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Prediction of Deformation of NATM Road Tunnels in Hokkaido, Japan

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1. Introduction

New Austrian Tunneling Method (NATM) is usually being used for tunnel construction in Japan. The method allows some deformation to utilize the maximum self-supporting capacity of the rock mass or soil to provide the stability of the underground opening. Monitoring is, therefore, very important in NATM to keep the deformation within a proper range. It is also very useful if the deformation can be predicted in designing, an early construction or construction stage. From this point of view, prediction of initial convergence rate (v_0), days to converging (d_1), and convergence at d_1 (u_1) were investigated based on ACOS (Advanced Comprehensive Operating System or All round Customer Oriented Systems) data which was made by NATM Group, Technical Subcommittee, Tunnel Research Committee, Association for Civil Engineering Technology of Hokkaido and Civil Engineering Research Institute for Cold Region¹⁾.

Fig. 1 is a schematic figure showing a typical relationship between time and convergence with excavation. v_0 (mm/day) is calculated as

$$v_0 = \frac{u_0}{t_1} \quad (1)$$

where u_0 (mm) is increment of convergence from the first measurement to the second measurement. t_1 (day) is the time between the first and second measurement and is 12 or 24 hours.

If convergence which is less than 1 mm/week is measured twice, displacement is considered to be converged. The time from initial monitoring to converging is d_1 (day). The convergence at d_1 is u_1 (mm).

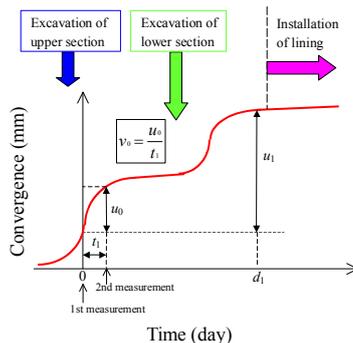


Fig. 1 Excavation and convergence

Prediction by three steps was planned.

1. Predictions of v_0 , d_1 and u_1 in designing stage
2. Predictions of d_1 and u_1 in an early construction stage
3. Predictions of u_1 in construction stage

2. Prediction in designing stage

Relationship of initial convergence rate, days to converging and convergence at d_1 with the competence factor (CF) was investigated (Fig. 2). Initial convergence rate, days to converging and convergence at d_1 become smaller with CF. However, it is difficult to express the relationships by specific equations.

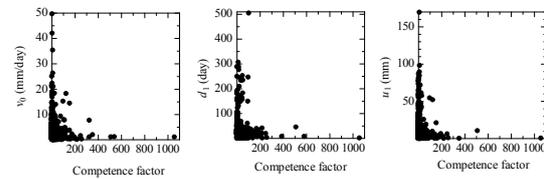


Fig. 2 Relationships of initial convergence rate, days to converging and convergence at d_1 with CF

3. Prediction in an early construction stage

Fig. 3 shows the relationship between the initial convergence rate and the days to converging or the convergence at d_1 . The clear relationship between the initial convergence rate and the convergence at d_1 is observed. On the other hand, the relationship between the initial convergence rate and the days to converging is unclear.

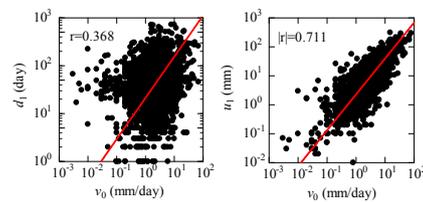


Fig. 3 Relationship between initial convergence rate and days to converging or convergence at d_1

Relationship of the initial convergence rate, the days to converging and the convergence at d_1 with the code for crack spacing (1: distance (d) \geq 1 m, 2: $1\text{ m} > d \geq 20\text{ cm}$, 3: $20\text{ cm} > d \geq 5\text{ cm}$, 4: $5\text{ cm} > d$) was investigated (Fig. 4). The initial convergence rate, the days to converging and the convergence at d_1 increase with for the crack spacing.

