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Stability Analysis and Support Design for the Deepening of the Main Shaft in Trepça Mine, Kosovo

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Abstract

In this paper, the stability analysis and preliminary support design for the Trepça main shaft deepening are addressed, thereby enabling the opening of new horizons (i.e., mining levels). Field investigations and rock mass classification systems (e.g., RMR, RMQR) indicate that the breccia, schist, and limestone rock masses along the shaft excavation exhibit stability problems, necessitating an optimal supporting structure. Using the finite element numerical method, the performance of the support systems recommended by the empirical methods was successfully evaluated. The numerical analyses and results showed that the empirical methods are not always valid and fail to investigate the performance of the supporting deep structures for weak and very weak rock masses. In this study, a series of numerical analyses was performed to evaluate different possible support scenarios. Accordingly, for three main different geological lithologies (e.g., breccia, schist, limestone), an optimal support system is proposed, with a concrete lining thickness ranging from30 to 50 cm with concrete class C25 and C30. Consequently, satisfactory results were obtained and analysed with respect to total displacements and the thickness of the plastic zone.

Keywords

Shaft deepening, Rock mass classification, Excavation support-interaction, Numerical modelling.

1 Introduction

The development of underground mines requires the construction of various openings such as vertical shafts, horizontal galleries, drifts, ramps, chambers, and other auxiliary excavations. Among these underground structures, shafts play a crucial role in overall mining operations, serving multiple purposes, including personnel transportation, installation of service pipelines, ore haulage, ventilation management, and supplying underground storage. Shaft sinking must ensure long-term stability and operational safety under varying geological and geomechanical conditions. Accordingly, the purpose of this study is to assess the stability and preliminary support design of the shaft at different excavation depths, while keeping the rock mass constant. The main shaft of the Trepça mine is located in the city of South Mitrovica, Stan Tërg village, Kosovo. The shaft is equipped with a skip hoist and a cage hoist used for the transportation of personnel, materials, and mined-out ore. Shaft sinking started in 1948, with work continuing until 1960, and connected to mining levels at + 610 m (1st level), +15 m (11th level). The shaft has a circular shape, and its diameter is 6.5 m along its entire length, while the useful diameter of the shaft is 5.5 m (Fig 1). The shaft is currently being investigated to be deepened from a level of -48 m (12th level) to approximately -168 m (14th level), so as to provide access to a new mining level at a depth of 930 m. Groundwater conditions were not identified as a major concern in the area of the shaft due to the low permeability of the schist rock mass and, in general, stable hydrogeological conditions. During shaft construction, when encountering highly deformable schist, the shaft requires a 50 cm lining thickness. The concrete lining was installed using metal formwork in sections 3 m in length. The officially designated production capacity of the mine initially stood at 500 t/day, was quickly increased to 1,500 t/day, and, from 1932, reached 2,000 t/day, remaining at this level until 1990. Currently, the mine's annual production capacity averages 150,000–200,000 t/year (Ademi 2025).

