Geotechnical Engineering Journal of SEAGS & AGSSEA

https://ph01.tci-thaijo.org/index.php/seags_agssea_journal

Overbreak Reduction by Optimized Drilling and Blasting Parameters: Lessons from the High-Speed Railway Project in Thailand

Kuo Chieh Chao[1], Jihou Zhong[2], Zhongju Tang[2], Rattanon Doungdeeying[1], Noppadol Phien-wej[1], and Krit Saowiang[1]

[1]Department of Civil and Infrastructure Engineering, Asian Institute of Technology, Pathumthani, Thailand

[2]China State Construction Engineering (Thailand) Company Ltd, Bangkok, Thailand

E-mail: geoffchao@ait.ac.th

ABSTRACT: This study investigates practical measures to reduce overbreak in drill-and-blast tunnel excavation using the New Austrian Tunneling Method (NATM). The project data from the Muak Lek tunnel section of the High-Speed Railway Project in Thailand was collected and analyzed in the study. Initial field observations revealed that Class IV rock conditions in the study area exhibited an average overbreak of approximately 30%, which significantly exceeded the allowable limits. A nearby double-track railway tunnel with similar rock conditions recorded lower overbreak values (11.7 – 14.0% across rock classes II – IV). Based on these findings and the authors' experience, an optimized blasting approach was developed involving reduced drill hole length, lowered powder factor, precise hole alignment, and smooth blasting with small emulsion charges and detonating cord. A field test was conducted to assess the effectiveness of the proposed approach in a selected Class IV rock section. In nearby sections at the test site, the percent overbreak values were 51.6% and 41.1%, while the improved section achieved a reduced overbreak of 9.3% after applying the proposed approach. The results confirm that adjusting drilling and blasting parameters to site and construction conditions can significantly improve excavation control, offering practical measures for similar NATM tunnel projects.

KEYWORDS: Overbreak, NATM, High-Speed Railway, Drill-and-Blast, and Smooth Blasting.

1. INTRODUCTION

Tunnels have been constructed since ancient times, originally for shelter, burial, defense, and mineral extraction (Tatiya, 2005; Chapman et al., 2017; Jayasiri et al., 2022). As civilizations evolved, tunnels were excavated to transport clean water and wastewater. Early construction techniques were primitive and relied heavily on manual labor. From the 17th century onward, tunnel excavation methods began to advance with the invention of mechanical equipment (Tatiya, 2005; Yamazaki et al., 2024).

Tunnel construction plays a significant role in infrastructure projects in Thailand, such as the track-doubling project and high-speed railway project. These projects are crucial for enhancing the country's transportation network, reducing logistics costs, and providing faster travel. The high-speed railway project between Bangkok and Nakhon Ratchasima is a collaboration between the Thai and Chinese governments. This route includes four tunnel sections, where conventional tunneling using drill-and-blast techniques is applied (Olofsson, 2003; Ramulu, 2010). Singh and Xavier (2005) stated that a significant concern in drill-and-blast tunneling is overbreak, which is defined as the zone excavated beyond the design tunnel boundary. Overbreak increases construction costs, delays project timelines, and requires additional support measures for safety (Mandal and Singh, 2009; Fodera et al., 2020; and Ekeberg et al., 2021). Therefore, reducing overbreak is a crucial objective for tunnel design and execution.

The objectives of this study are: (1) to assess the geological conditions, drilling patterns, and blasting design used in this project; (2) to evaluate the performance of the tunnel excavation with respect to overbreak; and (3) to propose methods for reducing overbreak and improving construction outcomes. The lessons learned from this project are highly valuable for future tunnel construction.

2. GEOLOGICAL AND GEOTECHNICAL CONDITIONS OF THE MUAK LEK TUNNEL

The Muak Lek tunnel is situated in a low mountainous area near Pha Sadet railway station in Saraburi Province, Thailand. The topography is characterized by karst and gully processes, with an elevation difference of about 151 meters. The entrance and exit of the tunnel lie on slopes ranging from 30° to 50°, and the surface is covered with well-developed vegetation (SRT, 2021a). Figure 1 shows the location of the Muak Lek tunnel exit.

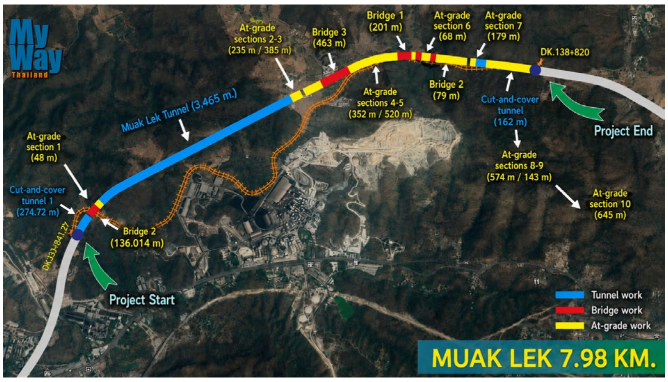


Figure 1 Location of the Muak Lek tunnel exit way

Geologically, the Muak Lek area features relatively simple structures, with minor folding and faulting (SRT, 2021a). The region lacks evidence of major fractures or tectonic activity, though some local secondary folds are present. The lithology along the tunnel alignment, from the surface downward, includes gravel, clay, and silty clay from the Quaternary-Holocene, followed by limestone, marl, and shale of the Upper-Lower Permian. Fine breccia soil, clay, and silty clay are scattered across the shallow sections near the tunnel entrances and exits, while deeper sections contain weathered and weak limestone, marl, and shale (SRT, 2021a). Figure 2 presents the longitudinal geological profile of the Muak Lek tunnel with the grading of surrounding rocks classified from Class III to Class V. As shown in Figure 2, the Muak Lek tunnel extends from Sta. 131+300 to Sta. 134+765 with a total length of 3,465 meters (SRT, 2018a). The tunnel cross-section measures 11.58 meters in width and 8.15 meters in height.

