REAL-TIME EVALUATIONS OF TUNNEL FACES AND PREDICTIONS OF GEOLOGICAL CONDITIONS AHEAD OF THE TUNNEL FACE BASED ON DRILLING DATA

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Abstract

The authors developed a system for predicting the geological conditions not just of excavated areas but also ahead of the tunnel face by processing drilling data using ordinary Kriging, a geostatistical approach, and by visualizing conditions in real time. Using auto-controlled face-drilling rigs, the authors confirmed the easy and rapid acquisition of drilling data from blast holes and rock bolt holes, along with three-dimensional coordinates. The authors deployed the system in real time to determine if pre-supports such as forepoling and facebolts would be necessary for a strongly sheared slate area at the tunnel faces of the Shin-Kuzakai Tunnel (provisional name).

1 Introduction

Choosing appropriate support systems and pre-supports are the key to ensuring quality, stability, and safety in tunnel construction projects. Typically, the tunnel face is observed during the excavation to evaluate the geological conditions. Although the tunnel face is generally observed once a day, excavations usually occur around four times a day[1)] This means that changes in geological conditions may be overlooked. In addition, as demonstrated by past incidents, the presence of a weak layer behind a tunnel face or a side wall may result in the collapse or significant deformation of a tunnel face or wall. To avoid these risks, tunnel excavation is carried out while investigating the geological conditions ahead of the tunnel face using advanced boring. Logging while drilling is a technology that enables logging of approximately 30 m in several hours using a drill jumbo, which is used in daily tunnel excavation work[2),3)].

The computer jumbo, which was introduced in recent years, has made it possible to automatically and easily determine the drilling energy when drilling blast holes and rock bolt holes. Using this data, some studies have evaluated the geological conditions around tunnels[4),5)]. However, in these studies, the distribution of drilling data is visualized in three dimensions, but the spatial characteristics of the rock mass are not reflected in the evaluation. In one

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study, the authors[6] evaluated the drilling energy of rock bolt holes by a conventional drill jumbo using Kriging to reflect the spatial characteristics of the three-dimensional distribution of the drilling energy around the tunnel. However, this method takes several weeks from data processing to data analysis, and it has not yet been used for making construction decisions based on evaluation results. In this study, we constructed a system that can predict the three-dimensional distribution of the drilling energy around a tunnel by analyzing the drilling energy obtained by the computer jumbo by Kriging. In this paper, we report the results of verification by applying it to the Shin-Kuzakai Tunnel (provisional name) on the Miyako-Morioka Cross Road. As a result, based on the theoretical variogram, it was clarified that highly accurate evaluation can be performed up to 5 m ahead of the tunnel face. In addition, it was confirmed that the data processing, data analysis, and visualization of prediction results can be automatically executed, the analysis results can be obtained in approximately 10 minutes after the data transfer, and the prediction results can be used for construction decisions.

2 Overview of the construction site

We introduced auto-controlled face-drilling rigs to the construction site of the Shin-Kuzakai Tunnel (provisional name) on the Miyako-Morioka Cross Road. This road tunnel and accompanying evacuation tunnel has an excavation cross-sectional area of approximately 110 m^2 for the main tunnel and an overall length of 4,998 m. To expedite the excavation of the main tunnel, as shown in Figure 1, the main tunnel was excavated simultaneously at four tunnel faces by excavating from both ends and using the evacuation tunnel as an access tunnel to the central part of the main tunnel. The face-drilling rigs used for the site include fully automatic, semiautomatic, and manual drilling rigs.

