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Tunneling influence zones for existing piles of bridge approach

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ABSTRACT

The development of tunneling influence zones for nearby pile foundations of bridge approach in Bangkok soft soil are presented, using the numerical analysis results. Three dimensional finite element method (3D-FEM) is used to simulate the interaction between an existing bridge approach pile and nearby tunnel construction, under various geometries of the pile and the tunnel, tunnel construction impact in term of volume loss. The unity ratio of pile settlement and ground settlement is used to distinguish the zones where the pile tip loses its stability and this boundary is the line of influence. Consequently, different influence zones can be obtained. With the aforementioned numerical data and criterion, tunneling influence zones for adjacent existing piles of bridge approach in soft soil can be obtained. The developed zones are also compared and discuss with those proposed from previous studies.

1. INTRODUCTION

In urban areas where many superstructures had been constructed, there is usually limited underground area among existing piled foundations remained for tunneling. Hence, it becomes necessary to construct a tunnel in a close proximity to the piles. When tunneling is near a pile foundation, there is possibility that the structure of pile foundation might be damaged or unable to serve the functions of superstructure due to excessive pile bending stress or excessive pile tip settlement. It is therefore necessary to ensure that such undesired phenomenon would not occur during tunneling adjacent to any existing structures.

Ground movements due to tunneling activity cause some degree of impact on nearby piles. The preliminary assessment is typically carried out for evaluating the potential of tunneling effect on existing piles so that the tunnel position design can be modified. This is currently carried out by defining a protection zone. The influence zone is conventionally assumed to rise at an angle of $\beta=45+\varphi/2$ to the horizontal from the

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tunnel boundary to the ground surface where the friction angle is φ. The β lines are based on the typical shear surfaces first proposed from model test results by Morton and King (1979). In addition to the concept of a typical shear surface, influence lines have also been proposed based on consideration of pile settlements in recent studies (Kaalberg et al. 1999; Jacobz et al. 2001; Jacobz et al. 2004; Lee and Bassett 2007) as shown in Fig.1.

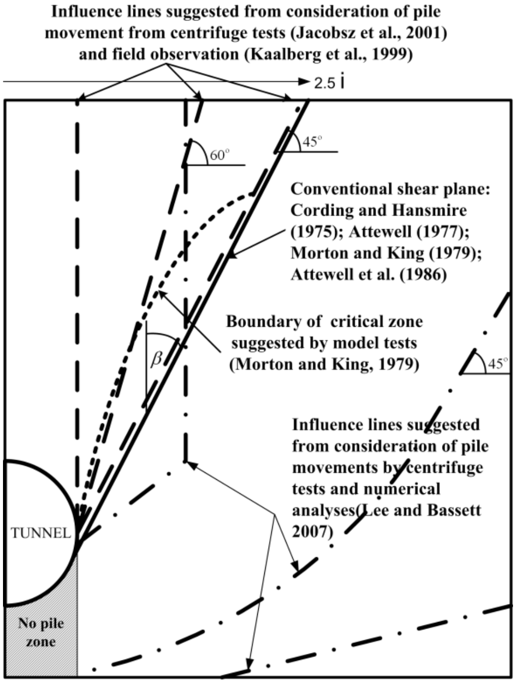


Fig. 1 Influence lines from previous studies (after Lee and Bassett 2007)

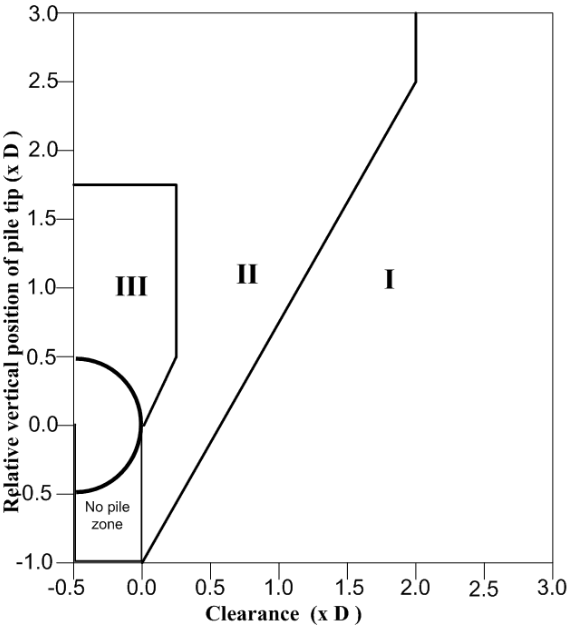


Fig. 2 Lines of influence and tunneling influence zones for Bangkok soft soil (Jongpradist et al., 2013)

