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Engineering-Geological characteristics of the terrain along the regional road in RN Macedonia, section of v. Novo Konsko – Dam Konsko

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Abstract

The regional road under consideration in this paper represents an important transportation link between the city of Gevgelija, the Kozhuf Ski Center, and the Konsko Dam. The section extending from the village of Novo Konsko to the Konsko Dam is situated in mountainous terrain, which has necessitated the construction of numerous cut slopes.

Most of the existing slopes require rehabilitation measures, including vegetation clearing, slope unloading, and the implementation of new protective systems. Detailed engineering-geological investigations were conducted for each slope, including engineering-geological mapping, slope zoning, structural-geological mapping, assessment of the strength of jointed rock masses using a Schmidt hammer, and sampling for laboratory testing.

The collected data provide a basis for the application of geological and geotechnical software analyses, enabling the determination of relevant parameters and supporting the design of appropriate slope stabilization and protection measures. These activities are aimed at ensuring the safety, stability, and long-term sustainability of the road infrastructure.

Keywords

Regional Road, Section Novo Konsko - Village to Konsko Dam, Engineering-Geological Characteristics, Slope Stability.

1 Introduction

This paper presents a brief excerpt from the project documentation prepared for the protection and rehabilitation of existing slopes along the regional road section between Konsko Dam and the village of Novo Konsko, North Macedonia.

The main objective of the project was to identify slopes requiring protection and rehabilitation through detailed field investigations. For this purpose, comprehensive investigations were conducted to define the lithological units, classify and zone the slopes according to their structural-geological characteristics, analyze discontinuities and failure mechanisms using appropriate geological software packages, and perform laboratory testing to determine the physical and mechanical properties of the materials involved.

The obtained data enable the application of geological-geotechnical software packages for analysis and the definition of parameters, providing the basis for further design of slope stabilization and protection measures, aimed at ensuring safe and long-term sustainable road infrastructure. The field investigations and laboratory testing were carried out during 2025 year.

2 Geological Characteristics of the Terrain

To obtain detailed and representative data for the investigated road section, particular attention was given to the geological characteristics of the wider area through detailed engineering-geological mapping. In addition to collecting data on geological and genetic characteristics, comprehensive mapping of all visible outcrops and identification of geological boundaries between the bedrock units were performed (Figure 1).



Fig. 1 Detailed mapping of all visible outcrops and monitoring of the geological boundaries of the bedrock in the terrain.

Subsequently, the degree of fracturing and weathering of the rocks was assessed, the visible tectonic and structural-geological elements of the present rock masses were identified, as well as the possible occurrence of recent geological processes and phenomena, the geomorphological features of the terrain, etc..

The engineering-geological characteristics of the terrain were determined primarily through investigations of the existing slopes along the regional road, which served as open profiles for detailed examination. A total of 53 measuring points were established and analyzed from an engineering-geological perspective.

To determine the engineering-geological, hydrogeological, and geotechnical characteristics of the terrain, an appropriate scope of investigative works was carried out at these measuring points. In addition to field structural-geological measurements, representative samples were collected for laboratory testing to define the physical and mechanical properties of the rock materials present within the terrain and along the slopes of the regional road. These data provided the basis for the subsequent analyses and the design of appropriate slope stabilization and protection measures.

2.1 Geological Structure of the Terrain

From a geological perspective, several lithogenetic units are present within the investigated area, characterized by different geological ages, physical and mechanical properties, and varying significance with respect to slope stability.

Along the studied road section, the slopes are predominantly formed as cut slopes on the left side of the roadway within a geological environment composed of wehrlites and troctolites, olivine gabbro, predominantly normal gabbro, and normal diabase. These rock masses constitute the bedrock of the terrain and exhibit varying degrees of weathering and fracturing, which directly influence the engineering-geological conditions of the slopes.

All of the aforementioned rock units are locally overlain by deluvial sediments of variable thickness, as shown in Figure 2.