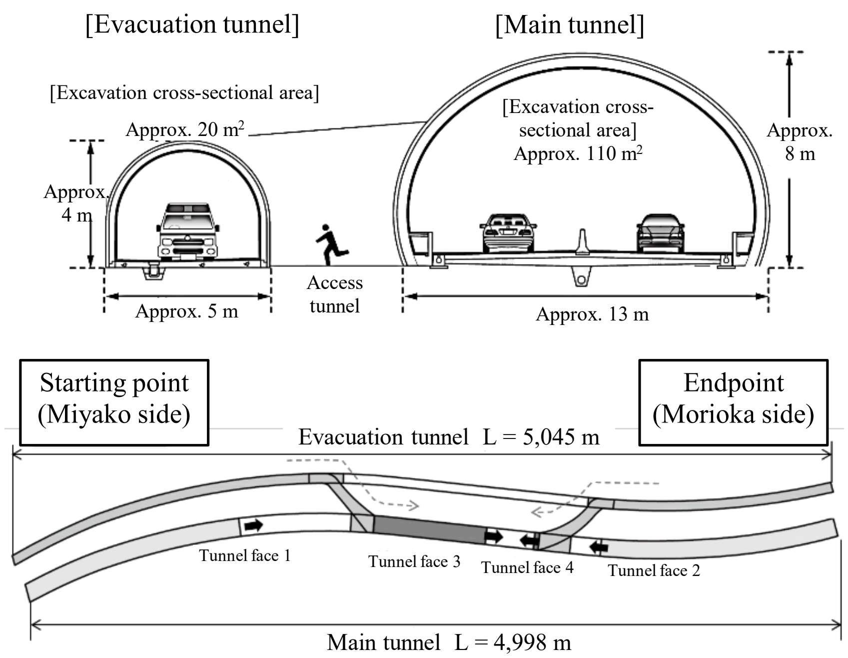


Fig. 1 Overview of specifications for Shin-Kuzakai Tunnel (provisional name).

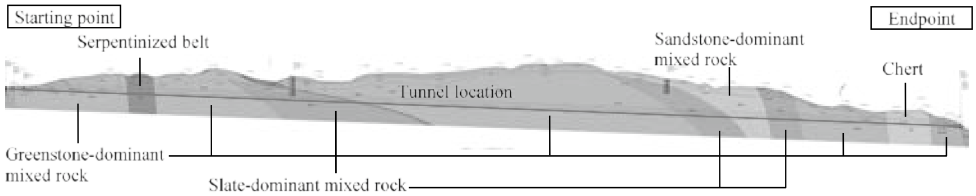


Fig. 2 Longitudinal section of Shin-Kuzakai Tunnel (provisional name) before excavation.

The geology at the tunneling site is a Carboniferous accretionary wedge (Nedamo Terrane), consisting of slate as a matrix and hard green rocks as brecciated blocks (Figure 2). Because the slate is weakened due to shearing by accretion, stress release by excavation results in loss of strength in certain areas. The distribution of the weak zones needs to be predicted because they may cause collapse or deformation of the tunnel.

3 System for predicting geological conditions ahead of the tunnel face and in the surroundings

Figure 3 shows the procedural flow of this system. All drilling data acquired by the auto-controlled face-drilling rig are automatically transmitted to a computer located in a site hut or office. The data is automatically uploaded into three-dimensional integrated visualization software and visualized within five minutes after uploading.