https://doi.org/10.14456/seagj.2026.11 Published on 24 June 2026

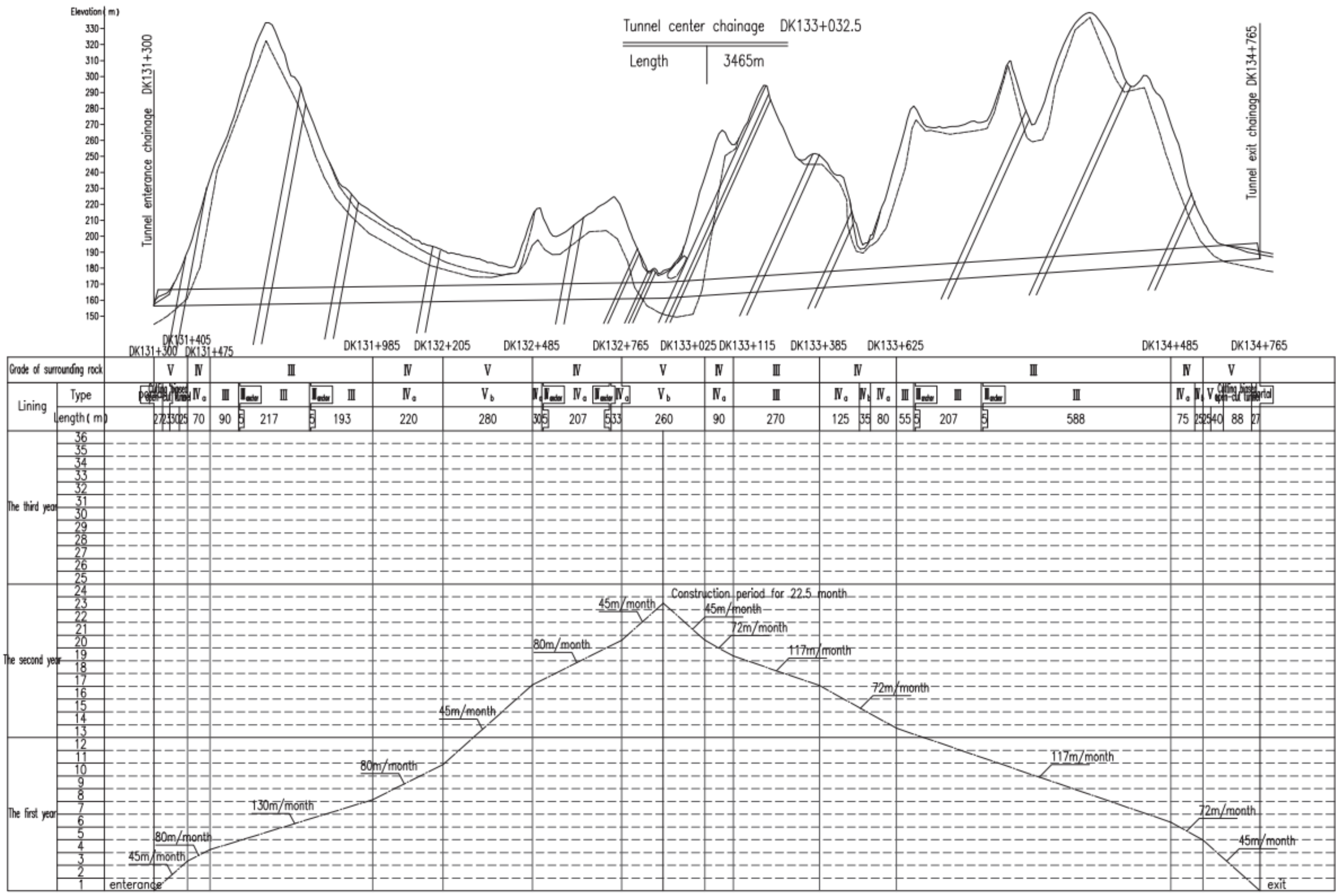


Figure 2 Longitudinal geological profile of the Muak Lek tunnel

3. DESIGN AND CONSTRUCTION METHODS OF THE MUAK LEK TUNNEL

The Muak Lek tunnel, part of Contract 3-2 of the high-speed railway project, was designed by the China Railway Design Corporation (CRDC). The design followed the current engineering standards, including the Code for the Design of Railway Tunnels (TB10003-2016) and the High-Speed Railway Design Code (TB10621-2014) (Johansen, 2010). The tunneling excavation of the project was carried out using the New Austrian Tunneling Method (NATM) (Chapman et al., 2017; Olofsson, 2003).

Figure 3 shows the typical excavation cycle used for the project (Spathis and Gupta, 2013). As shown in Figure 3, the process began with a survey, where the survey team was responsible for investigating and aligning the shape of the tunnel face using stable benchmarks (Eldert, 2017; Chao et al., 2006). This was followed by drilling work, using the TY-28 pusher rig to drill approximately 3.8-m-long blast holes in the rock using a V-cut pattern (Konya and Walter, 1991). This drill hole length was treated in field practice as a nominal 4.0-m round length. Next was charging and blasting, where emulsion explosives and MS detonators were used without stemming to shape the tunnel contour (Singh and Xavier, 2005; Singh and Verma, 2010). After blasting, hauling and mucking were carried out using side loaders and dump trucks to remove blasted material. Finally, support work was performed to stabilize the tunnel using rock bolts, steel ribs, shotcrete, wet-mix concrete, and small ducts, particularly given that the rock condition was classified as Grade 3 to 4 (Lunardi, 2008).

Figure 4 illustrates the tunnel excavation methods used in the project (Ramulu, 2010). As shown in Figure 4, the excavation methods were determined based on the rock classification (Classes III to V) along the tunnel route. Each method was designed to minimize ground disturbance and to provide timely support during excavation (Tatiya, 2005).

- For Class III (fair rock), a two-step excavation consisting of top heading and benching was used (refer to Figure 5).
- For Class IV (poor rock), a three-step method including top heading, middle bench, and lower bench was applied (refer to Figure 6).
- For Class V (very poor rock), the roof was highly unstable due to fragmentation and discontinuities. A seven-step excavation sequence using triple benches was employed to ensure safety (see Figure 7).

4. METHODOLOGY FOR OVERBREAK ASSESSMENT AND IMPROVEMENT OF DRILLING AND BLASTING PRACTICE

During excavation, geological and blasting data were systematically recorded, as emphasized by Eldert (2017), Fodera et al. (2020), and Salmi and Sellers (2021). After each blast, the geologist evaluated the tunnel face, and the survey team measured the tunnel profile to generate as-built cross-sections (Verma et al., 2018). These cross-sections were compared with the design profiles to assess the extent of overbreak and underbreak. The area beyond the payable excavation boundary is defined as overbreak (Singh and Xavier, 2005). This data is essential for engineers to evaluate the effectiveness of current drilling and blasting methods and to refine the design for subsequent rounds (Mohammadi et al., 2018).

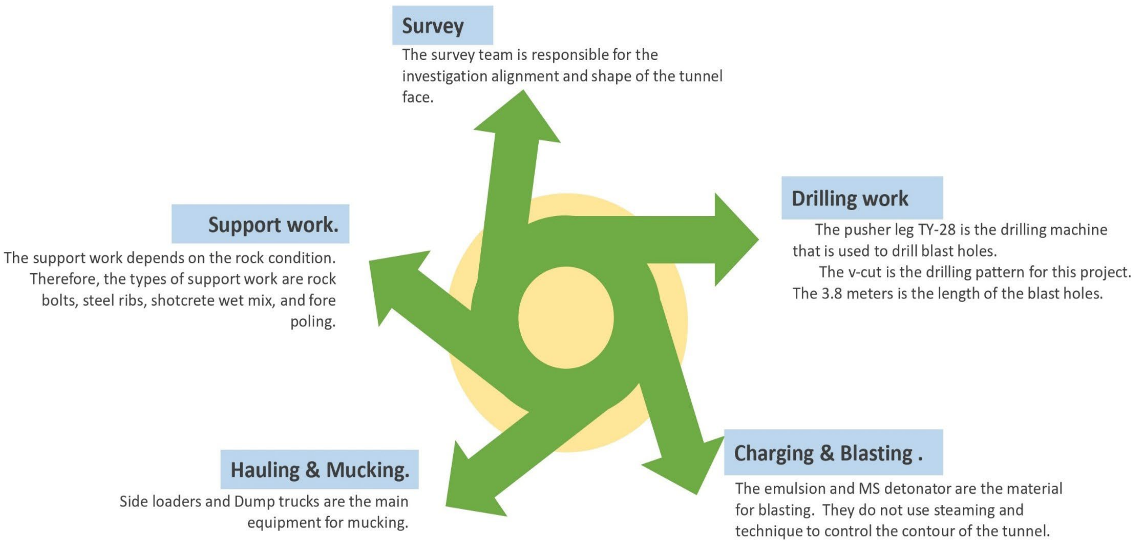


Figure 3 Typical tunnel excavation cycle used in the project (Spathis and Gupta, 2013)

