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Micromechanics of granular materials – A tribute to Ching S. Chang

Influence of soil conditioning on ground deformation during longitudinal tunneling

Mingjing Jiang[a,1], Zhen-Yu Yin[b,c,*,2]

[a] *Department of Geotechnical Engineering, and Key Laboratory of Geotechnical and Underground Engineering of Ministry of Education, Tongji University, 1239 Siping Road, Shanghai 200092, China*
[b] *Research Institute in Civil and Mechanical Engineering, UMR CNRS 6183, Ecole Centrale de Nantes, BP 92101, 44321 Nantes, France*
[c] *Department of Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, China*

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ABSTRACT

Soil conditioning is often adopted to facilitate EPB shield tunneling. However, the resulting improvement of soil fluidity and the reduction of friction forces will also raise the ground deformation problem. This paper aims to investigate the influence of soil conditioning on the ground deformation during longitudinal tunneling. DEM is employed for this study due to its advantages in analyzing large deformations and discontinuous processes. Soil conditioning is modeled by reducing the interparticle friction of soils in a specific zone around the cutterhead of the tunnel. The tunnel advance with different soil-conditioning treatments is thus modeled. Comparisons are carried out on the ground deformation, i.e. ground surface settlement, vertical and horizontal displacements. The influence of soil conditioning on the ground deformation is clarified, and is associated with the fluidity from poor to favorite, and the mechanical properties from dilative to contractive are associated with the increase of soil conditioning. The results are helpful to determine the conditioned soils and control ground deformation for real constructions.

1. Introduction

The earth pressure balance (EPB) shield tunneling is an efficient and commonly adopted way for the construction of the metro under clayey and sandy layers. During tunneling, soils at the cutting face are removed by using the rotating cutter. The amount of soil imported into the soil chamber is adjusted equal to that exported by the screw conveyor to keep the earth pressure balance state at the cutting face, i.e. chamber pressure equal to cutting face pressure. Under sandy ground, the sandy soil is difficult to excavate due to its poor fluidity and to the strong friction forces. Therefore, the lubricating mud or foam is often injected into the soil chamber, the screw conveyor and the cutter to improve the fluidity of sandy soil and reduce the soil friction forces [1]. Tunneling is thus facilitated by soil conditioning. However, at the same time, soil conditioning will also influence ground deformation during tunneling, since the fluidity and mechanical properties of conditioned soils have been greatly changed compared to virgin soils. Thus, the influence of soil conditioning on ground deformation is one of the most important issues for EPB shield tunneling.

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[*] Corresponding author. Tel.: +33 (0)2 40 37 15 88; fax: +33 (0)2 40 37 25 35.
E-mail addresses: mingjing.jiang@tongji.edu.cn (M.J. Jiang), zhenyu.yin@gmail.com (Z.-Y. Yin).

[1] Professor of Exceptional Rank of Tongji University.

[2] Guest Professor. Tel./fax: +86 21 3420 7964.

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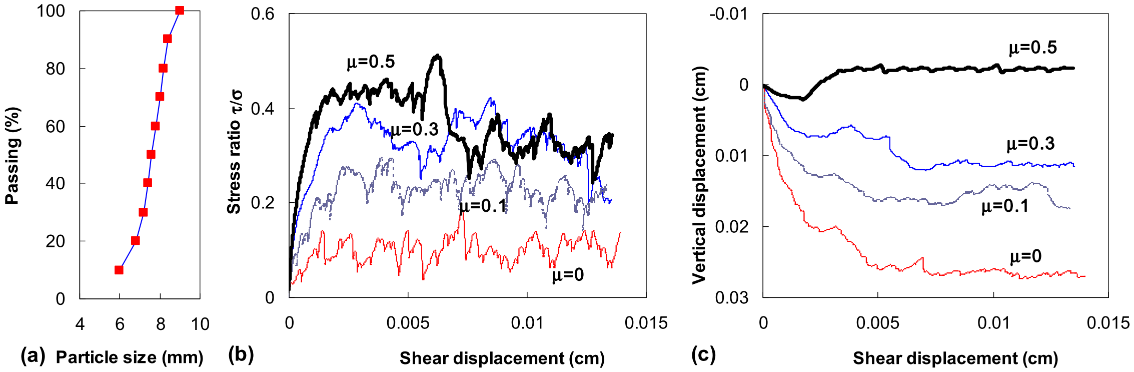

