Performance of Soil Nailed Wall and Ground Anchor as Retaining Structure for a Drill & Blast Tunnel Portal

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Abstract: Embedded retaining walls such as contiguous bored pile (CBP) wall, diaphragm wall or micropile wall with temporary anchorage or strutting system are commonly adopted as retaining structure for tunnel portal. Disadvantages of the abovementioned retaining wall system for drill and blast tunnel is that the contractor needs to cut the retaining wall reinforcements, which is time consuming and costly, in order to facilitate installation of the tunnel crown supporting system such as umbrella arch. In this paper, a cost effective and ease of construction design approach of soil nailed wall with gradient of 4v:1h as an alternative to the conventional embedded retaining wall will be presented. Combination of 12m long soil nails and 150mm thick reinforced shotcrete are adopted to resist the lateral earth pressure and facilitate the construction of umbrella arch. The performance of the soil nailed wall during excavation and tunneling works is presented in this paper to demonstrate its effectiveness. Micropile wall with temporary ground anchors are also adopted as temporary retaining system for the cut and cover tunnel. This paper will also present the instrumentation results such as inclinometers and load cell on the temporary ground anchors. Back analyses using Finite Element Modeling (FEM) was performed to evaluate the performance of the temporary retaining wall.

1 INTRODUCTION

The electrified double tracks project for northern part of Peninsular Malaysia is currently under construction with the purpose to improve the interstate transportation system. As part of the double tracks transverse through hilly terrain, a 2.9km length twin tunnels were proposed at Bukit Berapit, Perak. The twin tunnels will be constructed partly by cut and cover construction technique (shallow overburden condition) and partly as a conventional tunnel by drill and blast method (deep overburden condition). In view of its close proximity to North-South Expressway (PLUS), the most importance highway in Malaysia, micropile wall with temporary ground anchors are adopted as the retaining structure for the temporary tunnel portal excavation.

However, the contractor need to cut the reinforcement of the micropile wall, which is time consuming, in order to facilitate installation of the tunnel crown supporting system such as umbrella arch. Therefore, soil nailed wall was then proposed as an alternative retaining wall at the tunnel face area in order to overcome the time constraint issue. Whilst, micropile wall with temporary ground anchors are still adopted at other area as shown in Figure 1.

This paper presents the performance of the soil nailed wall in terms of deformation behavior during excavation and tunneling works. The finite element method (FEM) using PLAXIS computer software was used to predict wall lateral displacement and ground anchor forces. The difference between the predicted lateral wall displacement and ground anchor forces obtained from