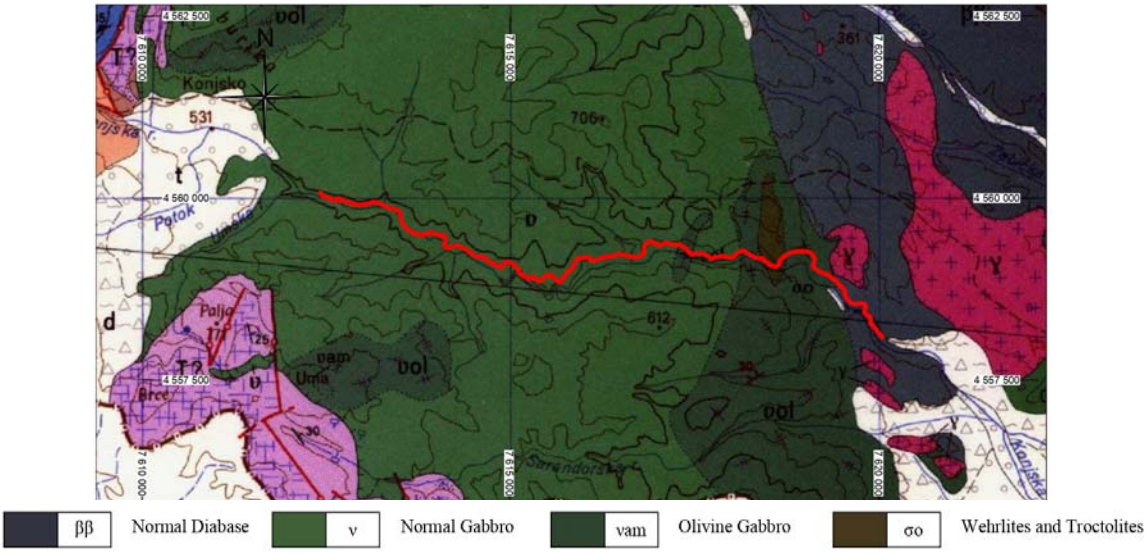


Fig. 2 Geological structure of the terrain and the represented geological units.

2.2 Contemporary Geological Processes and Phenomena Affecting Terrain Stability

Considering the geomorphological configuration and geological characteristics of the terrain within and around the investigated area, it can be concluded that modern geological phenomena and processes caused by the action of external factors are present, i.e. exogenous geological processes (atmospheric and hydrospheric influences), etc. In terms of the presence of modern geological processes, the existence of the following processes has been determined on the terrain:

- Rockfall and sliding processes involving portions of rock masses on unstable slopes along the section between Konsko Dam and Novo Konsko Village;
- Surface weathering processes affecting intact and fractured rock masses under the influence of atmospheric agents such as frost action, water infiltration, temperature fluctuations, and other weathering factors. These processes contribute to the gradual degradation of the rock masses and are particularly pronounced on the existing cut slopes that are the subject of monitoring and rehabilitation;
- Surface erosion processes, manifested as linear erosion and gully erosion of varying intensity. These processes result from the action of surface runoff and intermittent watercourses, which erode slope materials and transport sediments downslope. They are most pronounced within geological environments composed of deluvial sediments;

- Torrential deposition processes, observed in the steeper sections of dry gullies, where torrential deposits formed by flash-flood events are present. These deposits indicate the transport and accumulation of loose material, including locally large rock fragments and boulders.

3 Classification of Rock Masses

The conducted investigation works identified and characterized the materials present along the investigated route through detailed field mapping and laboratory testing. Based on these investigations, the physical-mechanical, strength, and deformability characteristics of the rock masses were determined.

For each representative measurement location, the most significant structural features of the rock masses were defined, including foliation, degree of fracturing, fracture systems, faults, and other discontinuity structures. These parameters were assessed in relation to the physical-mechanical properties and the overall condition of the rock masses.

Structural-geological measurements were carried out at locations where terrain conditions permitted detailed investigation, resulting in a total of 53 representative measurement points along the route.

The graphical presentation of the identified structural elements was incorporated into the Engineering-Geological Map (Figure 3), while the characteristics of each registered discontinuity set were systematically documented in the discontinuity (fracture) inventory database.

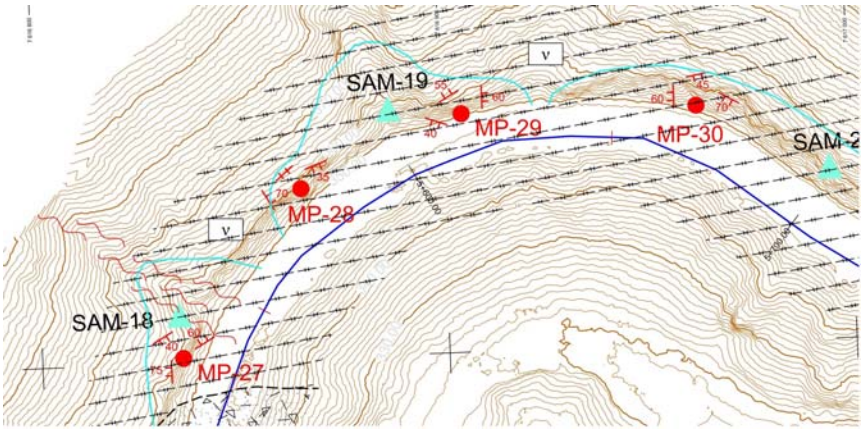


Fig. 3 Structural elements within the Engineering-Geological Map.

