Comparative study with the displacement controlled model on 2D numerical analysis of a shield TBM tunnel

Kwang Ho You & Young Jin Kim
University of Suwon, Korea

ABSTRACT: The shield TBM method is suitable to construct a tunnel at urban areas because it can reduce blast noise and ground loss. In this study, a new method was proposed to take account of gap parameter and compared with the DCM which has been most generally used for shield TBM modeling. To this end, numerical analysis was executed by using FLAC 2D for a shield TBM tunnel excavated in a single weathered soil layer with 30 m deep rock cover. Finally, the proposed method of this study was verified by analyzing and comparing the outputs with the DCM.

Keywords: Shield TBM, Gap parameter, Ground loss, DCM

1 INTRODUCTION

Recently, demand of roads/subways and development of underground space are increased to cope with a traffic congestion problem caused by urbanization. Commonly, big cities have been built along river and coast and thus weak ground could be often encountered in them. Since shield TBM tunnel construction method can be applied to various ground conditions such as hard rock and weak ground, it is advantageous to use it in urban areas (Kim et al., 2007). However shield TBM construction in weak ground conditions can damage adjacent structures due to surface settlement.

Generally, the DCM (Displacement Controlled Model) has been used to analyze ground loss about shield TBM tunnel. However, the DCM method has several weakness. First, it assumes that invert convergence isn't considered properly. Second, because the convergence is occurred artificially by pulling nodes, segment lining can't be modelled realistically. Therefore, to supplement the DCM, a method was proposed in this study to consider invert convergence and calculate the load distribution ratio that results in a specific gap parameter by the rule of trial and error. To this end, a shield TBM tunnel was assumed to be excavated in a single weathered rock layer with the depth of rock cover, 30 m. In this study, finally, a modeling method of simulating gap parameter properly was proposed and evaluated by comparing with DCM.

2 NUMERICAL ANALYSIS MODELING

2.1 *Numerical analysis outline*

In this study, FLAC 2D, a widely used geotechnical program, was used for modelling with the section shown in Figure 1. The horizontal range from the center of the tunnel to both right and left boundaries were 3.5 times of tunnel diameter (D), respectively. Also the length from the invert of the tunnel to the bottom boundary was twice as much D. A shield TBM tunnel was assumed to be excavated in a single weathered soil layer with the properties listed in Table 1. The depth of rock cover was applied to be 30 m. Excavation diameter was supposed to 8.5m (Cho, 2008). Finally, ground was modeled in Mohr-Coulomb elasto-plastic model and the segment linings were modeled by liner elements which can take account of plastic behavior by applying the residual strength as listed in Table 2. The size of an element around the tunnel was reduced to 5cm for better accuracy of numerical analysis. Finally analysis domain was 59.5 m wide and 55.5 m high. Right/left side and bottom boundary were fixed for horizontal and vertical direction, respectively.

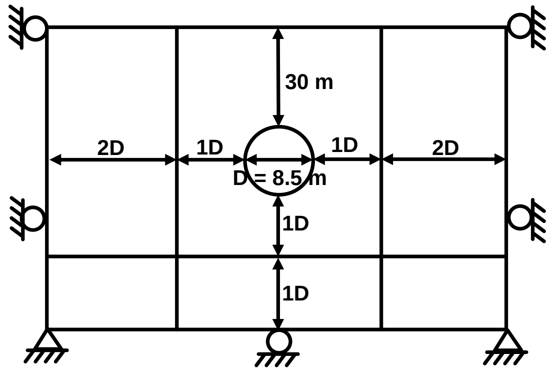


Figure 1. Generals of the analysis section

Table 1. Properties of ground (Western metro, 2016)