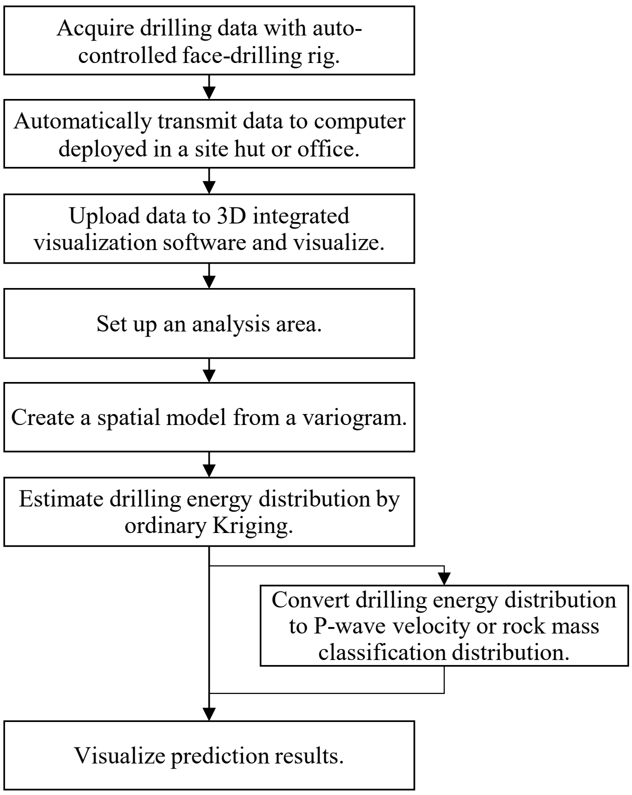


Fig. 3 Procedural flow of the system for predicting geological conditions ahead of the tunnel face and surroundings.

The ahead-of-tunnel-face prediction feature, developed as an add-on to the aforementioned software, is activated automatically and offers the following functions: it sets up an analysis area based on the location of the drilling at the time the drilling data is added; it creates a geostatistical spatial model from a variogram; and it estimates the distribution of the specific energy of drilling (hereafter referred to as “drilling energy”) in the analysis area by ordinary Kriging, then converts the drilling energy distribution to a P-wave velocity or rock mass classification distribution. The entire process is completed automatically within two hours of the data being uploaded, making it possible to feed forward the prediction result to the next cycle.

4 Predicting the distribution of weak slate areas and applying the prediction system to evaluate geological conditions

4.1 Assessing the need for pre-supports

A weak slate area arose in the slate-dominant mixed rock area of tunnel face 2 on the endpoint (Morioka side) (Fig. 1). Therefore, to prevent collapse, the installation of forepiling and facebolts (both length = 12.5 m) was considered as the first shift of pre-support. Based on drilling data for these supports, using the system, we performed real-time predictions. The results made it possible to determine whether pre-supports were required in the next shift.

Figure 4 shows a horizontal cross section of the spring line (SL) and a longitudinal cross section of the center line (CL) when we predicted the drilling energy distribution ahead of the tunnel face and in the surroundings based on drilling data for blast holes and rock bolt holes up to tunnel face 248 + 15.6 where the weak slate appeared and drilling data for forepiling

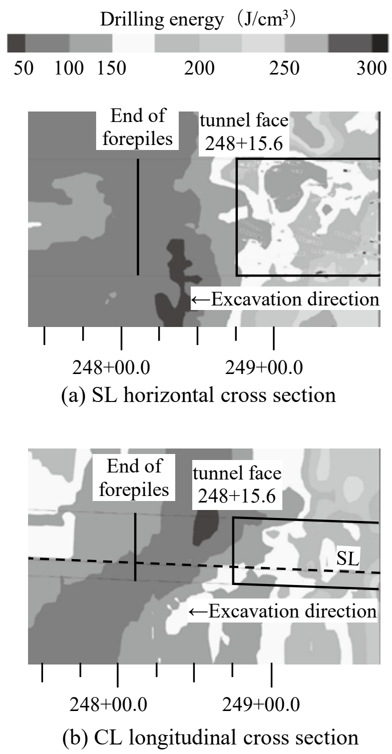
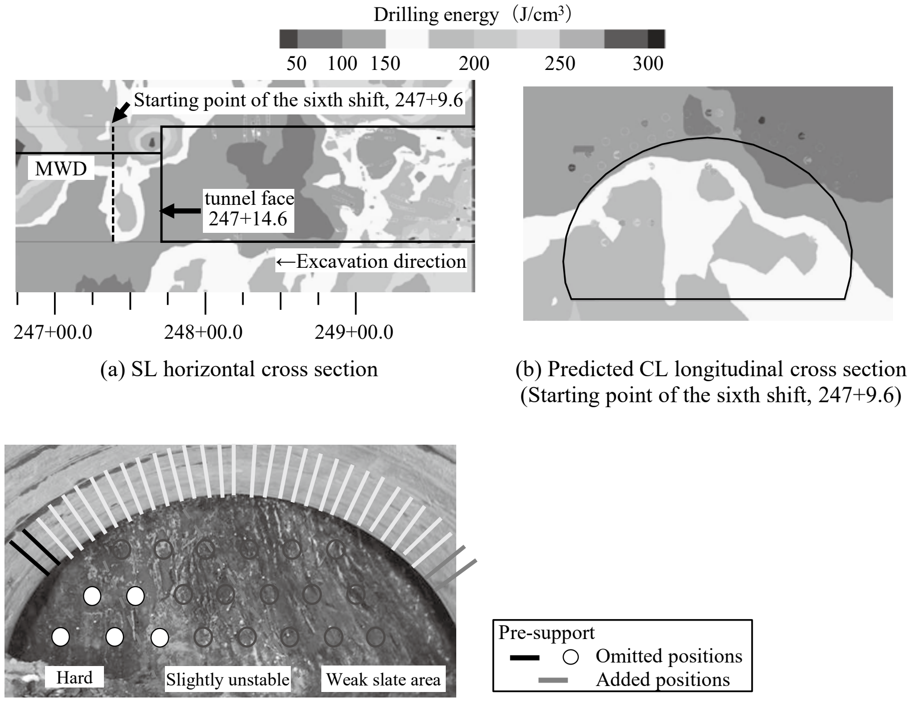


