Combined cut and cover and New Austrian Tunnelling methods for MRT station in Bangkok sub-soils

N. Phienwej
School of Engineering and Technology, Asian Institute of Technology, Thailand + Email: noppadol@ait.ac.th
C. Surarak
Griffith School of Engineering, Griffith University, Australia + Email: c.surarak@griffith.edu.au
H. Cai
Griffith School of Engineering, Griffith University, Australia + Email: hao.cai@griffith.edu.au
S. Suwansawat
Dept. of Civil Engineering, King Mongkut's Institute of Technology, Thailand + Email: kssuchat@kmitl.ac.th
H. Guan
Griffith School of Engineering, Griffith University, Australia + Email: h.guan@griffith.edu.au
A.S. Balasubramaniam
Griffith School of Engineering, Griffith University, Australia + Email: a.bala@griffith.edu.au

ABSTRACT

In this paper, ground surface settlement and diaphragm wall displacement of a combined cut and cover and New Australian Tunnelling Methods (NATM) MRT station have been studied using 2D finite element analysis. By assuming greenfield conditions, a FE study was conducted in which an elasto-plastic constitutive model was adopted to model the soil behaviour. Multi-stage construction of both cut and cover box and NATM tunnels were modelled according to construction sequences. The ground surface settlement values behind diaphragm wall, as induced by cut and cover box excavation, were in good agreement with those calculated from simplified method. Diaphragm wall displacements on the NATM tunnels side were reduced due to stress release from tunnels excavation. However, the ground surface settlements were further extended to 3 times of the settlement after construction of cut and cover box.

RÉSUMÉ

Ground surface settlement and diaphragm wall displacement of a combined cut and cover and New Australian Tunnelling Methods (NATM) MRT station has been studied using 2D finite element analysis. By assuming greenfield conditions, a FE study was conducted in which an elasto-plastic constitutive model was adopted to model the soil behaviour. Multi-stage construction of both cut and cover box and NATM tunnels were modelled according to construction sequences. The ground surface settlement values behind diaphragm wall, as induced by cut and cover box excavation, were in good agreement with those calculated from simplified method. Diaphragm wall displacements on the NATM tunnels side were reduced due to stress release from tunnels excavation. However, the ground surface settlements were further extended to 3 times of the settlement after construction of cut and cover box.

Keywords : Cut and cover station, NATM tunnelling and FE analysis

1 INTRODUCTION

The MRTA Blue Line Extension project is the second phase of an integrated transportation plan of Bangkok to moderate the traffic congestion in the southern part of Bangkok city. The project plan comprises a total length of 14 km (9 km elevated and 5 km underground route), including 7 elevated and 4 underground stations. This paper is focus on one of the underground station namely Wang Burapha Station, which is planned to construct within historically sensitive area. To minimise the disturbance on the ground surface, combined cut and cover and New Austrian Tunnelling Methods (NATM) is used in the design. Typical cross section and geometry of Wang Burapha Station is depicted in Fig. 1.

The main aim of this paper is to study the behaviour of ground movement induced by construction of combined cut and cover and NATM station. The conclusions drawn out from this study are based on the results from the following steps:

i. Soil parameter studies were carried out by means of both case history and laboratory result back analyses.
ii. A finite element model was established using Plaxis software. This model is designed according to construction sequences of cut and cover station box, followed by NATM tunnels construction.

