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Analytical prediction for tunnelling-induced ground movements in sands considering disturbance

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ABSTRACT

Construction inevitably leads to the disturbance to soils, which will change the properties of soils. Therefore, the physical and mechanical parameters obtained by the laboratory tests only reflect the properties of soils at a certain state, but not the true properties of soils during the whole process of construction. It is found that the initial relative density has a strong effect on the strength-deformation properties of sands on basis of a total of twenty-four triaxial compressed tests of dry sands. Based on Disturbed State Concept theory (Desai, 1974), a unified disturbance function is proposed by taking the relative density as the disturbance parameter. Furthermore, a novel approach that related the shear modulus with the degree of disturbance is developed. Then, according to former studies (Kondner and Zelasko, 1963; Kondner and Horner, 1965) and the proposed approach an analytical solution for ground movements considering construction disturbance is established. To study the validity of the proposed analytical solution one example is analyzed. It is found that both the positive (decrease in relative density) and negative (increase in relative density) disturbance have an obvious influence on the ground movements of the soil around the tunnel. The construction disturbance should be considered in predicting the ground movements by using the analytical solution.

1. Introduction

Tunnelling construction has developed rapidly in China in the past few decades. Meanwhile, geo-environment problems caused by tunnelling construction have become more and more serious. Construction will lead to the disturbance of soils, which will change the stress state, void ratio, water content et al. Therefore, the properties of strength and deformation of soils will also be influenced. The disturbance of soils can be evaluated by the degree of disturbance (D), which reflects the change of physical and mechanical parameters of soils (Xu et al., 2003). Hence, it is essential to establish the disturbed function which could correctly reflect the relationship between the change of the parameters and the degree of disturbance. To date, many literatures (Ladd and Lambe, 1963; Rowe and Lee, 1993; Xu et al., 2003) have been reported on the investigation of the soil disturbance problem. Desai (1974) treated a deforming material element as a mixture of the initial continuum or relative intact (RI) part and the fully adjusted (FA) part, and then, proposed the disturbed state concept (DSC) (Desai, 1974). At present, the DSC model has been applied to a wide range of materials including saturated clays (Katti and Desai, 1995), saturated sand and interfaces (Park and Desai, 2000; Pradhan and Desai, 2006; Zhu et al., 2011a), structured geomaterials (Liu et al., 2003), porous saturated materials (Desai and Wang, 2003), reinforced soil wall (El-Hoseiny and Desai, 2005), retaining wall (Zhu et al., 2011b) and so on.

It is essential to protect the pre-existing structures and underground works from damage during tunnelling in urban areas. Engineers responsible for the design and construction of tunnels must have some technique for estimating the potential ground movements, so that they can assess whether neighboring buildings will be subject to excessive differential settlements. There are mainly three different approaches readily used for prediction of the ground deformation associated with tunnelling, namely, empirical methods (Peck, 1969; Attewell and Woodman, 1982), finite-element methods (Eisenstein, 1986; Uriel and Sagaseta, 1989; Wong and Kaiser, 1991; Rodríguez-Roa, 2002) and analytical methods (Loganathan and Poulos, 1998; Sagaseta, 1987; Verruijt and Booker, 1996; Wei et al., 2005), those are commonly used in practice to estimate the ground deformations due to tunnelling. The selection of the appropriate method depends on the complexity of the problem. The finite-element methods are strongly dependent on the construction stages modeled, the constitutive law selected, and the appropriate assessment of the corresponding soil parameters. Moreover, the empirical methods have no theoretical

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basis and are subject to some important limitations such as in their applicability to different ground conditions and construction techniques and in the limited information they provide about the horizontal movements and subsurface settlements. Therefore, a proper analytical method is desirable to better estimate the tunnelling-induced ground movements. Unfortunately, the physical and mechanical parameters obtained from the laboratory tests only reflect the properties of soils at a certain state but not the true properties of soils during construction. Therefore, none of the analytical methods can predict the ground deformation during the whole process of construction.

In this research, a series of triaxial compressed tests of dry sands with different initial relative density are first conducted. According to the test results, a general disturbance function is proposed based on the DSC theory. On the basis of former studies and the proposed disturbance function a novel analytical solution for ground movements considering construction disturbance is established by refining the shear modulus of the proposed analytical method (Wei et al., 2005). Finally, one example is analyzed to study the validity of the novel analytical solution.

