Research on lining reinforcement design for the existing tunnel with void behind lining

Qiwei Lin(Student Member of JSCE), Yujing Jiang(Fellow of JSCE), Satoshi Sugimoto(Member of JSCE)
Graduate School of Engineering, Nagasaki University

1. Research background and purpose

Many of mountain tunnels in Japan were built rapidly during the period of high economic growth. And these tunnels have been functioning for 30 to 50 years. Therefore, it is necessary to design lining reinforcement based on field condition. In recent years, the detailed investigations for reinforcement of tunnel lining have been actively carried out due to the mandatory inspection of tunnels.

In this study, to improve the design of reinforcement, sensitivity analysis is performed by changing the input data of the framework analysis (range of the void, surface reaction force coefficient, etc.) and evaluate the influence of the void by analyzing bending moment and axial force of the lining.

2. Research method

Midas GTS NX software has been generally applied for simulating the behavior of tunnel lining structure. The cases of void behind tunnel lining were considered, and compared after changing the range, position and the number of voids.

About ground conditions and framework analysis model, the ground soil of tunnel is the granite of CL-class, and the deformation modulus is 20,000 kN/m². The buried depth of the tunnel is 3.18m, and the height of void behind lining is set to 0.45m, as consistent with the tunnel lining thickness. The simulation model section is designed as a horseshoe shape and the radius of semi-circle is about 5m.

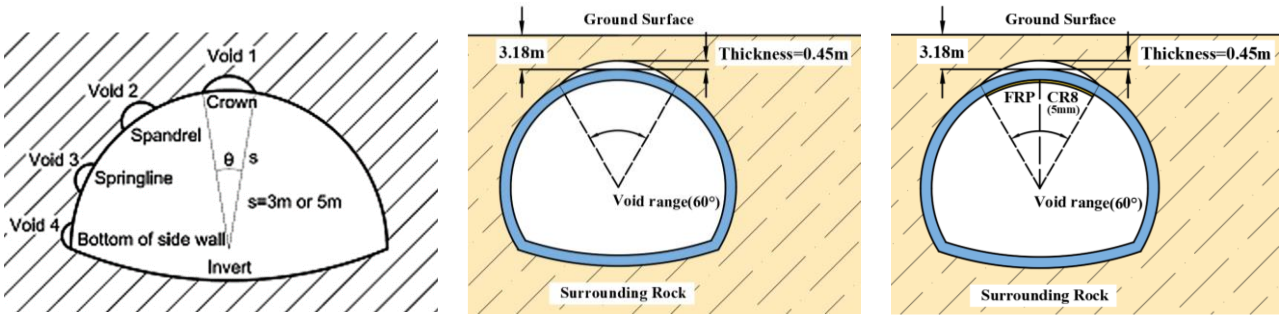

Fig.1 Numerical simulation model of tunnel cross section

3. Safety factors for evaluating stable state of tunnel lining

The basic model based on the actual situation of the void behind lining is presented in Fig 1. In this study, the influence of the typical patterns of void behind the lining on tunnel deformation was investigated in detail. Noting that ① the range of single void behind lining by different angle on the circumference (30°, 40°, 50°, 60°, respectively), and ② the distance between two voids on the circumference, which is also indicated by the angle (40°, 50°, 60°, respectively).

To examine the bending moment (M) and axial force (N) of lining when void occurred, the safety factor (K) is estimated as the following calculation formula based on the compressive strength and tensile strength within the rectangular cross section axis of lining concrete and the eccentric pressure receiving member.

$$K \leq \frac{\varphi \alpha R_a b h}{N} \text{ (Compressive strength)} \qquad K \leq \frac{\varphi 1.75 R_1 b h}{\frac{6e_0}{h} - 1} \text{ (Tensile strength)} \tag{1}$$

In the above formula, the index e_0 indicates the eccentricity distance of the lining cross section. The distribution of the safety factors for lining on the circumference were presented in Figs.2 ~ 7.

The left figure shows the distribution of bending moment and axial force while the right shows the distribution of the safety factor. The limit value of the safety factor is 2.00. When the safety factor of a certain position is less than the limit value, it is judged as unsafe state.

In this study, FRP grid was used as the reinforcing material for the lining area in unsafe state. CR4 represents the thickness of grid of 2mm. The bending moment and axial force after reinforcement are shown in Figs.6 ~ 7.

