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Challenges in the construction tunnel in BIM rocks: Case Study for Farish tunnels

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Abstract

It is generally recognized that excavation and construction of tunnels in so-called BIM rock masses (solid blocks bound by a weaker matrix) is very challenging task. Knowing the fact that all experiences from the practice related to excavations in such rock mass media, are welcomed, and the paper presents the authors' experience in constructing two parallel tunnels forming part of the Macedonian Prilep–Gradsko Expressway. The tunnels are located in the Farish Gorge, an area characterized by highly complex geological conditions due to the presence of carbonate breccia characterized with stronger core carbonate block in a weaker claylike matrix, at some zones intensely fractured. These specific geotechnical conditions represented a significant challenge for the excavation and stabilization of the tunnel profiles, as well as difficulties in selecting the appropriate blasting excavation methodology. During the construction phase, optimization of both the blasting excavation and the primary support methods was carried out; however, these optimizations led to a reduction in support measures due to the failure to consider the blocky structure of the BIM rock mass, which in turn affected the overall tunnel stability. In the present study, an overview of ground improvement measures is presented for this rock mass media, prone to rapid deformation development at the tunnel face. Gathered experiences from this study can contribute to a better understanding of the behavior of BIM rock masses during tunnel excavation and provides practical recommendations for their more effective engineering treatment in similar geological environment.

Keywords

Tunnel excavation, BIM rock masses, Primary support optimization, Ground improvement, Geotechnical challenges.

1 Introduction

Tunnel excavation in block-in-matrix (BIM) rock masses represents one of the most challenging problems in underground engineering due to the pronounced heterogeneity of these geological materials and their highly variable mechanical response. Unlike conventional rock masses, excavation stability is controlled by the interaction between competent rock blocks and the surrounding weaker matrix, making ground behavior difficult to predict using traditional rock mass classification systems (Medley 1994; Nikolaidis and Saroglou 2016).

These characteristics often result in localized excavation instability, requiring continuous adaptation of excavation procedures, support measures, and construction methodology throughout tunnel advancement (Napoli et al. 2021).

This paper presents a case study from the construction of two parallel road tunnels on the Prilep–Gradsko Expressway in North Macedonia. During construction, the initially adopted primary support system was revised to improve construction efficiency and reduce costs. At the same time, additional ground improvement measures were introduced in critical sections to maintain excavation stability under highly variable BIM rock mass conditions.

The objective of this study is to present the observed behaviour of the encountered BIM rock mass, evaluate the performance of the adopted support and ground improvement measures, and summarize the practical engineering experience gained during tunnel construction.

2 Geological and geotechnical setting

Two parallel tunnels are located within the Farish Gorge along the Prilep–Gradsko Expressway, an area characterized by complex geological and structural conditions associated with a regional fault-controlled valley. The maximum overburden reaches approximately 30 m above the tunnels, classifying both structures as shallow tunnels, where excavation stability is strongly influenced by local geological heterogeneity and stress redistribution.

The encountered rock mass consists predominantly of carbonate breccia exhibiting typical BIM (block-in-matrix) characteristics, composed of competent carbonate blocks embedded within a silty clayey matrix, consistent with the engineering characterization of block-in-matrix rock masses reported in the literature (Medley 1994; Nikolaidis and Saroglou 2016). Geological conditions vary along the tunnel alignment. At the portal sections, the proportion of carbonate blocks is generally lower, estimated at approximately 30–40%, with block sizes commonly ranging between 20 and 50 cm. Toward the central tunnel sections, block content increases to approximately 40–60%, accompanied by larger block dimensions, typically in the range of 50–100 cm. This gradual increase in block concentration and block size significantly influenced the mechanical response of the rock mass during excavation, in agreement with observations that volumetric block proportion strongly governs the mechanical response of BIM rock masses (Medley and Goodman 1994).

The surrounding rock mass is moderately fractured, with its structural condition strongly influenced by the regional tectonic setting. The wider valley itself represents a major fault zone, while a localized transverse fault crossing the tunnel axis was identified in the central part of the left tunnel. Despite the pronounced structural complexity, no significant lithological variation was observed between the portal and inner tunnel sections. Groundwater conditions were generally favourable, with predominantly dry excavation conditions recorded throughout construction, which significantly reduced the risk of matrix softening and contributed positively to excavation stability.