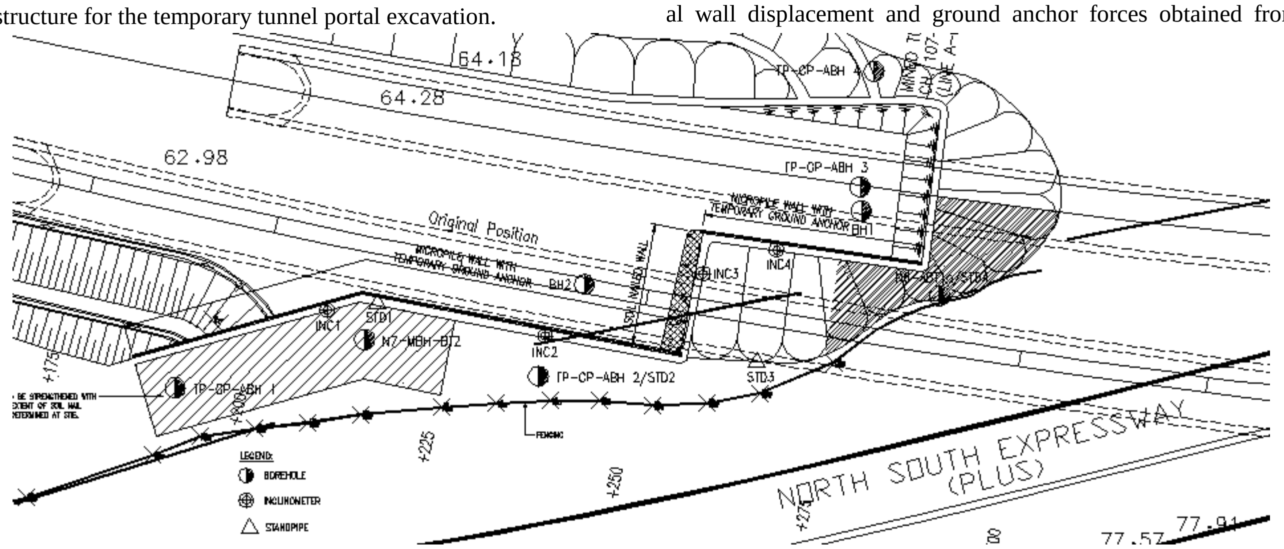

Fig. 1. Boreholes and instrumentation layout.

back-analyses and actual field measurements are presented and discussed.

2 GENERAL GEOLOGY AND SUBSOIL CONDITIONS

2.1 *General Geology*

General geological map of Perak, Malaysia indicates that the site is underlain by Granite Formation. The presence of Granite bedrock has been detected and confirmed during the subsurface investigation (S.I.) works.

2.2 *Subsoil Condition*

The subsoil strata generally consist of a layer of weathered residual soil material overlying the granitic bedrocks. The overburden subsoil mainly consists of sandy SILT according to British Soil Classification (BSCS). The interpreted borehole profiles showing the SPT-N values, major/minor components of soil and Rock Quality Designation (RQD) for rock are presented in Figure 2.

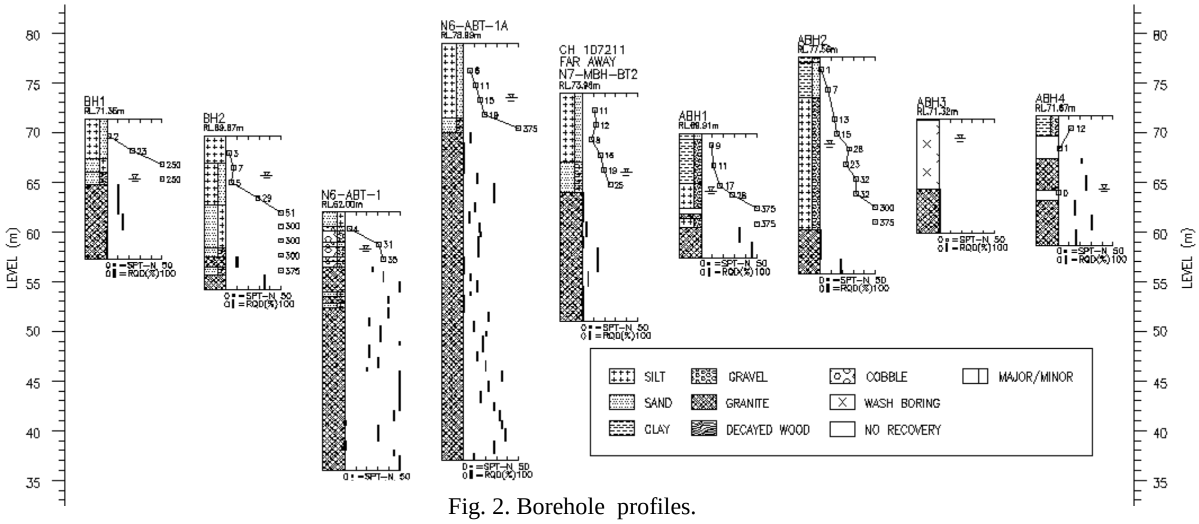

Fig. 2. Borehole profiles.

3 RETAINING WALL SCHEME AND CONSTRUCTION

The layout of the micropile wall and soil nailed wall is as shown in Figure 1. 300mm diameter micropiles were constructed at 500mm spacing to form the retaining wall. Micropile wall is adopted in view of its mobility as the project site is at hilly terrain which makes it not suitable for heavy machineries. The depth of micropile wall is generally about 12m to 16m into soil. However, if Granite bedrock was encountered at shallow depth below the final excavation level, 1m rock socket was found sufficient. 3 layers of temporary ground anchors were installed to support the 15.5m deep excavation as shown in Figure 3.

