Stability Analysis of a Double-deck Tunnel with a Diverging Ramp Tunnel

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Abstract

The construction of underground expressway has been receiving a great attention as the solution to unban traffic congestions in Korea. In this study, a main double-deck tunnel with a ramp tunnel constructed as a part of the underground expressway is considered. A numerical analysis using FDM was performed for the case in which a right directional ramp tunnel of 1-level is diverging from a main double-deck tunnel of 2-level. For the main tunnel and the diverging tunnel in different geometrical configurations at the divergence section depending on diverging conditions, the stability was investigated by using the Mohr-Coulomb failure proximity approach. The results showed that horizontal divergence condition is the most unfavorable in terms of stability.

Keywords: Underground expressway, Double-deck tunnel, Mohr-Coulomb failure proximity.

1. INTRODUCTION

A double-deck tunnel is often compared with parallel tunnels when determining the type of tunnel structure based on various factors such as constructability, economy, and safety. In this study, a situation that a part of underground network roads is built using a double-deck tunnel with ramp tunnels is considered. In that case, however, the construction at the divergence or confluence section for connecting the ramp tunnels to the main double-deck tunnel can be very complicated due to increased asymmetries between the main and the ramp tunnels. This paper presents the numerical analysis performed on the tunnels in the divergence section in different geometric conditions depending on diverging conditions and the results of tunnel stability obtained using the Mohr-Coulomb failure proximity approach based on the numerical analysis results.

2. METHOD

2.1. Numerical analysis

All the tunnels considered in this analysis were assumed to be constructed using NATM. Figure 1 represents the analysis conditions for the main and the diverging tunnels in different diverging conditions, including the size and the shape of each tunnel. Both the main and each diverging tunnel were assumed to be excavated in the same ground condition (i.e., RMR class IV rock mass with the ratio of horizontal stress to vertical stress of 1.0). The ground rock mass was modeled using Mohr-Coulomb and elastic parameters (Table 1). FLAC 2D (version 6.0) software employing finite difference approach was used for this numerical analysis.

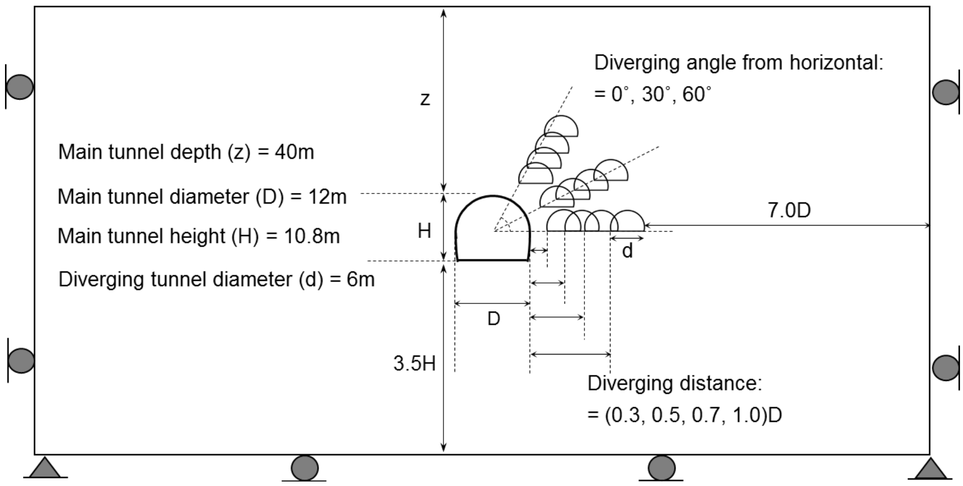


Figure 1. Numerical analysis conditions

Table 1. Model parameters and rock mass properties for analysis

Rock mass	Unit weight	Elastic Modulus	Cohesion	Friction angle	Poisson ratio
RMR class IV	24 kN/m^3	3,040 MPa	580 kPa	35°	0.25

2.2. Mohr-Coulomb failure proximity approach

The Mohr-Coulomb failure proximity approach is to determine the failure potential of a material by the degree of the proximity to the Mohr-Coulomb failure envelope of the Mohr's circle of the stress state in the material. The Mohr-Coulomb failure proximity *R* is expressed as the following Equation 1 and as shown in Figure 2 (Lee et al. 2016).