Fig. 4 Predictions based on drilling data from forepiling up to the first shift.



(a) SL horizontal cross section

(b) Predicted CL longitudinal cross section (Starting point of the sixth shift, 247+9.6)

(c) Actual tunnel face at 247+9.6

Fig. 5 Predictions based on drilling data from pre-supports up to the fifth shift and MWD data, and the actual tunnel face.

in the first shift was performed from the same tunnel face. Based on the prediction that a wide area associated with very low drilling energy would occur in the middle of the first shift, we made the decision to perform the second shift with full overlap (overlap of 6 m).

Figure 5 shows the prediction results of the distribution of drilling energies ahead of the tunnel face and in the surroundings. The prediction is based on drilling data for rock bolt holes up to tunnel face 247+14.6, drilling data for forepiling and facebolting in the fifth shift from the same tunnel face, and measurement-while-drilling (MWD) data from the same tunnel face. Figure 5(a) shows a horizontal cross section of SL; Fig. 5(b) shows a cross section of the tunnel face at the starting point of the sixth shift; and Fig. 5(c) shows the actual tunnel face at 247+9.6. An area with very small drilling energy still exists on the right, which corresponds to a weak slate area typical of slickenside, cleavage, and fold. The geological conditions near the wall on the left are predicted to be good. The corresponding area is so hard as to require relief blasting. The result was useful in reviewing the positions of forepiling and facebolting in the sixth shift. The predictions above were output in the morning after the two-day installation of pre-supports was completed. They were presented for discussions with the client in the afternoon, leaving ample time for decisions concerning pre-supports for the next shift. Real-time predictions of geological conditions using this system proved useful in assessing the need for pre-supports before their installation.

4.2 Consistency with support system

Figure 6 shows the distribution of drilling energies predicted based on data for pre-supports up to the eighth shift (Fig. 6(a)), the P-wave velocity distribution converted from

