A comparison study of 2D and 3D numerical analyses for shallow overburden tunnel by using elastic model

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1. INTRODUCTION

Tunneling is an inherently three-dimensional (3D) process. The advancing tunnel face creates a complex 3D stress path as explored by Eberhardt (2001) and by Cantieni and Anagnostou (2009). Even though the 3D analyses are true representation of actual tunnel field. But two dimensional (2D) modeling is still very much state of practice for tunnel engineering analyses (Hoek et al. 2008). The distance behind the tunnel face to the location where support is installed affects the tunnel closure and the tunnel loads. This is typically expressed as a longitudinal tunnel displacement profile (LDP) that relates tunnel displacement to the distance from the excavation face. In order to accurately simulate the loading of support or the effects of sequential excavation, the 2D model must capture not only deformation after face passage but also pre-face conditions. The LDP is used in 2D plane-strain models to estimate the 3D effect of tunnel advancement and to determine the appropriate timing for installation of support. Two methods are commonly employed in 2D analyses to simulate the effect of tunnel advancement on lining loads. The first method, called the core-replacement method and the second method, called the convergence-confinement method (CCM), uses a characteristic curve, a ground reaction curve (GRC), that is developed by progressively reducing the internal pressure within the excavation region and plotting this support pressure versus the tunnel closure. The incremental reduction of the internal pressure represents the effect of the advancing tunnel face. By knowing the installed support distance from the tunnel face and using the LDP, the amount of tunnel deformation that occurs prior to support installation can be calculated by relaxing the pressure to a given level corresponding to that deformation. Due to the topographic and route conditions the number of shallow overburden tunnels have been increasing. The conventional tunneling method has been thought to be suitable when excavating tunnels in mountainous areas. But in recent times, not only due to the advancement in construction and measurement techniques, but also due to the economic reasons, conventional tunneling methods has also become popular for shallow overburden tunnels excavations. The present paper focuses on the results of elastic 2D and 3D finite difference analyses of a shallow overburden (i.e. 15m) tunnel case in loose sandy ground conditions. Anisotropic stress conditions were assumed during the analyses. The results are presented in terms of ground deformation and by means of the stress path method with attention paid to the zone located in crown. It is shown that the stress path in this zone exhibit a more complex trend of behavior with respect to those typical 2D simplified numerical analysis.

2. OUTLINE OF NUMERICAL ANALYSES

3D and 2D analyses were carried out by using commercial code FLAC (developed by Itasca). A circular shape of tunnel with diameter of 10m was assumed in the analyses. The gravity loading scenario was considered in the analyses. In order to maintain symmetry in 2D and 3D model, a 2D model was developed as shown in Figure. 1 below. The same model was extrude for 3D analyses. In 3D case the length/depth of the model was 158m as shown in Figure. 2 below. In order to simulate the 3D effect in 2D case, CCM was sued in the 2D analysis. In 3D model excavation was carried out in stages. First 39m of excavation was carried out in the 13 stages (excavation round of 3m) which followed the next10m excavation with 2m excavation interval. After 49m of excavation remaining excavation was carried out until 81m with an interval of 1m. Ground behavior was assumed to be elastic. The modeled ground parameters are summarized in Table. 1 below.

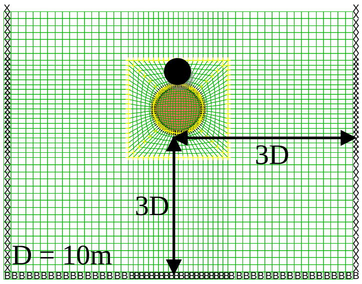

Fig.1 2D Analyzed Section

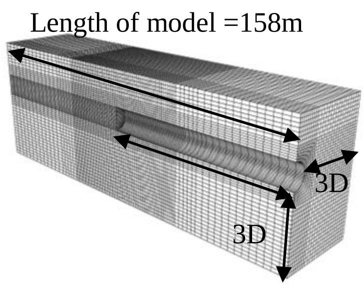

Fig. 2 3D Analyzed Section

Table 1. Model Parameters

Property	Value
Elastic Stiffness (E)	30 MPa
Density (ρ)	1805 kg/m^3
Poisson ratio (ν)	0.33
Ko	0.5

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3. RESULTS OF NUMERICAL ANALYSES

For the comparison of results, a section at the depth of y=0 was considered for 3D case. The same section was analyzed by the 2D analysis as well by using CCM. The results of numerical analyses are presented in term of deformation and stress evolution in Figures 3 and 4 respectively for the zone located above the tunnel crown. The positive distance (0m to 75m) and negative distance (0m to -40m) indicate the tunnel length behind and ahead of the target section respectively. During the excavation the tunnel boundary moves progressively as the tunnel face passes the modeled section. This inward displacement of the tunnel boundary, in 2D analysis is simulated by replacing the “material” inside the tunnel with an outward pressure Pi (initially equivalent to the in situ pressure Po) and reducing this internal pressure to zero over a number of model steps as shown in Figure 3 (GRC). This reduction of the internal “support pressure” results in a redistribution of stress within the model. Internal pressure is linked to tunnel closure. Closure, in turn, is linked to the actual axial position (which is marked by dash line in Figure 3) in the tunnel, relative to the tunnel face, through the longitudinal displacement profile or LDP.

