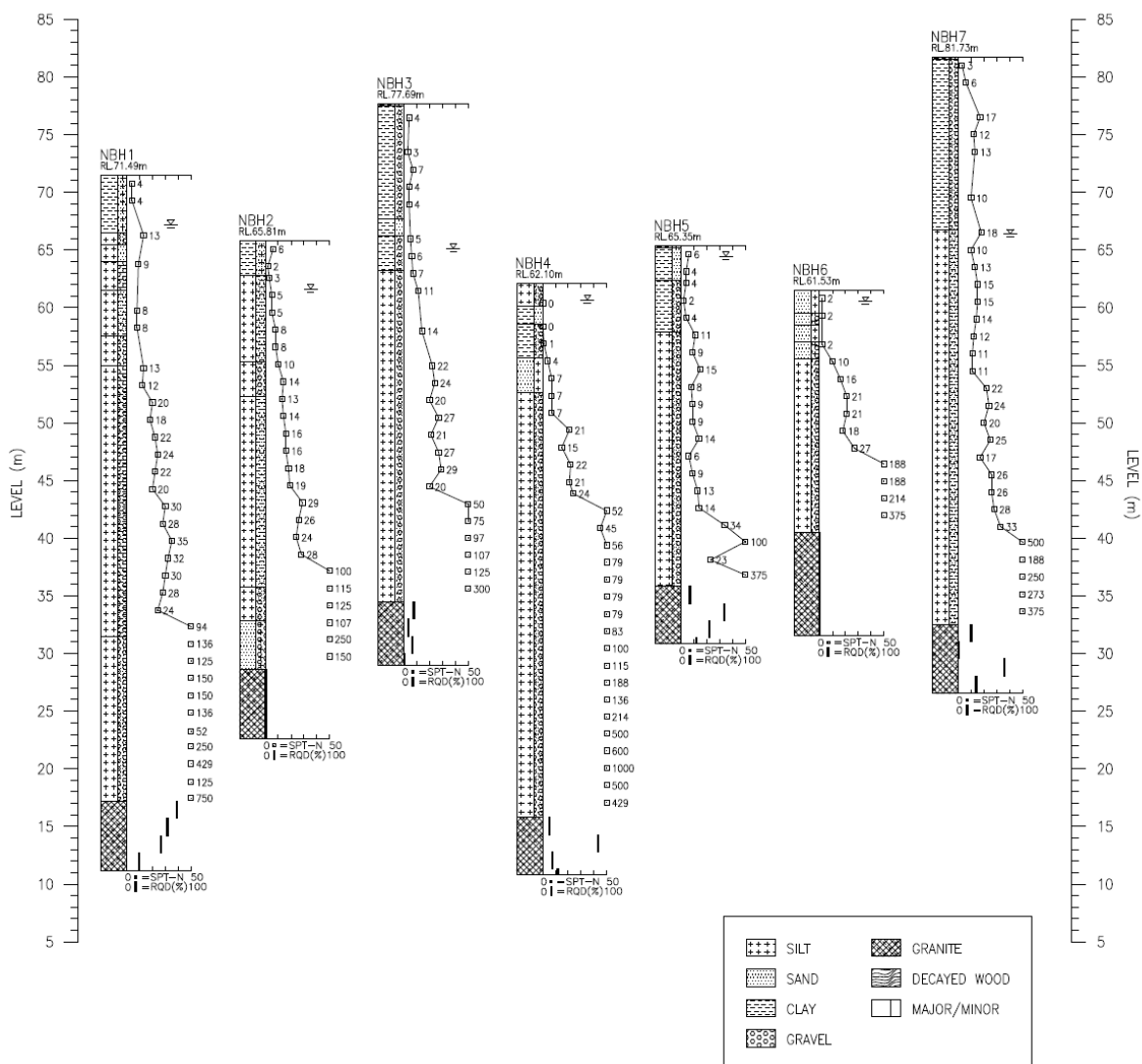


Figure 19: Typical simplified borelog profiles (Case History 2).

4.3 Design development

The original design requires retaining wall of up to 21m deep which is propped against the future basement structure as illustrated in Figure 20. Unbalanced forces will be induced onto the building frame as the supported height of the retaining wall differs significantly with one side of the ground significantly higher than the other side.