The concept of an influence zone is commonly used in engineering practice as a guideline to control tunnel position adjacent to pile foundations. These suggested zones are different from those based on the shear plane concept. Fig.2 shows the tunneling influence zones with consideration of pile settlement proposed for nearby pile foundations in Bangkok soft soil using the numerical analysis results by Jongpradist et al. (2013).

These influence zones were conducted for pile group or relatively large piles (diameter larger than 0.25 m). However, the tunnels for both utilities and transportation are commonly located in underground along the roads which usually have fly-over bridges. Tunnel construction may affect the piles of bridge bearing unit (diameter of piles is smaller than 0.25 m) as shown in Fig. 3. The influence zones developed in previous studies do not cover these relatively small piles. In this paper, the study is extended to consider the tunneling influence zones for bridge bearing unit piles. The numerical analyses on pile-tunneling interaction are carried out to obtain artificial data of pile responses and to suggest the tunneling influence zone.

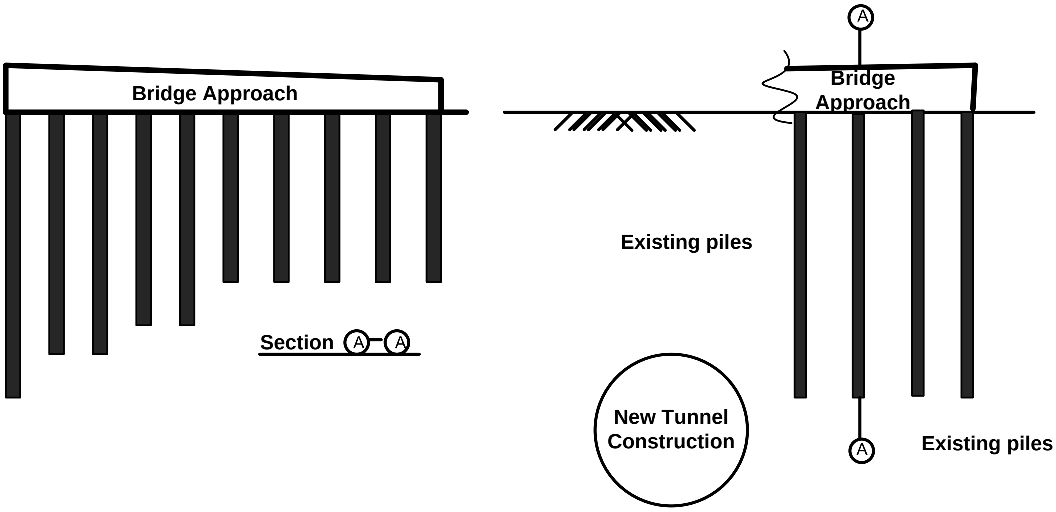


Fig. 3 New tunnel construction nearby existing loaded piles of bridge approach

2. NUMERICAL ANALYSIS

Fig. 4 shows an example of three-dimensional finite element mesh to model the existing pile and tunneling in this study. The geometries and properties of pile and tunnel are based on the existing piles and tunnels of respectively the DOH (Department of Highways), the MRTA (Mass Rapid Transit Authority of Thailand) and the MWA (Metropolitan Waterworks Authority).

