Computers and Geotechnics 80 (2016) 283–289

Contents lists available at ScienceDirect

Computers and Geotechnics

journal homepage: www.elsevier.com/locate/compgeo

Technical Communication

Upper-bound stability analysis of dual unlined elliptical tunnels in cohesive-frictional soils

Jian Zhang, Feng Yang, Junsheng Yang *, Xiangcou Zheng, Fanxuan Zeng

School of Civil Engineering, Central South University, Changsha, Hunan 410075, China

ARTICLE INFO

Article history:
Received 13 April 2016
Received in revised form 24 July 2016
Accepted 24 August 2016

Keywords:
Dual elliptical tunnels
Finite element limit analysis
Center-to-center distance
Upper-bound solution
Collapse mechanism

ABSTRACT

This study investigates the stability of dual unlined elliptical tunnels in cohesive-frictional soils using upper-bound finite element methods with rigid translatory moving elements (UBFEM-RTME). Results are determined in terms of dimensionless stability numbers, which increase with ϕ and decrease with increasing B/D and C/D, and collapse mechanisms, which mainly include two wedge-shaped zones and a complete non-plastic wedge. The center-to-center distance S significantly affects the stability of dual tunnels, and the interaction between the elliptical tunnels tends to disappear when S_c lies within (i) $2.5D$-$4D$ for $C/D = 1$, and (ii) $4D$-$11D$ for $C/D = 5$. The results agree well with those in literature.

1. Introduction

Multiple tunnels are often utilized prior to a single large tunnel in an urban tunneling infrastructure, as multiple tunnels provide higher security and deal with emergency situations more effectively. In addition, new tunnels may be constructed adjacent to existing tunnels in view of geological conditions and economic concerns. In these cases, an accurate assessment of tunnel stability, as well as potential collapse mechanisms, should be addressed.

Compared with the case for an isolated tunnel, there exists an interaction effect between dual tunnels when the center-to-center distance is not large enough. A number of studies on the interaction effect of dual tunnels have been conducted with numerical methods [1–7] and model tests [8–11]. However, only a few studies are available to investigate the stability of dual tunnels. Limit analysis method has often been employed to determine these issues. Osman [12] determined the undrained stability of dual circular tunnels with a continuous plastic deformation mechanism. Sahoo and Kumar [13] computed the stability of dual unlined circular tunnels under both drained and undrained conditions. Yamamoto et al. [14,15] and Wilson et al. [16,17] investigated the stability of twin circular tunnels and twin square tunnels in soils affected by surcharge loads.

In addition to circular and rectangular tunnels, horseshoe-shaped tunnels have been widely constructed in tunnel engineering. In general, horseshoe-shaped tunnels are comprised of more complex curves and may change significantly with a slight variance of the surroundings. Yang et al. [18] simplified these complicated tunnels as unlined elliptical tunnels, and then determined the stability of unsupported elliptical tunnels using an upper-bound finite element method with rigid translatory moving elements (UBFEM-RTME).

In the present analysis, the stability of dual unlined elliptical tunnels in cohesive-frictional soils is investigated using the UBFEM-RTME. No pressure is applied at the tunnel boundary or along the ground surface. The tunnel stability is determined in terms of a dimensionless stability number affected by soil properties, dimensionless depth C/D, dimensionless width B/D, and dimensionless center-to-center distance S/D. Slip-line collapse modes are presented to analyze the characteristics of collapse mechanisms for dual elliptical tunnels. The computational results are compared with those of dual circular tunnels reported in the literature.

2. Definition of the problem

Fig. 1 presents the plane strain stability analysis model for two parallel unlined elliptical tunnels in cohesive-frictional soils. To facilitate the analysis, only the right half of the problem domain and associated velocity boundary conditions are considered. The dual tunnels have span B, height D under depth of cover C, and center-to-center distance S. The soil mass is assumed as a Mohr-Coulomb material under drained conditions with unit weight γ,

* Corresponding author.
E-mail address: jsyang@csu.edu.cn (J. Yang).

http://dx.doi.org/10.1016/j.compgeo.2016.08.023

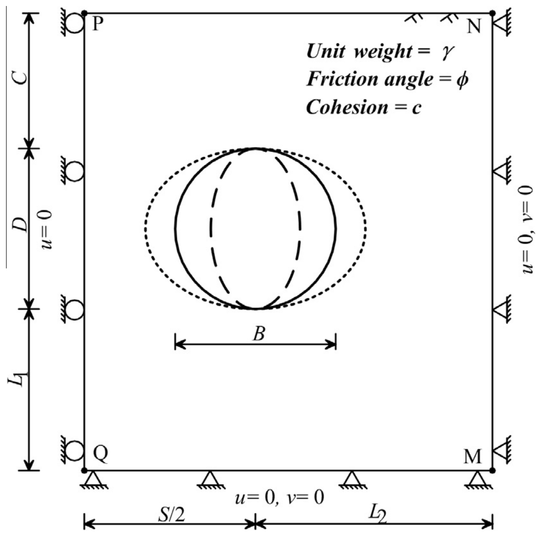

Fig. 1. Stability analysis models for dual unlined elliptical tunnels.

cohesion c, and internal friction angle ϕ. No surcharge loading acts on the ground surface and the tunnel boundary is free to move. The stability of the tunnels is conveniently described by a dimensionless stability number (N), which is defined as follows:

$$N = \gamma_{\max} D/c = f(\phi, C/D, B/D, S/D) \tag{1}$$

where $\gamma_{\max}$ is the maximum unit weight at which the dual tunnels can be borne without any collapse.