2. Triaxial test of dry sands

In this research, the sands are the ISO standard sand and the Fujian standard sand which are produced by the Xiamen ISO Standard Sand Company of China. For simplicity, the ISO standard sand and the Fujian standard sand are called as ISO sand and FJ sand, respectively. The particle sizes of the above two sands mainly range from 0.25 mm to 1 mm and the particle size distributions of them are shown in Figs. 1 and 2. The physical parameters of them are listed in Table 1. Where G_s is the specific gravity, e_{max} and e_{min} are the maximum and minimum void ratio, w is the water content, C_u is the uniformity coefficient and C_c is the coefficient of curvature.

Tests are performed on specimens prepared at four different initial relative densities (D_{r0}) which are shown in Tables 2 and 3. Where the parameter m is the total mass of one specimen which is filled with five layers, $\bar{m}$ is the mass of one layer. For every D_{r0}, the specimen is at confining pressures of 100 kPa, 200 kPa and 300 kPa. Therefore, a total of twenty-four standard triaxial compression tests of dry sands are conducted. The specimens tested are initially 39.1 mm in diameter and 80 mm in height, and are prepared using the techniques described by the The Professional Standards (1999). The shear strain rate is 0.808 mm/min and the failure criterion is controlled by the peak strength.

The stress–strain data for the ISO and FJ dry sands under each designed condition are shown in Figs. 3 and 4, respectively. Where σ_1 and σ_3 are the major and minor principal stresses, ε_1 is the axial strain.

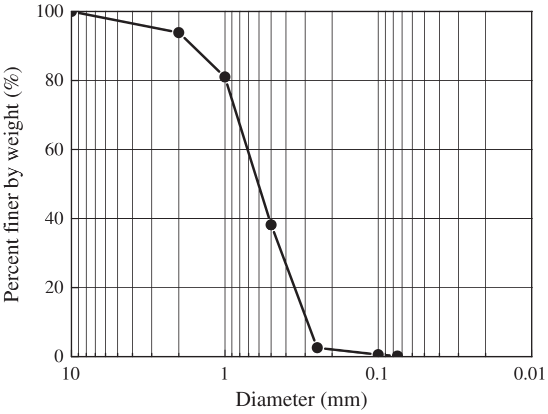

Fig. 1. Particle size distribution curve of the ISO sample.

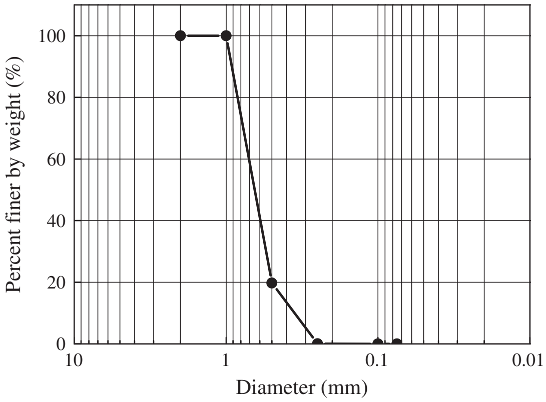

Fig. 2. Particle size distribution curve of the FJ sample.

Table 1
Physical index of sands.

Sand	w (%)	G_s	e_{max}	e_{mim}	C_u	C_c
ISO	0.046	2.681	0.723	0.382	2.267	1.408
FJ	0.045	2.697	0.926	0.645	1.442	0.923

Table 2
Experimental cases for FJ sand.

D_{r0}	m (g)	$\bar{m}$ (g)
0.4	162.338	32.468
0.5	165.892	33.178
0.6	169.607	33.921
0.7	173.481	34.696

Table 3
Experimental cases for FJ sand.

D_{r0}	m (g)	$\bar{m}$ (g)
0.5	145.047	29.009
0.6	147.352	29.470
0.7	149.754	29.951
0.8	152.251	30.450

As shown in Figs. 3 and 4, with increase of the initial relative density D_{r0}, the stress–strain curves for every confining pressure become more and more steep, meanwhile, the peak strengths become more and more large.

3. Analytical solution for ground movements considering disturbance

3.1. Unified disturbance function

Herein, the relative density D_r is defined as the disturbance parameter, the disturbance of decreasing D_r is called “negative disturbance” and the disturbance of increasing D_r is called “positive disturbance”. Moreover, defining the disturbance with the value of D range from −1 to 1, and considering the limit condition of sands including two states, the general disturbance function can be defined as:

(1) For “positive disturbance” ($D_r \leqslant D_{ri}$)