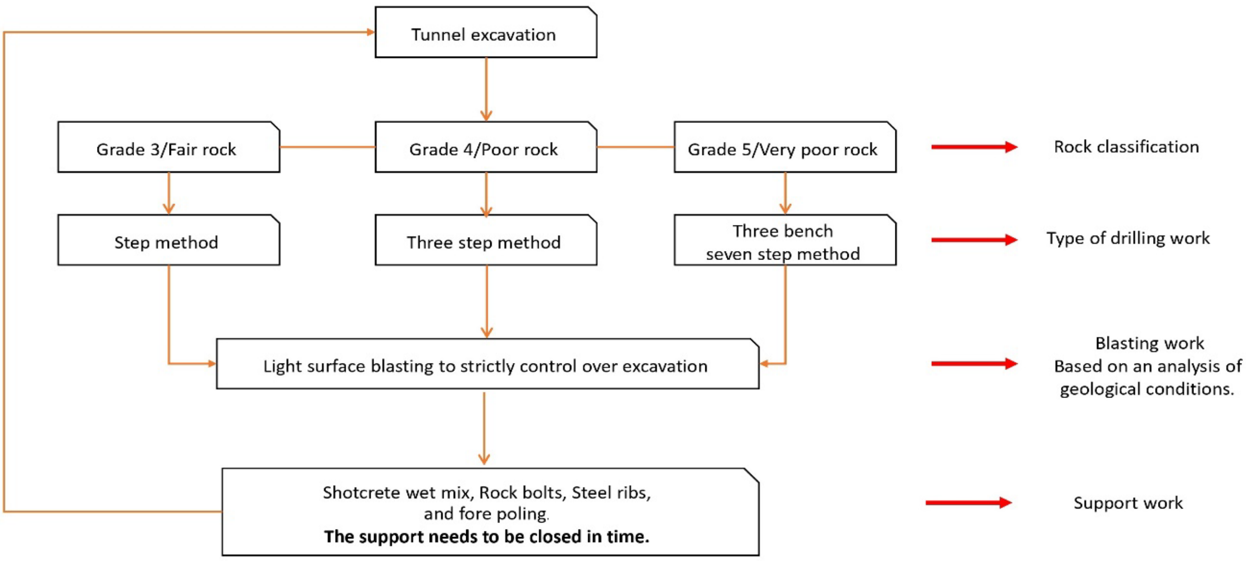


Figure 4 The tunnel excavation methods used in the project

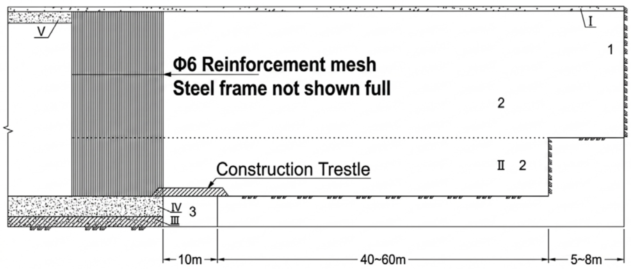


Figure 5 Excavation step for rock grade III (fair rock)

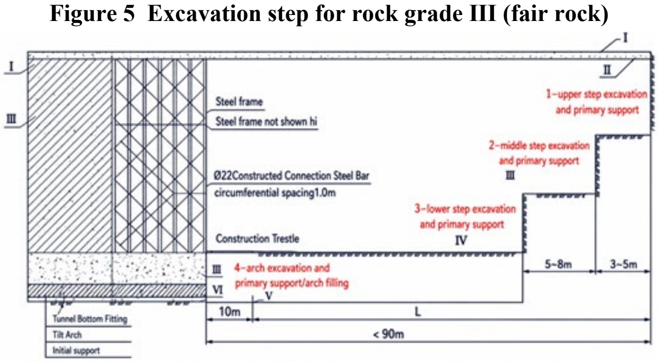


Figure 6 Excavation step for rock grade IV (poor rock)

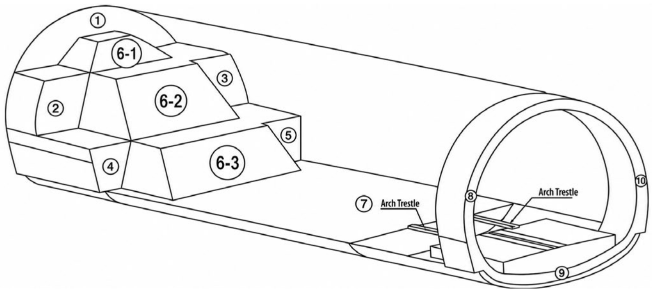


Figure 7 Excavation step for rock grade V (very poor rock)

In this study, the percent overbreak was calculated from the difference between the actual excavated cross-sectional area and the payable excavation area. The calculation is expressed as:

$$\boldsymbol{Overbreak}\ (\%) = \frac{A_{actual} - A_{payable}}{A_{payable}} \times \mathbf{100} \qquad \text{Eq. (1)}$$

Where A_{actual} is the measured post-blast excavated cross-sectional area, and $A_{payable}$ is the payable excavated cross-sectional area. This definition was used consistently for all percent overbreak values reported in this study, including the evaluation of the High-Speed

Railway Project and the comparison with the Double-Track Railway Project.

This study aims to identify and implement methods to reduce overbreak in tunnel excavation through optimized drilling and blasting practices in the high-speed railway project. To achieve this, construction data were collected and analyzed throughout the following analysis steps. The results of the overbreak analysis are provided in the following sections.

4.1 Evaluation of Overbreak Data Collected for the Project

Using the collected data, the volume and percentage of overbreak were calculated at several locations of the tunnel in the High-Speed Railway Project. This allowed the construction team to evaluate how the drilling and blasting patterns influence overbreak in different geological conditions. The collected overbreak data were compared with the project's allowable overbreak limits. According to the project specifications (SRT, 2018b), the allowable overbreak limits were defined by tunnel position and surrounding rock classification, as shown in Table 1. These allowable values are expressed as line overbreak, in centimeters, measured outward from the design excavation line. For field implementation, an average allowable line overbreak of 15 cm was used as the practical control reference for the arch section in rock Classes II to IV (SRT, 2018b).

Table 1 Allowable overbreak values for the High-Speed Railway Project

Excavation Position	Allowable Line Overbreak (cm)	Surrounding Rock Classification		
		I	II to IV	V to VI
Arch	Average	10	15	10
	Max	20	25	15
Side Wall	Average	10		
Inverted Arch and Tunnel Floor	Average	10		
	Max	25		

4.2 Comparison of Overbreak Data Obtained from this Project and the Double-Track Railway Project

The Double-Track Railway Project, located near the high-speed railway alignment, was selected for comparison due to its similar geological conditions, NATM excavation method, and rock classes ranging from III to V (SRT, 2019). Overbreak data, including cross-sectional surveys and geological mapping from multiple sections of the double-track tunnels, were recorded as shown in the monthly report of the project. Comparing these records with the Muak Lek tunnel data allowed assessment of differences in rock mass quality, drilling patterns, and blasting techniques, helping to identify construction practices that contributed to the lower overbreak percentages observed in the Double-Track Railway Project.

4.3 Proposed Approach to Reduce Overbreak

A comparison with the Double-Track Railway Project showed that excessive drill-hole length, high powder factor, and lack of contour control were significant causes of overbreak in the Muak Lek tunnel. In contrast, the SRT tunnel report (SRT, 2021b) indicated that the double-track tunnels achieved lower overbreak by matching drill hole length to rock quality, reducing explosive charges, and applying smooth blasting with dummy holes. Based on the findings and the authors' experience, an approach focusing on adjusting drill hole lengths, powder factors, and employing smooth blasting techniques was proposed to reduce the overbreak of the tunnel construction.

4.4 Assessment of the Proposed Approach

A test site was established near the Muak Lek tunnel entrance to evaluate the effectiveness of the proposed approach. This location was chosen because it presented typical Class IV rock conditions, including gray to dark gray limestone intersected by bedding planes and multiple joint sets, as well as zones of highly weathered shale. The SRT tunnel report (SRT, 2022) indicated that this section had a history of significant overbreak, making it suitable for assessing whether the adjusted drilling lengths, reduced powder factor, and smooth blasting techniques could improve excavation.

5. RESULTS OF THE OVERBREAK ANALYSIS

5.1 Evaluation of Overbreak Data Collected for the Project

The as-built cross sections of the tunnel profiles at several locations of the project were generated after the blasting. These as-built cross-sections were compared with the design profiles to assess the extent of overbreak and underbreak. In November 2022, at the exit of the tunnel where the rocks were classified as Grade IV (poor quality), the survey data indicated that local excavation deviations exceeded 1.5 m outward from the design line at some locations, particularly near the crown and sidewall areas. Figure 8 shows an example of the tunnel cross-section after the blast at station 134+457 near the tunnel exit point (SRT, 2022). Detailed cross-sections at the tunnel entrance between stations 131+560 and 131+718 were also generated. The geological mapping of the tunnel (SRT, 2022) indicates that the rock in this section consists primarily of shale, silty clay, and mudstone and is classified as Class IV (poor quality). The values of the overbreak percentage in this section are presented in Figure 9. As indicated in Figure 9, the overbreak percentage in the section ranges from approximately 16 to 174%, with an average value of 58%.

