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Research article

Numerical modeling of shallow tunnels in unconsolidated sandy soils using a hypo-plastic model

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Keywords

Shallow tunnels
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Loosened zone

English Extended Abstract

Summary

Correctly predicting the behavior of the ground during tunnel excavation compared to what will happen in reality is a very challenging matter, especially in urban tunnels. On the other hand, the faster this prediction is and without the need to spend more money, the more valuable it will be. In the present study, the goal is to investigate the effectiveness of a hypo-plastic model to predict the results of physical modeling in the laboratory. For this purpose, the behavior of the surrounding environment of a tunnel in sandy soil was simulated using a hypo-plastic behavioral model, and the resistance characteristics of the studied soil were validated based on the triaxial test results. At the same time as simulating the tunnel excavation process, the settlement of the ground surface and stress changes in the soil above the tunnel were measured for different values of soil densities and tunnel depths. The results of this research showed a good agreement with the results of physical and theoretical modeling. Based on the results of this research, the hypo-plastic model can predict the behavior of loose granular soils. Convergence of the tunnel leads to disturbance of the stress field around the tunnel, and due to the phenomenon of soil arching around the tunnel, the stress distribution deviates from the linear state. Under the same conditions, although the loosened zone above the tunnel expands with the increase of the tunnel depth, the settlement of the ground surface decreases.

Introduction

The constitutive model determines the stress-strain behavior of a material under an applied load through numerical simulation. The main factor is the linear or nonlinear behavior of the soil at small or large strains respectively [1-5]. The ground around the tunnel can experience different stress paths during excavation. Failure criteria should be updated based on the stress path through the model. It is an important parameter of the hypo-plastic material model that can be used to simulate critical conditions and stress path effects considering the soil void ratio [6,7]. The hypo-plastic constitutive model, like the hypo-elastic constitutive model, is a tensor function and does not divide the deformation into linear and nonlinear parts like the theory of plasticity, but defines a nonlinear function to relate the stress to the applied strain. [8-23]. This study compares the results of the physical and numerical simulation (with a hypo-plastic constitutive model) of the full-face excavation of the tunnel as well as the extension of the loosened zone based on the stress differences.

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Methodology and Approaches

The 15 numerical models were simulated based on the physical model [22] through Abaqus V6.13, and applying a hypo-plastic constitutive model as well as the length scale factor of 50. The plain strain numerical model with fixed side and upon boundary.

Hypo-plastic model was discredited by Wu and Kolymbas [26] as well as Wang and Wu [2] was used (Eq.1)

$$\dot{\sigma} = C_1(tr\sigma)\dot{\varepsilon} + C_2(tr\dot{\varepsilon})\sigma + C_3\frac{tr(\sigma\dot{\varepsilon})}{tr\sigma}\sigma + C_4(\sigma + \sigma^*)||\dot{\varepsilon}|| \quad (1)$$

To simulate the critical condition the function proposed by Wang et al. [24-25] was added to the constitutive model as Eq.2.

$$\dot{\sigma} = I_s\left[C_1(tr\sigma)\dot{\varepsilon} + C_2(tr\dot{\varepsilon})\sigma + C_3\frac{tr(\sigma\dot{\varepsilon})}{tr\sigma} + C_4(\sigma + \sigma^*)||\dot{\varepsilon}||I_e\right] \quad (2)$$

The constitutive model was calibrated based on triaxial test results, which done by three different soil densities.

Results and Conclusions

To verify the simulated models, the maximum settlement was compared. The results obtained from the physical and numerical models were in good agreement, however for dense soil especially for deep tunnel models, the settlement threshold for the numerical model was larger than the physical model. The physical model was prepared by compaction and sand pluviation method, and a modification parameter [22] was calculated to justify these two methods, which is calculated for shallow models and should be updated by deep model test results.

Briefly, the results of this study are summarized below:

1. The numerical model with the hypo-plastic constitutive model is consistent with the physical and theoretical model results and can simulate loose soils.
2. The non-linear stress field above the tunnel was verified by using a numerical model.
3. The surface settlement increases linearly with the convergence of the tunnel at the same depth and soil density.
4. For loose sand, the soil density has an unremarkable effect on the extension of the failure zone.
5. In addition to surface settlement, the height of the damage zone is directly related to the depth of the tunnel for the same soil density.

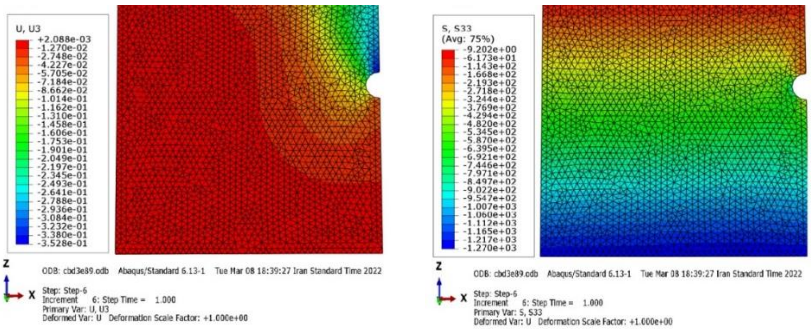

Fig. 1. **Numerical model; a) vertical settlement; b) vertical stress**

Table 1. Hypo-plastic constitutive model parameter

C_1	C_2	C_3	C_4	e_{c0}	λ	ξ	α	β
-80	-219.2308	-643.2608	-147.8565	0.91	0.34	0.95	0.85	6

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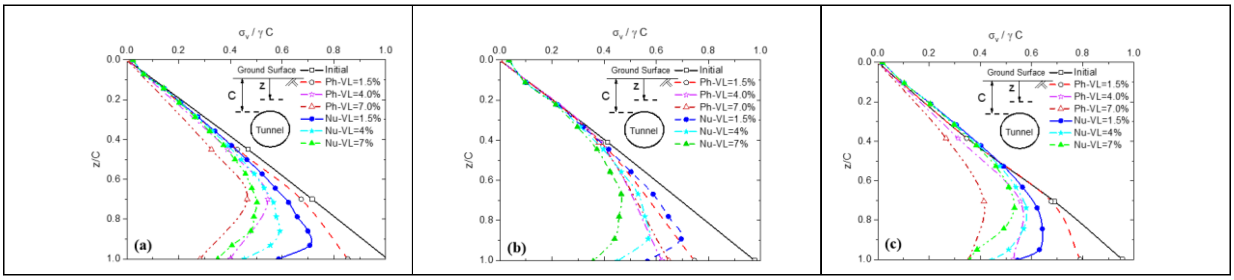

Fig. 2. Vertical stress over the tunnel for a sand density of the 1417 kg/m3; a) H/D=2,; b) H/D=3,; c) H/D=4

Table 2. Hypo-plastic constitutive model parameters

Density (kg/m³)	1482	1465	1441	1417	1400
Sand falling height (cm)	110	90	60	30	10
Void ratio (e)	0.78	0.80	0.83	0.86	0.89

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