$$R = \min[\frac{d_1}{D_1}, \frac{d_2}{D_2}] \quad (1)$$

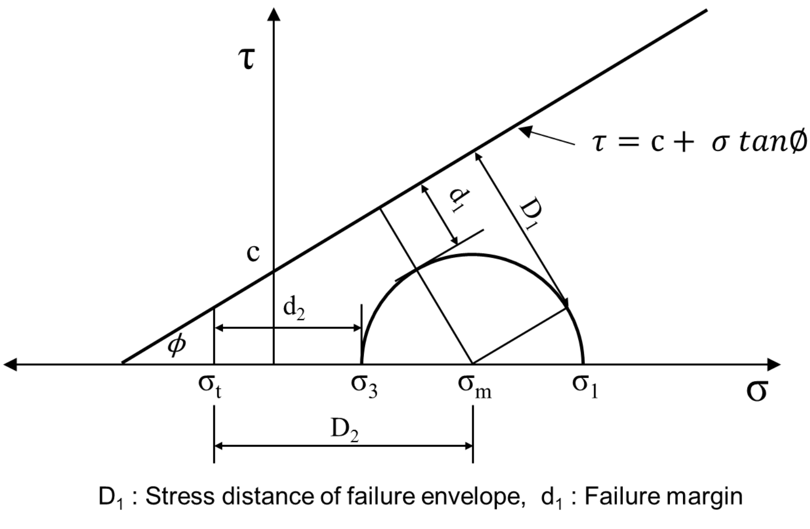


Figure 2. Mohr-Coulomb failure proximity approach concept

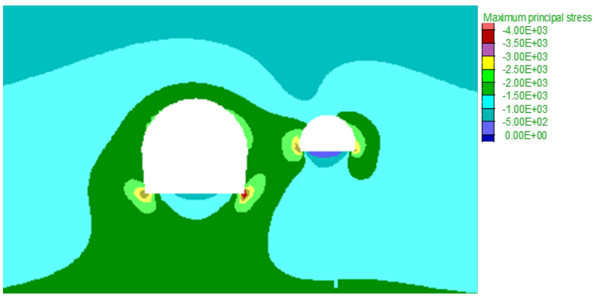
The concept of R displayed in Figure 2 can be used to draw the factor of safety for the material as expressed in the following Equation 2

$$FS = \frac{D_1}{r} = \frac{D_1}{\frac{\sigma_1 - \sigma_3}{2}} = \frac{\left(\frac{c}{\tan\phi} + \frac{\sigma_1 + \sigma_3}{2}\right)}{\frac{\sigma_1 - \sigma_3}{2}} sin\phi = \frac{\left(\frac{2c}{\tan\phi} + \sigma_1 + \sigma_3\right)}{\sigma_1 - \sigma_3} sin\phi \tag{2}$$

In the present study, the method described in the above was used to examine the stability of the tunnels in the divergence section based on the stress conditions derived from the numerical analysis. The stresses used in the calculation of the factor of safety by Equation 2 were obtained for the state of the moment when each diverging tunnel is excavated in full face while the main tunnel exists already.

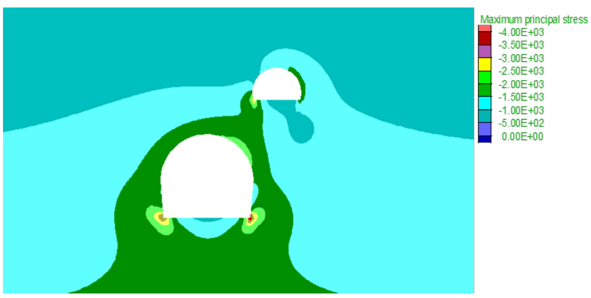
3. RESULTS

Figure 3 shows the contours of the major principal stresses induced around the main tunnel and the diverging tunnel, separated by 0.5D and 1.0D each for 0˚ and 60˚ diverging directions, respectively. The largest stress was induced in the invert corner for all the tunnels. For diverging tunnels, overall higher stresses were induced for 0˚ diverging direction, compared to 60˚ diverging direction.