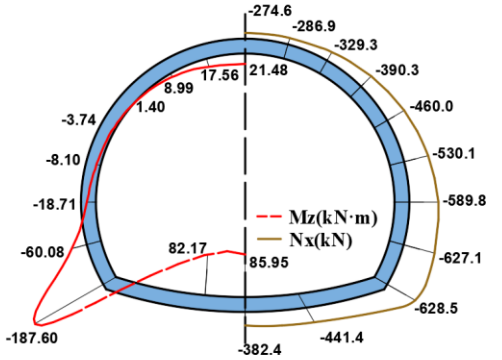

Fig. 2 Bending moment for lining and axial force (without void)

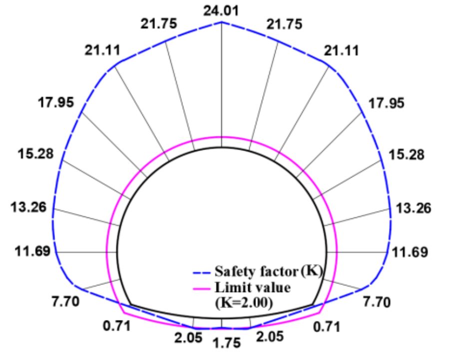

Fig. 3 Safety factor (without void)

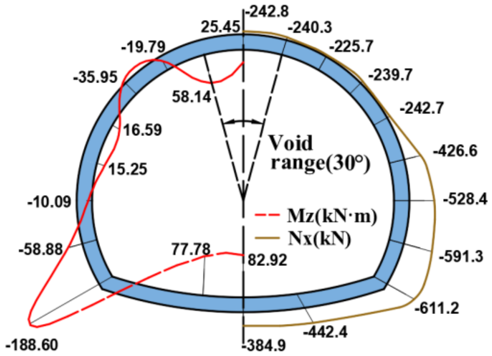

Fig. 4 Bending moment for lining and axial force (void-30°)

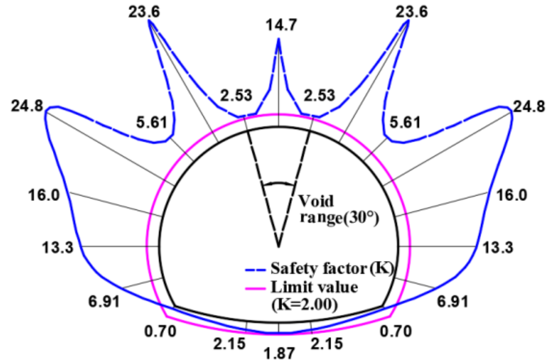

Fig. 5 Safety factor (without void-30°)

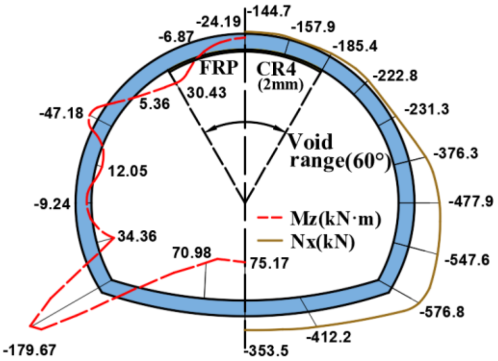

Fig. 6 Bending moment for lining and axial force

(void-60° and FRP-CR4)

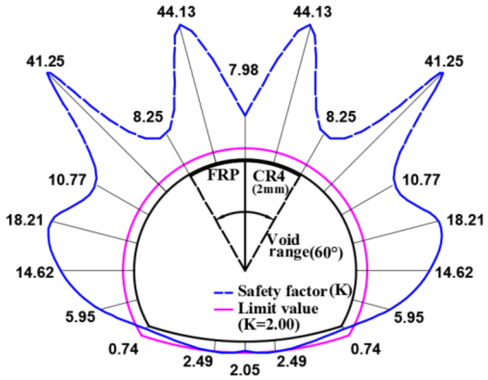

Fig. 7 Safety factor

(void-60° and FRP-CR4)

4. Summary

In this study, the influence of the void behind tunnel lining was quantitatively evaluated. The main results are as follows:

(1) The stress concentration generally occurs at the edge of the void that significantly increases the compressive force. At the limit point of compression and tension, the bending moment is close to 0, and the safety factor increases obviously.

(2) As the void range increases (from 30° to 60°), the stress type at the center of the void range changes from compression to tension. For concrete structures, the tensile strength is much less than the compressive strength, so the safety factor of the structure is significantly reduced. But reinforcement of lining is effective for improving the soundness in the void range.

(3) When multiple defects occurred, the safety factor decreases significantly and the range of reduction increases. And the distance between multiple defect parts obviously affects the soundness of the lining.

REFERENCES

1. Qiwei LIN, Wei HAN, Yujing JIANG and Dairiku KOGA: A Study on the Frame Structure Analysis for Lining Design of Existing Tunnel, *Proceedings of the 32nd Tunnel Conference of the Japan Society of Civil Engineers*, Tokyo, Japan, November (2022.11)

2. Jifei Wang, Hongwei Huang, Xiongyao Xie, Antonio Bobet: Void-induced liner deformation and stress redistribution, *Tunnelling and Underground Space Technology*, Volume 40, pp.263-276 (2013.11)