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Beam-spring analysis combined with back analysis algorithm for tunnel stability under operation

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ABSTRACT

Due to the increase of number and length of tunnel, the analysis on the structural stability is crucial for the performance evaluation of tunnel in-use. Recently, various monitoring techniques enable to detect the behavior of tunnel even after the construction. Although the structural analysis is essential for the performance evaluation, it cannot properly consider the current conditions obtained from monitoring system such as stress acting on the tunnel and measured displacement of tunnel lining. This study uses beam spring method to analyze the structural stability of segment lining. And differential evolution algorithm is combined with beam spring analysis for back analysis. Using the developed back analysis system, the structural stability of operating tunnel can be evaluated based on the multiple measured data in real-time.

1. INTRODUCTION

Tunnels are being designed and constructed for various purposes such as road tunnels, railway tunnels and utility tunnels. As the tunnel collapses, there is a huge loss of life and property damage, so it is very important to evaluate the stability properly when damage occurs. As the monitoring technique develops, the behavior of the tunnel can be grasped after construction, but the state of the tunnel lining can’t be properly taken into consideration only by the measured stress and displacement (An et al., 2016; 2017). In this study, beam spring method was used to analyze the structural stability of tunnel lining. In addition, in order to apply the measured data, back evolution was configured by combining the differential evolution algorithm.

2. DIFFERENTIAL EVOLUTION ALGORITHM(DEA)

The difference evolution algorithm obtains entities whose fitness is improved by crossover, mutation, and selection the initial population (Storn and Price, 1997). The

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vector generation formula for crossover is expressed as Eq. (1). The difference between the two individual vectors is multiplied by a weight to the third vector to generate a crossover vector, and a new vector is obtained by combining with the crossover vector.

$$\boldsymbol{v_{i,G+1}} = \boldsymbol{x_{r1,G}} + \boldsymbol{F} \cdot (\boldsymbol{x_{r2,G}} - \boldsymbol{x_{r3,G}}) \tag{1}$$

In order to increase the diversity of new entities, uniform crossover is mainly used and expressed as Eq. (2). Where $\mathrm{I_{rand}}$ is a random variable between 0 and 1, and CR is the crossover rate.

$$\boldsymbol{v_{ji,G+1}} = \begin{cases} \boldsymbol{v_{ji,G+1}\ if\ rand_j \leq CR\ or\ j = I_{rand}}, \\ \boldsymbol{v_{ji,G}\ if\ rand_j > CR\ or\ j \neq I_{rand}} \end{cases} \tag{2}$$

3. BACK ANALYSIS OF TUNNEL

The beam spring method is one of the numerical analysis methods of the tunnel structure analysis method, and it has an advantage that the complex shape can be analyzed (ITA, 2000). The lining of the tunnel is represented by a beam element, and the interaction with the ground can be expressed by a spring. Also, the hinge or spring between the beam elements may consider for a reduction in stiffness of the segment joint. In this study, a beam spring method was used to simulate the behavior of tunnel lining. Assuming that the tunnel lining was partially degradation, the situation where damage to the tunnel occurred during operation was simulated, and the reduction factor(λ) was used as a back analysis target variable considering the tunnel lining degradation.

3.1 Numerical analysis

The tunnel specification and properties used in numerical analysis are shown in Fig. 1, 2 and Table 1.

