Development of an Automated Angle Control System to Improve Safety and Productivity

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Abstract –

Currently, the high demands and needs to improve productivity and labor-saving in construction industries leads to many automation and mechanization. This report aims to address the shortage of skilled worker in the future as well as improvement of safety, productivity and quality. Comprehensive collection and utilization of information were carried out and with target to eliminate the over reliance of experience worker in mountain tunneling, "Automated Angle Control System" technology was developed to reduce the overbreak of tunnel during excavation. The concept of this method is to ensure that the productivity of drilling for blasting operation will not be influenced by the worker skills. This system was tested in Shin-Tomei Expressway Takatoriyama west tunnel construction project and results confirmed that the system successfully minimized the overbreak of tunnel during excavation. The authors hope that this report will contribute to the improvement of safety and productivity.

Keywords –

automated angle control system; overbreak; drilling energy; safety; productivity

1 Introduction

Over 40 years have elapsed since the introduction of the New Austrian Tunneling Method in Japan; notable advancements have been achieved with respect to the construction methods. However, reliance of experience and instinct of skilled workers still remain because of the heterogeneity and uncertainty of the ground conditions (bedrock) which is the primary material of the tunnel, whereas bridges and framework structures use concrete and other materials of consistent quality and standards.

The recent use of machines and automation to boost productivity, including reduced labor and improved construction methods, is a demand of the times and merits active involvement. In addition, the nature of public construction projects dictates that projects be implemented with greater transparency and objectivity.

Against this background, this paper strives to collect and utilize as much objective information as possible with the aim of achieving construction that does not rely on experience or instinct, resolving the future shortage of skilled laborers, and improving safety, productivity, and quality. To meet these objectives, the authors developed the automated angle control system as a technology for reducing overbreak in mountain tunnels.

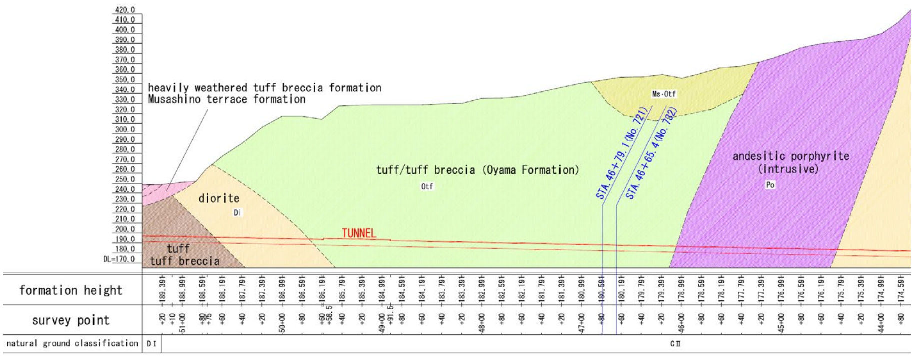


Figure 1. The geological profile and demonstration test area (outbound lane).

The concept of this overbreak reduction technology aims at improved productivity unaffected by skilled labor in explosive drilling and achieves the designed cross-section while allowing accurate formation with minimal overbreak. This reduces the occurrence of mucks as well as shortens time required for mucking and shotcrete. Moreover, it also has the benefit of preventing ground from loosening by smoothing the excavation surface. Additionally, this technology can be used effectively to serve as a safety indicator for preventing accidental flaking of the face as it is possible to understand its ground morphology by using the drilling energy obtained as a byproduct of the drilling work required for explosive drilling.

This paper will report on the results of the demonstration tests conducted in the Mt. Takatoriyama west tunnel construction project.

2 Construction Site Details and Geology of the Demonstration Test Area

Takatoriyama Tunnel is a twin-bore tunnel comprising two highway lanes, which connect the cities of Hadano and Isehara, and has a total length of 3.9 km. Its internal cross-sectional area is 80 m2, and the tunnel extensions on the western side measure 1,573 and 1,609 m for the inbound and outbound lanes, respectively, with downslopes of 2% being observed in both the lanes. The geological profile and demonstration test area are presented in Figure 1. The system trials were initiated in tuff and tuff breccia (Oyama Formation) that are suitable for blasting and proceeded while trying to adjust the system functions. Further, 14-m zones of STA.46+79.1–STA.46+65.4 is designated as demonstration test areas and validated the effectiveness of the system. The demonstration test area is primarily characterized by distributed weathered tuff, with a tunnel face evaluation grade point of 41–44 belonging to CII of the ground classification.

3 Automated Angle Control System

This system is characterized by its ability to reduce overbreak without skilled labor and to prevent face accidents by utilizing drilling energy. Figure 2 gives an overview of the entire automated angle control system.

