Ground Response for Dual Tunnel Bangkok MRT Subway

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Abstract

The first MRT subway project of Bangkok city consists of dual tunnels about 20km long with 18 subway stations. The tunnels are seated in the firm first stiff silty clay layer between 15-22 m. depth below ground surface having outside and inside diameter of 6.3 m., and 5.7 m., respectively. The behavior of ground deformation response based on instrumentation is presented. The back analysis based on plain strain FEM analysis was also presented and agreed with field performance. The shear strain of FEM analysis is in the range of 0.1-1% and agrees with the results of self boring pressuremeter tests.

1. Introduction

Construction of the first blue line subway 20 km long, the Metropolitan Rapid Transit Authority (MRTA) project has been started since 1996. The project consists of 18 underground stations running from the central main state railway station called the Hualamphong Station (S1) and goes through the business area, passes the bus terminal and ended at the Bangsue Station (S21) as shown in Figure 1. This first subway was completed and opened in August 2004.The next phase of the MRT subway will be extended from next year 2005. This paper briefly describes the MRT project, the principle of instrumentation to meet all design requirements, and safety control. The behavior of ground surface settlement during tunneling was presented based on instrumented record at various stages and time of construction. Back-analyses of ground surface response by means of FEM analysis are also presented

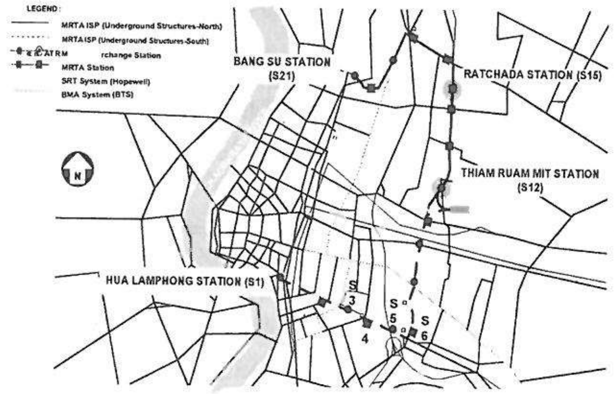

Figure 1. MRT Bangkok blue line subway

2. Bangkok Subsoil Conditions

Subsoil investigations were initially carried out during feasibility study. The post-tender site investigation were carried out during construction in order to confirm the subsoil conditions, to determine the existing piezometric levels, and to determine the design soil parameters. Over 200.boreholes as well as six numbers of self-boring pressuremeter tests were carried out. The general subsoil conditions are presented in Figure 2.

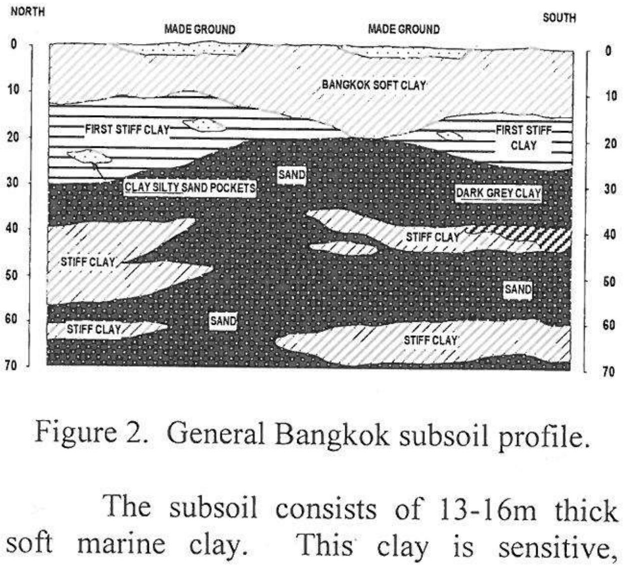

Figure 2. General Bangkok subsoil profile.

The subsoil consists of 13-16m thick soft marine clay. This clay is sensitive, anisotropic and creep (time dependent stress-strain-strength behavior) susceptible. These characteristics have made the design and construction of deep basements, filled embankments and tunneling in soft clay difficult. The first stiff to very stiff silty clay layer is encountered below soft clay and medium clay varying from 21 to 28m depth. This first stiff silty clay having low sensitivity and high stiffness is appropriate to be the bearing layer for the subway tunnels. The groundwater condition is hydrostatic starting from 1.0 m below ground level. Deep well pumping from the deep aquifers has led to the under drainage of the soft clay and stiff clay as well as deeper soil layer. The piezometric level or the phreatic surface of the Bangkok aquifer is, therefore, reduced and quite constant at about 23m below ground surface (Teparaksa, 1999(b)) as shown in Figure 3. The subway tunneling was designed to be seated mainly in the first stiff silty clay layer between 15-22 m. depth below ground surface which having very high stiffness and expecting very low or minor ground loss during TBM boring (Teparaksa, 1999, a, c and 2000).