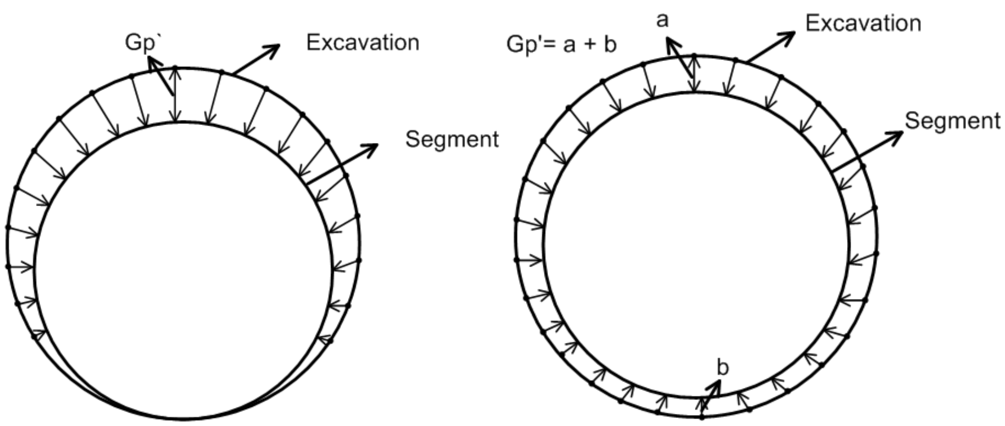
Ground conditions	Unit Weight (kN/m^3)	Deformation Modulus (MPa)	Poisson's Ratio	Friction Angle (°)	Cohesion (kPa)
Weathered Soil	19	25	0.32	29	20

Table 2. Properties of segment lining (You et al., 2007)

Deformation Modulus (MPa)	Moment of Inertia (m^4)	Thickness (m)	Allowable Bending Compressive Stress (MPa)	Allowable Bending Tensile Stress (MPa)	Residual Stress (MPa)
31.0	7.59 ×10-3	0.45	26.5	1.3	0.65

2.2 *Gap parameter modeling*

In the DCM method, the invert displacement of a tunnel is assumed to be not generated as shown in Figure 2(a). A ground loss is described by moving node of mesh inward while maintaining the shape of the excavation surface with reference to gap parameter(G_p). G_p', reduced by a tail void reduction factor (α), is rather used because inward displacement varies with ground conditions and type of grouting injection. In addition, because segments are immediately installed without grouting, the result of the DCM can be different from actual behavior.



(a) The DCM (b) This study

Figure 2. Modeling methods of a shield TBM tunnel

In this study, the load distribution ratio that generates a specific gap parameter was searched for a better description of shield TBM tunnel excavation stage. After excavating the tunnel, the load distribution ratio resulting in the gap parameter of interest (5, 10, 15 cm), defined by the sum of crown (a) and invert

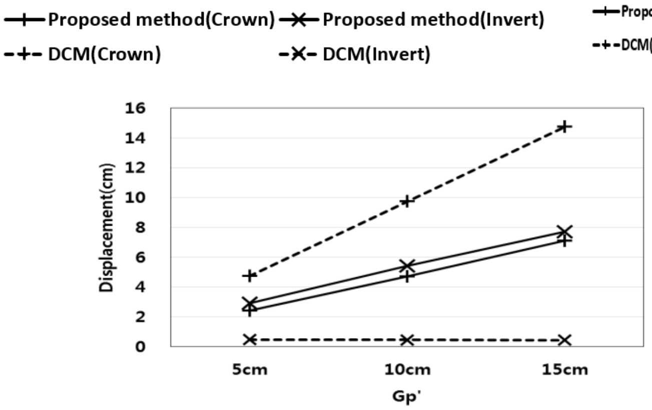
(b) displacement, was found by the rule of trial and error. It was finally found as shown in Table 3. By applying the corresponding load distribution ratio, the gap parameter was generated and segments are installed without backfill grouting.