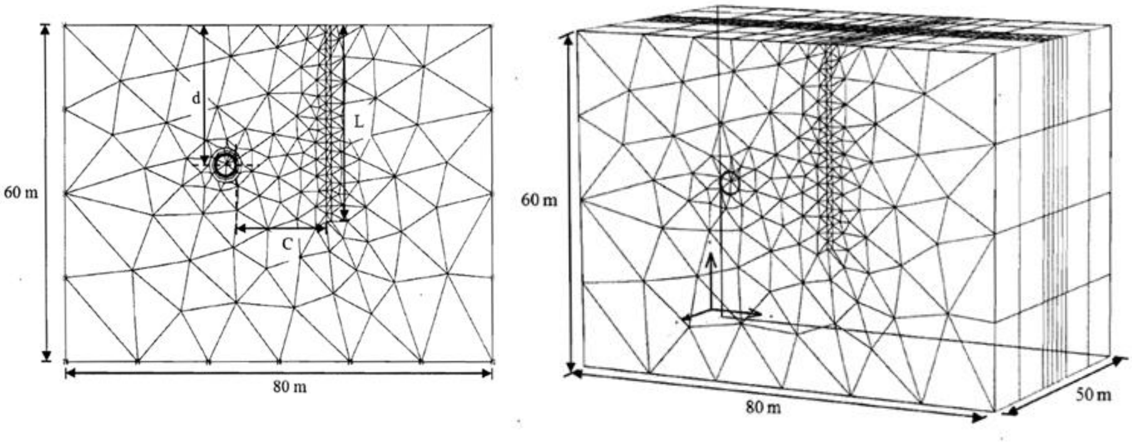


Fig. 4 Three dimensional mesh used for modeling the tunnel-pile interaction problem

To avoid any boundary effect, the side and bottom boundaries were largely extended from the area of interest to an extent that they have no significant effect on the analyzed results. The dimensions of the entire generated mesh are 50 m in longitudinal direction, 60 m in depth and 80 m in width. The configurations of pile and tunnel were varied to quantitatively study the effects of tunneling as follows. The depth of the tunnel axis is d beneath the ground surface. The shortest horizontal distance between the pile foundation and the tunnel axis is C while the pile length is L. The diameter of tunnel (D) of 6.3 and 4.76 m which are the typical size used by MRTA and MWA were selected in this study. The pile diameters of 0.18 m and 0.22 m were selected for parametric study.

The analyzed subsoil layers and their distribution with depth are shown in Fig. 5. Tables 1 and 2 summarize the material parameters assumed in the numerical analyses. They are derived from the design values widely adopted for Bangkok soil and comprehensive testing results from previous construction projects. A linear elastic material model was used for the pile and the tunnel lining. A Hardening Soil (HS) model was used to model the clay layer. On the other hand, sand layers were assumed to behave as elastic-perfectly plastic material, described by Mohr-Coulomb model (MC). The details of model descriptions and model parameters can be found in Rukdeechuai et al. (2009). All the analyses were based on undrained conditions. In the numerical simulation, the elements presenting pile and soil were directly connected without any interface element since the relative displacement between the pile and the soil (slippage) was expected to be insignificant.

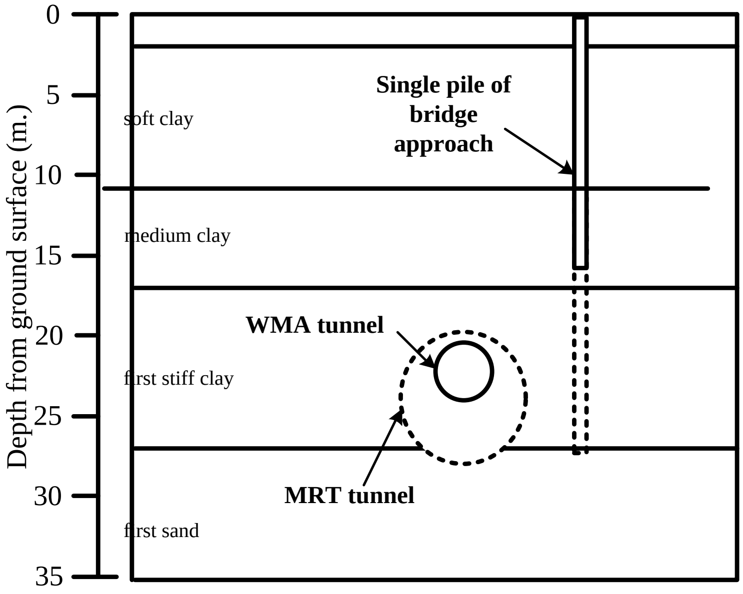


Fig. 5 Soil Profile and typical section used in this study

Table 1 Material properties of the tunnel lining

Parts	Young's modulus of concrete, E (kN/m^2)	Poisson's Ratio of concrete, v_c	Unit weight of concrete, γ_c (kN/m^3)
Tunnel lining	3.1×10^7	0.20	24
Bored pile	3.0×10^7	0.20	24

Both front and rear sides are restrained against lateral movements while free to move vertically. Therefore, there is no movement perpendicular to the mesh side planes. The bottom of the mesh is fixed against both vertical and horizontal movements. The top surface has no restraint and therefore is free to move. These conditions are used for all finite element meshes throughout the analysis.