Whilst, for the tunnel face, 10m high soil nailed wall with gradient of 4v:1h and combination of 12m long soil nails and 150mm thick reinforced shotcrete as shown in Figure 4 was adopted as an alternative to conventional embedded retaining wall. The advantages of soil nailed wall compared to conventional embedded retaining wall are as follows:

a) Cutting of retaining wall reinforcements, which is time consuming, is not required during the installation of the tunnel crown supporting system such as umbrella arch
b) More cost effective as conventional embedded retaining wall need to design for different wall behaviors namely before and after cutting of the wall reinforcements

4 DESIGN AND PERFORMANCE OF SOIL NAILED WALL

4.1 *Design*

The design of soil nailed wall was carried out with reference to “Manual for Design and Construction Monitoring of Soil Nail Walls” by the Federal Highway Administration, U.S. Department of Transportation (FHWA) to prevent three (3) potential failure modes namely nail tendon failure, nail pull out failure and face failure. Whilst, the overall stability of soil nailed wall was assessed using limit equilibrium method in accordance to Hong Kong Geotechnical Manual of Slope (GCO 1984).

4.2 Performance

One (1) inclinometer, INC3, was installed at the back of the soil nailed wall as shown in Figure 1 to monitor the wall displacement. Figure 5 shows the measured wall displacement during various stages of excavation and installation of tunnel crown supporting system. The soil nailed wall has moved laterally about 16mm at the final excavation with relatively fixed toe embedment. Whilst, during the installation of first course of the tunnel crown supporting system, the recorded wall lateral displacement is only 13mm.

Fig. 3. 15.5m deep excavation with 3 levels of temporary ground anchors

Fig. 4. Soil nailed wall for tunnel face

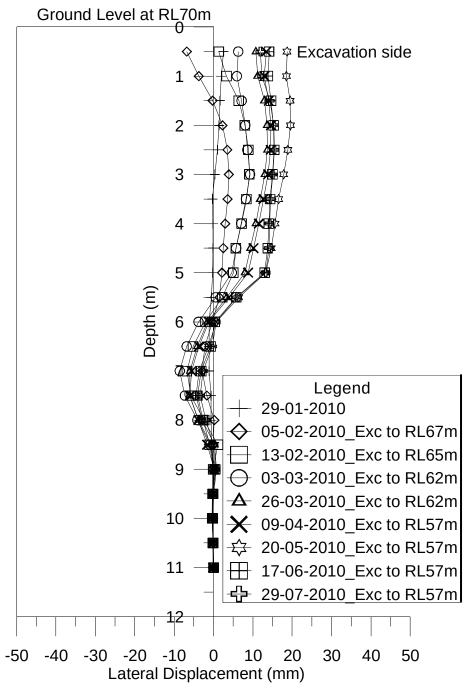

Fig. 5 Lateral displacement of soil nailed wall

5 BACK ANALYSES

5.1 *Introduction*

The simulation of the excavation processes was carried out using finite element modeling (FEM) software, PLAXIS. Figure 6 shows the FEM model of micropile wall with temporary ground anchors at the final stage utilizing 15-node element under 2-D plane strain conditions. Effective stress parameters using Hardening Soil Model is adopted to model the soil behavior in the retaining wall analyses. The soil material is assigned with undrained behavior and coupled with consolidation analyses to simulate the actual soil behavior from undrained to drained condition due to dissipation of pore water pressure. The undrained soil model coupled with consolidation analyses is able to predict a more representative wall displacement and wall bending moment relative to the construction sequence as compared to conventional drained analyses.

The original subsoil parameters adopted in the back analyses are tabulated in Table 1.

5.2 *Results and Discussion*

The back analyses results presented in this paper include relative wall lateral displacement, ground movement and ground anchor loads. The wall lateral displacement profiles from both actual measurement and back analyses are shown in Figure 7. Generally, there is good and reasonably match between the measured and back analyzed wall lateral displacement profiles. Hence, it is evident that the behavior of residual soil can be modeled using "Hardening Soil Model" for excavation analyses.

It is observed that the wall top displacement (the first 8m) for all stages obtained from back analyses overestimated the wall displacement. Whilst, the back analyses results were quite tallied with the measured lateral displacement for the subsequent depth (from 8m and below). This may due to the suction behavior of the partially saturated subsoil as the groundwater table is at RL65.5, which is about 8m below top of wall level. The less lateral displacement measured by inclinometer as compare to FEM back analyses for the top 8m is probably cause by the suction effect of the partially saturated material which may not be considered in the FEM analysis in view of software limitation.