Figure 8 Example of tunnel cross-section at station 134+457 after the blasting

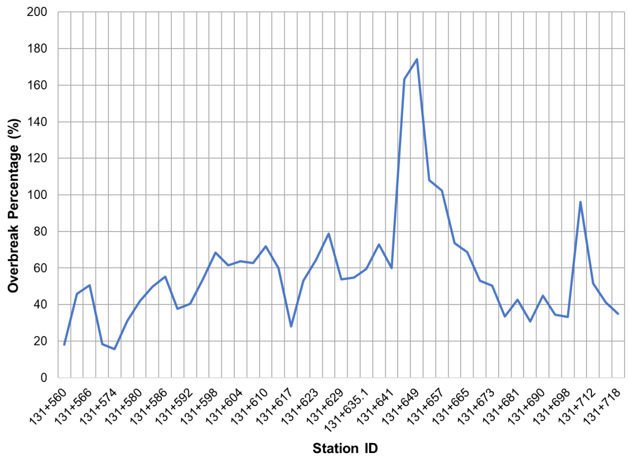


Figure 9 Overbreak percentage for Sta. 131+560 to 131+718

The survey data observed in sections with poor rock conditions showed significant differences between the designed excavation methods and the actual construction practices (SRT, 2022). Possible reasons for overbreaking were examined by comparing the geological conditions, design, and construction methods from this project with those of the nearby Double-Track Railway Project. The results of this comparison are presented in the following sections.

5.2 Comparison of Overbreak Data Obtained from this Project and the Double-Track Railway Project

5.2.1 Introduction of the double-track railway project

The Double-Track Railway Project on Thailand's Northeastern Line from Map Kabao to Thanon Chira Junction included the construction of four new tunnels parallel to the existing railway line. Tunnel One from Map Kabao to Hinlap lies near the alignment of the high-speed railway (refer to Figure 10). The lithology encountered in Tunnel One consists of silt, silty clay, limestone, marl, and highly weathered rock fragments (SRT, 2021b). The surrounding rock classes vary from Class III to Class V. The tunnel excavation was carried out using the NATM method. Therefore, Tunnel One was selected as a case study for comparison of the overbreak data due to its similar geological conditions and construction method.

A total of four sections at Tunnel One were selected for analysis: (1) Sta. 136+400 to 136+847.5, (2) Sta. 136+910.0 to 137+022.5, (3) Sta. 137+643.76 to 138+375.0, and (4) Sta. 140+875 to 141+600. The locations of these sections are shown in Figure 11. The SRT tunnel report (SRT, 2021b) indicated that these sections cover a total length of 2,433.74 meters and include data from 783 cross-sections.

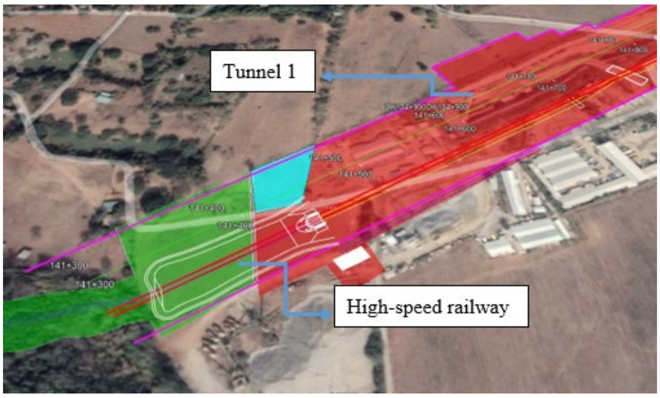


Figure 10 Location of tunnel one relative to the high-speed railway project

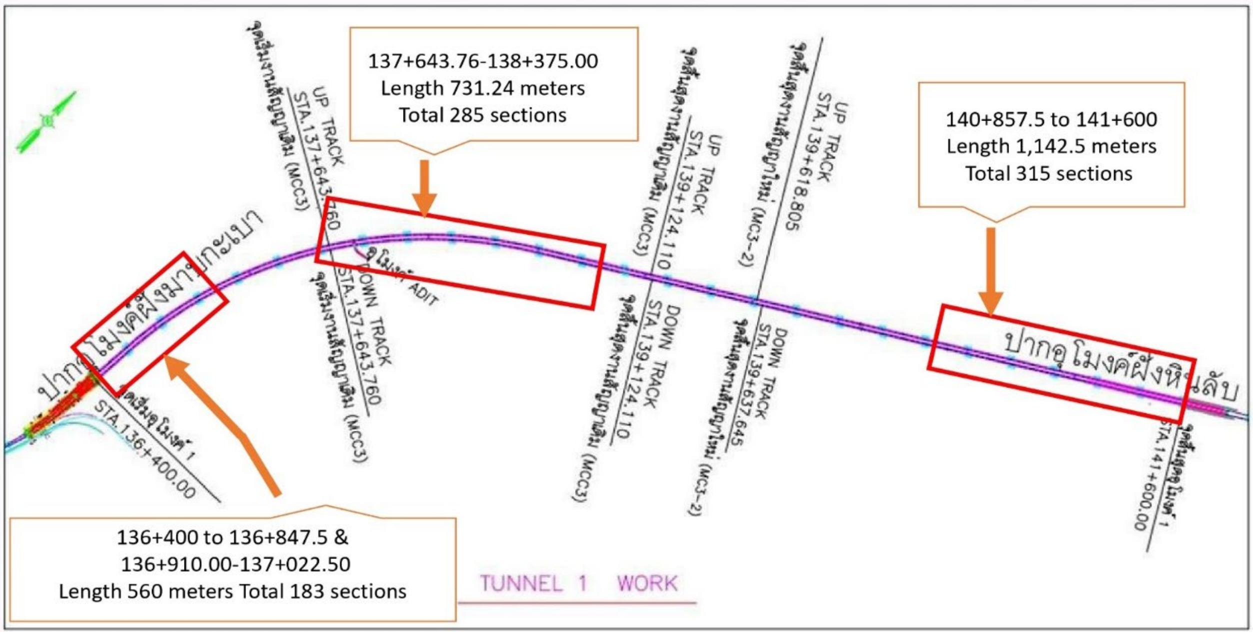


Figure 11 Location of surveyed sections at tunnel one

5.2.2 Overbreak data for the double-track railway project

Figure 12 presents the overbreak percentage values for rock classes II, III, and IV at Tunnel One. The figure illustrates the variation in overbreak percentage across different rock mass quality classes. The average values of the overbreak percentage for rock classes II (good rock), III (fair rock), and IV (poor rock) are 11.7%, 12.5%, and 14.0%, respectively. The results shown in Figure 12 indicate that the overbreak percentage tends to increase as the rock quality decreases. This trend confirms that rock strength and quality significantly influence the extent of overbreak during tunnel excavation. Softer or more fractured materials, which characterize lower rock classes, are more prone to instability during and after blasting.

A specific example can be observed at Station 137+822.5. Figure 13 illustrates that highly weathered silty clay was observed at the crown of the station. It was recorded that, despite the use of smooth blasting techniques, the crown section collapsed (the brown-shaded area near the crown of the tunnel in Figure 13) due to the presence of highly weathered silty clay (SRT, 2021b). These findings highlight the importance of tailoring blasting designs and support systems to the expected ground conditions, particularly in areas with low rock quality (Mohammadi et al., 2018).

5.2.3 Comparison of overbreak data for both projects

The rock type for the area where the overbreak percentage data was collected at the High-Speed Railway Project is Class IV (refer to Figure 9). Therefore, the overbreak data collected at the same rock type for the Double-Track Railway Project (refer to Figure 12(c)) was used for the comparison. For Class IV rock, the average overbreak in the High-Speed Railway Project was 58%, compared with 14.0% in the Double-Track Railway Project. This represents a difference of 44 percentage points, or approximately 4.1 times greater average overbreak in the High-Speed Railway Project. The tunnel construction methods and procedures for both projects were therefore evaluated to identify possible reasons for this discrepancy. It was concluded that this discrepancy could be attributed to the following factors:

- **Drill Hole Length Control:**

In the Double-Track Rail Project, the drill holes were limited to 2 meters and adjusted based on rock conditions (SRT, 2021b). In contrast, approximately 3.8-m-long blast holes, treated in field practice as a nominal 4.0-m round length, were used in the High-Speed Railway Project. This length was excessive for the Class IV rock conditions encountered in the study section (SRT, 2022).