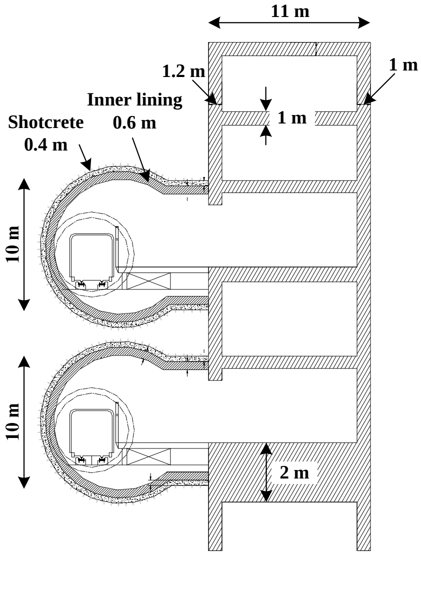

Fig. 1: Wang Burapha station cross section

iii. FE results of settlement at the back of diaphragm wall due to cut and cover box excavation were compared with simplified method (Ou and Hsien, 2000).

iv. Finally, the analysis of NATM tunnels located beside the cut and cover box was continued. The results obtained from this analysis are discussed.

2 CONSTRUCTION SEQUENCES

Construction sequences of Wang Burapha station can be summarised as follow:

i. Destruction of existing 4 storey buildings above the cut and cover box construction area;

ii. Construction of 1.2 m and 1.0 m diaphragm walls on the left and right hand side, respectively, the diaphragm walls will be installed down to Very Dense Sand layer at the depth of 42.4 m ;

iii. 3.0 m excavation steps until the base slab level at the depth of 32 m, each 3.0 m excavation step will follow immediately by the installation of temporary steel strut at 4.5 m longitudinal spacing;

iv. Installation of 2.0 m thick base slab;

v. Soil improvement of Dense Sand layer in the area below the base slab and the inverse part of lower tunnel;

vi. Construction of two stacked tunnels with excavation diameter of 12.4 m using NATM, for practical reasons, the lower tunnel will be excavated first follow by the upper one.

3 METHODOLOGY

The methodology followed in this paper is summarised in this section.

3.1 Parametric study

The use of advanced soil model like Hardening-Soil (HS) model deals with a more sophisticated soil behaviour resulting in additional input hardening parameters to define the changes of soil behaviour as plastic strain occur. Some parameters can be obtained directly from laboratory and field testing results reporting from Feasibility Study (BMTD, 2006) and also from model calibration back-analysis of UU and CU triaxial test results. These parameters are then compared with the parameters reported from literatures (Suwansawat, 2002; Phienwej et al., 2007). The final input soil parameters are summarised in Table 1.

3.2 Finite element modeling

Due to asymmetrical shape of Wang Burapha Station cross section, the selected cross section (CS-A) has been modelled in full geometry. Ground water level is assumed at 1.2 m below ground surface. The existing 4 storey buildings and roads are considered as distributed load of 50 and 16.7 kPa, respectively. For an area of pile foundation, an approximation method (Fleming et al., 1985) is used to obtain combined axial stiffness of piles and soil. Diaphragm wall and slab are modelled using plate element whilst spring and tunnel elements are selected for strut and NATM tunnel, respectively. The 2D plain-strain model and mesh generation are depicted in Fig. 2. The model consists of 3086, 15-noded triangular elements.

3.2.1 Soil constitutive model

Hardening-Soil model (HS) from Plaxis was adopted this study. In HS model, the total strains are calculated using a stress-dependent stiffness different from virgin loading and unloading/re-loading stiffness. The plastic strains are governing by two yield surface criterion. The hardening is assumed to be isotropic depending on both shear and volumetric strains. Cap hardening is assumed to follow the associated flow rule whist frictional hardening is assumed non-associated (Schanz et al., 1999).