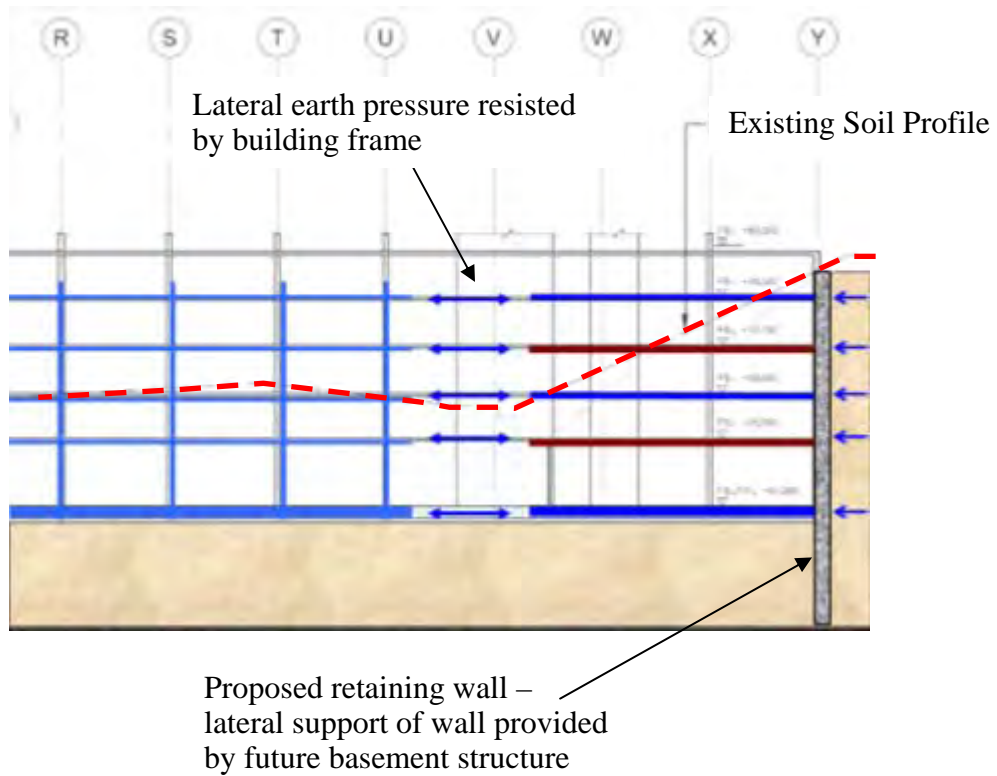


Figure 20: Conventional retaining wall system supported by building structural frame.

As part of the value-engineering exercise carried out, an alternative system using soil nail is explored. However, the required space in order to accommodate the soil nail system within the site boundary requires re-designing of the entire basement. As such, the alternative soil nail system requires the Architect and the Geotechnical Engineer to work closely together in order to produce the optimum solution based on the building needs and existing site conditions. A typical section of the final product of the soil nail system is shown in Figure 21.