- **Blasting Technique:**

The Double-Track Rail Project applied the smooth blasting technique (with dummy holes or perimeter control) along the contour line (SRT, 2021b). This technique was not implemented in the High-Speed Railway Project, which contributed significantly to higher overbreak.

- **Timely Support Installation:**

In the double-track tunnel, supports were installed immediately after excavation (SRT, 2021b). Delays in support installation at the high-speed site may have led to increased rock loosening and additional overbreak (SRT, 2022). In weak/clayey reaches adjacent to rock headings, controlling ground displacement becomes as critical as contour control; jet-grouting case histories show that pre-support can effectively cap settlements in plastic clays (Cheng et al., 2023; Shakya et al., 2023).

5.3 Proposed Approach to Reduce Overbreak

An approach to reduce overbreak was developed based on observations of the construction methods and procedures for both projects, a review of projects constructed with similar design and construction methods, and the authors' experience. Maerz (1996) indicated that overbreak can be significantly reduced if the construction team strictly follows the design sequence and adjusts the drilling and blasting plan to match geological conditions. Ramulu (2010) and Salmi and Sellers (2021) demonstrated that regular documentation and data collection are crucial for identifying the causes of overbreak and refining excavation strategies. Figure 14 recommends measures to minimize overbreak during tunnel excavation, organized into three main stages: (1) survey work, (2) drilling work, and (3) blasting work.

- **Survey Work:**

Survey work involves preparing accurate cross-sectional measurements to identify and monitor overbreak or underbreak. This step ensures that deviations from the design profile can be detected promptly and that corrective measures can be implemented (Maerz, 1996).

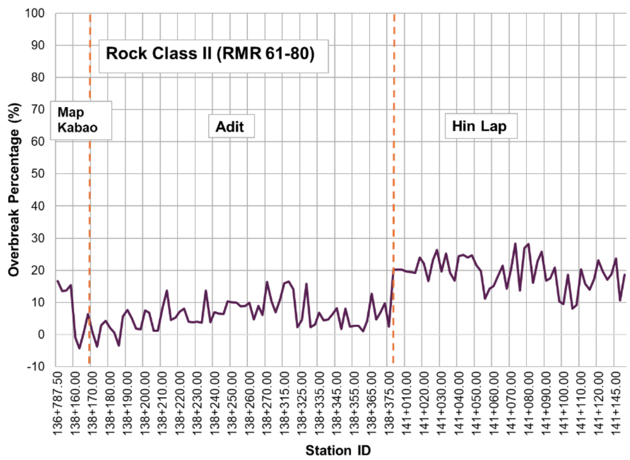
- **Drilling Work:**

This work requires careful planning and control to maintain excavation accuracy. Drill holes should be clearly marked prior to drilling, and drilling operations must be closely monitored. As a general guideline, the drilling length should be adjusted according to rock mass quality, with typical round lengths ranging from approximately 4 m in competent rock to less than 1 m in very poor ground or soil-like conditions (Ramulu, 2010). This range is cited as a general reference and should not be interpreted as the actual drill hole length used in the field test.

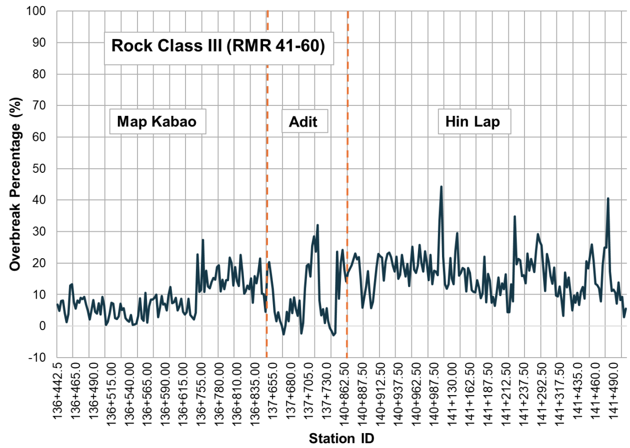
- **Blasting Work:**

Blasting work focuses on techniques to minimize overbreak and optimize the utilization of explosive energy. Methods such as smooth blasting or smooth blasting with dummy holes are recommended to create a controlled excavation profile (Ramulu, 2010). Stemming should be applied to confine and maximize the efficiency of explosive energy. Detailed blasting records should be maintained to evaluate performance and inform adjustments for subsequent rounds (Ramulu, 2010).

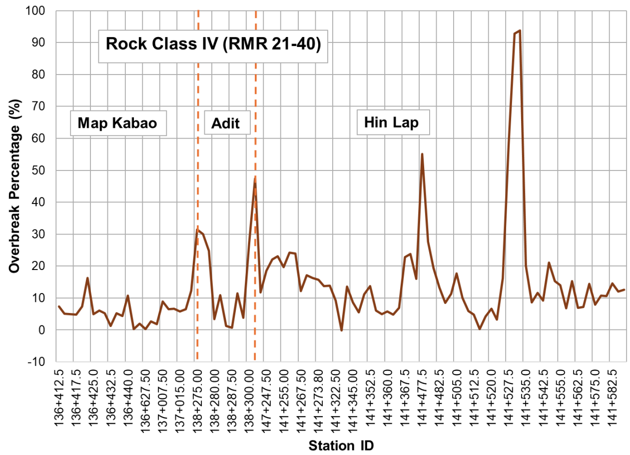
Illustrations for smooth blasting with dummy holes for crown control and cushion blasting techniques for tunnel trimming following pilot excavation are depicted in Figure 14. Cushion blasting, which uses closely spaced trimming holes, is effective for refining the tunnel perimeter to the desired profile while minimizing damage to the remaining rock mass (Ramulu, 2010).



(a) Rock Class II



(b) Rock Class III



(c) Rock Class IV

Figure 12 Overbreak percentage for rock classes II, III, and IV at tunnel one

5.4 Assessment of the Proposed Approach

To assess the effectiveness of the proposed overbreak control measures, a field test was conducted at Sta. 131+718.40, near the Muak Lek tunnel entrance. The rock mass in this section consists primarily of gray to dark gray limestone, intersected by bedding planes oriented 265°/59° with a spacing of approximately 0.5 meters. Four major joint sets were observed by the tunnel geologists of the project at 359°/83°, 114°/77°, 160°/82°, and 079°/32°, with joint spacing ranging from 0.1 to 0.2 meters and silt-filled joints.