Table 1. Soil Parameters – Wang Burapha Station

Parameter	Fill	Bangkok Soft Clay (BSC)	First Stiff Clay (FSC)
γ (kPa)	18	16	16 to 17.5
c’ (kPa)	0	17 to 27	40 to 52
ϕ’(degree)	25	23	26
ψ (degree)	0	0	0
E^{ref}_{50} (MPa)	5	6.5 to 9.0	10 to 15
E^{ref}_{oed} (MPa)	5	6.5 to 9.0	10 to 15
E^{ref}_{ur} (MPa)	25	65 to 72	100 to 150
υ_{ur} (-)	0.2	0.2	0.2
Power, m (-)	0.5	1.0	0.85

Parameter	Dense Sand (DS)	Hard Clay (HC)	Very Dense Sand (VDS)
γ (kPa)	17.5	18	17.5
c’ (kPa)	0	68	0
ϕ’(degree)	41	23	41
ψ (degree)	7	0	14
E^{ref}_{50} (MPa)	37	19	37
E^{ref}_{oed} (MPa)	30	19	30
E^{ref}_{ur} (MPa)	90	190	90
υ_{ur} (-)	0.2	0.2	0.2
Power, m (-)	0.8	0.8	0.5

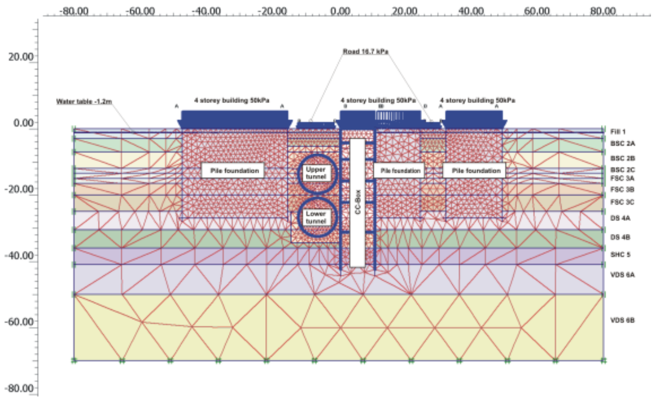

Fig. 2: Geometry and finite element mesh in Wang Burapha Station

3.2.2 Simulating the construction process

Construction process of both cut and cover box and NATM tunnels are divided in to a number of calculation steps. However, only four salient steps are presented in this study (Table 2). For the construction of cut and cover box, some existing buildings have to be destructed before the diaphragm walls can be installed. Then, the part of cut and cover box can be excavated using nine levels of temporary strut support excavation.

Table 2: Summary of calculation steps

Calculation Steps	Descriptions
Step 9	- Excavation depth is at 15 m
Step 14	- Excavation depth is at 32 m
Step 28	- After lower NATM tunnel is constructed
Step 40	- After both lower and upper NATM tunnels are constructed

4 CALCULATION RESULTS

4.1 Results after construction of cut and cover box

A simplified method based on shapes or types of the ground surface settlement observation from many deep excavation case histories has developed by Ou and Hsieh (2000).

In this method, ground surface settlement at the back of retaining wall is divided into Concave and Spandrel types. Ou and Hsien (2000) also proposed the concepts of Primary Influence Zone (PIZ) and Secondary Influence Zone (SIZ) which are the zones that contain large (steeper settlement slope) and small (gentle settlement slope) influences on existing building. The ground surface settlements calculated from FE analysis at 15 and 32 m of excavation depth are compared with the simplified method predictions (Figs. 3 and 4).

The comparisons of simplified method and FE analysis revealed reasonable good agreement in the PIZ for both location and magnitude of maximum settlement. It can be seen that location of PIZ has not changed as the excavation increase. In an area of SIZ, the results from FE analysis seem to be larger.

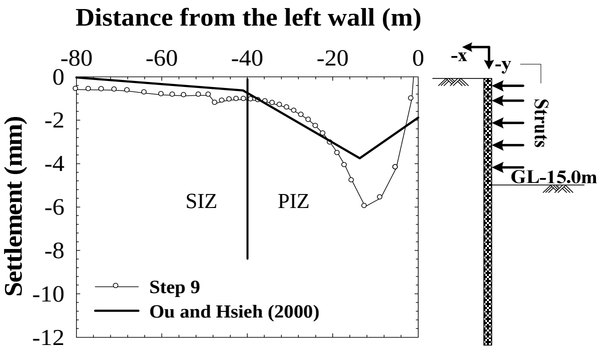

Fig. 3: Comparison between FE analysis and simplified method (Step 9: 15 m excavation depth)