Figure 8 showing the groundwater level profile recorded by standpipe installed at about 8m from soil side of wall. The initial recorded groundwater level is about RL65m (8m below the wall top level) and draws down to about RL61m during the excavation process. As compared to the monitored results, the groundwater level in the back analyses is similar with the trend of monitored groundwater level with differential of 1m.

Figure 9 shows the comparison between measured and computed ground anchor loads from installation stage to final excavation. The ground anchor loads were measured by vibrating wire load cell installed at every layers of ground anchors. It is observed that the back analyses results overestimated the ground anchor loads by 6% to 23% at the final stage for all levels of ground anchors. No significant increase in load for the first level of ground anchor is recorded and this tallied with no significant lateral wall displacement for the first 8m as shown by the inclinometer reading. In addition, some ground anchors have shown reduction of prestressed load (about 4% to 6% of the prestressed load) during ground anchor installation and excavation process. This reduction was probably due to prestress of surrounding ground anchor after the instrumented ground anchor was locked to designed prestressed load.

6 CONCLUSIONS

Based on the discussions in earlier sections, the following conclusions can be made:

a) Soil nailed wall was adopted successfully as an alternative to conventional embedded retaining for tunnel face in view of its construction practicality and cost effectiveness.
b) Back analyses by FEM produce reasonable prediction of wall lateral displacement and ground anchor loads expect for partially saturated material (above groundwater table) as the suction behavior might have further enhanced the stiffness of the subsoil.
c) The effective Young's Modulus (E′) and the effective unloading/reloading Young's Modulus (E'_{ur}) which are correlated based on 3000xSPT-N and 9000xSPT-N respectively are suitable to be adopted for Granite Formation residual soil in FEM modeling of excavation analyses.

Table 1. Subsoil parameters

Reduce levels (RLm)	Soil type	SPTN/ RQD	Unit weight (kN/m^3)	Permeability (m/s)	c'	phi'	E_{50}	E_{oed}	E_{ur}
77 - 73	sandy CLAY	N=5	18	1.00E-07	5	28	15000	15000	45000
73 - 69	gravely SILT	N=13	18	1.00E-07	10	31	39000	39000	117000
69 - 66	gravely SILT	N=24	18	1.00E-07	15	33	72000	72000	216000
66 - 63	gravely SILT	N=32	19	1.00E-08	15	34	96000	96000	288000
63 - 60	gravely SILT	N=100	20	1.00E-09	20	35	300000	300000	900000
60 - 57	fracture granite	RQD=0	22	1.00E-07	30	42		E = 1000000	
57 - 40	granite	RQD=20	22	1.00E-07	100	45		E = 2000000	