Table 2 MC and HS soil model parameters (Rukdeechuai et al. 2009)

Soil layer	Made Ground	Soft Clay	Med. Clay	Stiff Clay	Sand
Material Model	MC	HS	HS	HS	MC
γ_{sat}[kN/m^3]	17	16	18	18	20
ν' [-]	0.32	0.33	0.33	0.33	0.3
φ' [°]	22	22	22	22	36
c [kPa]	8	5	10	18	0
E' [kPa]	6000	-	-	-	80000
E_{oed}^{ref} [kPa]	-	5000	20000	60000	-
E_{50}^{ref} [kPa]	-	5000	20000	60000	-
E_{ur}^{ref} [kPa]	-	15000	100000	180000	-
m [-]	-	1	1	1	-
p_{ref} [kPa]	-	100	65	95	-

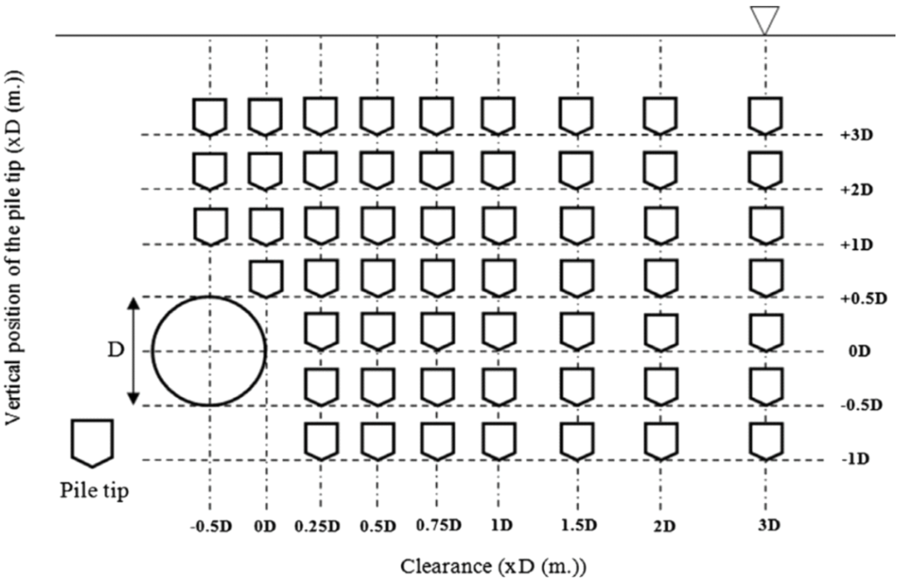


Fig. 6 Pile tip locations varied in parametric study

In all analyses in this study, the finite element analysis is performed in two stages. The first stage concerns the application of the pile axial loading which exists before the construction of the tunnel. The second stage concerns the construction of the tunnel modeled by deactivation of soil elements situated in excavation zone and activation of lining. During each excavation step, soil elements are removed with simultaneous application of pressure on the tunnel face. The pile tip locations are varied in analyses as shown in Fig. 6.

3. ANALYSIS RESULTS

This section presents the results obtained from the numerical analyses as well as the development of tunneling influence zones for nearby existing piles. The discussion of the obtained tunneling influence zones in this study with that proposed by Jongpradist et al. (2013) is also made.

3.1 Validation of tunneling simulation and pile response due to nearby tunneling

To verify the tunneling analysis method, the MRTA Bangkok Tunnel was selected to simulate and the measurement data are compared to the analysis results. Fig.7 shows the comparison of ground settlement between from Finite element analysis and observation data of MRTA tunnel in section CS-8B. By observing the settlement profile, it is seen that the analysis results from FEM give satisfactory tendencies in term of the settlement profile shape. By assuming the volume loss of 0.75% (construction record reported 0.5-1%), the analysis can quantitatively give good agreement to the measured data as shown in the figure.