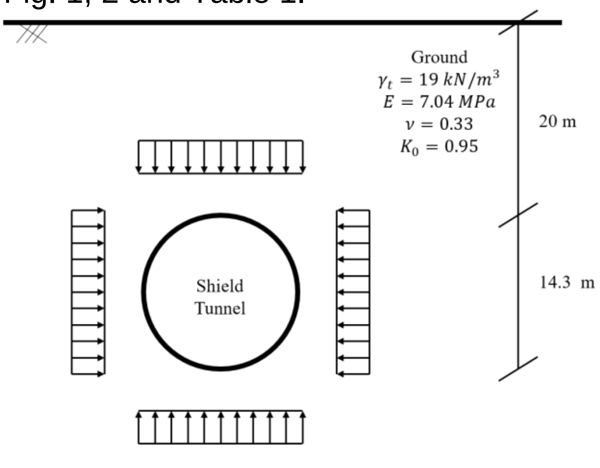

Fig. 1 Numerical model condition
(Kang et al., 2017)

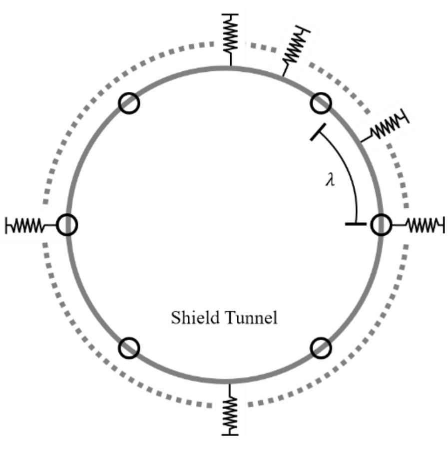

Fig. 2 Variation range of lining degradation

Table 1. Concrete lining and DEA parameter used in the numerical analysis

	Concrete lining	DEA	
γ_t (unit weight)	$26\ \mathrm{kN/m^3}$	F (mutant constant)	0.8 (0~2)
E (elastic modulus)	38.82 GPa	CR (crossover constant)	0.8 (0~1)
ν (poisson's ratio)	0.18	NP (number of population)	10 ~ 40
λ (reduction factor)	0.7 / 0.8 / 0.9 / 1.0	Itermax (max. iteration)	10 ~ 40

3.2 Result of analysis

Numerical analysis was conducted for 3 cases, varying from 1.0 to 0.8 for the lining segment reduction factor(λ), and the results are shown in Fig. 3 and 4 and Table 2. In all cases, the error rate was less than 2%, and it was confirmed that the BS-DEA system could be operated within the overall error range for the back analysis target variable. In Fig. 3 and 4, shear forces and bending moments of beam elements 18 - 24 were not common, and the decrease of stiffness was found to affect the factor of safety.

Table 2. Results of numerical analysis

Cases	Stiffness reduction factor (λ)		Error rate (%)
	Input	Output	
Case_1	1.0	0.985	1.52
Case_2	0.9	0.884	1.76
Case_3	0.8	0.795	0.65

