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Consulting activities for slopes protection and rather other geotechnical problems for Express road A2 Rankovce– Kriva Palanka, RN. Macedonia

S. Georgievski, D. Todorova, Lj. Zrlev & T. Dimitrievski
Geing L.T.D, Skopje, N.Macedonia
saso.g@geing.com.mk

Abstract

The A2 express road section Stracin–Kriva Palanka represents a major infrastructure project of strategic importance for the northeastern region of the RN Macedonia. Due to the complex engineering-geological and morphological conditions of the terrain, a total of 50 slopes were designed and constructed within the project. Detailed engineering-geological control was carried out for each slope, including field geological mapping and, where required, additional geotechnical investigations. Potential and active instabilities were identified, and both verification and back-analyses of slope stability were performed. 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. Based on the obtained results, optimized technical solutions were proposed and harmonized with the actual engineering-geological conditions, with particular emphasis on slope inclinations, berms, anchoring systems, protective meshes, and bioengineering measures. The process was accompanied by continuous analysis of ongoing and planned activities, as well as verification and approval of design modifications. The implemented engineering-geological activities were evaluated from geotechnical, techno-economic, economic, and visual perspectives, with the aim of ensuring stable, safe, and long-term sustainable road infrastructure. The collected data provide 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

Expressway A2, Engineering-geological control for construction, Slopes.

1 Introduction

The construction of modern express road infrastructure represents one of the most important factors for economic development, improved connectivity, and increased traffic safety. During the design and construction of the A2 expressway section Rankovce – Kriva Palanka, geotechnical investigations play a particularly significant role. They enable a detailed understanding of the engineering-geological and geomechanical characteristics of the terrain, with the aim of ensuring safe, stable, and cost-effective road construction. 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. Geotechnical investigations serve as the basis for the proper design of the road structure, slopes, embankments, retaining structures, and facilities along the route. Through these investigations, the composition and bearing capacity of the soil and rock masses, the groundwater level, terrain stability, and potential geological risks are determined.

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 for micro locations for structures and also 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. 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. In the part of soil materials, erosion and landslides forms were determined. 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. 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. The most represented are schists rock mases covered by deluvial sediments from quaternary age.

3 Method of geotechnical investigations and geotechnical problems along the route

The geotechnical investigations were carried out through field and laboratory testing. Geotechnical investigations are consisted of site investigations and laboratory testing. Site activities included: engineering-geological mapping, exploratory boreholes, excavation of trial pits; SPT and CPT tests, geophysical investigations, measurement of groundwater levels. The following parameters and calculations were determined during the laboratory and desk work: moisture content, grain size distribution, plasticity, density, cohesion, angle of internal friction, bearing capacity and deformability.

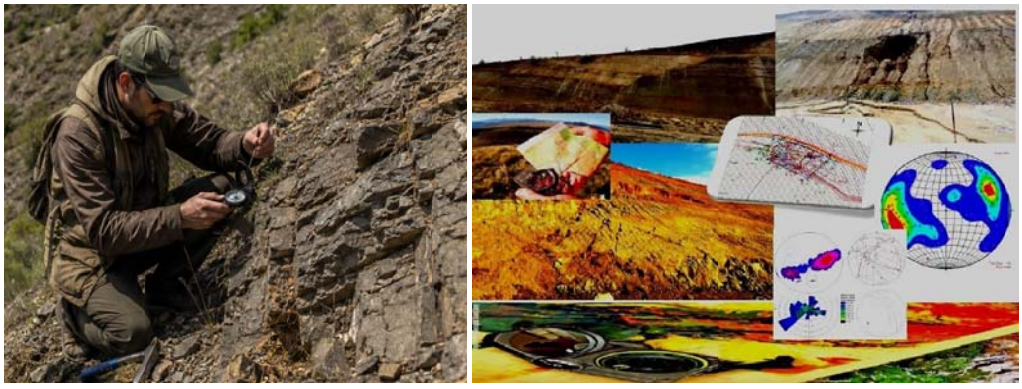


Fig. 1 Geotechnical structural investigations for cut km 9+389 – km 9+585.

Geotechnical investigations provide the necessary data regarding the stability and bearing capacity of the terrain, enabling safe and durable road infrastructure. During investigations of such road sections, the following issues most commonly occur: occurrence of landslides, slope erosion, instability of

excavations, presence of groundwater, weak bearing soils. To overcome these problems, various engineering solutions are applied, such as: retaining walls; drainage systems, slope reinforcement; geogrids and geotextiles; installation of anchors and protective meshes; installation of piles in unstable zones; construction of gabions in unstable zones; rehabilitation and stabilization of the terrain. 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. 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 strength of the intact rock portions was determined by evaluating the point load strength 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. 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).