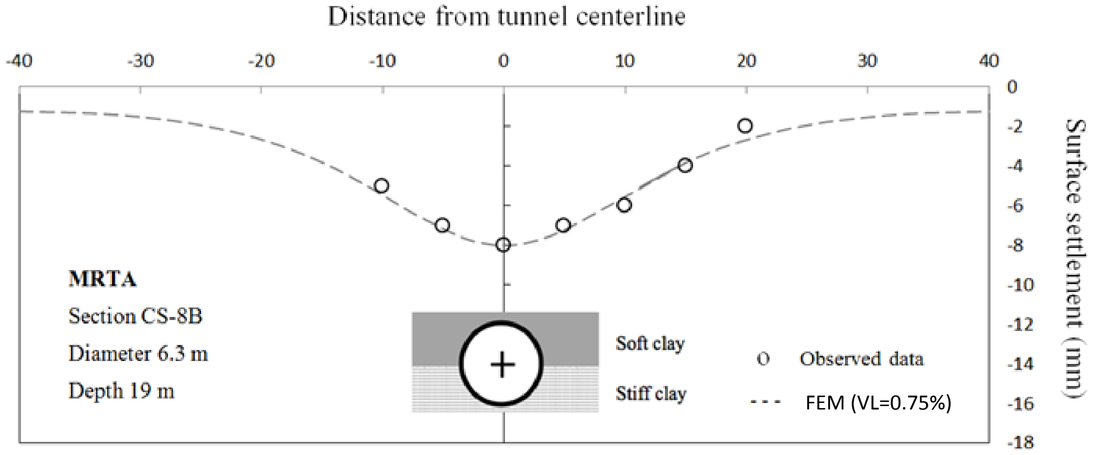
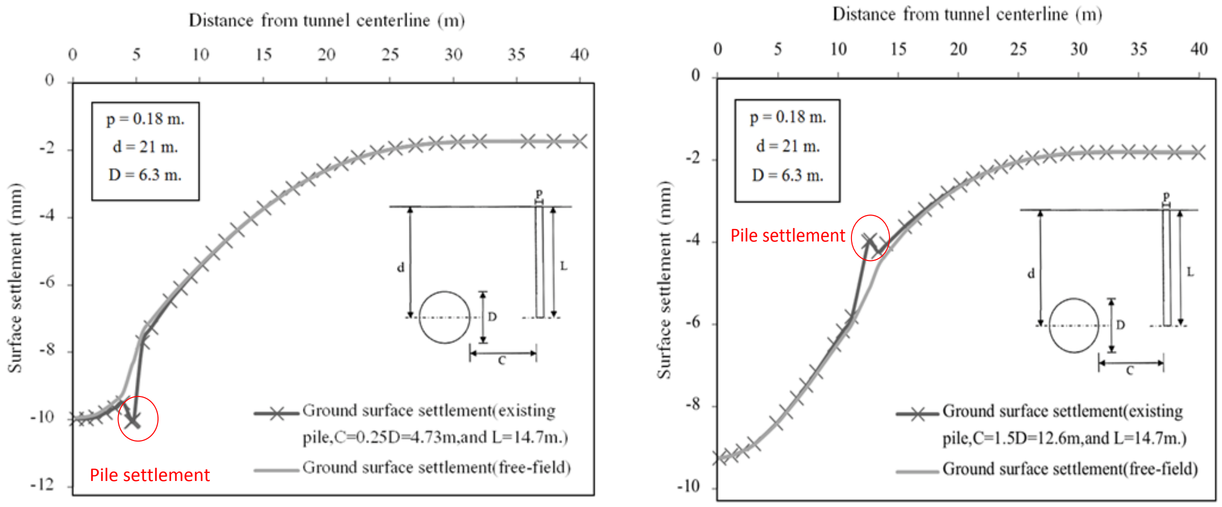


Fig. 7 The comparison of Finite element analysis result and observation data

From the preliminary analysis results, it is seen that when the distance between the pile axis and the centre of the tunnel increase, both tunneling-induced pile settlement and lateral movement significantly decrease. Previous study (Kaewsri, 2009) revealed that the pile settlement (δpile) and/or pile movement values occurred from tunneling at the same depth and distance for various cases (different pile and tunnel diameters, ground loss ratios), are varied. When the pile tip is located above the tunnel horizontal axis, the pile settlement continuously increases with a decrease in clearance. However, different pile settlement was occurred with different condition. Therefore, it is difficult to use the pile settlement for obtaining the influence lines.