The strength of the intact rock portions was determined by evaluating the strength index through laboratory testing using a Franklin Point Load Tester, complemented by field assessments performed with a Schmidt hammer.

The shear strength and deformability parameters of the rock masses were determined according to the empirical Hoek–Brown failure criterion for rock masses. These parameters provide a more realistic representation of the mechanical behavior of the rock mass than the properties of intact rock alone, as the stability and deformation characteristics are controlled by the overall condition of the rock mass, including the presence and characteristics of discontinuities.

Following the field and laboratory investigations conducted at each measurement point, and based on the determined physical-mechanical properties and the condition of the rock masses, a classification of the rock masses was performed according to the Slope Mass Rating (SMR) system proposed by Romana (1985).

The SMR classification is specifically designed for the assessment of rock slope stability and enables the evaluation of potential failure mechanisms, including planar sliding, wedge sliding, toppling, and rockfall processes (Figure 4).

Classification of slopes according to SMR according to Romana 1985
Slope 19, measuring point MP-29, compact gabbro: **SMR=51.75**

A. Classification parameters and their ratings									
$RMR_b = \Sigma$ RAITINGS (BIENIAWSKI)									
Parameter			Range of values						
1	Strength of intact rock material	Point load strength index I_s (MPa)	>10	4÷10	2÷4	1÷2	<1		
		Uniaxial comp. strength σ_p (MPa)	>250	100÷250	50÷100	25÷50	5÷25	1÷5	<1
	Rating		15	12	7	4	2	1	0
2	Drill core quality RQD (%)		90÷100	75÷90	50÷75	25÷50	<25		
	Rating		20	17	13	8	3		
3	Spacing of discontinuities		>2 m	0,6÷2 m	0,2÷0,6 m	0,06÷0,2 m	< 0,06 m		
	Rating		20	15	10	8	5		
4	Condition of discontinuities		very rough surfaces not continuous no separation unweathered wall rock	slightly rough surfaces separation < 1mm slightly weathered walls	slightly rough surfaces separation < 1 mm highly weathered walls	slickensided surfaces or gouge < 5 mm thick or separation 1-5 mm continuous	soft gouge >5 mm thick or separation > 5 mm continuous		
	Rating		30	25	20	10	0		
5	Ground water	General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
	Rating		15	10	7	4	0		

B. Rating adjustment for discontinuity orientations						
Failure case		a_j –dip direction of discontinuity; b_j –dip angle of discontinuity; a_s –dip direction of slope; b_s –dip angle of slope;				
		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Planar failure	(a_j-a_s)	>30°	30-20°	20-10°	10-5°	<5°
Toppling	$(a_j-a_s-180°)$	>30°	30-20°	20-10°	10-5°	<5°
values of : F_1		0.15	0.40	0.70	0.85	1.00
Relation		$F_1 = [1-\sin(a_j-a_s)]^2$				
b_j		<20°	20-30°	30-35°	35-45°	>45°
Planar failure		0.15	0.40	0.70	0.85	1.00
Toppling		1.00				
Relation		$F_2 = tg^2\, b_j$				
Planar failure	b_j-b_s	>10°	10-0°	0°	0-(-10°)	<-10°
Toppling	b_j+b_s	<110°	110-120°	>120°	/	/
values of : F_3		0	-6	-25	-50	-60
Relation		F_3 – relation between dip angle of slope and discontinuity				
Correction factor for excavation method		Natural slope	Previously contoured	Smooth blasting	Normal blasting	Very poor blasting
values of : F_4		+15	+10	+8	0	-8

C. Description of SMR classes					
$SMR = RMR_b+(F_1 \times F_2 \times F_3)+F_4$					
Rating	100-81	80-61	60-41	40-21	0-20
Class number	I	II	III	IV	V
Description	Very good	Good rock	Favorable rock	Bad rock	Very bad
Stability	Completely stable	Stable	Partially stable	Unstable	Completely unstable
Potential Failure	No failure	Some block failure	Failure in some of the cracks or a few wedges	Planar fracture or big wedges	Big planar failure or in the form of soil
Support measures	No support	Occasional support	Systematic support	Large-scale corrective measures	Unloading or complete excavation

Fig. 4 SMR classification.