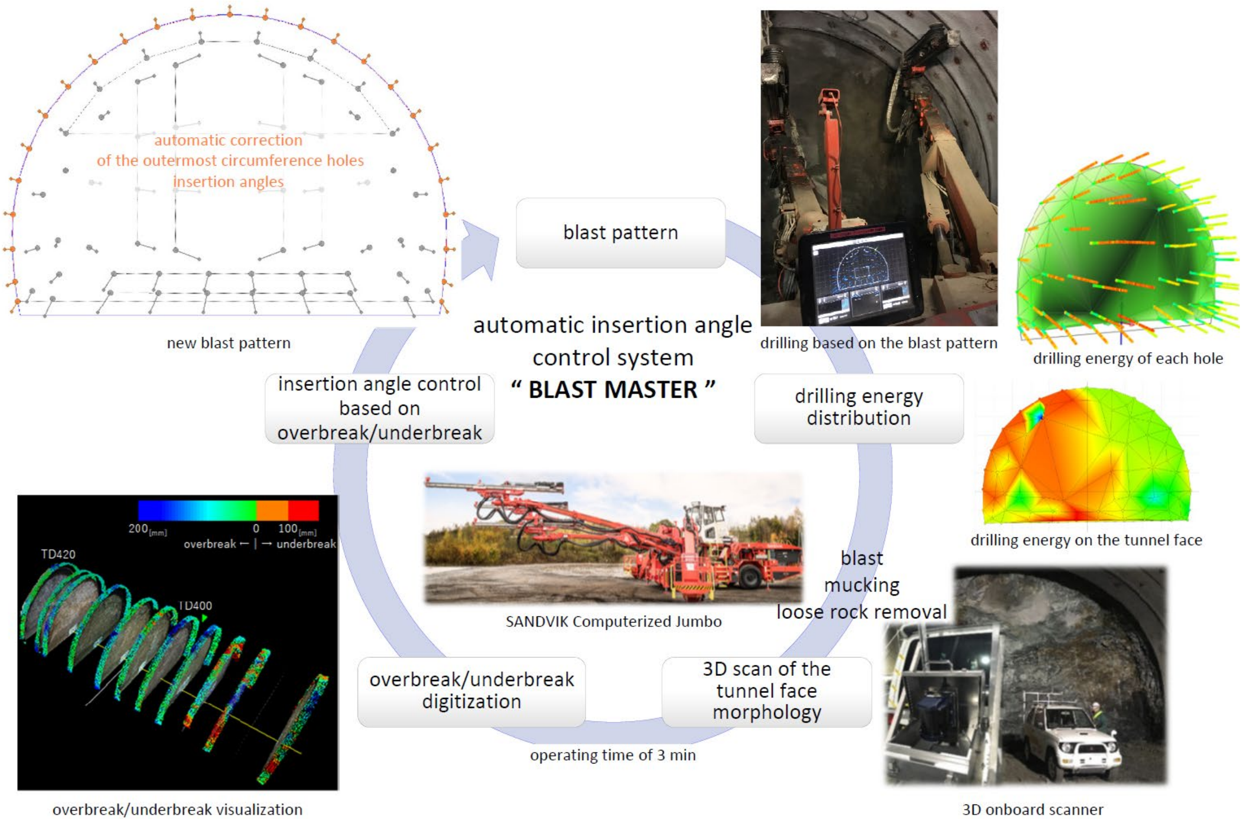


Figure 2. Overview of the automated angle control system.

3.1 Overbreak reduction technology without the need for skilled labor

The authors believe that there are limits for the reduction of overbreak even if a computerized drill jumbo is used to improve the drilling accuracy based on the predefined blast patterns because of the influence of the ground heterogeneity and bedrock fissures. The results supporting this assumption have been obtained from a previous report (1) (2).

Conventionally, the skills of experienced workers are relied on to reduce the overbreak in heterogeneous ground. Our system (Figure 2) solves this issue. The overbreak reduction mechanisms (steps) can be given as follows:

Step I: A blast pattern is created and displayed it on the computerized drill jumbo operating screen (the initial blast pattern is set based on the prior experience and ground strength).

Step II: The jumbo operator accurately performs face drilling based on the generated blast patterns (at this time, the drilling energy is automatically calculated and recorded).

Step III: After charging, blasting, and mucking, scaling will be carried out to ensure the safety of the tunnel face area is confirmed. Subsequently, a three-dimensional (3D) onboard scanner is set in front of the tunnel face, and the face morphology is scanned immediately after the excavation (with a duration of approximately 3 min).

Step IV: The scan result is digitized and examined on the spot to confirm the overbreak/underbreak amounts (underbreaks are eliminated on the spot).

