Numerical Analysis of Elastic Surface Settlement Due to Seepage Force

Abdollah Rohani Hajiagha[1], Abolfazl Riahi Nouri [2]

1- M.Sc., Department of Civil Engineering, Hormozgan University, Bandar Abbas
2- Assistant Professor, Department of Civil Engineering, West Tehran Branch, Islamic Azad University,

Email: sasanrohani@gmail.com

Abstract

In order to study elastic surface settlement owing to steady-state seepage condition, a tunnel subjected to water-flow was considered. The relationship between surface settlement in a block of soil due to seepage force and other parameters such as soil elasticity, permeability and tunnel diameter was explored. It was shown that elastic settlement due to seepage force can be remarkable to make damage on the building above the soil and soil permeability has major effect on differential settlement.

Keywords: Seepage, Elastic settlement, Numerical analysis.

1. INTRODUCTION

Water-flow can cause instability and deformation through soil in a region leading to damage on structures and their foundations. There are three common types of water-flow that bring such deformation and instability: (a) soil consolidation, (b) dewatering and (c) seepage flow (steady or non-steady).

A great deal of previous research into soil deformation due to water-flow has focused on soil consolidation and dewatering. In order to simulate gradual squeezing and settlement of one-dimensional saturated soil column, a physical model was introduced; this phenomenon named consolidation after Terzaghi [1]. The idea of consolidation developed mathematically for three-dimensional problems by Biot [2]. In addition, some authors utilized finite element method to model soil consolidation [3]. On the other hand, dewatering is inevitable in some projects which is being constructed below water-table. In such projects by designing cutoff wall and retaining wall systems are based on controlling base stability and deformation of excavated soil walls [4].

Although, some worthwhile studies have been performed on soil consolidation and dewatering, few studies have investigated soil settlement due to seepage [5].understanding this type of settlement can play an important role in addressing the issue of damage in building in the exposure of such settlements. A related example is surface settlement owing to water-flow through tunnel face in tunneling underground water. It is still not known whether seepage forces can cause remarkable deformation and particularly differential settlement on the ground leading to damage and cracks on the buildings and structures as shown in figure 1.

In the present paper surface settlement due to water-flow thorough tunnel face investigated numerically. The relationship between surface settlement in a block of soil due to seepage force and other parameters such as soil elasticity and permeability and tunnel diameter was explored.

Figure 1. Detrimental effects of surface settlement on an ancient bridge

2. PROBLEM STATEMENT AND METHODOLOGY

A tunnel driven in a coarse-grained soil, and water-flow, was considered as shown in Figure 1, to determine the amount of elastic surface settlement owing to the seepage force in front of the tunnel face. It was assumed that the tunnel face is stable by applying sufficient amount of face support pressure on the tunnel face.