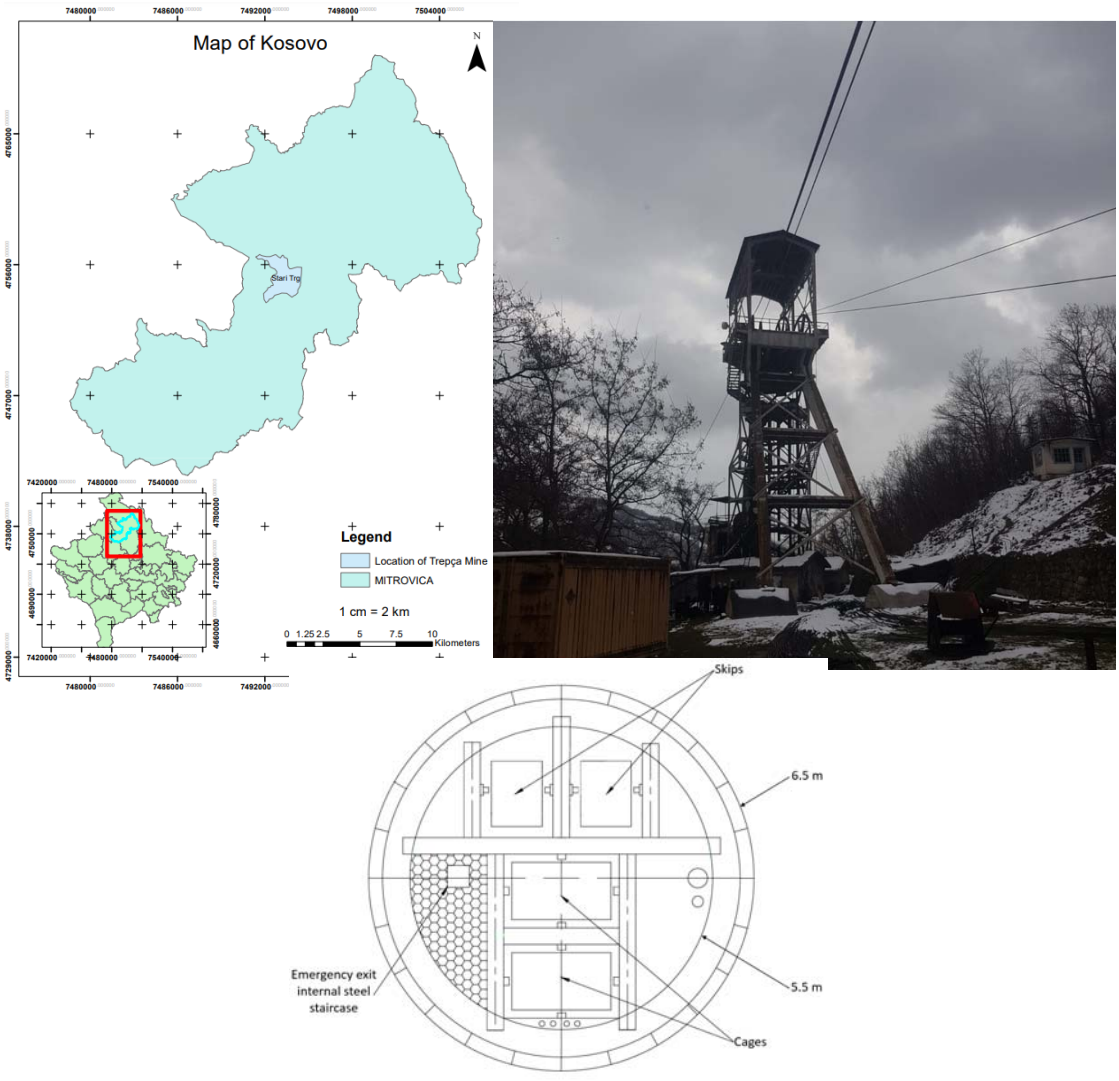


Fig. 1 Shaft headframe and a plan view schematic of the mine shafting showing cage and skip compartments.

2 Rock mass engineering characteristics

2.1 Intact rock parameters

Comprehensive geotechnical field investigations, combined with laboratory testing, provide essential data for shaft stability and preliminary support design within a level range of +15 m to -165 m, which have been taken into consideration. Owing to the lack of laboratory test data for the modulus of deformation (E_i) and m_i, these parameters were estimated using empirical equations derived by the authors (Hoek and Diederichs 2006). The fundamental rock mechanical parameters of intact rock material, RQD values for different geological lithologies in levels +75 m to -165 m, are summarized in Table 1.

Table 1. Fundamental rock mechanical parameters of intact rock for different lithological units (Ademi 2025).