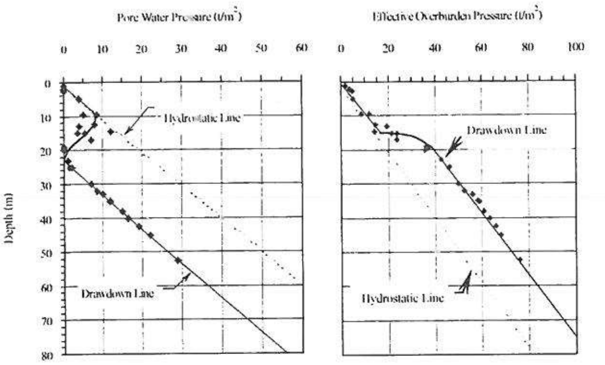

Figure 3. Piezometric level of Bangkok subsoils.

3. Subway Construction Technique

The subway construction technique was firstly started with only a small launching shafts at one end of the station, then followed by tunneling works and concurrently subway station construction by top down construction technique. The instrumentation related to monitoring the soil displacement during tunneling consists of the surface settlement points, extensometer, inclinometer and convergent bolts. The tunnel was designed as a reinforce concrete segmental lining of about 0.3 m. thick with outside and inside diameter of 6.3 m., and 5.7 m., respectively. The Earth Pressure Balance (EPB) shield technique was used to bore the tunnel. Generally, dual tunnels in parallel arrangement with spacing between tunnel of about 15 m. is designed as shown in Figure 4. However, between station S1 (Hua Lumpong) to S6 (Sirikit) due to the obstruction of the existing main Bangkok water supply tunnel (MWA Tunnel) of about 3.5 m. in diameter, the dual tunnels were arranged in vertical stack direction as shown in Figure 5.

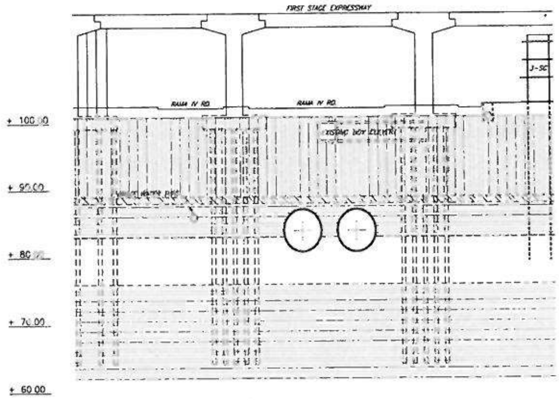

Figure 4. Parallel Dual Tunnel.

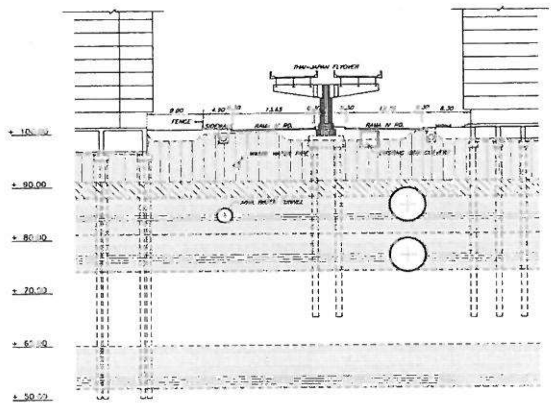

Figure 5. Vertical Stack Dual Tunnel.

4. Soil Deformation Response Due to Bored Tunneling

The ground surface displacement response during bore tunneling was monitored by means of geotechnical instrumentation (Teparaksa, 2001). The ground surface and subsurface response due to shield tunneling can be classified according to position of TBM passing through the measured point into 3 stages as the deformation ahead the shield, deformation at the shield, and deformation behind the shield. This deformation behavior recorded between stations Bonkai (S5) to Sirikit (S6) is presented in Figure 6. The deformation ahead the shield is mainly due to soil flow into the shield, while deformation behind the shield is due to effect of tail void and setting time. It is clearly showed that the displacement behind the shield is the major displacement both surface and subsurface due to tail void phenomena.

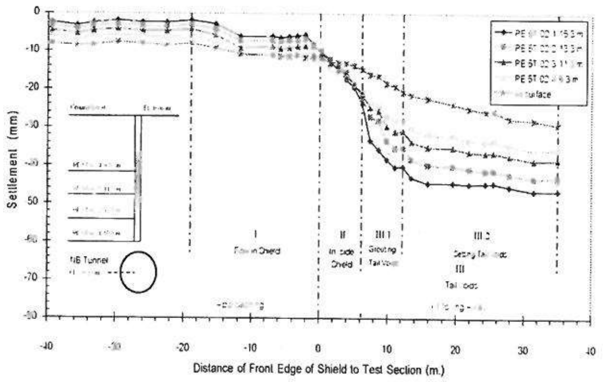

Figure 6. Behavior of Ground displacement caused by EPB bored tunnel.

