A coupled hydromechanical modelling of internal erosion around shield tunnel

Jie Yang, Zhen-Yu Yin, Farid Laouafa, Pierre-Yves Hicher

A coupled hydromechanical modelling of internal erosion around shield tunnel

J. YANG[a,b], Z.Y. YIN[b,c,*], F. LAOUAFA[a] and P.Y. HICHER[b]

[a]INERIS, Verneuil en Halatte, France
[b]Research Institute of Civil Engineering and Mechanics (GeM), UMR CNRS 6183, Ecole Centrale de Nantes, Nantes, France
[c]Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China

[*] zhenyu.yin@polyu.edu.hk; Zhenyu.yin@gmail.com

Introduction

Tunnel leakage is one of the most important factors of the ground movement (Zhang et al. 2017). However, the effect of the loss of fines has not been deeply discussed in the previous study. The leakage of underground water through the cracks and joints of lining commonly carries fines in the form of silt and clay from the surrounding ground, i.e. internal erosion (Bonelli and Marot 2011). The change of porosity due to loss of fines affects the mechanical behaviour of the surrounding soil (Yin et al. 2014; Yin et al. 2016). Conversely, the change of porosity influences the permeability of the sand and, therefore, its hydraulic conductivity. In this study, the effect of leakage on the tunnel in sand layer was investigated numerically with a coupled hydro-mechanical continuum approach, considering the internal erosion phenomenon induced by the local flows of underground water.

Formulation of the time-dependent physical problem

The mass balance equations are based on the porous media theory (de Boer 2000). The saturated porous medium is modelled as a system of 4 constituents: the solid skeleton, the erodible fines, the fluidized particles and the fluid. The fines can either behave as a fluid-like (described as fluidized particles) or a solid-like (described as erodible fines) material. Thus, a liquid-solid phase transition process is considered by a mass production term in the corresponding mass balances. Furthermore, the flow in the porous medium is governed by Darcy's law, in which the permeability of the medium depends on porosity. The mechanical behaviours of the solid skeleton are reproduced by a critical state based constitutive model (Jin et al. 2016; Yin et al. 2013, 2016), which is able to take into account the influence of the change of porosity on the mechanical behaviours of the soil during the process of internal erosion.

Numerical analysis of internal erosion around shield tunnel

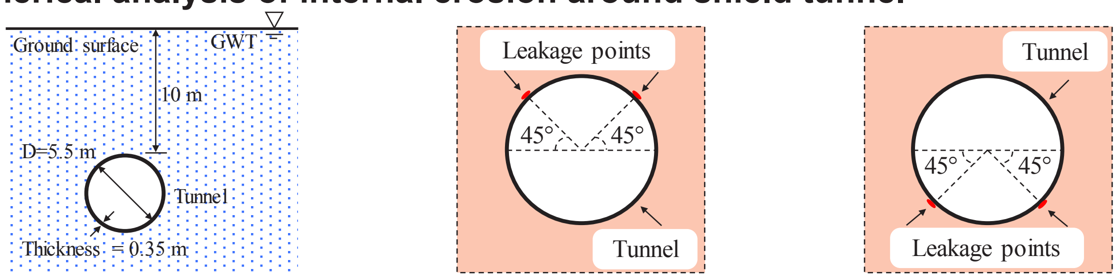

Fig. 1. Problem geometry and leakage location at tunnel lining

The suggested numerical model was conducted to investigate the hydro-mechanical response of an existing tunnel installed in sand layer and experiencing a local internal erosion due to the leakage of underground water from the damaged joints or cracks. The tunnel was assumed to have a circular shape with an inner diameter of 5.5m and to be constructed at a depth of 10m below the ground surface. The locations of the leakage points are shown in Fig. 1.