From a geotechnical perspective, the most commonly observed instability mechanism involved localized loosening and detachment of individual carbonate blocks from the excavation boundary, frequently leading to the formation of cavities around larger embedded blocks. In isolated sections, occasional block falls from the excavation face and crown were also recorded, although these events remained limited in extent. Overall, the dominant engineering challenge was associated with the heterogeneous block–matrix structure of the rock mass and its locally unpredictable response during excavation, which is characteristic for tunnel excavation in heterogeneous BIM geological media (Napoli et al. 2021).

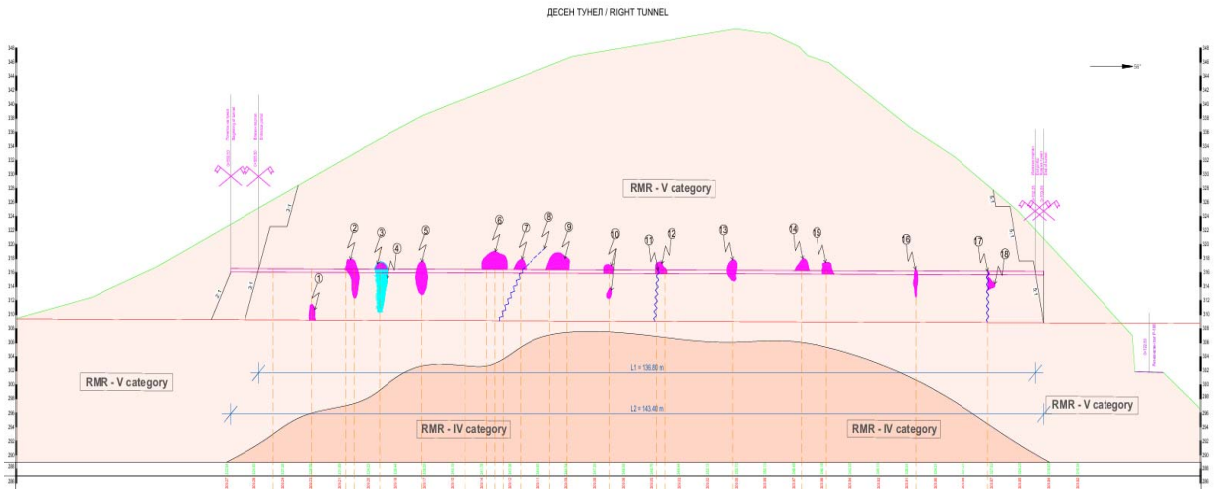


Fig. 1 Geological longitudinal profile of the right tunnel with a display of instability zones.

3 Primary Support Concept and Ground Improvement Measures

The two tunnels were excavated using the drill-and-blast method in two stages, comprising top heading excavation followed by bench excavation, with immediate installation of primary support after each blasting cycle. Excavation advance was adjusted according to ground conditions, while support installation was completed in close proximity to the excavation face to maintain stability in the shallow and structurally complex tunnel environment.

Based on the initial design investigations, primary support systems corresponding to Bieniawski rock mass Classes III and IV were originally adopted. However, during construction it became evident that the encountered carbonate breccia exhibited typical BIM rock mass behavior, locally corresponding to weaker and structurally more complex ground conditions. Consequently, an additional support class equivalent to Class V was introduced, consisting of dense self-drilling anchors, heavy steel ribs, thick reinforced shotcrete lining, and a closed invert arch. Although structurally robust, this support concept proved highly demanding in terms of construction time, operational complexity, and cost.

To improve construction efficiency while maintaining tunnel stability, the support concept was revised through collaboration between the contractor, investor, supervision team, and technical consultant. The optimized support system retained the general philosophy of Class IV support, including 5.0 m adhesive rock bolts, 15 cm reinforced shotcrete with steel mesh, and staged excavation, while increasing steel rib density to 0.75 m spacing, consistent with Class V support. At the same time, the invert arch was omitted. This hybrid solution significantly reduced construction time and material consumption while preserving adequate structural confinement for most excavation sections.

Additional ground improvement measures were applied in critical zones. The main stabilization measure consisted of a pipe roof umbrella system formed by 39 perforated steel pipes (Ø114.3 mm, 15.0 m length) installed around the crown at 0.45 m spacing and inclined at 4° relative to the horizontal axis. Following installation, the pipes were pressure-grouted using a cement–bentonite mixture (water-to-dry-mass ratio 1:1), with a 4.5 m longitudinal overlap maintained between adjacent sections to ensure continuity of pre-support.