Fig. 1. (Color online.) Properties of granular material used in the DEM analyses: (a) distribution of grain size, (b) simulated shear stress ratio versus shear displacement, (c) simulated vertical displacement versus shear displacement.

Table 1
Material parameters used in DEM analysis.

Parameters	Soil
Particle size (d)	6–9 mm
Density of particles (ρ)	2600 kg/m^3
Normal spring stiffness of particles (k_n)	1.5×10^8 N/m
Tangential spring stiffness of particles (k_s)	1.0×10^8 N/m
Coefficient of interparticle friction (μ)	0.5
Normal spring stiffness of wall (k_n)	1.5×10^8 N/m
Tangential spring stiffness of wall (k_s)	1.0×10^8 N/m
Coefficient of friction between wall and particle (μ)	0

Ground deformation associated with real tunnel constructions is complicated due to tail void, uncertainties of natural soil variation, grouting, soil conditioning, etc. To simplify the problem, experimental investigations have been carried out focusing on some of factors, i.e. tail void, buried depth, screw conveyors, dynamic loading, etc., through physical modeling [2–7]. However, limited investigations have been made to address the influence of soil conditioning on the ground deformation during longitudinal tunneling. Furthermore, it is practically difficult to eliminate the variation of the testing models when conducting a series of tunnel tests with various soil conditions.

More recently, the discrete element method (2D/3D DEM) has been employed to model the longitudinal tunneling process and mostly to investigate the tunnel face failure [8–10]. The advantage of DEM lies in that it can physically capture the behavior of particulate materials, and as a discontinuous analysis method it can simulate the large deformation and discontinuous process of discrete particles assembly under quasi-static and dynamic conditions [11–19]. Therefore, it can potentially overcome the shortcomings of the finite element method (FEM) and is a powerful numerical tool for computing the motion of a large number of particles in the large deformation and discontinuous analyses during tunneling. However, few investigations by DEM on the influence of soil conditioning related to ground deformation during longitudinal tunneling have been conducted up to now.

Therefore, in this paper we focus on investigating the influence of soil conditioning on ground deformation during longitudinal tunneling. Due to the advantages of DEM in simulating the large deformation and discontinuous processes, and because it provides identical sample and construction conditions compared to physical modeling or field testing, DEM has been adopted for this study. Soil conditioning is modeled by reducing the interparticle friction of soils in a specific zone. The advance process of EPB shield tunnel is thus modeled using various conditioned soils. All results on ground deformation are compared to each other.

2. Discrete element modeling

2.1. Material properties and mechanical behavior

A dried granular material with a distribution of particle size shown in Fig. 1(a) has been used in our DEM studies. The numerical simulation has been performed with a particle flow code in two dimensions (PFC^{2D} [20]), which is a commercial DEM code originally proposed by Cundall and Strack [11]. The material is composed of discs with a maximum diameter of 9 mm; a minimum diameter of 6 mm; an average grain diameter $d_{50} = 7.6$ mm and a uniformity coefficient $C_u = d_{60}/d_{10} = 1.3$. Material parameters are shown in Table 1 with reference to [12]. Figs. 1(b) and 1(c) marked with $\mu = 0.5$ present results of a simple shear test with an initial planar void ratio of 0.196, with a global stress ratio $\tau/\sigma = 0.31$ representing a global critical state friction angle of 17.2°, where $\tau = (\sigma_1 - \sigma_3)/2$ and $\sigma = (\sigma_1 + \sigma_3)/2$ are defined with σ_1 and σ_3 representing