Three-dimensional Analysis of Shield Tunnel By Using Rigid Segment Model

Kyoto University Fellow T.Tamura
Kyoto University Student member ○ C.Chanvanichskul

1. Objectives

A three-dimensional simulation of shield tunnel is done with the assumption that perfectly rigid segments are connected by paired-springs at all joints to which the total deformation of the tunnel is attributed. This study aims to apply the proposed model to the full-scale loading test on rectangular rings of Kyoto Subway Tozai Line Rokujizo-Kita Construction Section Project.

2. Rigid Segment Model[1)2)]

Rigid segment model is based on the assumption that prefectly rigid segments are connected by paired-springs at all joints. Deformation and transmission of internal forces are represented by deformation of the spring system. Displacement of each segment can be completely described by rigid body motion which consists of 6 components.

There are three types of 3D-springs used in this model: segment spring, ring spring and ground reaction spring. Table 1 shows types of spring constants of spring and Fig. 1 shows the spring position settings.

Table 1: Types of spring constants

Segment spring	normal spring const. (k_{sn})
	shear spring const. (k_{ss})
Ring spring	normal spring const. (k_{rn})
	shear spring const. (k_{rs})
Ground spring	tunnel axis spring const. (k_{en})
	radial spring const. (k_{es})
	tangential spring const. (k_{es})

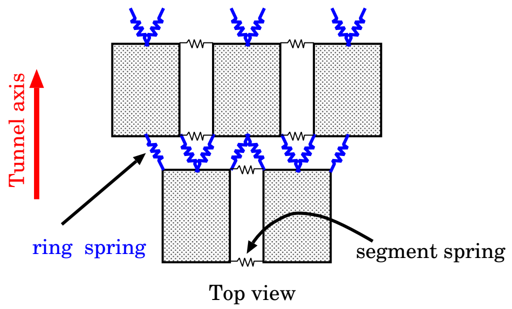


Fig. 1. Spring position settings

4. Full-scale loading test of 3 rings[3)]

This full-scale loading test was carried in order to evaluate the safety of the linings and the adequacy of the design method. In this loading test, three composite segmental rings were applied by eight load jacks from eight directions as shown in Fig. 2. First, the isotropic loading condition was applied to segmental rings (ring 1, 2 and 3 from top) by 10 kN/load jack. Then, for each step segmental rings were applied by the incremental 10% of maximum load of each load jack. The number of loading steps were 10 steps. After each step of loading, the amounts of lining displacement, generated stresses of segment body and joints, joint openings and slips between adjacent rings were measured.

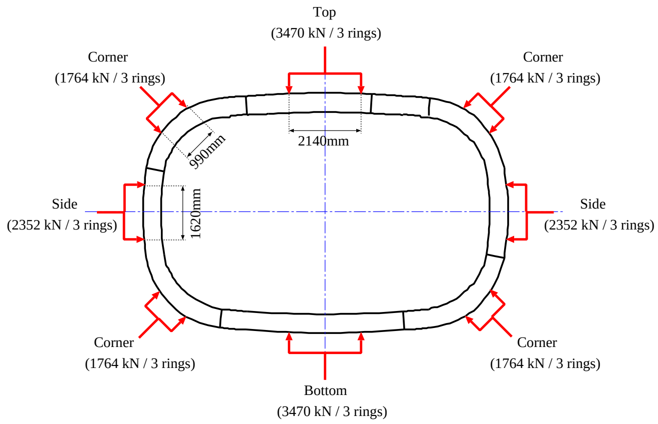


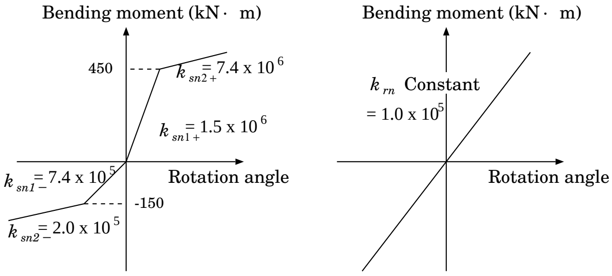
Fig. 2. Loading condition for full-scale loading test

5. Numerical analysis[4)]

The numerical analysis was carried out and the comparison between the numerical results and the observed data from the full-scale loading test was made. The spring constants used in this analysis were obtained from the parameters used in beam-spring model which is the practical tunnel design method for Kyoto Subway Tozai Line Rokujizo-Kita Construction Section Project.