5. Prediction of Ground Displacement Response

The numerical approach to predict ground displacement response was performed based on FEM analysis. The two dimensional FEM namely PLAXIS (Teparaksa, 2002) is used for modeling of the interaction between soil and structure. With this approach, a complete modeling of the system including the stress-strain distribution and ground water condition, the deformation and section force in the lining was also possible.

5.1 Soil Modeling

The constitutive model was based on an elasto-plastic (Mohr-Coulomb) failure criteria. As the recorded ground displacement response, it was occurred in the short term conditions, therefore, undrained soil parameters were assumed for the cohesive soil layers. The effect of ground water flow as well as consolidation was not considered in the model. The standard ground model used for the FEM analysis was based on the soil stiffness parameters. Generally the stiffness of the Bangkok subsoils has the non-linear behavior depended on the shear strain level (Teparaksa, 1999, c and 2000). For practical point of view, the plain strain concept with the Mohr-Coulomb soil model was used in the FEM analysis. Mair (1993) proposed the soil stiffness depending on the order of the shear strain as shown in Figure 7. The range of shear strain for bored tunnel was recommended in the range of 0.1-1.0%. Six number of self boring pressuremeter test were carried out along the MRT route. Teparaksa (1999, a and b) reported the results of the self-boring pressuremeter tests in Bangkok subsoil that the soil stiffness was depended on the degree of shear strain. According to the shear modulus from pressuremeter test and the order of shear strain for tunneling works recommended by Mair (1993) between 0.1-1 %, the soil stiffness was assumed for FEM analysis as Eu/Su = 240 and 480 for soft clay and stiff clay, respectively. The strength and definition soil parameters were summarized in Table 1.

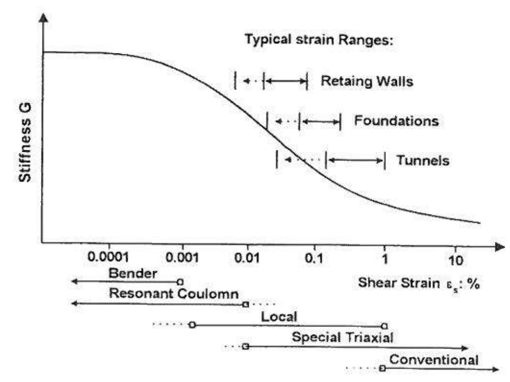

Figure 7. Typical shear modulus and shear strains for foundation works (after Mair 1993).

Table 1. Soil parameters for FEM Analysis

Soil Layer	Su (kN/m^2)	Eu/Su	E' (kN/m^2)
Made Grou	35	300	-
nd	17 – 22	240	-
Soft Clay	100 – 15	480	-
Stiff Clay	0	-	$2000N_{60}$
Silty Sand	-		

Su : Undrained shear strength, Eu : Undrained modulus, E' : Drain Modulus

5.2 FEM Analysis

Figure 8 shows the comparison between FEM predictions of ground surface deformation response with the field performance for case of parallel dual tunnel between stations Sirikit (S6) –Bonkai(S5). Figure 9 presents the comparison between FEM predictions of ground surface deformation response with the field measurement for case of vertical stack dual tunnel between Lumpini (S3) to Silom (S4) station. It can be seen that the FEM prediction of ground surface deformation response agrees well with the field performance. The range of shear strain between 0.1-1 % as recommended by Mair (1993) and Menzies (1997) as well as the soil stiffness in terms of modulus tested by means of self boring pressuremeter tests, therefore, can be used combination with Mohr-Coulomb constitutive soil modeling to predict ground response due to bored tunnel.

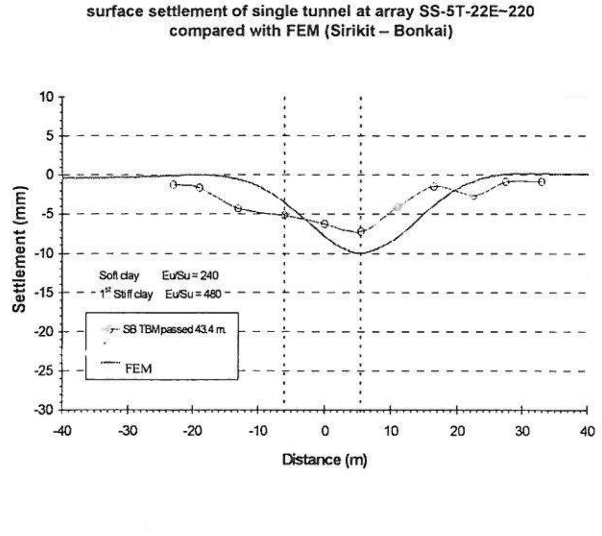

Figure 8 (a). FEM prediction of ground surface displacement for single (parallel) tunnel.