In addition, fiberglass face bolts (Ø22 mm, 9.0 m length) were installed in portal and near-portal zones as localized face reinforcement. Their function was to prevent block detachment and localized face collapse while allowing continued excavation through the reinforced zone, since fiberglass elements could be cut during excavation. The combined application of pipe roof pre-support and localized face reinforcement proved highly effective in improving excavation stability under shallow BIM rock mass conditions.

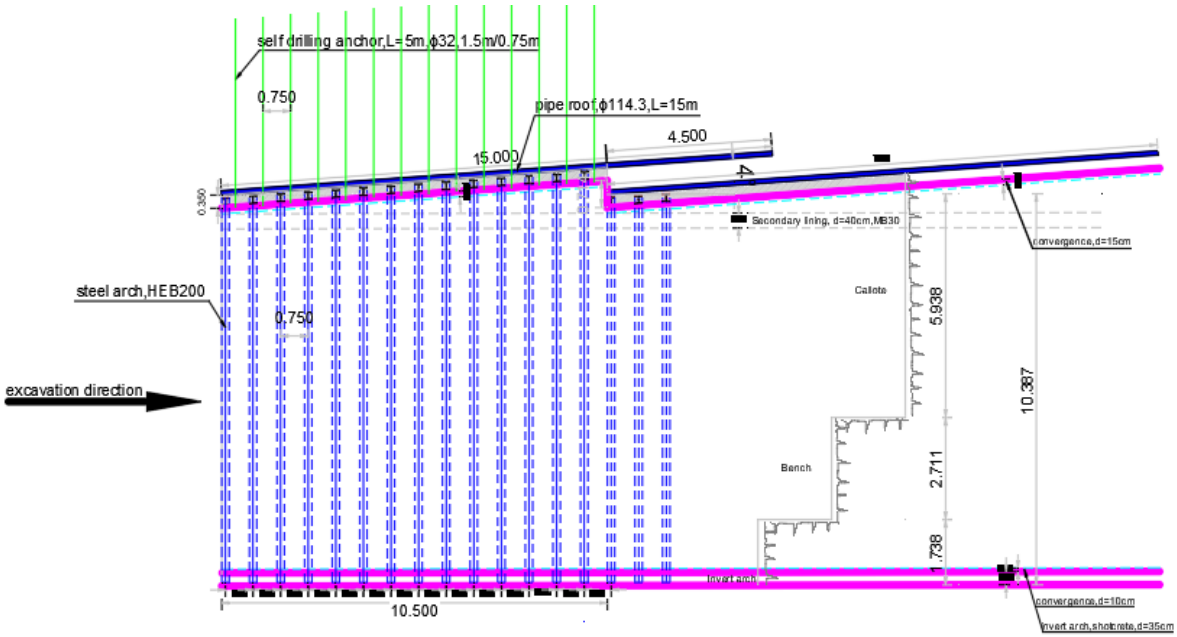


Fig. 2 Overview of ground improvement measures, primary support and tunnel excavation for Farish tunnels.

4 Observed Tunnel Behavior and Support Performance

Field observations during excavation highlighted that the dominant geotechnical challenge in the encountered BIM rock mass was not excessive global deformation of the tunnel opening, but rather localized instability associated with detachment of individual carbonate blocks and the formation of cavities around larger embedded blocks within the block–matrix structure. These instability mechanisms developed rapidly following excavation, typically immediately after blasting and prior to the installation of primary support, indicating that the most critical stability window occurred between excavation and support installation.

A particularly important observation was the strong correlation between excavation stability and the presence of pre-support measures. In the portal sections, where pipe roof support was systematically installed over approximately the first 25–35 m of excavation length, tunnel behavior was notably stable, with a significant reduction in block detachment, cavity formation, and local collapses. Based on construction observations, the application of pipe roof pre-support reduced the occurrence of excavation instabilities by more than 90%, demonstrating its high effectiveness in improving ground arching, confinement, and short-term face stability in shallow BIM rock mass conditions. Similarly, in zones reinforced with fiberglass face bolts, no significant face instability or block collapse was recorded, confirming the effectiveness of localized face reinforcement near tunnel portals.

A clear change in excavation behavior was observed beyond the termination of pipe roof support zones. As excavation progressed outside the pre-supported sections, the frequency and intensity of localized block detachments increased noticeably, particularly in structurally disturbed zones where discontinuities were present around the excavation boundary. These observations suggest that, despite the generally favourable dry groundwater conditions and relatively stable matrix consistency, the inherent heterogeneity of the BIM rock mass remained a dominant controlling factor for local excavation stability. Under such conditions, excavation methodology also required continuous adaptation, particularly regarding blasting patterns and charge distribution, in order to minimize overbreak and reduce disturbance of the already structurally sensitive block–matrix system.