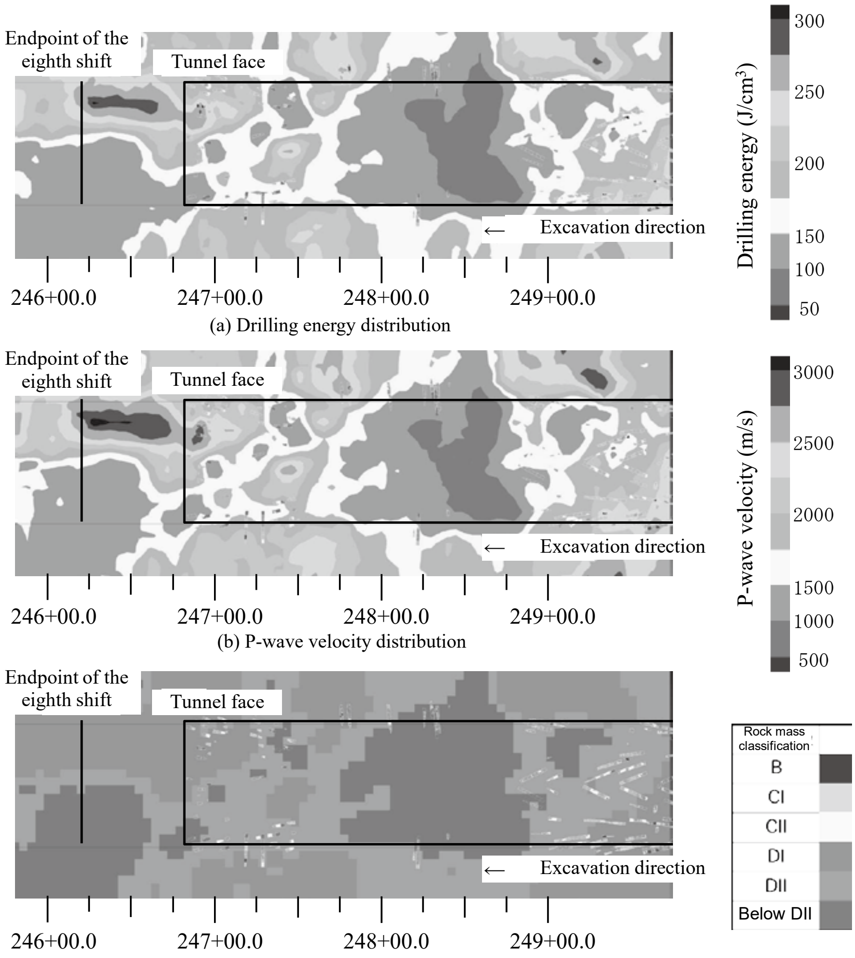


Fig. 6 Predictions based on drilling data for auxiliary supports up to the eighth shift (SL horizontal cross section).

drilling energy (Fig. 6(b)), and the rock mass classification distribution (Fig. 6(c)). The P-wave velocity distribution is obtained using a correlation equation derived from the database accumulated by a method shown in Shirasagi et al. (2016)[7]. The rock mass classification distribution is converted in accordance with the rock mass classification based mainly on P-wave velocity for road tunnels (Japan Society of Civil Engineers, 2016[1]). This distribution shows that most of the area is at DII or lower levels (Fig. 6(c)).

As a result of excavating the place judged as DII by this system, fragile bedrock was confirmed by observation of the tunnel face, and DII was applied. In addition, it was confirmed from the results of tunnel convergence that the application of DII is appropriate. From the above, the applicability of this prediction method was demonstrated.

5 Conclusions

We developed a system for predicting geological conditions not just of excavated areas but also ahead of the tunnel face by processing drilling data using ordinary Kriging, a geostatistical approach, and by visualizing conditions in real time. Using auto-controlled face-drilling rigs, we confirmed the easy and rapid acquisition of drilling data from blast holes and rock bolt holes, along with three-dimensional coordinates.

We deployed the system in real time to decide whether pre-supports would be necessary for a weak slate area on tunnel face 2 on the endpoint side of the Shin-Kuzakai Tunnel (provisional name). The prediction provided information that was essential for decisions on construction methods. It also enabled safe streamlining of the process of deploying pre-supports.

Furthermore, it is possible to evaluate the rock mass classification distribution from the database of drilling energy and P-wave velocity. As a result of excavating the place evaluated as DII distribution by this system, it was evaluated as DII by observation of the tunnel face, and it was confirmed that DII is appropriate from the results of tunnel convergence. From the above, the validity and effectiveness of this system were demonstrated.

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