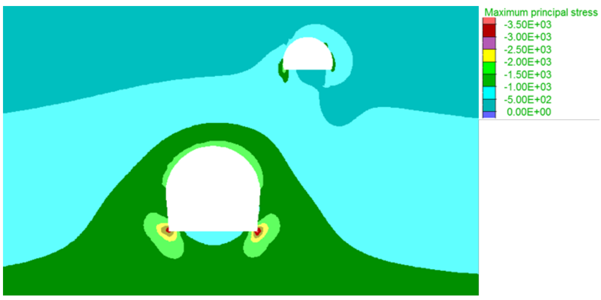


(a) Inter-tunnel distance 0.5D in diverging direction 0˚

(b) Inter-tunnel distance 1.0D in diverging direction 0˚



(c) Inter-tunnel distance 0.5D in diverging direction 60˚



(d) Inter-tunnel distance 1.0D in diverging direction 60˚

Figure 3. Major principal stress contour

Figure 4 displays the factor of safety obtained using the Mohr-Coulomb proximity approach as expressed in Equation 2 for three diverging directions (i.e., 0˚, 30˚, 60˚) along the inter-tunnel distance of 0.5D. The most unfavorable condition was found to be 0˚ diverging direction condition for which the lowest level of the factor of safety was obtained along the inter-tunnel distance.

The average values of the factor of safety along each inter-tunnel distance are plotted over all the diverging conditions in Figure 5. As expected, the average safety factor value increased gradually with increasing the inter-tunnel distance from 0.3D to 1.0D and with increasing with diverging direction angle from 0° to 60°. It was also found that the effect of the diverging direction angle on the factor of safety gradually vanishes as the inter-tunnel distance increases.

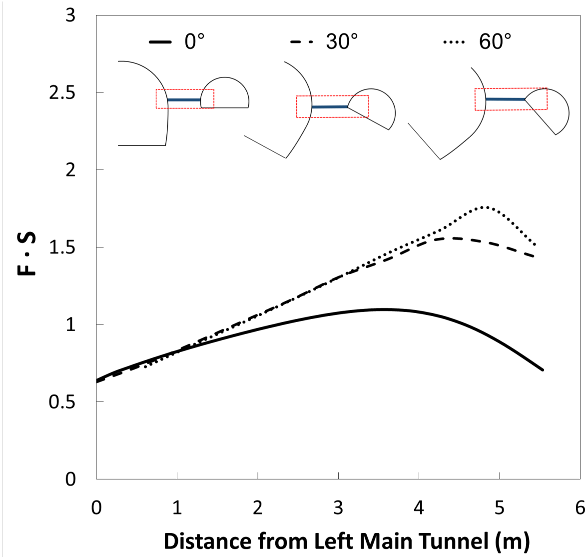


Figure 4. Variation of factor of safety along inter-tunnel distance

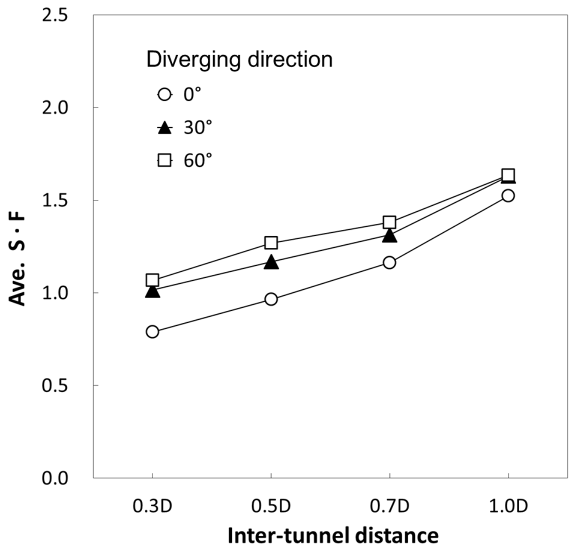


Figure 5. Average safety factor value for different inter-tunnel distances and diverging directions

4. CONCLUSION

The result of numerical analysis showed that the largest stress is induced in the invert corner for both the main and the diverging tunnels. For diverging tunnels, overall higher stresses were induced for 0° diverging direction, compared to 60° diverging direction. The level of the factor of safety obtained using the Mohr-Coulomb proximity approach was found to be the lowest for 0° diverging direction condition.

ACKNOWLEDGMENTS

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