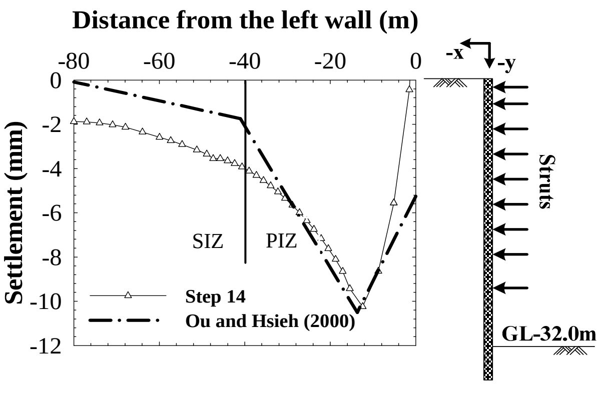

Fig. 4: Comparison between FE analysis and simplified method (Step 14: 32 m excavation depth)

According to research on deep excavation numerical analysis with small strain stiffness (Brinkgreve et al., 2006) ground deformation outside the influence zone is governing by small strain stiffness which ranges from 2.5 to 10 times higher than the unloading stiffness in soft soils. These will lead to shallower settlement trough in FE prediction.

4.2 Results after construction of NATM tunnels

All four steps of calculation, according to Table 2, from FE analysis are shown here for both lateral wall displacement and ground surface settlement at the left wall (Fig. 5) and right wall (Fig. 6). As can be seen from Fig. 5, maximum ground surface settlement and lateral wall displacement increase with the excavation depth (from Step 9 to Step 14). However, after the lower and upper NATM tunnels are constructed (Step 28 and 40), maximum wall displacement has reduced from the peak value of 21 mm to 14 mm. Stress release due to NATM tunnels excavation has caused the tip of left diaphragm wall to move toward the retained area. In addition, maximum ground surface settlement has increased to 21 and 31 mm after the construction of lower and upper NATM tunnels, respectively. In Fig. 6, the right wall shows continuous movement into the excavated area as further construction step is applied. It should be noted that magnitudes of right wall movement are higher than the ones on left wall due to the smaller size of diaphragm wall. In contrast, settlements behind the right wall are relatively small (maximum settlement of 7 mm). This should be due to the stiffer material modulus, as approximation method to combine pile and soil stiffness was adopted.

5 CONCLUSIONS

This paper presented results from FE analysis of combined cut and cover and NATM for MRT station in Bangkok sub-soils. Based on the analysis results, conclusions can be drawn:

i. For construction of cut and cover box, the settlements behind retaining wall as obtained from 2D FE analysis using non-linear-elastro-plastic HS model are agreed well with simplified method in PIZ. If the settlements in SIZ are to be matched, more sophisticated small-strain stiffness modulus should be applied.

ii. Stress release due to NATM tunnels construction has caused the wall to move back to the retained area. As a result, maximum wall displacement was reduced.

iii. Contrary to the wall displacement, ground surface settlements above the NATM tunnels have substantially increased after completion of lower and upper NATM tunnels.

iv. Approximated stiffness modulus of pile and soil has resulted in unrealistically small settlement behind the right wall. To obtain better soil behaviour in this area, 3D FE analysis is recommended.