Engineering-geological characteristics of the cuts: Left side of the road: When mapping the terrain on the left side of the road, first of all, an fill material is present, then decomposed and cracked albite-epidote-chlorite schists (Sep') and compact albite-epidote-chlorite schists with fracture systems (Sep). The materials present are characterized by pronounced schists, which at this location has a favourable dip, but there are fracture systems in relation to the slope, which could cause landslides. **Right side of the road:** When mapping the terrain on the right slope of the road, intensively decomposed albite-epidote-chlorite schists to diluvial sediments (d/Sep'') are noted, followed by decomposed and cracked albite-epidote-chlorite schists (Sep') and compact albite-epidote-chlorite schists with fracture systems (Sep). However, there are fracture systems that have a favourable dip. When determining the material parameters, the cohesion between the fracture system was first varied, which ranged from 0-10 kPa for different materials, while the strength of the rock itself did not play a major role in the stability of the slope. Generally, the materials present in this section have a foliation dip of 35º-65º and generally move from north to southwest, and these characteristics are favorable for the slope, while in some parts they have an unfavorable impact. The adopted geotechnical parameters for the present materials is shown in table 1.

Table 1. Parameters of lithological units, from geotechnical investg structural investigations.

Rock type	Unit weight γ(kN/m^3)	Joint set internal friction φ(º)	Rock massive internal friction φ(º)	Joint set cohesion c(kPa)	Rock massive cohesion c(kPa)	Transition angle from weathered to solid rock A-B (º)	Dip angle of the rock massif ccw to 1 (º)
Sep	23	30	45	5	30	30-31	40
Sep'	22	30	35	0	25	30-31	-70
d	19	/	28	/	15	/	/

4 Stability analyses and measures

4.1 Calculation of stability

To check the stability of the cuts, the software package Slide 2D 7.0 was used, in which the geometry of the respective cut was modeled and, in accordance with the geological and geotechnical parameters from the mapping, a calculation model was created. When calculating the slopes, the material model (Anisotropic linear) was used, which allows two values to be set for the massif, i.e. the strength of the massif and the strength of joints can be set. The model can also simulate the foliation of the rock massif, i.e. the bedding of the layers of the massif and the transition from the decayed to the healthy schists. First, to determine the parameters of the massifs, regression analyses were performed to determine the strength of the massif at which its stability was disrupted or Fs≈1.00, and with those parameters, an analysis of slope stability was further conducted. The stability analysis on the proposed cut slopes are concerning the notes and recommendation for cuts where landslides have been registered. The input parameters used in the back analyses are taken from geological data, gathered during the site inspections. In the analysis was determined the cohesion of the material along the

foliation and joint sets. There are several steps in the range between 0-10 kPa. After the values of the strength properties are estimated for predetermined factor of safety of Fs 1,00 and slip surface, the next analyses stage is carried out i.e. reshaping of the cut slopes. The back analysis considers the occurred slip surface before reshaping of the cut slopes. The established results give the strength properties which trigger the instability. The provided values of the strength parameters are later used in the stability analysis and bring us to the conclusion that cut slopes should be reshaped in order to provide satisfactory stability. There are 3 load cases. **Load case 1** – this load case introduces reshaped cut slope and considers static loading in order to check the cut slope stability under static loading. The foliation and joint sets are modeled using anisotropic linear material model. The minimum required factor of safety for stable cut slopes should be higher than Fsmin=1,50. **Load case 2** - considers the impact of the rainfalls and climate change on the cut slopes. In this particular case modification of the pore pressure ratio Ru=0,15 in several steps is done. The Consultant from Faculty of Civil engineering and the Designer considering the site geology have agreed that building up of pore pressure is not expected, but yet the impact of the intensive rainfall and ground saturation is considered in the calculation model. Regarding the calculation models and the climate impact it is emphasized that the rock formation encountered on site is schist which cannot be saturated and the ground water flow cannot be developed. Anyway, piezometers can be installed as a part of the future monitoring system. This will be also helpful to resolve any concerns on possibility of high saturation of the ground. **Load case 3** – considers the combination of the rainfall impact i.e. Ru=0.15 and seismic loading (pseudo-static analyses) involving kh=0.1 and kv=0.05 according to seismic zoning of the site. As per existing design code such load cases are not considered and if such load case is used than conservative results on slope stability are expected to be provided.