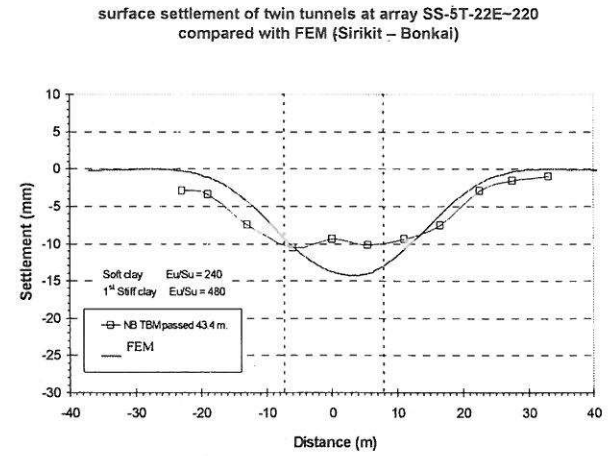

Figure 8 (b). FEM prediction of ground surface displacement for twin parallel tunnels.

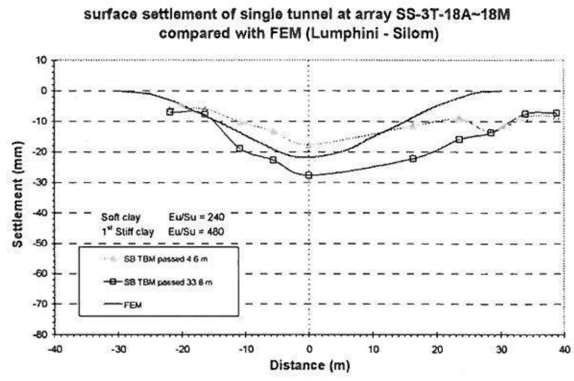

Figure 9 (a). Predicted surface settlement from FEM for single tunnel of vertical stack tunnel.

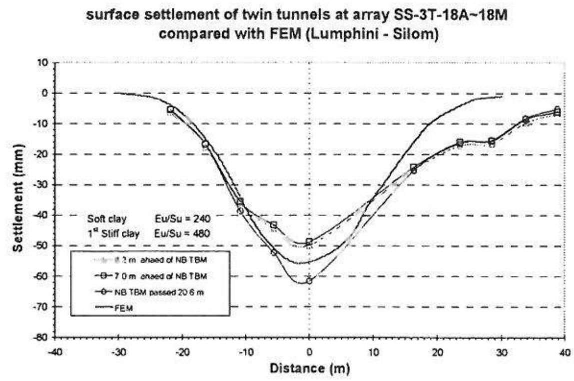

Figure 9 (b). Predicted surface settlement from FEM for twin vertical stack tunnels

6. Conclusions

The ground surface settlement was monitored during and after completion of the MRT subway tunneling in Bangkok city. The behavior of ground surface deformation response based on instrumentation was presented. The soil stiffness based on self boring pressuremeter test is proposed. The predicted ground surface settlement based on plain strain condition FEM analysis using Mohr-Coulomb soil modeling was also presented. The prediction of ground surface response due to shield tunneling by FEM analysis agreed with field performance.

7. Acknowledgment

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References

[1] Mair, R.J. 1993. Development in geotechnical engineering research, application to tunnels and deep excavations, Proceedings of the installation of Civil Engineers an Civil Engineering.
[2] Menzies, B. 1997. applying modern measures, Ground Engineering, pp. 22-23.
[3] Teparaksa, W. 1999 a. Geotechnical aspects on the design and construction of the MRTA subway in Bangkok, Journal of the Society of Professional Engineering Thailand, Vol. 24, pp.21-34.
[4] Teparaksa, W. 1999 b. Performance of diaphragm wall and soil parameters for design and construction of sub structures in Bangkok subsoil, Annual Conference on National Civil Engineering, Engineering Institute of Thailand.
[5] Teparaksa, W. 1999 c. Principle and application of instrumentation for the first MRTA subway project in Bangkok, 5th International Symposium on Field Measurements in Geomechanics, Singapore.
[6] Teparaksa, W. 2000. Displacement behavior of soil for the first MRTA subway in Bangkok subsoil, 13th KKNN Symposium on Civil Engineering, Taipei, Taiwan, pp.349-354.
[7] Teparaksa, W. 2001. Performance and behavior of soil and tunnel displacement due to bored tunneling of MRT project, Guest speaker, 7th National Conventional Conference, Engineering Institute of Thailand, pp. INV 75-90.
[8] Teparaksa, W. 2002. Training course on PLAXIS, Two Plus Soft Co. Ltd., Bangkok, Thailand.