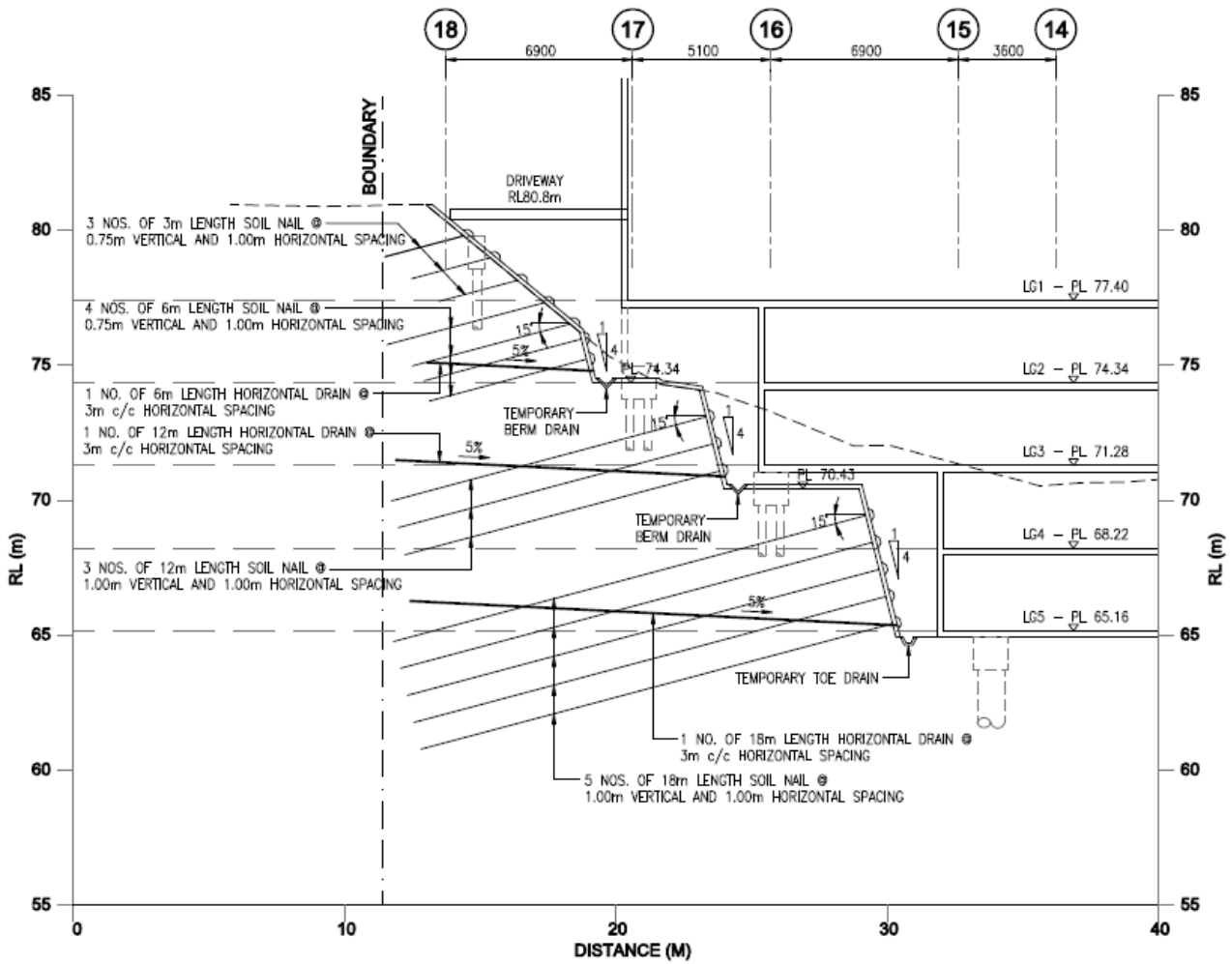


Figure 21: Alternative soil nail system for basement construction.

As can be seen from [Figure 21](#), the basement for the alternative soil nail system is more complicated in order to accommodate the space required for the soil nail. The basement layout has to be adjusted and proper planning of foundation system is also required in order to support the superstructure. The alternative soil nail and foundation system are planned in such a way that the building design above the basement parking is not affected. The required time input for such design is therefore more than conventional design and the system requires careful coordination between the Architect and the Geotechnical Engineer to ensure the design is coordinated. For example, a 3-D SketchUp Model was drawn by the Geotechnical Engineer in order to assist the team in visualizing the soil nail system as shown in [Figures 22 and 23](#).