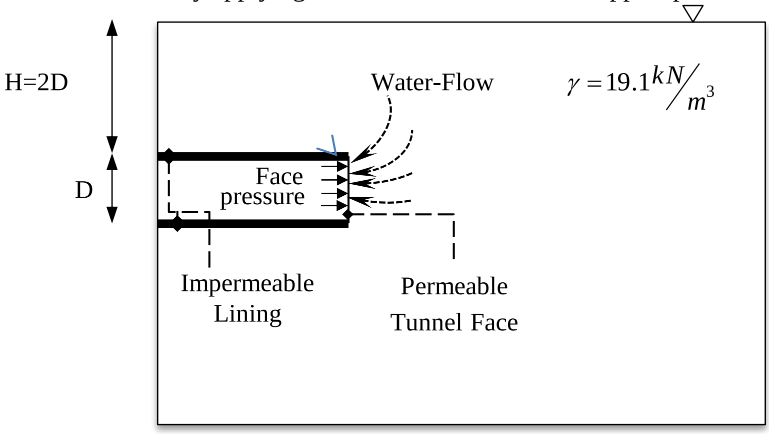

Figure 2. A typical shallow tunnel in saturated, permeable soil with water-flow

For simulating the above-mentioned tunnel, a number of fully-coupled 3D finite element analyses were performed employing ABAQUS software [6]. The geometry and dimensions of the soil around the tunnel are depicted in Figure 2. Due to the symmetry in the geometry of the model, only half of the geometry is simulated in the modeling process and symmetry boundary conditions are applied on the symmetry plane. After a number of analyses, outer boundaries are chosen far enough from the tunnel so that they have less effect on the results. The soil was modeled by 3D solid elements using reduced integration 20-node brick element with pore pressure (C3D20RP), while the lining was modeled using 8-node doubly curved shell elements (S8R) and embedded in the soil as shown in Figure 3.

The movement of nodes in vertical sides of the model in x or y direction are restrained. Besides, considering the bottom nodes, all degrees of freedom are fixed, while there is no constraint on the top nodes of the model. It is considered that there are "no-flow" conditions in vertical sides of the model. The water-table is located on top of the model and remains constant through the analyses. Lining of the tunnel is assumed waterproof, while, there is flow through the tunnel face to establish seepage condition.

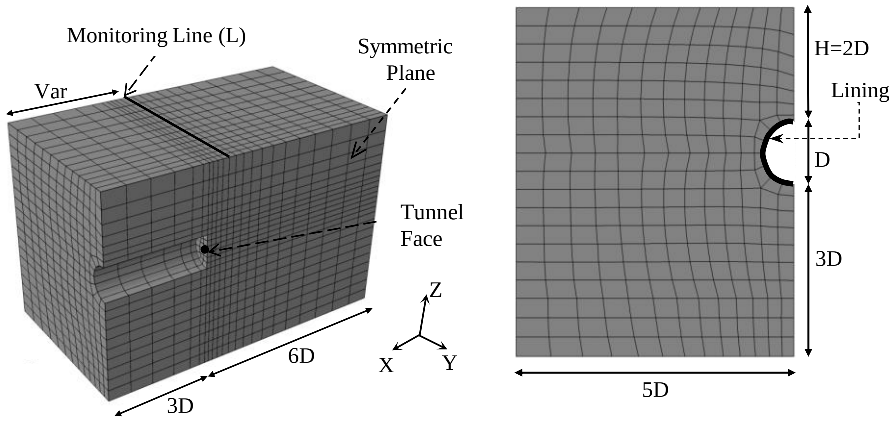

Figure 3. Finite element model of the simulated tunnel

3. NUMERICAL RESULTS AND DISCUSSION

In order to investigate the influence of physical parameters of soil such as elasticity and permeability, as well as other efficient parameters such as hydraulic head in the chamber and the tunnel diameter on the surface settlement, a parametric study was done as described in the following sections. In all cases the soil material is assumed elastic-perfectly plastic conforming Mohr-Coulomb criterion with non-associative flow rule. Figure 4. depicts total head distribution steady-state seepage condition established completely thorough the soil model.

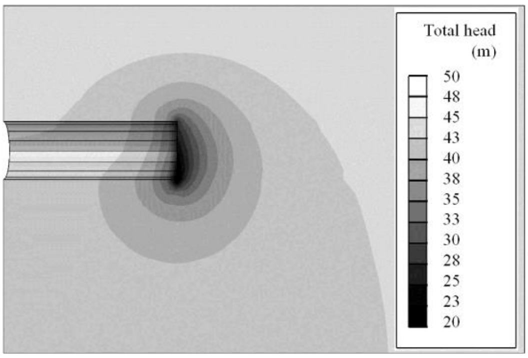

Figure 4. Hydraulic head distribution thorough model

3.1. EFFECT OF SOIL PHYSICAL PARAMETERS ON ELASTIC SETTLEMENT

To investigate the effect of soil elasticity and permeability on the ground surface settlement, a number of analyses were performed for soils with different values for modulus of elasticity (E= 13 and 25 MPa) and isotropic permeability coefficient (k= 0.001 and 1 m/sec). As shown in Figure 5 the greater elasticity coefficient leads to smaller surface settlement while soil permeability has no effect on the maximum surface settlement. However, miniscule soil permeability can cause differential settlement.