The UBFEM-RTME, which abandons the complicated recursive computational procedures of geometrical parameters and velocity parameters in rigid block systems, is applied to analyze the stability of the dual elliptical tunnels. The problem domain is artificially discretized into a series of three-node rigid triangular elements, and the element size is gradually reduced towards the tunnel contour. Node coordinates and element velocities are now all treated as decision variables to be investigated during the solution procedure. The meshes have kinematically admissible velocity discontinuities along all edges that are shared by two adjacent elements. A kinematical admissible velocity field, which should satisfy the velocity boundary conditions, associated flow rule, and be compatible with the velocity conditions along velocity discontinuities, can be obtained through adjustment of velocity discontinuities during the solution procedure. An upper bound on the critical unit weight $\gamma_{\max}$ can be obtained by minimizing the power dissipation along velocity discontinuities less the power done by the soil weight. All steps involved in formulating a non-linear programming problem were described by Yang et al. [18].

Note that two parallel tunnels are generally excavated in a sequential order in the field construction. The analysis model assumes that these two tunnels are constructed by means of simultaneous excavation, and the obtained stability numbers with this assumption are more conservative than the practical results.

3. Analysis of upper-bound solutions

3.1. Comparison calculation for dual circular tunnels

Fig. 2 shows the stability numbers for dual unlined circular tunnels with various C/D and ϕ. For comparison purposes, the results from (i) the upper-bound (UBFEM) and lower-bound (LBFEM) finite element method of Yamamoto et al. [14] and (ii) the UBFEM of Sahoo and Kumar [13] are also included in Fig. 2. It can be found that the presented stability numbers agree well with upper-

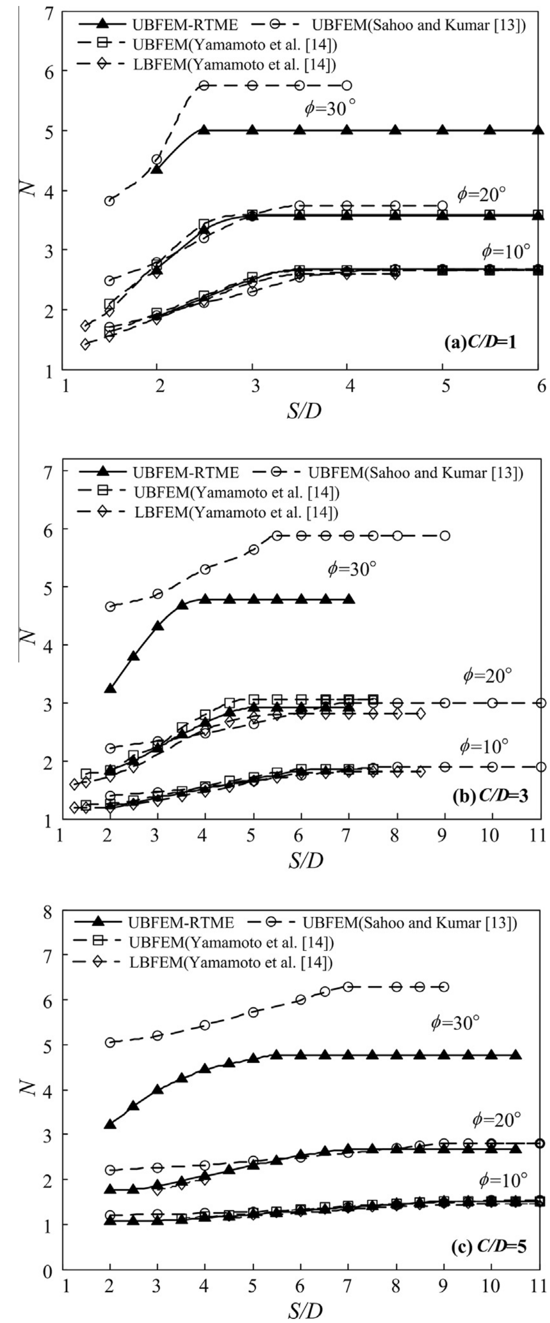

Fig. 2. Comparison calculation for dual circular tunnels for cases with (a) $C/D = 1$, (b) $C/D = 3$, and (c) $C/D = 5$.

bound solutions obtained by Yamamoto et al. [14] and Sahoo and Kumar [13], and these results are slightly greater than lower-bound solutions of Yamamoto et al. [14]. These comparisons indicate that the UBFEM-RTME can provide upper-bound solutions with fine accuracy owing to its automatic adjustment of velocity discontinuities in the solution process, especially for cases with $\phi = 30°$.

3.2. Variation of stability numbers

Figs. 3 and 4 show the stability numbers (N) for dual unlined elliptical tunnels with (i) C/D varying between 1 and 5, (ii) ϕ varying from 5° to 30°, and (iii) B/D varying between 0.5 and 1.5. It can be found that N increases strictly with increasing ϕ, and it