Step V: The corrected drilling angle value is automatically calculated from the predefined correction value derived from the relationship between overbreak amount and drilling angle (the corrected value does not rely on the ground morphology).

Step VI: The corrected value is utilized in the blast patterns of the next cycle, automatically generating the subsequent blast pattern (go to Step II).

3.2 Technology for preventing face accidents by utilizing drilling energy

As indicated in Step II above, face drilling based on the blast patterns also records the drilling energy distribution in the depth direction of the drilling positions as shown in Figure 3. Figure 4 shows the face as seen from the ground.

The drilling energy distribution map shown in Figure 4 is generated by calculating the mean of the drilling energy data obtained 0.5m below the face surface or deeper and projecting the result of each drilled hole onto the face surface. The parts that are relatively shallow from the face surface (less than 0.5 m

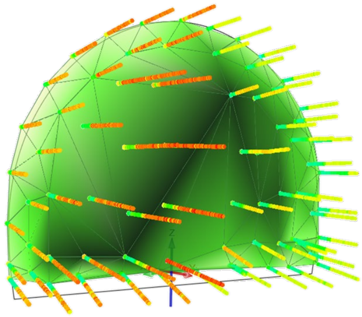


Figure 3. Face drilling in action

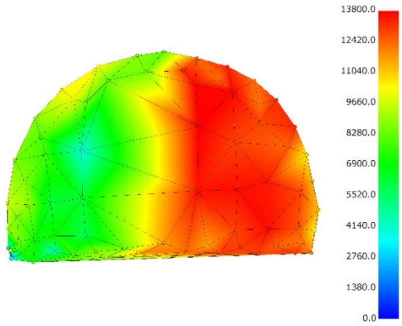
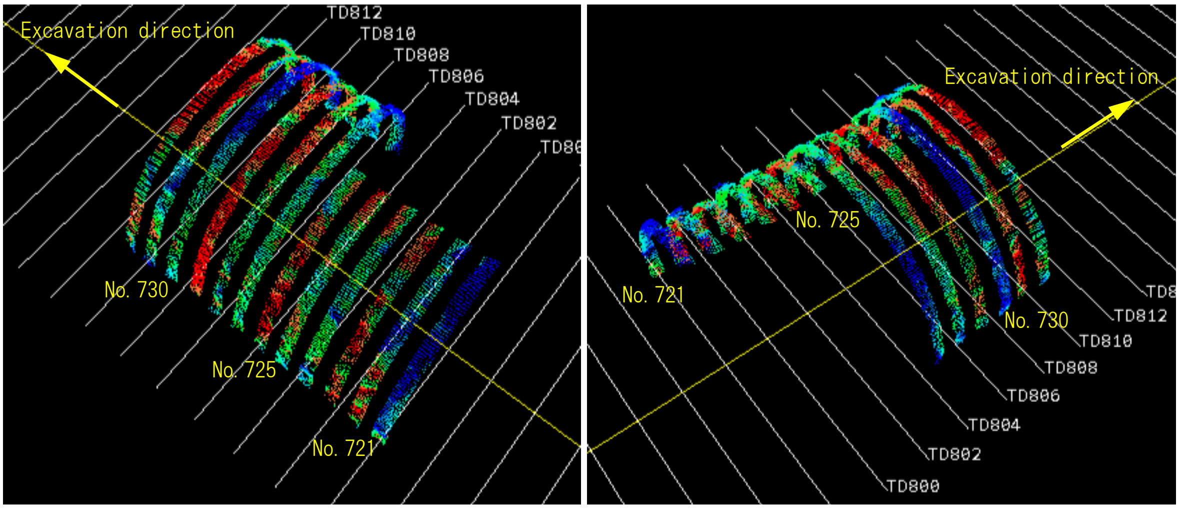


Figure 4. Distribution of drilling energy at completion of drilling

Figure 5. Map streamed to computer jumbo screen

Figure 6. Face monitoring personnel monitors the face



[Left wall] [Right wall]

Figure 7. Measurement results of the 3D scanner used in the demonstration test area

from the surface) are excluded from the evaluation data set because previous blasts and face sprayed concrete can obscure the true ground morphology. Figure 4 is automatically generated at the completion of face drilling.

A face drilling energy distribution map generated such as the one shown in Figure 5 gives an objective indication of the ground morphology distributed along the face, which is referred to as a face safety index in this system, and is used to prevent face accidents.

When the drilling work has been completed, a drilling energy distribution map is generated, after which the face safety index is immediately and automatically streamed to mobile devices such as smartphones and tablets of all tunnel construction personnel, including face monitoring personnel, jumbo operators, and JV personnel. This allows all personnel to continue working with the latest face information. Figure 6 shows the face monitoring personnel observing the face while checking the face safety index.