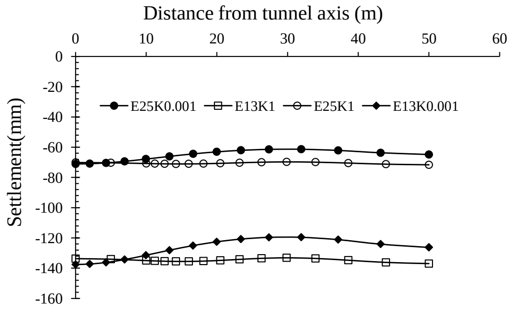

Figure 5. Elastic surface settlement for different modulus of elasticity (E) and permeability coefficients (k) of the soil

3.2. EFFECT OF TUNNEL DIAMETER AND HYDRAULIC HEAD ON ELASTIC SETTLEMENT

To study the effect of channel's dimension on the elastic settlement, three different tunnel diameters, i.e. 6m, 10m and 15m were considered. In all cases the proportion of tunnel cover (H) to diameter (D) ratio was 2. In addition, hydraulic head effect was studied by increasing pore water pressure in the chamber (tunnel face). In this regard parameter "dh" defined as follows:

$$dh = \frac{h}{h_{\max}} \quad (1)$$

Where h is the difference between hydraulic head in the tunnel face and ground surface and $h_{\max}$ is maximum value for h which occurs for zero pore water pressure in the tunnel face the results in Figure 6 show that an increase in the channel diameter leads to greater surface settlement. In addition, the greater differential head, the greater surface settlement.

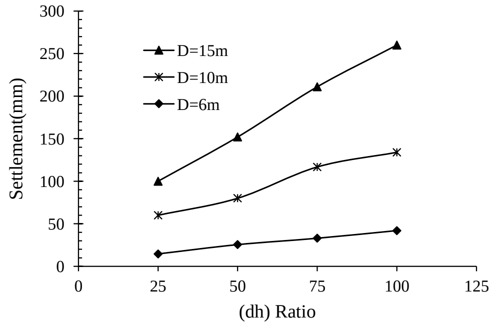

Figure 5. Elastic surface settlement for dimensions (D) of channel and differential heads (dh)

4. CONCLUSIONS

In order to illustrate elastic surface settlement because of seepage force, a tunnel under water-table was considered. Effect of some determining parameters such as soil elastic modulus and tunnel diameter and soil permeability on the settlement was studied. Based on the numerical results the following major conclusions were drawn:

1- Seepage force can cause remarkable elastic deformation in soil and corresponding surface settlement on the ground surface.
2- Elastic settlement has linear relationship with soil elastic modulus as 7cm and 13.6cm settlement occurred when the soil elastic modulus was 25 MPa and 13 MPa respectively.
3- When soil permeability is low enough about 0.001 m/sec, the ground surface experiences up to 2 cm differential settlements.
4- Greater tunnel diameter leads to higher surface settlement.

5. REFERENCES

1. von Terzaghi, C., Erdbaumechanik auf bodenphysikalischer Grundlage. 1925: Deuticke.

2. Biot, M.A., General theory of three-dimensional consolidation. Journal of applied physics, 1941. **12**(2): p. 155-164.

3. Sandhu, R.S., H. Liu, and K.J. Singh, Numerical performance of some finite element schemes for analysis of seepage in porous elastic media. International Journal for Numerical and Analytical Methods in Geomechanics, 1977. **1**(2): p. 177-194.

4. Wu, Y.-X., et al., Characteristics of groundwater seepage with cut-off wall in gravel aquifer. I: field observations. Canadian Geotechnical Journal, 2015. **52**(10): p. 1526-1538.

5. Chen, Y., et al., Modeling coupled processes of non-steady seepage flow and non-linear deformation for a concrete-faced rockfill dam. Computers & Structures, 2011. **89**(13): p. 1333-1351.

6. Manual, A.U.s., Version 6.8. Dassault Systems Simulia Corp., USA, 2008.