Rock parameters	**Geological lithology**		
	Breccia	Schist	Limestone
γ (kN/m^3)	28.6	26.4	28.3
$I_{s(50)}$ (MPa)	3.04	1.98	2.81
σ_{ci} (MPa)	66.9	43.6	61.8
RQD (%)	33.4	27.7	52.8
E_i (GPa)*	33.5	29.4	52.5
m_i	19±5	10±3	9±3
v	0.17	0.18	0.19

*$E_i = MR \times \sigma_{ci}$

2.2 Rock mass classifications and parameters

In this study, the Rock Mass Rating – RMR (Bieniawski 1989) and Rock Mass Quality Rating – RMQR (Aydan and Ulusay 2013) systems were used to estimate rock mass quality and recommend support systems, and the Geological Strength Index-GSI (Hoek et al. 1995) system was adapted to determine rock mass strength parameters. The input rock mass strength parameters for analytical and numerical modelling are tabulated in Table 2.

Table 2. Rock mass classification systems and Hoek-Brown rock mass parameters for different lithological units.

Rock parameters	**Geological lithology**		
	Breccia	Schist	Limestone
RMR_{89}	49	38	58
RMQR	47	36	56
GSI = RMR_{89} - 5	44	33	53
σ_{cm}(MPa)	2.8	1.1	4.8
E_m(GPa)	7.01	3.34	20.3
m_b	2.57	0.91	1.68
s	0.00198	0.00058	0.0054
a	0.51	0.51	0.50

2.3 Pre-mining stress

In the absence of in-situ stress field measurements, hydrostatic conditions were assumed. Considering the average unit weight of the overburden rock of 27 kN/m^3, estimated values of the horizontal and vertical stress at a depth range of 800 m to 930 m vary between 21.6 and 25.1 MPa.

3 Shaft stability and support design

3.1 Empirical method

Before any support system selection, the self-stabilizing span and the maximum stand-up time should be determined for a particular rock mass based on empirical classification systems for preliminary study analysis. Clearly, this study suggests that it cannot meet the shaft stability requirements; therefore, it is necessary to select an optimal support system for deeper excavation sections.

Accordingly, the RMR and RMQR suggestions include rock bolts, shotcrete, and steel ribs, which have been taken into consideration, and the results are shown in Tables 3 and 4.As a matter of fact, the current vertical main shaft support system consists of a0.3 to 0.5 m thick concrete lining, which functions as a rigid passive support and is in good alignment with RMQR suggestion (see Table 4). However, in practice, RMR suggestions regarding concrete lining could not be accommodated or adapted freely in this engineering problem. On the other hand, authors (Zhao et al. 2023) found that, in deep rock excavations, such a support system (i.e., a single concrete lining) is unable to effectively accommodate the high in-situ stresses of the surrounding rock, often resulting in local stress concentrations and reduced stability.

Table 3. RMR empirical support system guide (Bieniawski 1989).

Rock mass class	Rock bolts	Shotcrete	Steel ribs
RMR:41-60 Fair rock **(49)&(58)**	Systematic bolts 4 m long, spaced 1.5–2 m in crown and walls with wire mesh	50 – 100 mm in the crown and 30 mm in sides	None
RMR:21-40 Poor rock **(38)**	Systematic bolts 4-5 m long, spaced 1–1.5 m in crown and walls with wire mesh	100 – 150 mm in crown and 100 mm in sides	Light ribs spaced 1.5 m where required

Table 4. RMQR empirical support system design (Aydan and Ulusay 2013).

Rock mass class	Rock bolts		Shotcrete	Steel ribs		Wire mesh	Concrete lining (mm)
	L_b (m)	e_b (m)	t_s (mm)	Type	e_y (m)		
60≥RMQR>40 (**47**)&(**56**)	4-5	1.5	150	Medium	1.2	Yes	300
40≥RMQR>20 (**36**)	5-6	1.0	200	Heavy	1.0	Yes	500

Therefore, a more effective approach is to use active support systems, such as rock bolts, which allow controlled deformation and improved interaction between the lining and the surrounding rock mass. For numerical and analytical analysis, geometrical and mechanical engineering parameters for different rock support systems given by RMR and RMQR are summarized in Table 5.

Table 5. Geometrical and mechanical engineering properties of support systems used in numerical analysis.