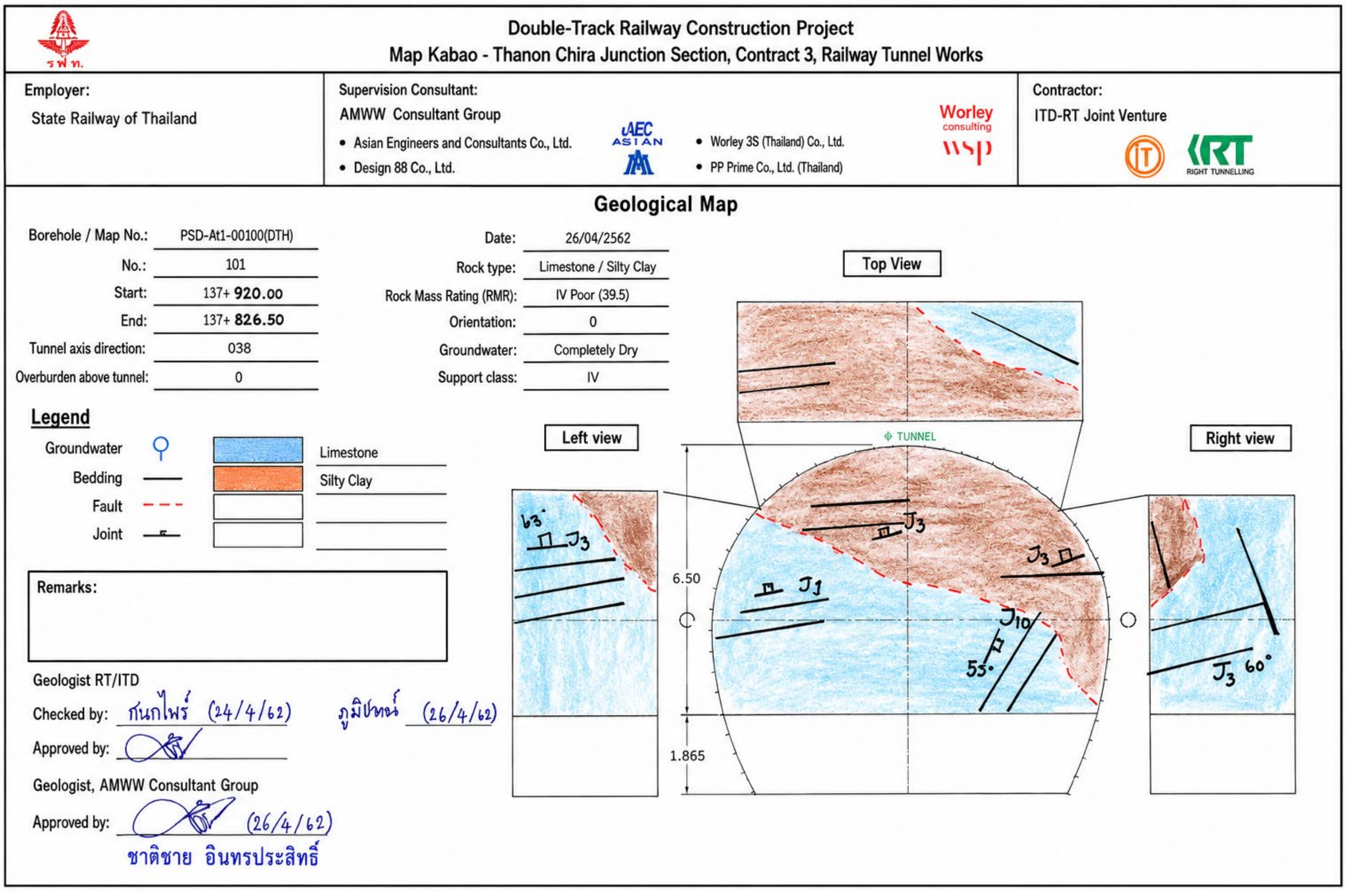


Figure 13 Geological mapping at Sta. 137+820 to 137+826.5

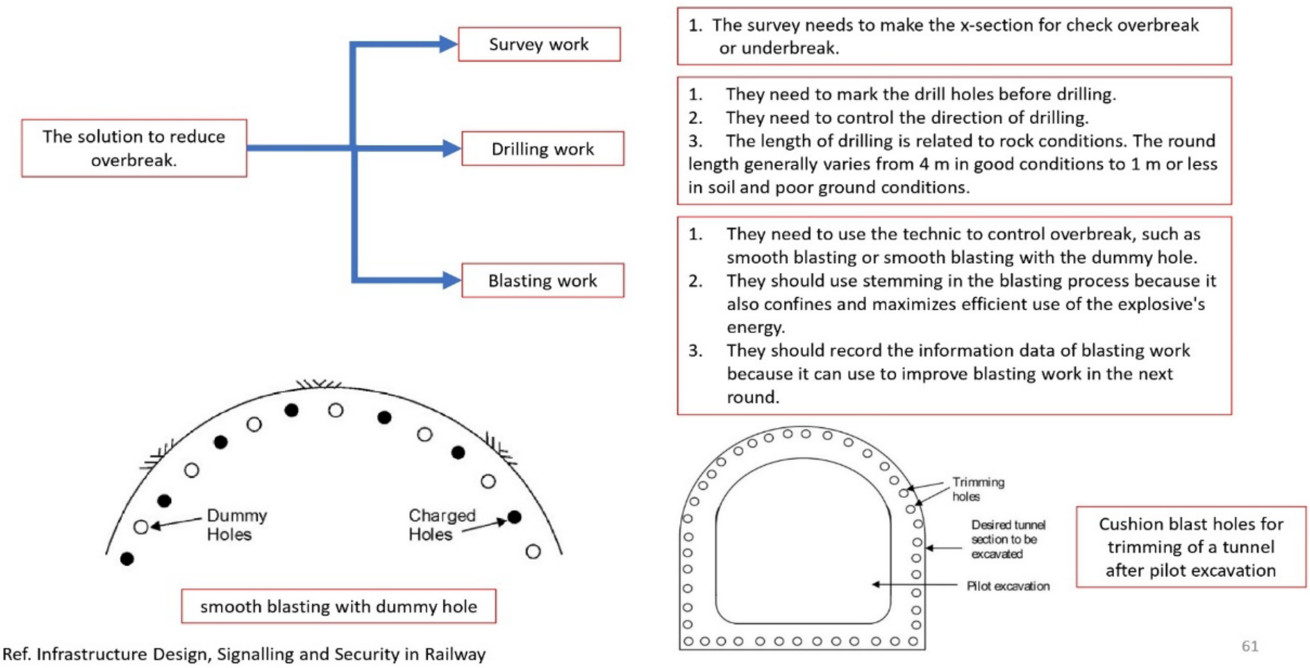


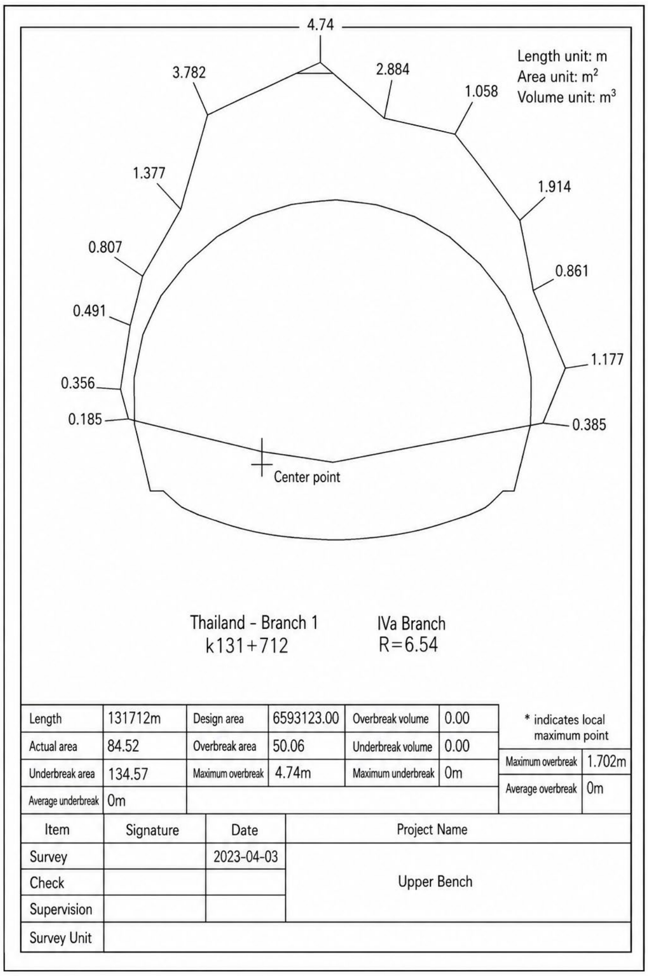
Figure 14 Proposed control workflow to reduce overbreak for tunnel construction

On the right side of the tunnel face, highly weathered shale with a yellowish-brown color and moisture presence was encountered. Based on rock mass classification, the overall quality was identified as Class IV. The uniaxial compressive strength (UCS) of the limestone ranged from 25 to 50 MPa, and the RQD (Rock Quality Designation) was below 25%, indicating poor rock quality. Figure 15 shows an example of the rock condition at the tunnel face of Sta. 131+718.40, as mapped by the tunnel geologists of the project.

