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Impact assessment of shield tunnelling in Bangkok MRT Orange Line on existing piled foundation

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ABSTRACT

The Mass Rapid Transit Authority (MRTA), Ministry of Transport, Thailand is implementing the MRT Orange Line Project which bored tunnels and deep excavation works will be conducted. There are several existing flyovers are situated at close proximity to the tunnels. A simplify analytical method based on computer program “PRAB” has been used in this project in order to assess the impact on existing pile foundations induced by tunnelling. The validity of analysis has been verified with some published solutions and measurements. Good agreements between this analysis and finite element method by using PLAXIS program are demonstrated in this study. This method is then used to investigate the impact on the existing pile foundations adjacent to tunnelling with efficiently for numerous of cases.

Keywords: impact assessment; simplified analysis method; existing piles; ground movement; tunnelling

1 INTRODUCTION

According to the demand of underground space using in urban area, this may lead to the tunnel being constructed in proximity to superstructure foundations. Generally, Tunnelling in soft grounds naturally induces ground movements, both vertical and lateral, which may impact on existing pile foundations (Fig.1). In such cases, two major issues must be considered by the designer consist of:

(1) The additional axial force and bending moment induced by tunnelling.

(2) The allowable movement for superstructure serviceability.

Fig. 1. Scheme of Pile Deformation Induced by Tunnelling.

In 2017, The Mass Rapid Transit Authority (MRTA), Ministry of Transport, Thailand is implementing the MRT Orange Line Project which runs along one of the most congested road of the city. There are numerous flyovers founded on piles situated at close proximity to the tunnel alignment. Their potential impact from the EPB shield tunneling need to be assessed.

In the definitive tunnel alignment design stage, a number of alternative calculations may be required such as changing of both vertical and horizontal alignment. Hence, the impact to existing piles according to this alternative will be change. As a preliminary routine investigate tool of a pile response to tunnelling, A computer program PRAB (Pile Raft Analysis with Batter piles) developed by Kitiyodom and Matsumoto (2002) has been considered to estimate responses of the pile foundation subjected to ground movement due to tunnelling as part of preliminary assessment.

Some previous researches on the analysis of effect of tunnlling on existing pile foundations have been done. Xu and Poulos (2001) and Loganathan et al (2001) conducted the three-dimensional coupled boundary element approach to investigate the pile subjected to ground movements induced by tunnelling. Jongpradist et al, carried out the parametric study of pile response to tunnelling using finite element method (FEM) and proposed the influence zone.

However, a finite element analysis is not suited for a large numbe

• First, preliminary assessment on the existing pile foundation according to the free-field ground movements induced by tunnelling by using PRAB.

• Second, for such pile foundations which are susceptible to damage by tunnelling as determined from preliminary assessment, further assessment shall be performed by using FEM method.

2.1 Method of Analysis (PRAB)

2.1.1 Estimation of Free-Field Ground Movements Induced by Tunnelling

A simple closed form analytical solution proposed by Loganathan and Poulos (1998) has been used for estimating free-field ground movements induced by tunnelling. The following equations 1-3 illustrate the closed form analytical method. These solutions are incorporated into the computer program PRAB.

$$U_{z=0} = \varepsilon_0 R^2 \frac{4H(1-\nu_s)}{H^2+x^2} \exp\left\{-\frac{1.38x^2}{(H+R)^2}\right\} \quad (1)$$

$$U_z = \varepsilon_0 R^2 \left\{ \frac{-(z-H)}{x^2+(z-H)^2} + \frac{(3-\nu_s)(z+H)}{x^2+(z+H)^2} - \frac{2z\left[x^2-(z+H)^2\right]}{\left[x^2+(H+z)^2\right]^2} \right\} \times \exp\left\{-\left[\frac{1.38x^2}{(H+R)^2} + \frac{0.69z^2}{H^2}\right]\right\} \quad (2)$$

$$U_x = \varepsilon_0 R^2 x \left\{ \frac{1}{x^2+(z-H)^2} + \frac{(3-4\nu_s)}{x^2+(z+H)^2} - \frac{4z(z+H)}{\left[x^2+(H+z)^2\right]^2} \right\} \times \exp\left\{-\left[\frac{1.38x^2}{(H+R)^2} + \frac{0.69z^2}{H^2}\right]\right\} \quad (3)$$

where U_z=0 is the ground surface settlement, U_z the sub surface settlement, U_x the lateral soil movement, R the tunnel radius, z the depth below the ground surface, H the depth of tunnel horizontal axis level, ν_s the soil Poisson's ratio, ε_0 the average ground loss ratio, and x is the lateral distance from the tunnel centerline.

