Finite Element Study of Tunnel-Soil-Pile Interaction

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Singapore is currently one of the major tunneling hubs in the world with large-scale projects in progress such as the Marina Line (13km) and Deep Tunnel Sewerage System (49km). In addition, several other tunnel lines (Circle Line, Kallang-Paya Lebar Expressway, Paya Lebar Cable Ducts) are in the planning stage either to facilitate transportation or to lay service utilities. Given the large number of tunneling works, it is of great importance that ground movements are predicted to a high degree of accuracy to minimize the risk of damage to existing structures (ie. piled foundations, existing tunnels) or services (pipe, sewer lines). This project/study was initiated to assess the behaviour and performance of piled foundations when subjected to tunneling induced ground movements. 3D Finite Element (FE) analysis was performed to overcome limitations associated with 2D plane strain analysis thus requiring powerful computational resources.

One case history analysed was the construction of the North East Line tunnels which run on opposite sides of a vehicle viaduct (Figure 1). Field data from a 2x2 pile group supporting a section of the viaduct was compared with results from 3D FE simulation. The most critical loading on the pile corresponds to the case where tunnel face has passed the pile location (ie. plane strain condition) and this was simulated in the analysis. Zero thickness contact elements were used to realistically model soil-pile interaction behaviour. The constructed mesh and pile group geometry is as shown respectively in Figures 2 and 3. Symmetry about the transverse tunnel axis of the 2x2 pile group is exploited to reduce the size of the problem.

Preliminary computed results for induced pile bending moments (Figure 4(a) and (b)) and axial force (Figure 5(a) and (b)) are encouraging and show reasonably good agreement when compared with field data. Pile 1/2 corresponds to piles directly beside the Southbound (SB)/Northbound (NB) tunnel. Figure 6(a) and (b) show the contour plot of tunnel-soil-pile displacements due to SB and subsequently NB tunnel excavation. The deformed shape of the pile group after SB tunnel excavation (Figure 7(a)) and subsequently the NB tunnel excavation (Figure 7(b)) are as intuitively expected.

Meshing of the geometry was performed using PATRAN v.2001 (MSC, 2001) while ABAQUS v.6.31 (HKS, 2002) was used for processing and post-processing the problem. Aside from offering access to these softwares, the Supercomputing and Visualisation Unit (SVU) provided invaluable support by reducing computational time as multiple processors (8-processors) were available to run the analysis consisting 8600 elements (107805 degrees of freedom).
Fig. 1 Viaduct Pier, Pile and Tunnel Layout
Fig. 2  Mesh Geometry of North East Line tunnel project (Pier 1)
Fig. 3  Pile geometry with provision for interface elements

31.5m with interface elements
(pile cap not included)

57m

24m without interface elements

1.8m

3.6m
Fig. 4. Variation of induced bending moment for (a) Pile 1 and (b) Pile 2 with passage of SB and NB tunnel

Fig. 5. Variation of induced axial force for (a) Pile 1 and (b) Pile 2 with passage of SB and NB tunnel
Southbound Tunnel Excavation

Northbound Tunnel Excavation (after Southbound)

Fig. 6 Contour plot of soil and pile group displacements due to (a) SB and subsequently (b) NB tunnel excavation
Fig. 7 Deformed pile group (x1000) with displacement contour plots after (a) SB and subsequent (b) NB tunnel excavation.