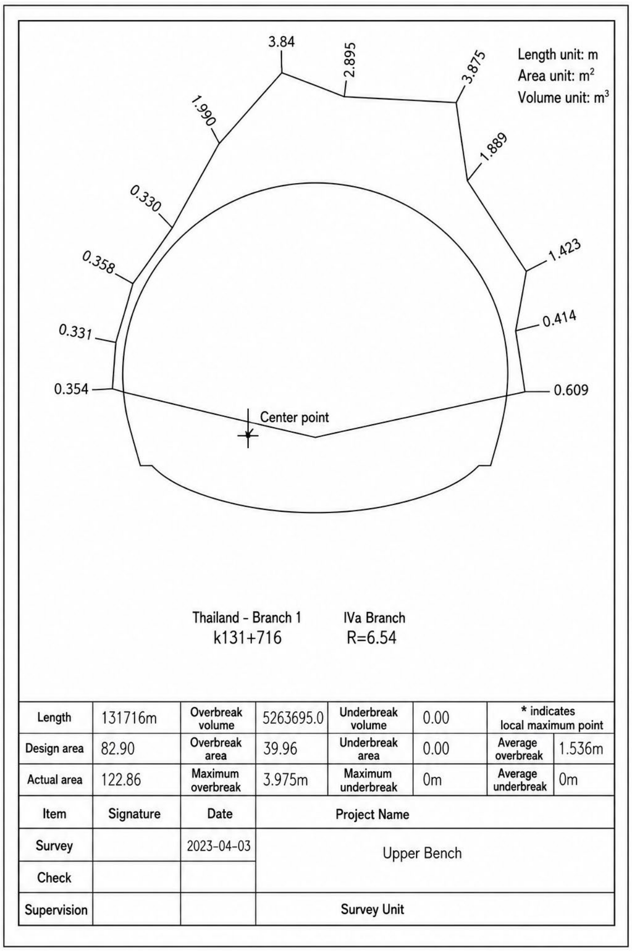
Prior to the field test, excessive overbreak, up to 2 meters at the crown, as shown in Figure 16, was recorded in this area. Figure 16 indicates that the overbreak percentages were measured to be 51.6% and 41.1% for Sta. 131+712.00 and Sta. 131+716.00, respectively.

Figure 15 Rock conditions at the tunnel face of Sta. 131+718.40

Prior to the field test, the nearby Class IV sections were excavated using approximately 3.8-m-long blast holes, corresponding to a nominal 4.0-m round length, with limited contour control and relatively high explosive energy for the weak and jointed rock condition. For the field test section, the blasting practice was modified to improve excavation control. The drill hole length was reduced to 1.5 m, and the drill holes were more carefully aligned and marked along the contour line before drilling. The V-cut pattern was retained for tunnel advance, while smooth blasting was applied along the perimeter using small emulsion charges and detonating cord. The explosive charge distribution and powder factor were also reduced and adjusted to better match the Class IV rock condition.



Sta.131+712.00



Sta. 131+716.00

Figure 16 Overbreak percentages at tunnel face Sta. 131+712.00 and Sta. 131+716.00

The tunnel face was surveyed after the actions mentioned above were taken at the section. The results of the tunnel face survey are presented in Figure 17. Figure 17 indicates that the percent overbreak, calculated using the area-based definition described in Section 4, was 9.3% after applying the proposed approach. This value was significantly lower than the percent overbreak measured at the nearby sections shown in Figure 16. A photograph of the tunnel face after blasting at the station is shown in Figure 18.

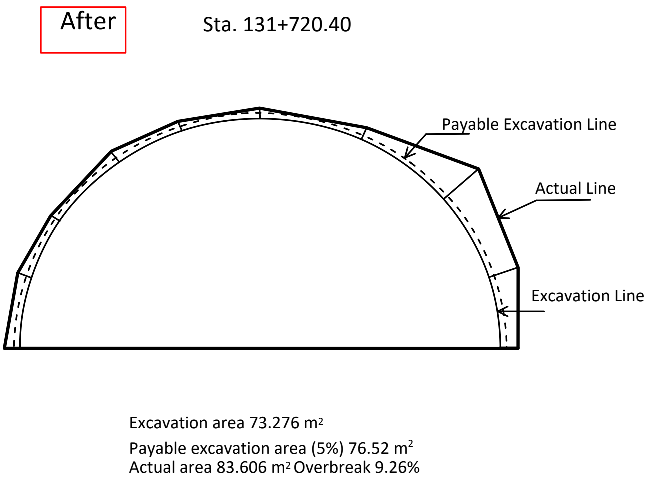


Figure 17 Overbreak percentages at Sta. 131+720.4 using the proposed approach

Figure 18 Tunnel face after blasting at Sta. 131+720.4 using the proposed approach

The reduction in overbreak was mainly attributed to the combined effects of shortening the drill hole length, improving contour marking and hole alignment, applying smooth blasting with small emulsion charges and detonating cord, and adjusting the explosive charge distribution and powder factor to better match the Class IV rock condition.

6. CONCLUSIONS AND RECOMMENDATIONS

This study investigated the issue of overbreak in drill-and-blast tunnel excavation, focusing on the Muak Lek tunnel section of Thailand's high-speed railway project. Overbreak has significant implications for project cost, safety, and scheduling. To address this issue, the study compared construction practices between the High-Speed Railway Project and a nearby Double-Track Tunnel Project. An approach to reduce overbreak was proposed, and a field test was conducted to assess its effectiveness. The key findings from the study were summarized as follows:

- Post-blasting survey data showed significant overbreak in the selected Class IV rock section of the Muak Lek tunnel. The overbreak percentage in the analyzed section ranged from approximately 16% to 174%, with an average value of 58%. This finding demonstrates the importance of regular post-blast profile surveys and documentation for identifying overbreak problems and supporting timely adjustment of drilling and blasting parameters.
- The comparison with the nearby Double-Track Railway Project indicated that drilling and blasting practice strongly influenced overbreak performance. For Class IV rock, the average overbreak in the High-Speed Railway Project was 58%, compared with 14.0% in the Double-Track Railway Project. This difference suggested that overbreak was affected not only by rock quality, but also by drill hole length, contour control, explosive energy, and support timing. Hindistan (2006) indicated that adjusting the hole length based on rock quality resulted in better control.
- The field test confirmed that the modified drilling and blasting approach reduced overbreak in Class IV rock. At the field test section, the drill hole length was reduced from approximately 3.8 m, corresponding to a nominal 4.0-m round length, to 1.5 m. Together with improved contour marking, smooth blasting using small emulsion charges and detonating cord, adjusted charge distribution, and reduced powder factor, the percent overbreak was reduced to 9.3%. This was substantially lower than the nearby pre-improvement sections, where overbreak values of 51.6% and 41.1% were recorded.
- Sumiya and Kato (2007) indicated that using small emulsions and detonating cords along the tunnel boundary ensures more controlled breakage and helps preserve the excavation shape. Smooth blasting and improved perimeter control were important components of the successful field test. The use of small emulsion charges and detonating cord along the tunnel perimeter helped reduce excessive damage to the surrounding rock mass and improved the final excavation profile. This finding supports the use of controlled perimeter blasting in weak and jointed Class IV rock.
- Highly weathered shale and weak rock zones require special attention during excavation. Field observations at the test section showed the presence of highly weathered shale, closely spaced joints, and moisture-sensitive weak zones. These materials may contribute to crown instability, secondary loosening, and additional overbreak after blasting. Therefore, moisture sensitivity, slaking behavior, and rapid support installation should be considered when excavating similar weak rock zones. Furthermore, in clay-rich shale zones, time-dependent softening, slaking, and potential swelling upon wetting can reduce shale shear strength and contribute to secondary overbreak and crown instability. It is therefore recommended that swelling susceptibility and moisture sensitivity be assessed as potential contributors to secondary overbreak (Nelson et al., 2012 & 2014; Chao et al., 2014 & 2018; Nelson et al., 2017).

7. ACKNOWLEDGMENTS

The authors would like to express their sincere gratitude to all individuals and organizations who supported this study. Special thanks are extended to the engineers, site supervisors, and survey teams involved in the High-Speed Railway and Doubling-Track Projects for providing access to essential data and field observations.

8. REFERENCES

Chao, K.C., Kang, J. B., and Nelson, J.D. (2018). "Evaluation of Failure of Embankment Slope Constructed with Expansive Soils." Geotechnical Engineering Journal of the SEAGS & AGSSEA, 49(2), 140-149.