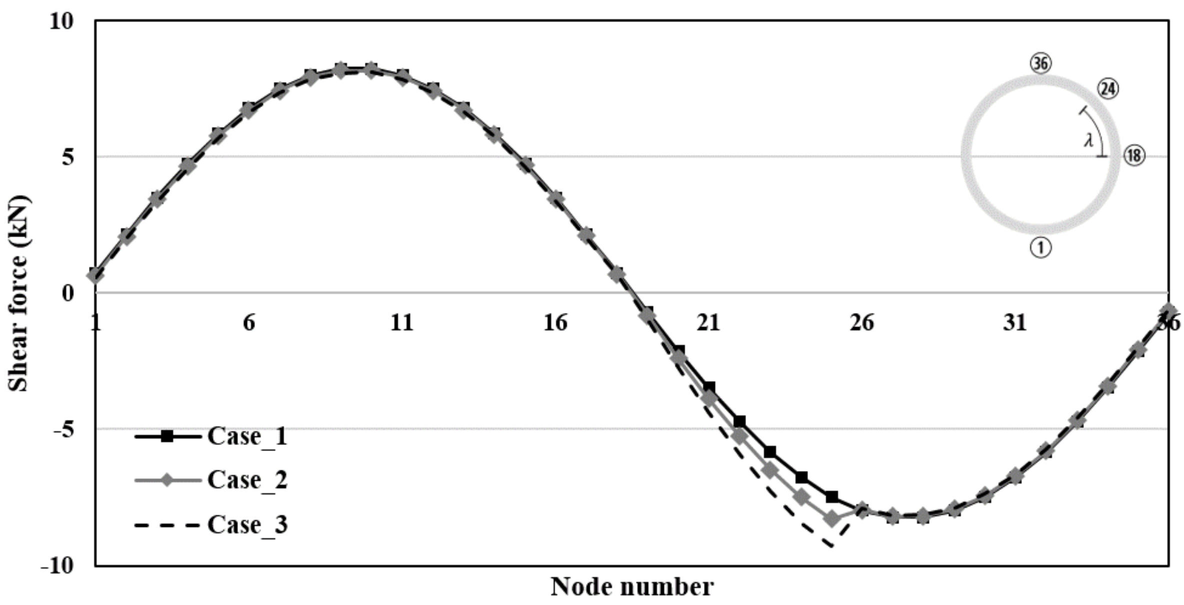

Fig. 3 Shear force diagram

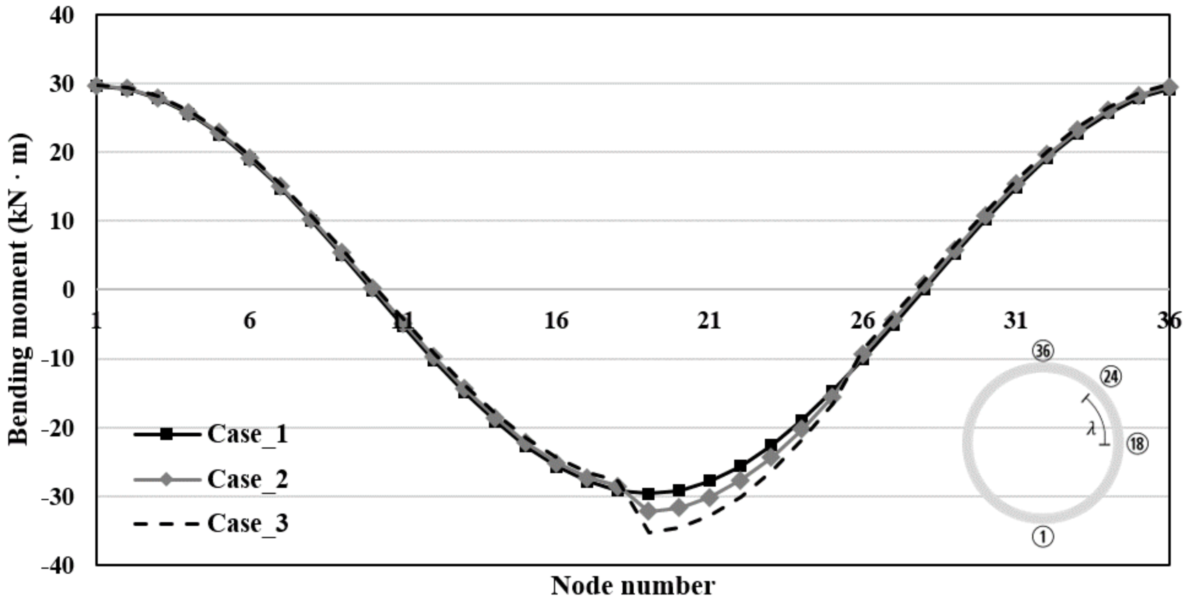

Fig. 4 Bending moment diagram

4. CONCLUSIONS

In this study, numerical analysis is performed assuming that measurement data on displacement is obtained in an operating tunnel. It is confirmed that the error rate is less than 3% when the measured data is input to the developed BS-DEA system and the back analysis is performed, and it is confirmed that the factor of safety is affected when the stiffness of the tunnel lining decreases. In addition, the back analysis time of the developed system is less than 5 minutes per case, so it is considered that real - time stability evaluation is possible.

Acknowledgement

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