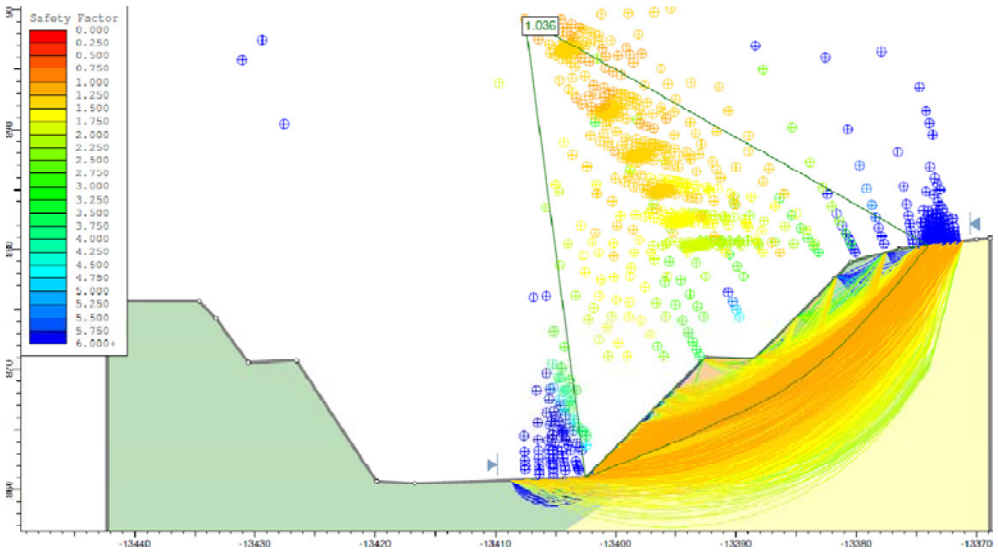


Fig. 2 Back analysis output and stability analysis output involving GWT for cut km 10+075 - km 10+225.

4.2 Slope protection measures

For the protection and stabilization of slopes along the Rankovce – Kriva Palanka expressway route, a so called Type 1 reinforced road mesh made of high-quality steel wire mesh combined with a system of geotechnical anchors was applied. This type of protection is used on unstable rock and soil slopes to prevent rock falls, erosion, and the falling of rock fragments onto the roadway. The mesh is most commonly made of galvanized high-strength steel wires resistant to corrosion and atmospheric influences. It is installed directly on the slope surface and fixed with anchors at specified intervals. The anchors provide additional fastening and transfer forces to more stable layers within the foundation ground, thereby improving the overall stability of the terrain. This system provides long-term slope protection, increased traffic safety, and a reduced risk of landslides and rock falls. Type 2 reinforced road mesh with steel cables and anchors represents a system for active protection of unstable slopes and rock cuttings along the Rankovce – Kriva Palanka expressway route. The system consists of high-strength steel mesh additionally reinforced with supporting steel cables, enabling even distribution of loads and improved stabilization of the surface layer of the slope. The mesh is fixed using geotechnical anchors installed in previously drilled boreholes, while the anchors are grouted with cement mortar to ensure a strong bond with the ground. This type of protection is applied on terrains with an increased risk of rock falls, disintegration of rock material, and erosion.

Type 3 protection is presented with road mesh with polypropylene 3d geogrid and anchors. It is applied for protection against erosion, surface sliding of material, rock falls, and for improving the stability of slopes, embankments, excavations, and landslides. The main elements of the system are polypropylene 3D geogrid with high resistance, steel anchors / anchor bolts, steel plates and tensioning elements, surface drainage when required, biotechnical protection and humus covering. The ddvantages of this system are seen in the low weight and easy installation, resistance to atmospheric influences, possibility for vegetation growth, long-term stability, cost-effective solution for unstable terrain.



Fig. 3 Road mesh with polypropylene 3D geogrid and anchors for cut km 5+900 – km 6+100.

Type 4 protection is presented by road mesh with polypropylene 3d geogrid and without anchors. It is applied on gentler slopes and terrains with lower risk of rock falls and sliding, mainly for erosion control and retention of the surface layer. Main elements of the system include polypropylene 3D geogrid, surface fixing with pins or fasteners, humus layer and vegetation, surface drainage when required. The system enables fast and simple installation, low weight, cost-effective solution, good integration with natural vegetation, resistance to atmospheric influences and UV radiation.



Fig.4 Road mesh with polypropylene 3D geogrid without anchors for cut km 8+425 – km 8+820.

Type 5 protection - Grassing / Grass Covering of Slopes. It consists of sowing grass seeds on the soil surface in order to create a vegetation layer that protects the soil from erosion. The root system of the grass binds the soil, increases its stability, and reduces washing caused by rainwater and wind.



Fig. 5 Covered slope with grass for cut km 21+045 – km 21+845.

5 Conclusions

According 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 and discontinuity orientations, the following slope stabilization and remediation measures were adopted:

- Removal of fallen and loose material followed by installation of protective galvanized steel wire mesh and removal of fallen and unstable material, drilling and installation of rock anchors, and installation of protective galvanized steel wire mesh and removal of unstable rock blocks and placement of protective galvanized steel wire mesh;
- Installation road mesh with polypropylene 3d geogrid and anchors and installation road mesh with polypropylene 3d geogrid and without anchors, grassing / Grass Covering of Slopes;

To ensure quality of the application of measures, control documents were used for: quality control (QA/QC), verification of completed works, geotechnical and construction inspection, acceptance of works.

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