Fig. 8 shows the tunneling analysis results in case of free-field and presence of existing pile. The figure shows that the ground surface (δsoil) settlement profile of the case with presence of existing pile is asymmetry when compared with the free-field case. The settlement of pile near tunnel (C=0.25D) is larger than the ground surface settlement (free-field) at the same position as shown in Fig. 8(a). In this case, the pile stability is lost by tunneling effect, so the pile tip has to settle to the firm layer to achieve a new stable state. In contrast, the settlement of pile far from tunnel (C=1.5D) is smaller than the ground surface settlement (free-field) at the same position as shown in Fig. 8(b). This implies that the pile in this case does not get the impact from tunneling, it acts as a reinforcement in the soil mass.



(a) Case which $\delta_{pile} > \delta_{soil}$

(b) Case which $\delta_{pile} < \delta_{soil}$

Fig. 8 Ground surface settlement profiles and pile settlement induced from tunneling.

From the above investigation, it is reasonable to use the ratio of pile-to-soil settlement ($R = \delta_{pile}/\ \delta_{soil}$) to distinguish the zones where the pile receives the tunneling impact. In the zone of the pile settlement is larger than that of the soil or the ratio is greater than unity ($R > 1$), the pile loses its tip stability. This concept will be utilized for development of influence zone for adjacent pile.

3.2 Analysis for development of tunneling influence zone of pile

In this study, the ratio between pile settlement and ground settlement is introduced as a potential parameter for constructing the influence lines. With the simulated results for various cases as depicted in Fig. 6, the contour lines of ratio between pile settlement and ground settlement can be constructed as shown in Fig. 9.

The thick line represents the line having value of one (R=1), in the other words, line of equal settlement between the pile and the ground. Fig. 10 shows lines of R=1 for various cases (different pile and tunnel diameters, ground loss ratios). The detail of analysis can be found in Jongpradist et al. (2013). It is seen that the lines for different cases are coincide and a critical line to distinguish the influence zones may be suggested as shown in Fig. 11.

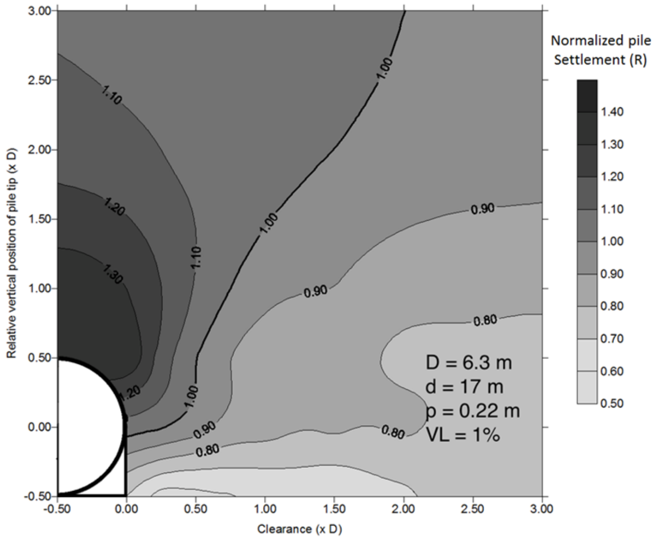
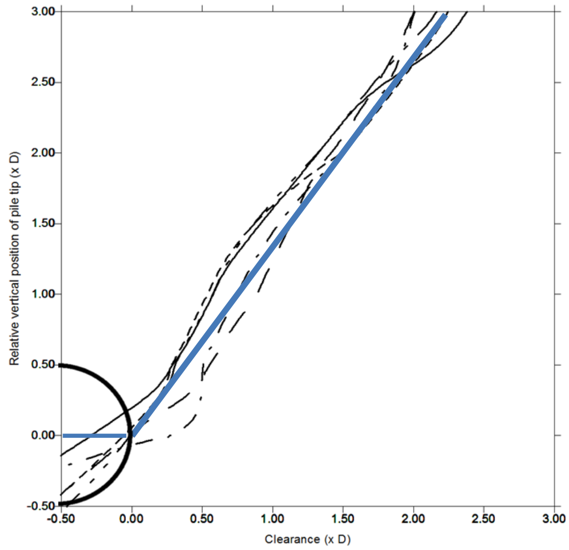