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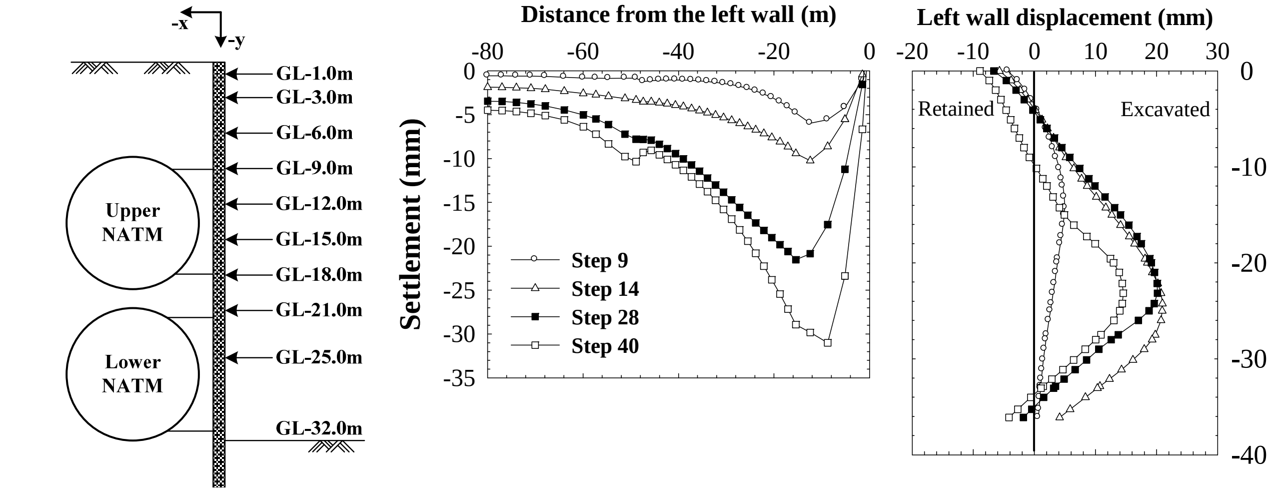

Fig. 5 Ground settlement and wall displacement on the left side

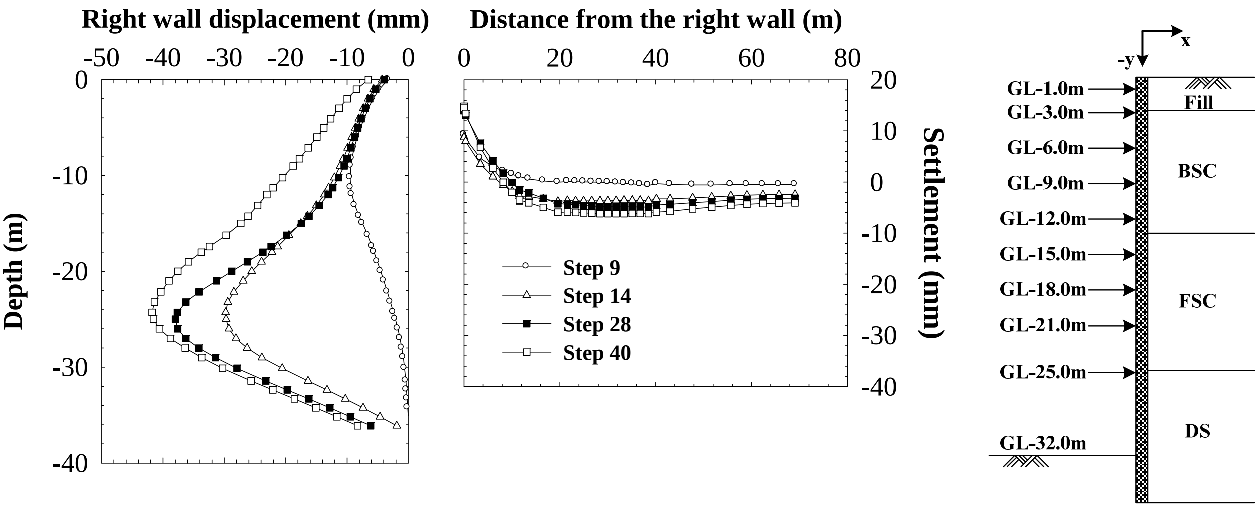

Fig. 6 Ground settlement and wall displacement on the right side

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