2.1.2 Analysis for Piled Foundations Responses

For the existing pile cap and pile, the structural analysis based on beam-on-spring foundation method. The flexible pile cap is modelled as a thin plate as well as the pile as elastic beams, and the surrounding soils are considered as interactive springs.

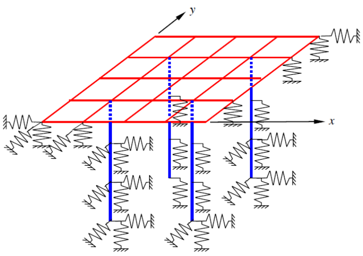


Fig. 3. Plate-beam-spring modelling for Soil-Structure Interaction (Kitiyodom et al., 2005).

2.2 Method of Analysis (PLAXIS)

For pile foundations, which are susceptible to damage by tunnelling as determined from preliminary assessment estimated by PRAB, the geotechnical engineering finite element program PLAXIS 2D will be used to analyze such soil-structure interaction according to ground movement due to tunnelling. The finite element used will be 15-node triangular elements, which provide a fourth-order interpolation for displacements and numerical integration involving 12 Gauss points per element.

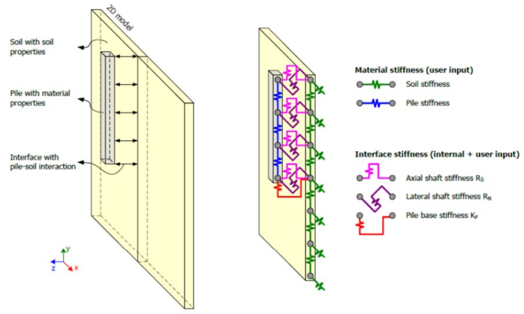


Fig. 4. Principle of 2D Embedded Pile Row (Sluis, 2012).

Soils are modelled as elastic-perfectly plastic materials following the Mohr-Coulomb failure criterion. Pile caps are modelled as linear-elastic plate elements with material properties defined by flexural rigidity EI and axial normal stiffness EA. Piles are modelled as embedded pile row elements. The "embedded pile row" element can be used to simulate a row of piles with certain spacing perpendicular to the model area. The piles properties are entered per pile consisting of elastic modus, unit weight, skin friction and bearing capacity. This structure element is not directly coupled to the mesh. It is coupled via a line to line interface. The principle of 2D embedded pile row element is shown in Fig 4.

3 VERIFICATION BY COMPARISON WITH CASE HISTORY

A case history of the Singapore Mass Rapid Transit (MRT) north-east line reported by Pang (2006) has been used to verify the responses of a pile subjected to tunnelling. Fig. 5 shows the position of the pile foundation supporting the bridge (Pier 20) and tunnels. The foundation consisted of 4 bored piles diameter of 1.2 m with spacing 3.6m and a length of 62 m. Strain gauges were installed in the piles in order to monitor the induced bending moment and axial force developed along pile depth during tunnelling.

Fig. 6 presents the pile P1 responses after SB tunnelling using PRAB compared with other analysis methods reported by Basile (2014) and measured results obtained from the instruments. It can be seen that the results of PRAB match very well with the results for all aspects.