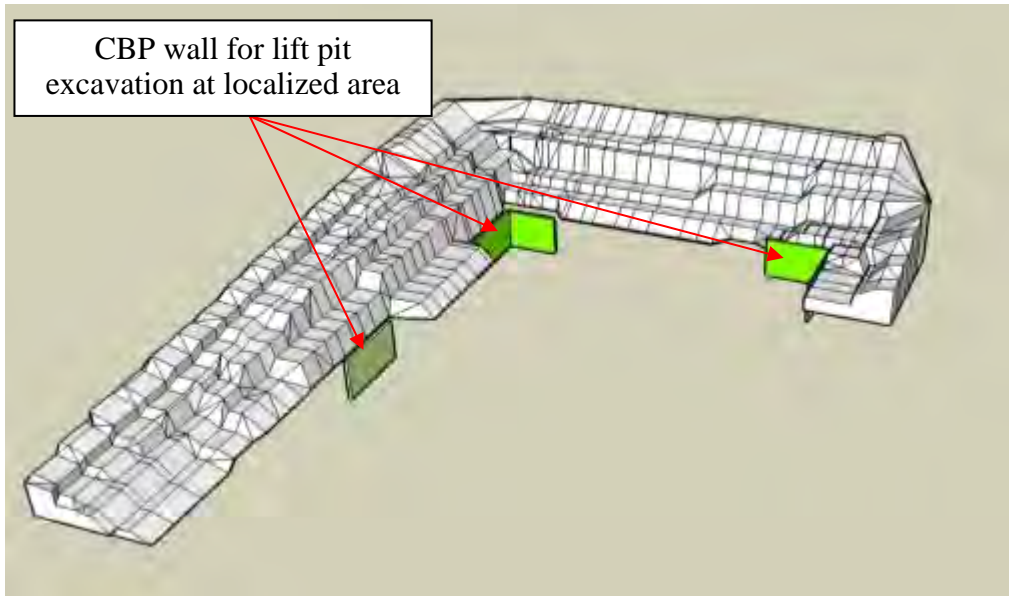


Figure 22: 3-D model of soil nail system.

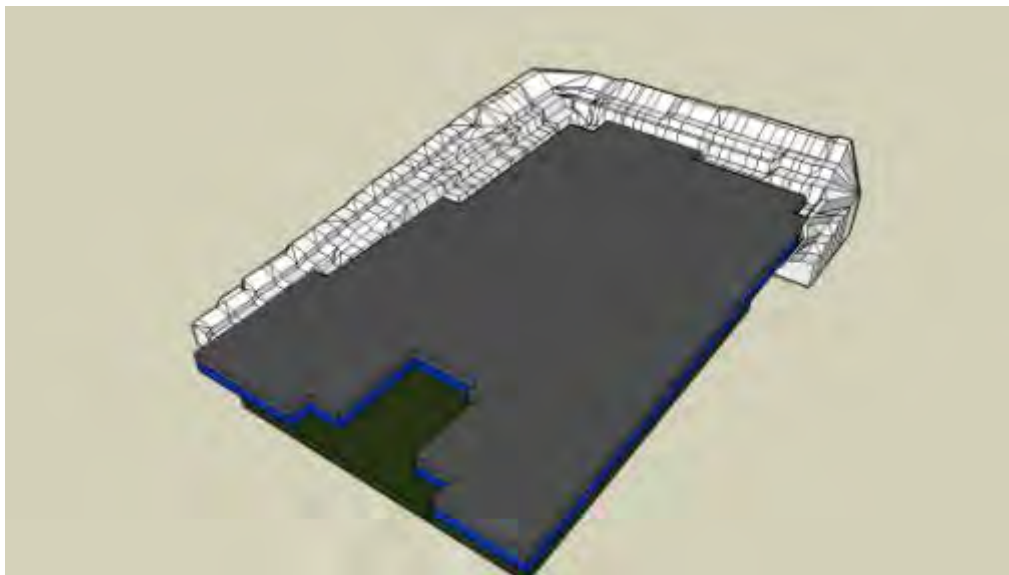


Figure 23: 3-D model showing layout of basement floors superimposed onto soil nail slope.

Due to the collaborative effort of the Architect and Geotechnical Engineer together with a supportive Client, the cost savings by adopting soil nail system to replace conventional retaining wall system is approximately RM19 Million. In summary, this case history illustrates the enormous benefits to a project brought by close cooperation of the Client, Architect and Engineer from the planning stage.

5 CONCLUSIONS

Soil nail system offers a viable and practical alternative for conventional retaining wall system typically adopted for deep excavation works such as diaphragm wall especially for project site with relatively large area (typically more than 6 acres). Soil nail system has demonstrated to offer significant cost and time savings in addition to offering advantages in terms of a robust system with relative ease of construction. In Malaysia, deep basement of up to 30m deep with close proximity of existing sensitive structures has been successfully designed and constructed using soil nail system as alternative to conventional retaining wall system and it is envisaged that more future projects using the same system will be adopted.

The system requires close cooperation between the Architect, Structural Engineer, Geotechnical Engineer and Client and therefore, the participation of the Geotechnical Engineer should begin from early development planning stage in order to optimize the basement design.

ACKNOWLEDGEMENTS

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