Fig. 2(a) shows the evolution of the fines during the leakage process. Internal erosion took place, leading to the decrease of the fines which was initially uniform in the whole soil volume. The decrease was critical in the vicinity of the cavity, which created a highly eroded zone. Furthermore, it is observed that for two-dimensional simulation, the lower leakage location results in a larger ground surface settlement, as shown in Fig. 2(b). Moreover, about 50% of the total settlement for 300 days is produced at very early stage of leakage. This is due to the change of effective stress induced by the change of boundary condition of pore pressure at the leakage point before the development of eroded area. After that the settlement keeps increasing and tend towards stabilizing. Significant increase of bending moment of linings was observed as well.

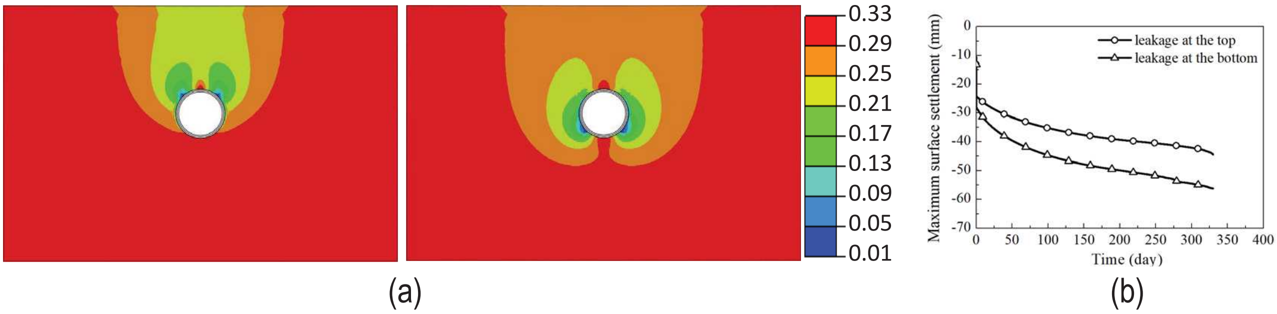

Fig. 2. (a)Spatial distribution of fines for the two cases after 300 days of leakage; (b) Time history of maximum ground surface settlement for different leakage locations

Conclusion

In this study, the effect of leakage on the tunnel in sand layer was investigated numerically with a coupled hydro-mechanical approach, considering the internal erosion induced by the local flows of underground water. The investigations indicated that with the development of ground water leakage and internal erosion, there is an obvious increase in the maximum bending moment in the tunnel lining and the ground sur-face settlement.

Acknowledgements

A financial support was provided by the National Institute for Industrial Environment and Risks of France (INERIS). This support is gratefully acknowledged.

References

Bonelli, S., and Marot, D. 2011. Micromechanical modeling of internal erosion. European Journal of Environmental and Civil Engineering, 15(8): 1207-1224.

de Boer, R. 2000. Contemporary progress in porous media theory. Applied Mechanics Reviews, 53(12): 323-370.

Jin, Y.-F., Yin, Z.-Y., Shen, S.-L., and Hicher, P.-Y. 2016. Investigation into MOGA for identifying parameters of a critical-state-based sand model and parameters correlation by factor analysis. Acta Geotechnica, 11(5): 1131-1145.

Yin, Z.-Y., Xu, Q., and Hicher, P.-Y. 2013. A simple critical-state-based double-yield-surface model for clay behavior under complex loading. Acta Geotechnica, 8(5): 509-523.

Yin, Z.-Y., Zhao, J., and Hicher, P.-Y. 2014. A micromechanics-based model for sand-silt mixtures. International Journal of Solids and Structures, 51(6): 1350-1363.

Yin, Z.-Y., Huang, H.-W., and Hicher, P.-Y. 2016. Elastoplastic modeling of sand–silt mixtures. Soils and foundations, 56(3): 520-532.

Yin, Z.-Y., Jin, Y.-F., Shen, S.-L., and Huang, H.-W. 2016b. An efficient optimization method for identifying parameters of soft structured clay by an enhanced genetic algorithm and elastic–viscoplastic model. Acta Geotechnica: 1-19.

Zhang, D., Huang, Z., Yin, Z., Ran, L., and Huang, H. 2017. Predicting the grouting effect on leakage-induced tunnels and ground response in saturated soils. Tunnelling and Underground Space Technology, 65: 76-90.