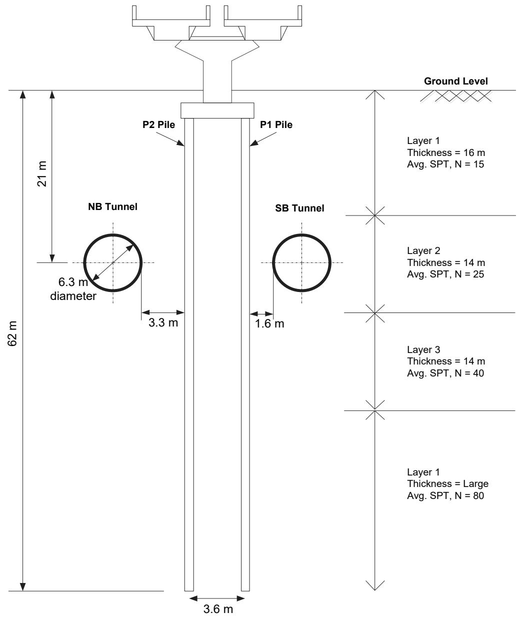
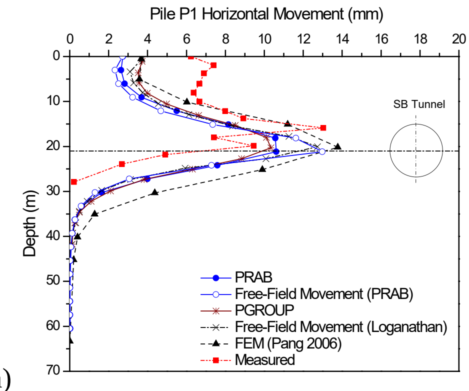
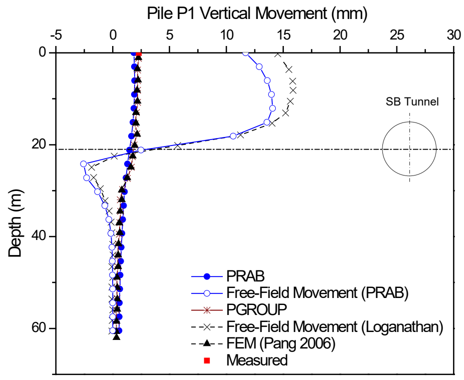


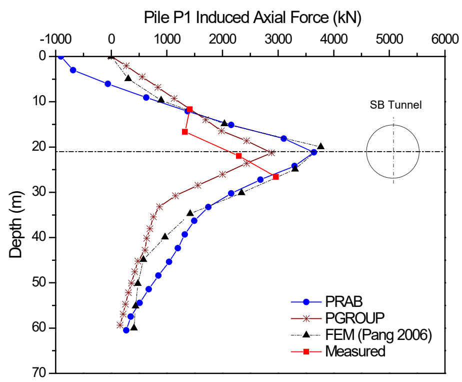
Fig. 5. Piles and Tunnel Section at Pier 20 of Singapore MRT (Pang, 2006).



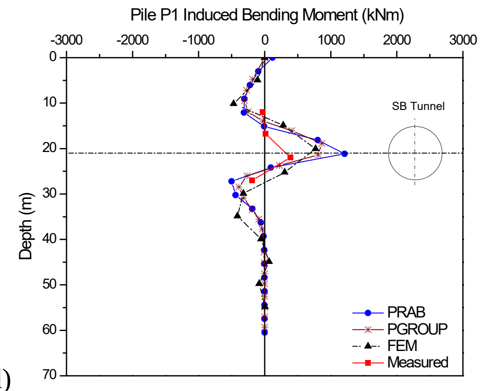
(a)



(b)



(c)



(d)

Fig. 6. Pile Responses due to Tunnelling (a) Horizontal Movement (b) Vertical Movement (c) Axial Force Distribution (d) Bending Moment Distribution

4 RESULTS OF IMPACT ASSESSMENT IN BANGKOK MRT ORANGE LINE PROJECT

In the MRT Orange line project, there are several existing structures which close to the tunnels such as expressway foundation, building, footbridge and so on. In this study, the impact assessment for Pier no P494/3 of Sirat expressway flyover has been used to present the analysis results of pile responses to tunnelling. Fig. 7 shows the relative position of the tunnels and the piles of the pier P494/3 and the soil boring log. The 4.6 m squared footing of the pier has been supported by the bored piles 1.0 m diameter and 40 m length. The twin bored tunnels are located with 1.49 m clearance between tunnel linings to the adjacent pile surface. The depth below ground surface of each tunnel east bound tunnel (EB) and west bound tunnel (WB) is 15.0 m and 27.3 m respectively. The ground volume loss has been assumed as 1.5% for each tunnel in the assessment.

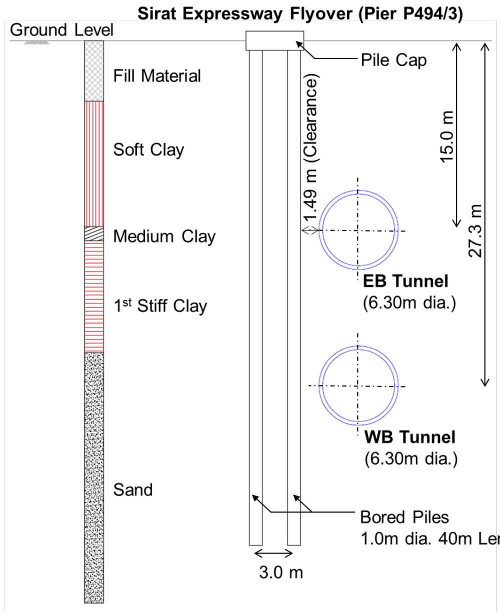


Fig. 7. Piles and Tunnel Section at Pier 494/3 close to MRT Orange Line Alignment.