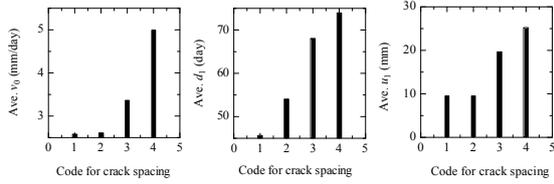


Fig. 4 Relationships between the code for crack spacing and average initial convergence rate, average days to converging or average convergence at d_1

From **Fig. 3**, the following equation is proposed for the prediction of u_1 from v_0 .

$$u_1 = 2.29v_0^{1.24} \quad (2)$$

The following equation can also be obtained based on a multi-variable analysis (**Table 1**).

$$y = a_1x(1) + a_2x(2) + a_3x(3) + a_4x(4) + a_0 \quad (3)$$

This equation, however, is not better than eq. (2) because the correlation coefficient of this equation is less than eq. (2).

Table 1 Regression variable

| Regression variable $x(n)$ | Regression constant a_n |
|---|---------------------------|
| $x(1)$: Initial convergence rate (v_0) | 1.76 |
| $x(2)$: Competence factor | -0.275 |
| $x(3)$: Code for face condition | 1.64 |
| $x(4)$: Code for crack spacing | 3.75 |
| a_0 : Constant | -6.62 |

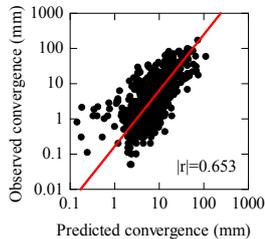


Fig. 5 Predicted convergence and observed convergence by the multi-variable analysis

4. Prediction in construction stage

(1) Approximation by using a hyperbolic function

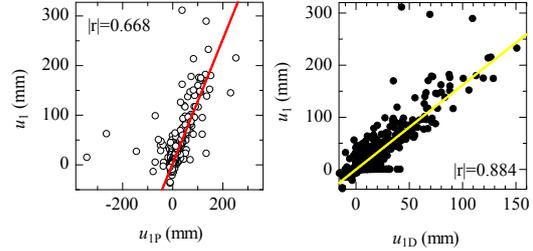
Convergence can be approximated by the following hyperbolic function²⁾.

$$u = \frac{t}{a + bt} \quad (4)$$

where u is convergence at t . t is time from initial monitoring. a and b are constants. The constants a and b

are calculated for each section from v_0 , u_3 (convergence at 3 days) and u_{1D} (convergence at 1D). The following equation was obtained between u_1 (measured) and u_{1P} (predicted).

$$u_1 = 1.25u_{1P} + 3.29 \quad (5)$$



(a) By eqs. (4) and (5) (b) By eq. (6)

Fig 6 Predicted and observed convergence

(2) Prediction by a linear equation

The relationship between u_1 and u_{1D} can also be represented by the following simple equation (**Fig. 6 (b)**).

$$u_{1P} = 1.62u_{1D} \quad (6)$$

4. Conclusions

It was very difficult to predict the displacements in designing stages. The equation to predict the convergence at d_1 from the initial convergence rate in an early construction stage was proposed. The prediction of u_1 from u_{1D} was much easier and more precise than that based on the approximation by the hyperbolic function in the construction stage.

The obtained equations represent the average deformation behavior of NATM Road Tunnels in Hokkaido and can be adopted to predict convergence in the construction stages. They also suggest a new criterion for stability of NATM road tunnels in Hokkaido. For example, if a measured convergence is large but less than very large predicted value, it is considered that the support system is functioning. If a measured convergence is small but larger than very small predicted value, it is considered that there might be some factors which cause instability.

References

- 1) NATM Group, Technical Subcommittee, Tunnel Research Committee, Association for Civil Engineering Technology of Hokkaido (2004 in Japanese): Contract Report on Analysis of NATM Data
- 2) Dohi, M., Takahashi, Y., and Nakajima, K. (2001): *Proc. 18th Symp. Rock Mech*, pp.26-30