4 Condition of Fracturing

To characterize the fracturing condition of the rock masses, structural-geological methods based on detailed measurements of rock mass discontinuities were applied. These investigations included the determination of discontinuity density, strike and dip orientation, persistence (length), aperture, infilling material, surface condition, and other relevant discontinuity characteristics.

Structural measurements were carried out at representative measuring points located on open profiles, primarily on the cut slopes formed during the construction of the regional road. The orientation of the discontinuity systems is pronounced and often complex; therefore, a detailed description and classification of the identified discontinuity sets were systematically documented in the Fracture Cadastre (Discontinuity Inventory).

To better illustrate the relationship between the discontinuity systems and the slope geometry, geological cross-sections were prepared, clearly showing the orientation (strike and dip) of the discontinuities relative to the slope faces and terrain morphology.

It is well established that the spatial distribution and orientation of discontinuities exert a significant influence on the mechanical behavior, physical-mechanical properties, and potential failure mechanisms of hard rock masses. Consequently, particular attention was devoted to the characterization and analysis of discontinuity properties using the software package **Dips (Rocscience)**.

The collected structural data were processed through statistical and graphical analyses based on stereographic projection techniques. These analyses enabled the identification of the dominant discontinuity sets and the assessment of their influence on the structural control of slope stability. Furthermore, the obtained results provided the basis for kinematic analyses aimed at identifying potential instability mechanisms, including planar sliding, wedge sliding, and toppling failures (Figure 5).

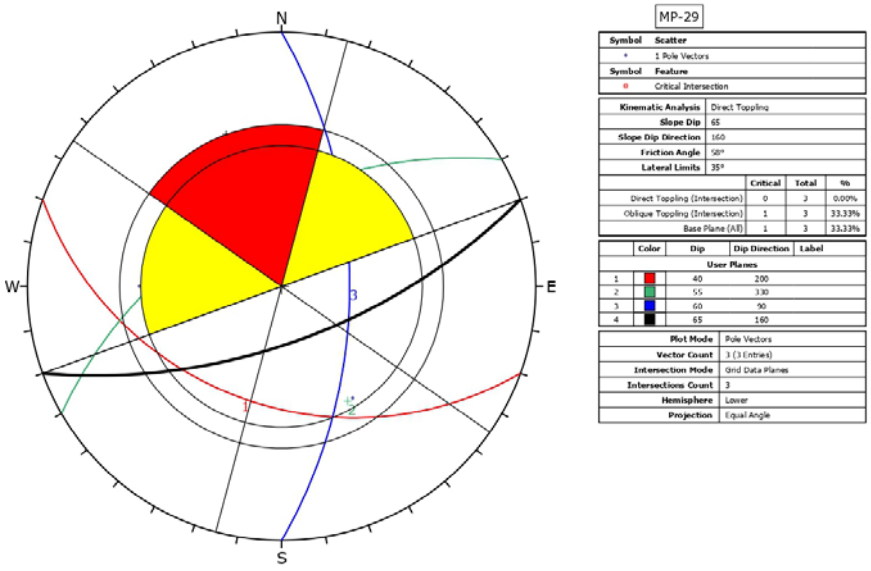


Fig. 4 Kinematic analysis of discontinuities using the software program "Dips-Rocscience".

For each surveyed measurement point (MP) within the slope zones, a kinematic analysis was performed. In correlation with the slope stability assessment conducted according to the Romana (1985) SMR classification system, appropriate stabilization and protection measures were proposed for each slope. These measures are described in detail in the following section.

5 Conclusions

Dr. Hoek's Based on the conducted analyses of the geological, engineering-geological, and geotechnical characteristics of the terrain, including the structural and textural properties of the rock masses, discontinuity systems, discontinuity orientations, and slope geometry, appropriate slope stabilization and protection measures have been recommended.

Depending on the specific geological and geotechnical conditions of each slope, different stabilization approaches may be applied either individually or in combination to ensure long-term slope stability and road safety.

The proposed slope stabilization and remediation measures include:

- Installation of protective galvanized steel wire mesh;
- Installation of protective galvanized steel wire mesh combined with slope regrading (slope flattening);
- Removal of fallen and loose material followed by installation of protective galvanized steel wire mesh;
- Removal of fallen and unstable material, drilling and installation of rock anchors, and installation of protective galvanized steel wire mesh;
- Removal of unstable rock blocks and placement of protective galvanized steel wire mesh.

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