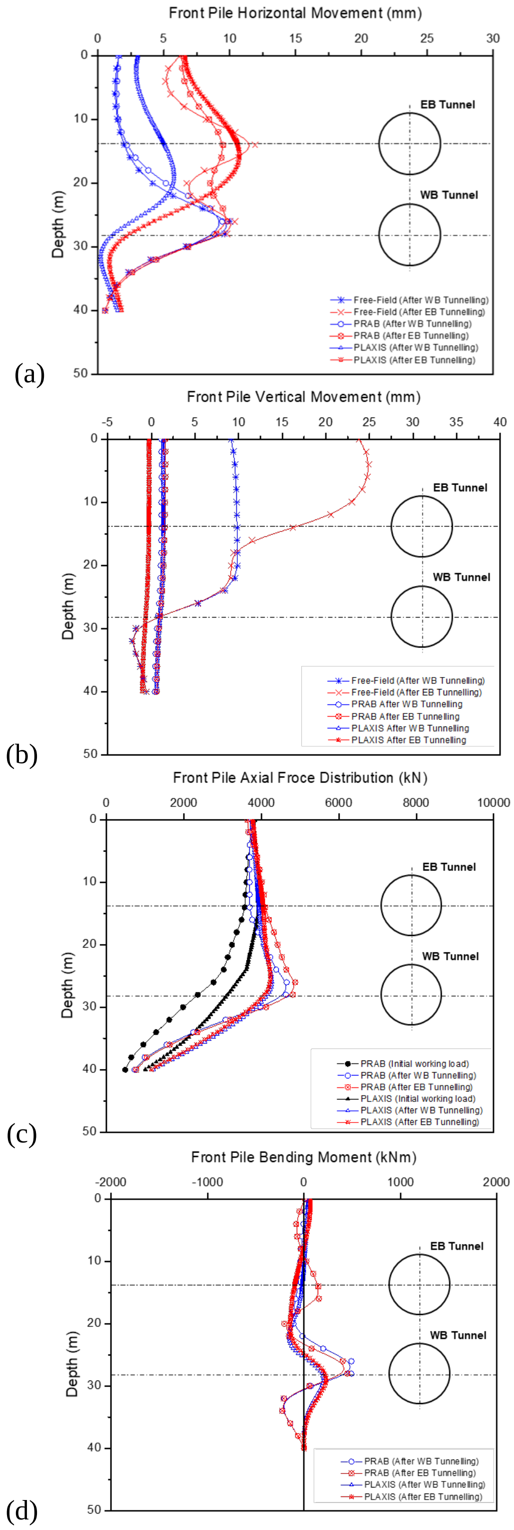


Fig. 8. PRAB and PLAXIS Results of Existing Pile Responses due to Tunnelling (a) Horizontal Movement (b) Vertical Movement (c) Axial Force Distribution (d) Bending Moment Distribution.

According to the impact assessment results in MRT Orange Line Project, Fig. 8. Illustrates the comparisons of the computed responses of the pile close to tunnels by using PRAB and PLAXIS. Comparisons of the induced horizontal and vertical deformation profiles of pile induced by tunnelling are shown in Fig. 8(a) and Fig. 8(b). The induced axial force and bending moment distribution along the pile are shown in Fig. 8(c) and Fig. 8(d).

It can be seen that the estimation of pile foundations responses to tunnelling obtained from PRAB match well comparing with FEM analysis by using PLAXIS 2D with modelled pile foundation as embedded pile row elements. For short pile cases, on the other hand, results obtained from PRAB do not match well because axial force induced by tunnelling at pile toe developed more than geotechnical end bearing capacity of the piles.

5 CONCLUSION

A simplify analytical method by a computer program PRAB is employed to investigate the induced deformation, axial force and bending moment distribution on the existing piles due to adjacent tunnelling in Bangkok MRT Orange Line Project. The proposed method was verified through various comparisons with some published method and measured instrumentation. As a result, this method can be used to estimate the impact on piled foundation due to tunnelling with efficiently for a large number of cases.

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