Chao, K.C., Kang, J.B., and Nelson, J.D. (2014). "Challenges in Water Migration Modeling for Expansive Soils." In Proceedings of the GeoShanghai Conference, Shanghai, China. DOI: 10.1061/9780784413388.021

Chao, K.C., Overton, D.D., and Nelson, J.D. (2006). "Design and Installation of Deep Benchmarks in Expansive Soil." Journal of Surveying Engineering, ASCE, 132(3), 124-131, DOI: 10.1061/(ASCE)0733-9453(2006)132:3(124)

Chapman, D., Metje, N., and Stark, A. (2017). "Introduction to Tunnel Construction (2nd ed.)". CRC Press, Taylor & Francis Group. DOI: 10.1201/9781315120164

Cheng, S.H., Chao, K.C., Wong, R.K.N., and Wang, I.M. (2023) "Control of Jet Grouting Process Induced Ground Displacement in Clayey Soil." Transportation Geotechnics. March. DOI: 10.1016/j.trgeo.2023.100983

Ekeberg, R., Holmes, H., and Paraskevopoulu, C. (2021). "A Quantitative Approach to Predict Tunnel Overbreak Based on the Q-System." Mechanics and Rock Engineering, from Theory to Practice, IOP Conference Series: Earth and Environmental Science, 833, 012165. DOI: 10.1088/1755-1315/833/1/012165

Eldert, J. v. (2017). "Measuring of Over-Break and the Excavation Damage Zone in Conventional Tunneling." Proceedings of the World Tunnel Congress 2017 – Surface Challenges – Underground Solutions, Bergen, Norway. Luleå University of Technology.

Fodera, G. M., Voza, A., Barovero, G., Tinti, F., and Boldini, D. (2020). "Factors Influencing Overbreak Volumes in Drill-and-Blast Tunnel Excavation: A Statistical Analysis Applied to the Case Study of the Brenner Base Tunnel – BBT." Tunnelling and

Underground Space Technology, 105, 103475. DOI: 10.1016/j.tust.2020.103475
Hindistan, M. A. (2006). "Drilling & Blasting as a Tunnel Excavation Method." Ankara, Turkey.
Jayasiri, N.S., Chao, K.C., Noppadol, P.W, Duangsano, O., and Asanprakit, A. (2022). "Design and Analysis of Tunnel Cross-Passage Openings: 3D Finite Element Analysis Versus 3D Shell-Spring Approach." Innovative Infrastructure Solutions, 7:204, March. DOI: 10.1007/S41062-022-00805-Z
Johansen, J. (2010). "Modern Trends in Tunnelling and Blast Design." CRC Press.
Konya, C. J., and Walter, E. J. (1991). "Rock Blasting and Overbreak Control." National Highway Institute, FHWA-HI-92-001.
Lunardi, P. (2008). "Design and Construction of Tunnels: Analysis of Controlled Deformation in Rocks and Soils (ADECO-RS)." Springer Berlin Heidelberg. DOI: 10.1007/978-3-540-73875-6
Maerz, N. (1996). "Overbreak and Underbreak in Underground Opening Part 1: Measurement Using the Light Sectioning Method and Digital Image Processing." Geotechnical and Geological Engineering. DOI: 10.1007/BF00421946
Mandal, S. K., and Singh, M. M. (2009). "Evaluating Extent and Causes of Overbreak in Tunnels." Tunnelling and Underground Space Technology, 24(1), 22–36. 10.1016/j.tust.2008.01.007
Mohammadi, H., Barati, B., and Chamzini, A. Y. (2018). "Prediction of Blast-Induced Overbreak Based on Geo-mechanical Parameters, Blasting Factors and the Area of Tunnel Face." Geotechnical and Geological Engineering. DOI: 10.1007/s10706-017-0336-3
Nelson, E.J., Chao, K.C., Nelson, J.D., and Overton, D.D. (2017). "Lessons Learned from Foundation and Slab Failures on Expansive Soils." Journal of Performance of Constructed Facilities, ASCE., 31(3), June. DOI: 10.1061/(ASCE)CF.1943-5509.0000958
Nelson, J.D., Chao, K.C. (2014). "Relationship Between Swelling Pressures Determined by Constant Volume and Consolidation-Swell Oedometer Tests." Proceedings of the Sixth International Conference on Unsaturated Soils, Sydney, Australia, 2–4 July. 891-896.
Nelson, J.D., Chao, K.C., Overton, D.D., and Schaut, R.W. (2012). "Calculation of Heave of Deep Pier Foundations." Geotechnical Engineering Journal of the SEAGS & AGSSEA. 43(1), 12-25.
Olofsson, S. O. (2003). "Applied Explosives Technology for Construction and Mining." 2nd Edition, RWS Publications.
Ramulu, M. (2010). "Special Tunnel Blasting Techniques for Railway Projects." Central Institute of Mining & Fuel Research, Nagpur, India.
Salmi, E. F., and Sellers, E. J. (2021). "A Review of the Methods to Incorporate the Geological and Geotechnical Characteristics of Rock Masses in Blastability Assessments for Selective Blast Design." Journal of Engineering Geology, 281, 105970. DOI: 10.1016/j.enggeo.2020.105970
Shakya, S., Inazumi, S., Chao, K.C., and Wong, R.K.N. (2023). "Innovative Design Method of Jet Grouting Systems for Sustainable Ground Improvements." Sustainability. 15(6), 5602. DOI: 10.3390/su15065602
Singh, S. P., and Xavier, P. (2005). "Causes, Impact and Control of Overbreak in Underground Excavations." Tunnelling and Underground Space Technology, 20(1), 69–96. DOI: 10.1016/j.tust.2004.05.004
Singh, T. N., and Verma, A. K. (2010). "Sensitivity of Total Charge and Maximum Charge per Delay on Ground Vibration." Geomatics, Natural Hazards and Risk, 1(3), 259–272. DOI: 10.1080/19475705.2010.488352
Spathis, A. T., and Gupta, R. N. (2012). "Tunnelling in Rock by Drilling & Blasting." Taylor & Francis Group. DOI: 10.1201/b13762
State Railway of Thailand (SRT) (2018a). "Detailed Design Volume III: Drawings." Contract 3-2:(DK 130+841 – DK.138+820) & (DK 186+800 – DK.191+050), Section Book 5 of 8: Tunnel, State Railway of Thailand.
State Railway of Thailand (SRT) (2018b). "Tender Documents Volume IV: Technical Specifications." Contract 3-2: Civil works for tunnels (Muak Lek and Lum Takong Section), Book 2 of 3: Civil Work, State Railway of Thailand.
State Railway of Thailand (SRT) (2019). "Method Statement Construction of Tunnel 1." Track Doubling project for Northeastern line Map kabao – Thanon chira junction contact 1. Bangkok, Thailand.
State Railway of Thailand (SRT) (2021a). "Method Statement of Tunnel Excavation and Primary Support Construction." Geology of Tunnel, High-speed railway project contact 3-2. Bangkok, Thailand.
State Railway of Thailand (SRT) (2021b). "Tunnel Report at Muak Lek Tunnel." Track Doubling Project for Northeastern Line Map Kabao – Thanon Chira Junction Contact 1, Bangkok, Thailand.
State Railway of Thailand (SRT) (2022). "Tunnel Report at Muak Lek Tunnel." High-Speed Railway Project, Bangkok, Thailand.
Sumiya, F., and Kato, Y. (2007). "A Study on Smooth Blasting Technique Using Detonating Cords." Science and Technology of Energetic Materials, 68(6).
Tatiya, R. R. (2013). "Surface and Underground Excavations – 2nd Edition, Methods, Techniques and Equipment." Balkema Publishers.
Verma, H. K., Singh, P. K., Swarup, A., Arora, H. L., and Singh, D. V. (2018). "Overbreak in Underground Excavations – Some Key Insights." Proceedings of the 12th International Symposium on Rock Fragmentation by Blasting, Luleå, Sweden, 11–13.
Yamazaki, J., Chao, K.C., Wong, Ricky K.N., and Wang, I-M. (2024). "Development of the Jet Grouting Method: Evolutionary History, Mechanism Insights, Innovative Approaches, and Future Prospects." Geotechnical Engineering Journal of the SEAGS & AGSSEA, 55(1), 11-23. DOI: 10.14456/seagj.2024.2