Fig. 3 Appearance of characteristic cracks and collapses of blocks from the tunnel crown.

Differences in excavation response were also observed between the two parallel tunnels. The right tunnel, excavated after completion of the left tunnel, exhibited noticeably greater localized block instability and more frequent block detachments. Although this observation was primarily qualitative, it is considered likely that excavation of the first tunnel induced stress redistribution within the relatively narrow rock pillar separating the two openings, thereby influencing the mechanical response of the surrounding rock mass during excavation of the second tunnel.

Despite these localized instability phenomena, the performance of the optimized hybrid primary support system proved highly satisfactory once installed. No significant post-support instability, structural distress, or excessive deformation was observed. Convergence monitoring along the tunnel alignment recorded displacements generally in the range of 20–25 mm at multiple measurement sections, which can be considered very favourable behavior for tunnels excavated in such complex BIM geological media. The absence of significant groundwater inflow was an important positive factor contributing to the overall stability and satisfactory support performance.

5 Discussion and Conclusions

The presented case study demonstrates that successful tunnel excavation in BIM rock masses requires an engineering approach that extends beyond the direct application of conventional rock mass classification systems. Although such classification methods provide a useful basis for preliminary support design, the excavation behavior observed at the Farish tunnels confirmed that local geological conditions and block–matrix interaction govern excavation stability to a much greater extent than the overall rock mass classification. Consequently, continuous engineering geological observations during construction proved essential for adapting excavation procedures and support measures to the actual ground conditions encountered.

The observations obtained during construction are generally consistent with previous studies on BIM rock masses, which emphasize that excavation response is primarily controlled by the interaction between competent rock blocks and the weaker surrounding matrix rather than by the average mechanical properties of the rock mass (Medley, 1994; Napoli et al., 2021). However, unlike most published studies, which primarily focus on the engineering geological characterization and classification of BIM rock masses, the present case study provides practical evidence from full-scale tunnel construction, highlighting the relationship between ground improvement measures, primary support optimization, and observed excavation performance under predominantly dry BIM rock mass conditions.

The Farish tunnel case further demonstrates that local geological conditions, particularly the absence of significant groundwater inflow, may substantially influence the required support philosophy. Under the predominantly dry conditions encountered during construction, excavation, instability was governed mainly by localized block detachment and cavity formation, while large-scale deformation

of the excavation profile remained limited. These observations indicate that, in similar geological environments, engineering effort may be more effectively directed towards improving the surrounding rock mass than towards adopting increasingly conservative primary support systems.

Another important practical observation concerns the need for continuous adaptation of excavation procedures. Due to the pronounced heterogeneity of the BIM rock mass, blasting patterns, charge distribution, and excavation sequences required frequent modification as geological conditions changed along the tunnel alignment. Such adjustments, together with continuous geological mapping and monitoring, enabled safe excavation despite the locally unpredictable behaviour of the rock mass.

The experience gained from the Farish tunnels indicates that, under shallow and predominantly dry BIM rock mass conditions, greater engineering benefit can be achieved by investing in understanding and improving the ground ahead of excavation—particularly through extended pipe roof pre-support—rather than by simply increasing the intensity of the primary support system. The optimized hybrid support concept applied in this project provided satisfactory structural performance while significantly improving construction efficiency and reducing construction costs. The practical observations and engineering experience presented in this study may contribute to more reliable, economical, and adaptable tunnel design and construction in similar BIM rock mass environments.

References

Medley E (1994) *The engineering characterization of mélanges and similar block-in-matrix rocks (BIMROCKS).* PhD Dissertation, University of California, Berkeley.

Medley E, Goodman RE (1994) Estimating the block volumetric proportions of mélanges and similar block-in-matrix rocks (bimrocks). *Proceedings of the 1st North American Rock Mechanics Symposium*, Balkema, Rotterdam, pp 1031–1038

Napoli ML, Barbero M, Scavia C (2021) Tunneling in heterogeneous rock masses with a block-in-matrix fabric. *International Journal of Rock Mechanics and Mining Sciences*138:104655. DOI: 10.1016/j.ijrmms.2021.104655.

Nikolaidis G, Saroglou C (2016) Engineering geological characterisation of block-in-matrix rocks. *Bulletin of the Geological Society of Greece***50**(2):874–884. DOI: 10.12681/bgsg.11793.