Fig. 9 Example of contour of R ($\delta_{pile}/\ \delta_{soil}$)



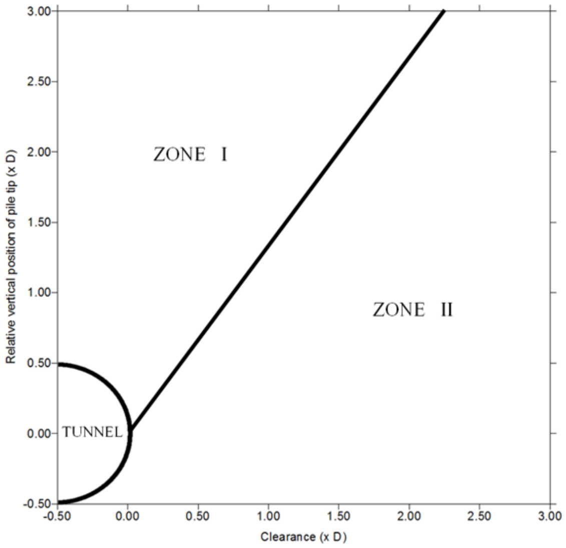


Fig. 10 Contour lines of R=1 from all cases

Fig. 11 Lines of influence with defined influence zones suggested from this study

Fig. 12 shows the critical line of influence zone that were proposed by many researchers. The critical line form this study is located between the conventional shear plane and critical line from Jongpradist et al. (2013). By comparison with existing zones proposed by Jongpradist et al. (2013), the influence zone which considers from pile settlement in this study is narrower and shallower. The comparison shows that the large pile is affected by the tunneling more than the small pile.

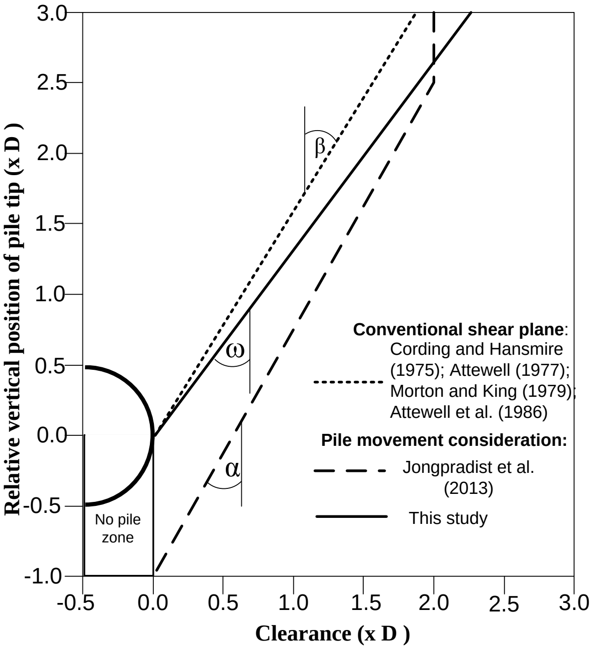


Fig. 12 Lines of influence suggested from this study and previous studies

4. CONCLUSIONS

The finite element parameters were varied to generate the artificial data for pile responses in tunnel construction. These include the tunnel diameter (D), the volume loss (VL), the pile diameter (p), the length of pile (L) and clearance (C). By these numerically generated data together with the selected criteria, line of influence can be suggested. The normalized pile settlement is selected to be the criteria for suggesting the zones of influence for tunneling adjacent to bridge approach piles. The influence zone suggested from this study is narrower and shallower that that of previous studies which considered larger piles.

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