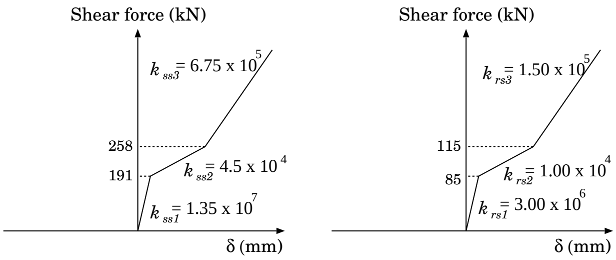
This study was carried out by varying the spring constants and the values at the inflection points of characteristic curves. The characteristic curves of normal spring constants are illustrated in Fig. 3 and those of shear spring constants are illustrated in Fig. 4. The ground reaction spring constants were neglected in this study. All the shear spring constants were varied from 0.05 % to 100 % of values in Fig. 4. Values at inflection points of shear spring curve were set to be half of values in Fig. 4.

Keywords: Rigid Segment Model, Spring, Shield tunnel, Rectangular ring, Full-scale loading test, Segment design
Contact: Dept. of Civil Engineering, Kyoto University, Sakyo, Kyoto 606-8501, Japan Tel., Fax: 075-753-4794



(a) Segment spring (b) Ring spring

Fig. 3. Characteristic curves of normal springs



(a) Segment spring (b) Ring spring

Fig. 4. Characteristic curves of shear springs

6. Numerical results

Firstly, consider the deformation of segmental ring referring to Fig. 5 which shows the deformation of ring 1 when $k_{rs1}/k_{sn1} = 0.1$. It can be found that when $k_{rs1}/k_{sn1} = 0.1$ the deflection of top crown of segmental ring is very close to the observed data. But the deflections of the left and right sides of segmental ring are much smaller than the observed data in all cases. This error may be explained by the reason that the segment in this model is perfectly rigid but the real segment is more flexible. Therefore, the deformation obtained from the analysis should be smaller than the obtained data.

Next, consider the bending moment and axial force generated in segmental ring 1. Fig. 6 and Fig. 7 show the bending moment diagram and axial force diagram of ring 1 when $k_{rs1}/k_{sn1} = 0.1$, respectively. We can find the good agreement between the bending moment diagram of numerical analysis and observed data. On the other hand, the axial force diagram obtained from the numerical analysis is apparently smaller than that of observed data.

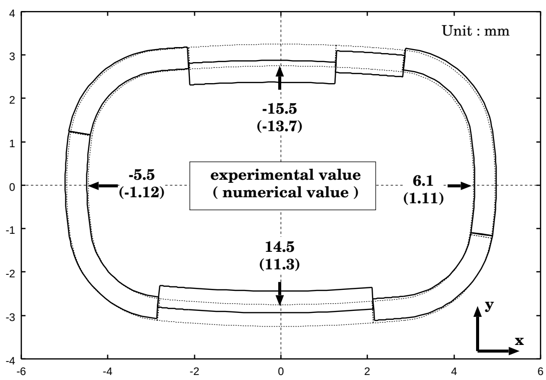


Fig. 5. Deformation of ring 1 ($k_{rs1}/k_{sn1} = 0.1$)

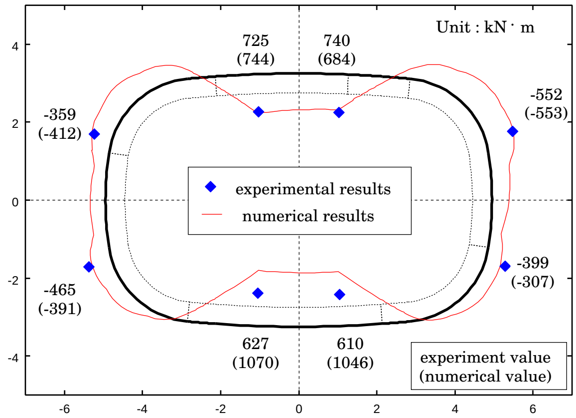


Fig. 6. Bending moment diagram of ring 1 ($k_{rs1}/k_{sn1} = 0.1$)

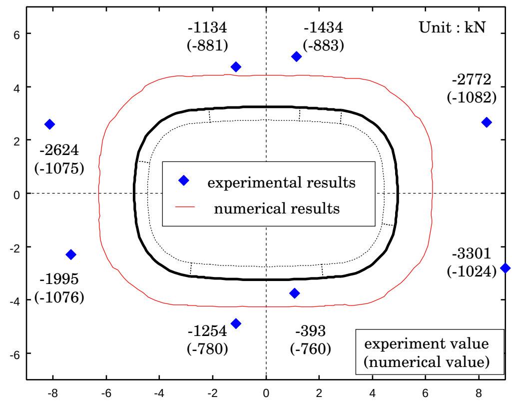


Fig. 7. Axial force diagram of ring 1 ($k_{rs1}/k_{sn1} = 0.1$)

7. Conclusions

The numerical analysis of shield tunnel by using the rigid segment-spring model can be expected to apply in the design of tunnel lining. However, the study on the modification of parameters i.e., spring constants, must be carried out further. Furthermore, the experiments for determining the spring constants directly used for this model should be done in the future. Also, the error due to the real flexibility of the segment should be introduced into the consideration.

References

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