4 Automatic Drilling Angle Control System Demonstration Test Results

The results from the 3D scanning employed in the demonstration test area are presented in Figure 7. The red and blue colors represent the underbreaks and overbreak, respectively, enabling us to understand the overbreak and underbreak locations. The maximum and mean overbreak based on the obtained scanned data organized in a time series are presented in Figure 8. The following can be stated based on the results obtained from Figures 7 and 8.

No. 721 can be attributed to explosive drilling from the initial blast pattern (set by considering the past experience and ground strength), with all the drilling angles in the outermost circumference drilled at the same angle. The maximum and mean overbreaks were 67.0 and 30.2 cm, respectively, with an increase in the crown area.

Subsequently, the drilling angle of the outermost circumference was individually corrected using the results obtained from the overbreak/underbreaks in No. 721–724. Thus, it can be confirmed that No. 725 showed the lowest number of underbreaks and the overbreak considerably decreased. The maximum and mean overbreaks were 21.0 and 6.6 cm, respectively, with decreases of approximately 69% and 78%, respectively, when compared with the results obtained from the initial blast pattern.

Based on the drilling performance of the entire demonstration test section, it can be assumed that by operating the system several times, it is possible to reduce the effect of excessive overbreak and smooth the excavation surface.

Figure 9 shows the statistical treatment of the relation between the corrected drilling angle of the outermost circumference among all the drilling results in the demonstration test area and the overbreak volume generated from that drilling angle. Despite the lack of sufficient drilling results for obtaining a definitive evaluation, an overbreak value of zero is predicted at a drilling angle of 2°–4°. Therefore, planning with a blast pattern involving drilling angles of 2°–4° is a logical choice for future drilling in a geological terrain similar to that of the Takatoriyama Tunnel (i.e., tuff breccia).

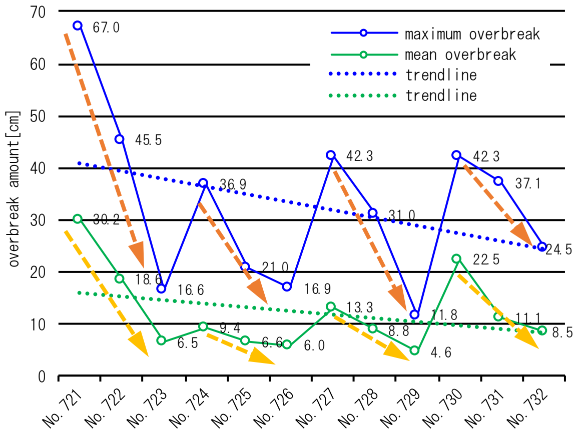


Figure 8. Overbreak reduction effects (tuff/tuff breccia)

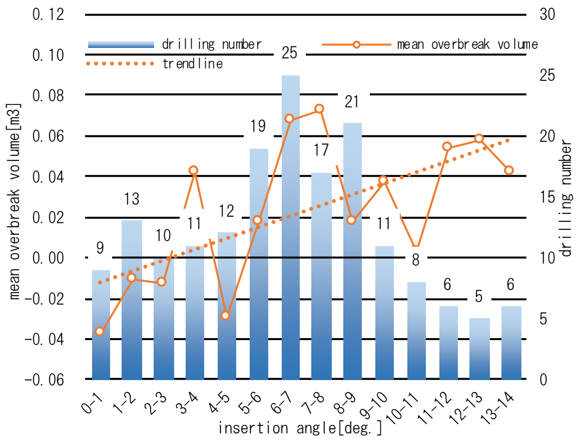


Figure 9. Relation between the drilling angle and overbreak amount (tuff/tuff breccia)

5 Summary

The implementation of the automated drilling angle control system in multiple drilling cycles confirmed a reduction in the maximum and mean overbreak by approximately 69% and 78%, respectively. These values are observed to vary based on the ground conditions (e.g., ground heterogeneity and influence of rock fractures).

Although the effectiveness of overbreak reduction differ based on the ground conditions, this test demonstrate that the system can effectively decrease the overbreak amount without relying on skilled labor forces.

Based on these results, the authors expect to find the most suitable drilling angle and angle correction logic by applying this system to the various ground conditions.

Face drilling energy is used to objectively show the ground conditions distribution in the face, which is regarded as a “Face Safety Index” in this system and used to prevent tunnel face accidents.

While the authors do not consider this index to be an absolute assurance of safety, it has been recognized as a means for offering peace of mind by providing tunnel work personnel, such as face monitoring personnel and workers at the tunnel face, with the most recent ground conditions information that cannot be obtained by visual observation alone, as soon as the drilling work is completed.

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