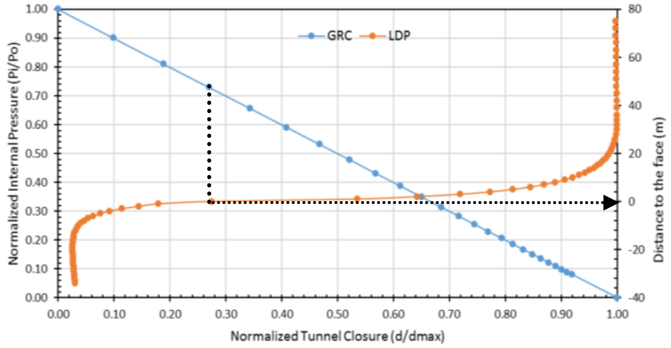

Fig. 3 Relationship between LDP and GRC

Due to this internal pressure relaxation the stress in the model redistribute to form a new equilibrium conditions. The stress evolution during the 3D and 2D simulations are shown in Figure 4. In this Figure, the results in terms of following the stress path as the tunnel excavation approaches and passes through a unit volume of soil are shown for the case of 3D analysis. As mentioned above the monitoring point selected was at the depth of y=0m, the monitoring point show the influence of excavation from 20m behind the face until the tunnel passes through that point and reaches to 6m ahead of the target section. The stresses evolution during the CCM is also shown in Fig.4.

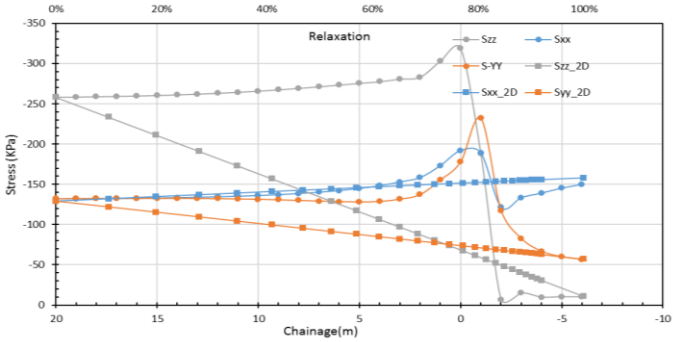

Fig. 4 Stress evolution during 3D and 2D analyses

It’s quite evident that the starting and ending points are same for both 3D and 2D analyses but 3D follows a complex stress transformation near the face. When tunnel face reaches approx.1D from the monitoring point, there is an increase in stresses magnitudes. This behavior is not captured in 2D case. While in 2D case the stresses follow the monotonic trend. This trend was further confirmed in the stress path as shown in Figure 5. In the 3D case, there is an increase in mean and deviatoric stresses ahead of the face, once the face passes through the monitoring point which is labeled as black circle, mean and deviatoric stresses reduce. This decreasing trend (tunnel face passes), was also observed in the 2D case. Until reaching a certain stage, there is again an increase in mean and deviatoric stresses for 2D and 3D cases. This increase is due to the stress tensor reorientation. As after the excavation σ_{xx} become the major while σ_{zz} becomes the minor at the tunnel crown.

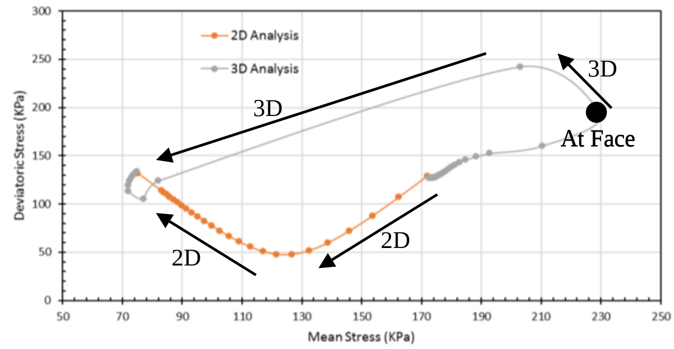

Fig. 5 Stress path during 3D and 2D analyses

4. CONCLUSION

Despite the difference in stress evolution results. The 2D analysis with some modification still can be used to capture the 3D stress conditions ahead of the face by using the higher K_0 ratio prior applying the tunnel support to capture the actual ground stresses, which in turn will affect the loads on lining. 2D analysis in direct comparison to their 3D analysis, when modelling stresses and tunnel convergence near the tunnel face must be corrected to account for stress redistribution and excavation sequencing. A further study to propose some methodology to enhance 2D analyses capabilities is warranted.

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