Table 3. Load distribution ratios resulting in gap parameters

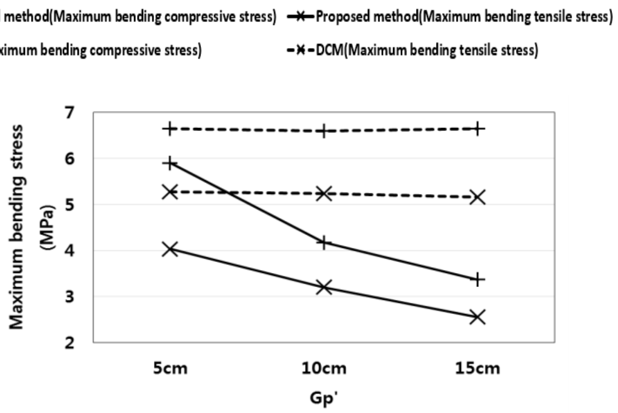
Gap (cm)	Load Distribution Ratio (%)
5	23
10	39
15	55

3 SENSITIVITY ANALYSIS

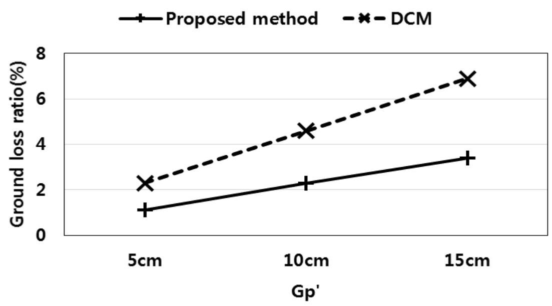
In results of numerical analyses, except $G_p{}'$ is 5 cm, the vertical convergence of the DCM turned out to be approximately 0.8 ~ 2.5 % larger than that of this study as shown in Figure 3(a). In this study, the almost same amount of displacement was occurred at both crown and invert. Because the displacement of the invert was assumed to be zero in the DCM, most of the vertical convergence was resulted from the crown. For this reason, it can be inferred that compressive and tensile bending stress are predicted approximately 23~50% bigger from the DCM than from this study as shown in Figure 3(b).



(a) Displacement



(b) Bending stress



(c) Ground loss ratio

Figure 2. Results of a numerical analysis

Ground loss ratio, the area ratio between before and after the excavation, was increased 42% on average as $G_p{}'$ was increased 5 cm. As can be seen in Figure 3(c), ground loss ratio obtained by the DCM was 50% bigger than that by the proposed method of this study. It can be also explained by the fact that most of the DCM vertical convergence occurred at the crown. As a result, the DCM can lead to over design since the DCM can predict bigger ground loss ratio and the consequent bending stress than the proposed method.

4 CONCLUSIONS

In this study, a new shield TBM modeling method was proposed and compared with the DCM for validation.

1. As the gap parameter was increased, vertical convergence and ground loss ratio were increased proportionally. Therefore it can be inferred that the method proposed in this study is reasonable.
2. Because the DCM assumes that displacement is not allowed at the invert, it led to larger bending stresses and ground loss ratio than the proposed method. As a result, the proposed method can bring about more economical design.

For further study, backfill grouting between segment lining and ground can be considered for more accurate model.

REFERENCES

Cho, J. S. (2008), *Analysis of ground movements and lining segment in shield TBM based on Three dimensional finite element method*, Master's Dissertation, Pukyong National University, 58p.

Kim, D. H., Cho, J. S., Kim, D. Y., Jung, D. H. (2007), "Analysis of ground movements and lining segment in shield TBM based on three dimensional finite element", KSCE 2007 Convention, No. 10, pp.2975-2978.

Western Metro (2016), *Final Design of Private Infrastructure Investment Project on OO-OO Double Track Railway (zone 4)*, Tunnel Analysis Report, 906p.

You, K. H., Lee, M. H., Park, Y. J. (2007), "Comparison and validation on shotcrete modelling method for the quantitative stability estimation of a tunnel", Korean Tunneling and Underground Space Association, Vol. 9, No. 2, pp.99-107.