Critical Strain Concept-Based Simple Method for Pre-Evaluation of Tunnel Face Safety using RMR

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Abstract

This study was intended to predict the total displacement using RMR evaluation of tunnel face and a simplified stability evaluation technique which was based on a strain concept before starting excavation. To that end, a three-dimensional numerical analysis was carried out and based on result, the formulas for calculating the total displacement without reinforcement, reinforcement effect and total displacement with reinforcement were developed and finally, a simplified stability pre-evaluation technique based on a critical strain concept was proposed.

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1. INTRODUCTION

A tunnel behavior during excavation is quantified through measurement process and measurement result provides important data needed for evaluating the tunnel stability. Sakurai(1982) predicted the strain of the rock around the tunnel using displacement so as to proposed the stability evaluation technique based on critical strain concept for evaluating the stability. A critical strain concept was evaluated to identify the possibility of being used as safety evaluation standard during tunneling process (Sakurai 1997; Hoek 2001) British Tunnelling Society(2004) hinted the possibility of using a critical strain concept as tunnel crown displacement control standard.

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In this study, a simplified evaluation approach which will predict the displacement using only the result of RMR evaluation of the face as well as to approximately evaluate the stability based on a critical strain concept was conducted in an effort to quickly evaluate the stability of the face before measuring.

2. 3-D NUMERICAL ANALYSIS

To predict the total displacement of the rock in tunnel by rock category with and without reinforcement, a three-dimensional numerical analysis was carried out. The conditions of the analysis models by rock category are divided 5 types and it's assumed to be a separate excavation for upper bench and lower bench, respectively. Soil constants used for analysis were determined using a back analysis approach.

3. ESTIMATION OF TOTAL DISPLACEMENT

The relationship between total displacements without reinforcement estimated using a numerical analysis and RMR at 180 faces is described in Figure 1. And the relationship between the two is represented using the following equation.

\[ U_{fn} = 73.14 - 0.57RMR \]  

where, \( U_{fn} \) is the total displacement including preceding displacement.

As shown in Figure 2, the difference between the total displacement with reinforcement and the total displacement without reinforcement is considered to be the reinforcement effect. The total displacement with reinforcement can be controlled within a certain level by appropriate reinforcement selected depending on rock assessment result, and thus the lower the RMR the larger the reinforcement effect. Reinforcement effect is heavily dependent on reinforcement pattern and even a same pattern varies depending on geological features of the rock. Thus a multivariate analysis was conducted by the pattern of reinforcement and the formula to calculate the reinforcement effect with RMR factors as parameters was developed in this study.

The final total displacement with reinforcement occurred during excavation may be calculated by excluding reinforcement effect from the total displacement without reinforcement. In other word, it may
be determined using RMR only from equation (1) and the formula to calculate the reinforcement effect. The coefficient of correlation ($r^2$) between the total displacement with reinforcement calculated using above method and the total displacement with reinforcement estimated based on numerical analysis was 0.87, indicating a relatively high correlation.

4. SIMPLE METHOD FOR PRE-EVALUATION ON TUNNEL FACE SAFETY

4.1. Basic concept of critical strain

British Tunnelling Society (2004) proposed a stability evaluation technique using a critical strain concept through the tunnel lining design guide. The concept was developed based on uniaxial compression test of the rock by Sakurai (1982) and the critical strain concept was defined according to stress-strain relationship (Figure 3). That is, it refers to the relationship between the behavioral characteristics of the rock in early elastic range and uniaxial compressive strength in failure, which is represented in equation (2).

$$\varepsilon_c = \frac{\sigma_c}{E_i}$$  \hspace{1cm} (2)

Where, $\sigma_c$ refers to uniaxial compressive strength of the rock and $E_i$ refers to modulus of elasticity at early stage. A critical strain concept was evaluated by Sakurai (1997) and Hoek (2001) to identify the applicability as stability evaluation indicator at tunnel site (Figure 4).

![Figure 3: Relationship between critical strain and uniaxial compressive strength (Sakurai, 1982).](image)

![Figure 4: Relationship between the measured strain and hazard warning levels (Sakurai, 1997).](image)

4.2. Critical strain concept-based simple method for pre-evaluation of tunnel safety

A critical strain table was used in a bid to conduct the strain-based simple evaluation method using total displacement prediction result obtained through face evaluation. A simple evaluation method is to predict the total displacement using RMR evaluation of the face only, which provides approximate stability before measuring. The process is as follows.

RMR evaluation of the face is conducted first to estimate the total displacement without reinforcement and then compare the total displacement without reinforcement with a critical strain table to evaluate the
preliminary stability. At this stage, total displacement without reinforcement usually exceeds the control limit. And the reinforcement effect is predicted using designed reinforcement pattern and RMR and the reinforcement effect is excluded from the total displacement without reinforcement to estimate the total displacement with reinforcement and the stability is assessed. When the result falls into unstable range, the design needs to be rechecked. A simple stability evaluation method is summarized in Figure 5.

Figure 5: Flow chart of Simple Method for Pre-Evaluation of Tunnel Face Safety.

5. CONCLUSIONS

A critical strain concept-based stability pre-evaluation method is the simple evaluation approach to quickly check the stability using RMR data only. Using this method, stability could be predicted based on simple rock evaluation result and could be carried out by the site engineer together with RMR evaluation of the face. However given this method is to evaluate the displacement using a simple RMR method, various ground and geological conditions are not considered. Thus, upon starting the measurement, it’s necessary to compare the displacement with a critical strain table and check if the value exceeds the control limit on a real-time base to assess the stability.

References