Rock bolts		Shotcrete/Concrete lining		Wire mesh	
D (mm)	23	E_c (GPa)	30; 32	a (m)	0.6
E_b(GPa)	200	ν	0.2	d (m)	0.012
σ_t(MN)	0.1	σ_c(MPa)	30; 37	I (m^4)	1.02×10^{-9}
σ_{rt} (MN)	0.01	σ_t (MPa)	1.8; 1.9	E_w(GPa)	200
a (m)	1	t_c (m)	0.3; 0.5	ν	0.25
				σ_c (MPa)	400
				σ_t(MPa)	400

3.2 Analytical method

To analyse this problem, the Convergence Confinement Method (CCM) proposed by Carranza-Torres and Fairhurst (2000) is used. For comparison and validation, analytical results are provided in Table 6. Hence, both numerical and analytical results show a good match and provide a “face effect” of approximately 3 to 4 meters.

3.3 Numerical method

Even though the empirical rock mass classification systems used by engineers help them design the preliminary support system, they still do not provide any information on the extent of the plastic zone around underground excavations and the total maximum displacement needed for optimal support installation time.

Table 6. Radius of plastic zone values obtained from the convergence-confinement method (CCM) and numerical analysis (FEM) for non-supported and lining-supported structures.

Lithology	**Shaft sinking depth and in-situ stress**	**CCM Radius of the plastic zone, R_{pl}/R**		**CCM Total maximum displacement, u_{rmax} (mm)**	
		Unsupported	Supported	Unsupported	Supported
Breccia	P_o = 21.6 MPa	1.4	1.2	20.5	13.6
Schist	P_o= 23.2 MPa	2.9	2.2	151.8	83
Limestone	P_o= 24.8 MPa	1.7	1.4	10.7	6.8

For these purposes, to validate the suitability of the proposed support systems described in Section 3.1, was investigated by the FEM numerical simulation program Phase[2]and the Convergent-Confinement Method (Carranza-Torres and Fairhurst 2000), with respect to the maximum total displacement and thickness of plastic zone development around the shaft mining both unsupported and supported conditions for different depths (e.g., 800 m, 860 m, and 920 m).In this study, the Hoek-Brown failure criterion was used. The rock mass was assumed to behave as an elastic-perfectly-plastic material. Numerical solution accuracy is closely linked to the size of the boundary. Thus, the external boundary was defined as a circle with a radius of 110 m. Mesh and discretization settings are as follows: radial mesh type; a four-nodded quadrilateral element unit was adopted, whereas the surrounding rock in the shaft area was densified. A total of 12,000 nodes and 11,840 quadrilateral elements were used. In Fig 2, the established numerical model of the shaft is shown together with the shaft support models. Even though some of the investigations in this study indicated no rock bolt support system requirement for the shaft excavation along the breccia rock mass, rock bolts might be applied to protect the openings against rock sliding/falling. This suggestion is based on the fact that the main underground excavations, including shafts, serve as the main artery connecting the surface to the underground. Length of the bolts should be 3.0 m with bolt spacing of 2.0 m. Hence, the numerical results given in Fig 2 show that the application of a concrete lining of thickness 300 mm is sufficient to maintain equilibrium total displacement and to inhibit the extent of the plastic zone. Total displacement values after support decreased to 15 mm, and the plastic zone/radius of opening ratio decreased to 1.3. From the support capacity diagrams (Fig 2), it is well understood that shaft deepening in breccia and limestone requires a combined support such as wire mesh with a diameter of 6 mm and a concrete lining thickness of 30 cm corresponding to C25 concrete class parameters. Whereas, shaft deepening in the schist rock mass requires a wire mesh with a diameter of 6 mm and a concrete lining thickness of 50 cm corresponding to C30 concrete class parameters, as are tabulated in Table 5.

4 Conclusion

This study elaborated on 2D numerical modelling of shaft stability using the finite element method. Conducted numerical analysis investigated the maximum total displacement and thickness of the plastic zone. Based on the numerical and supported by empirical and analytical results, suggestions were finally made to select the proper support system during shaft deepening along three different geological lithologies. Rock support suggestions made based on the numerical modelling are close to those estimated based on the RMQR system. Nevertheless, some differences exist. This study provides a global procedure for stability assessment and rock support design for underground excavation projects.