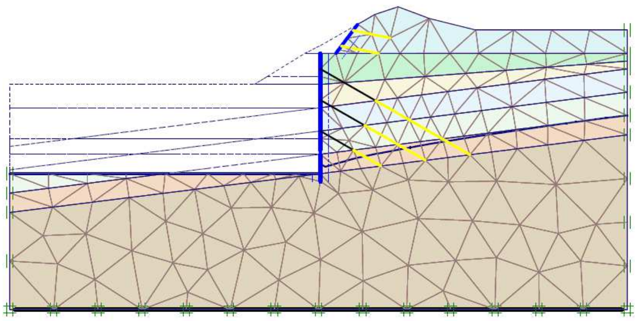

Fig. 6 Finite element modeling of excavation

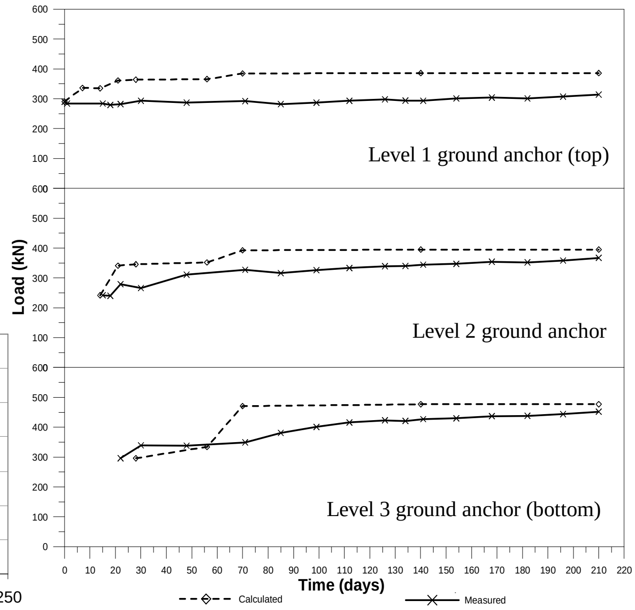

Fig. 9 Ground anchor loads profiles

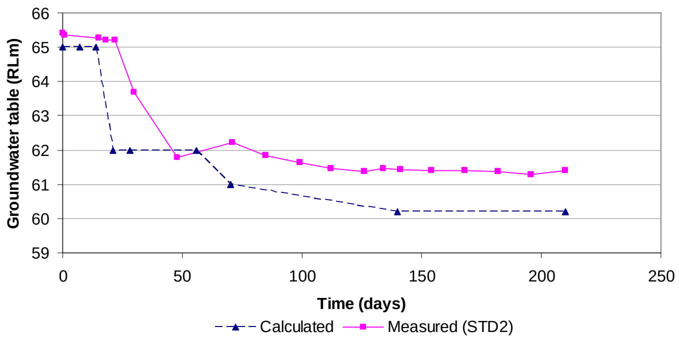

Fig. 8 Groundwater level profile

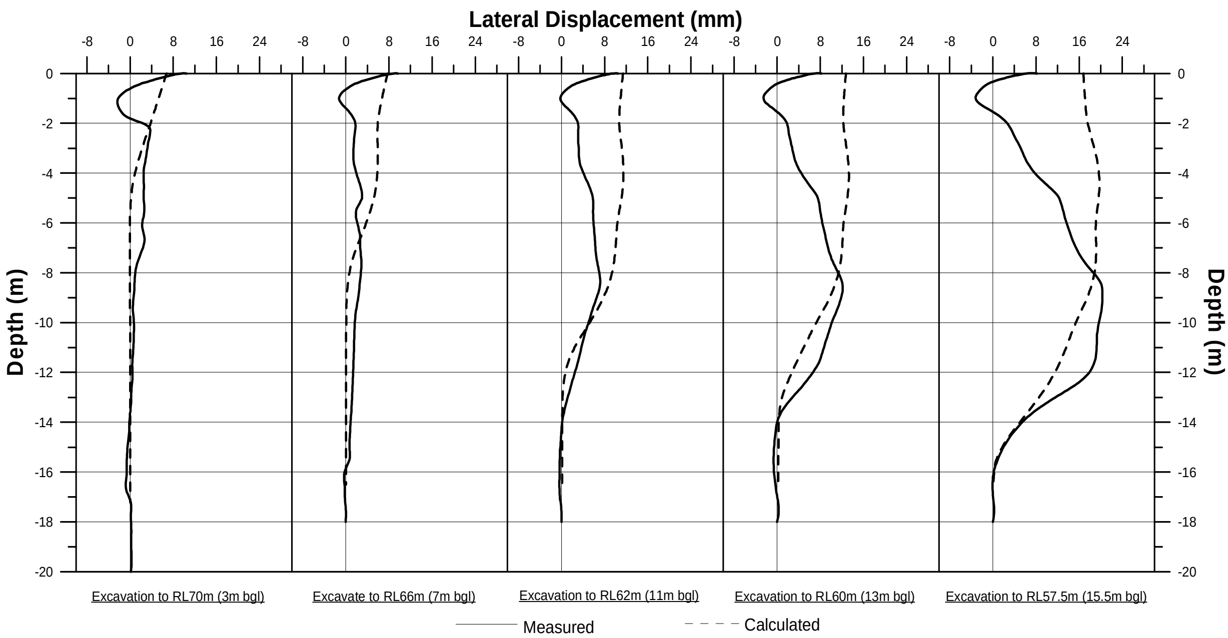

Fig. 7 Wall lateral displacement profiles