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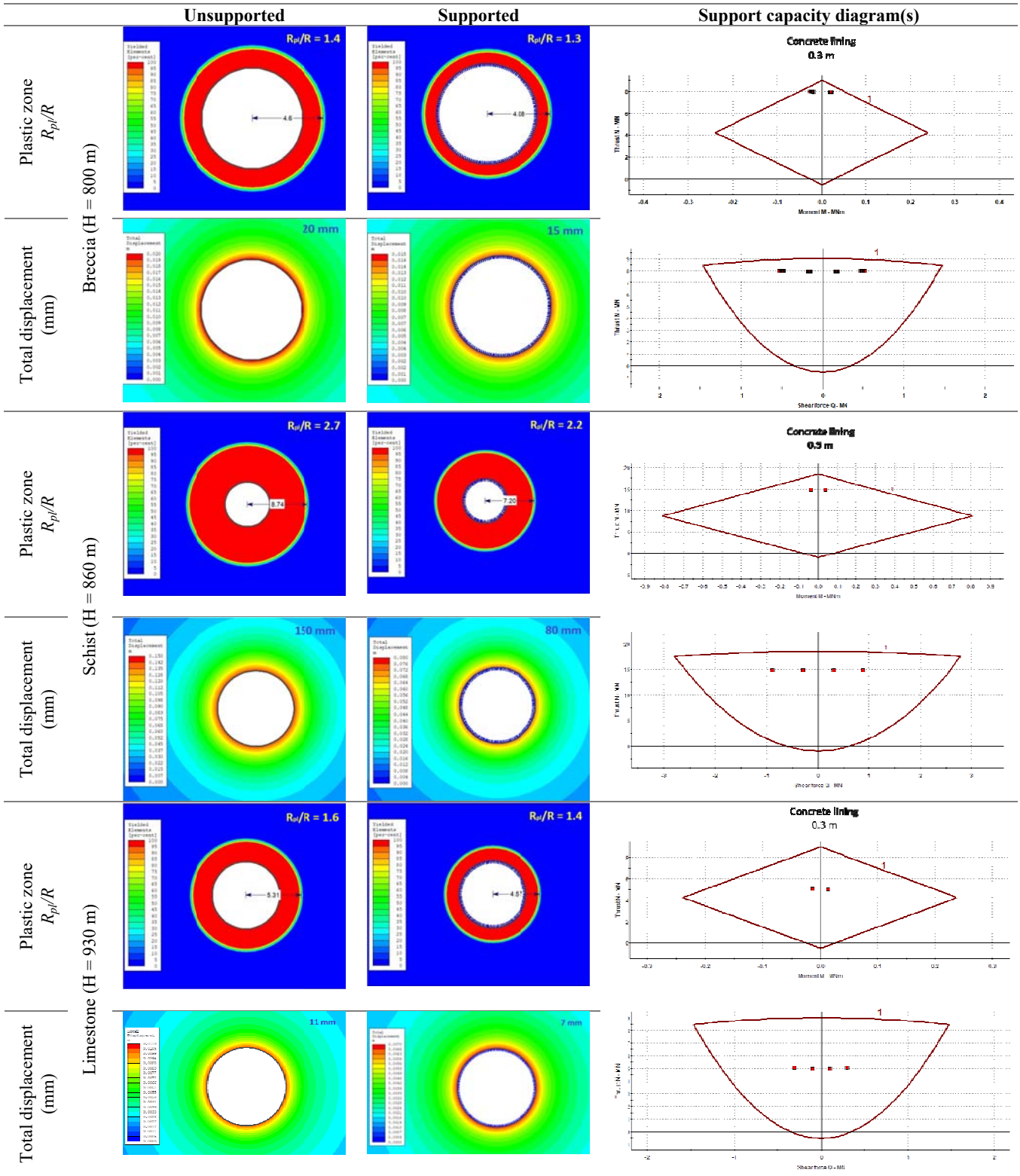


Fig. 2 Numerical model results for shaft deepening along breccia, schist, and limestone rock masses.