GEOTECHNICAL CONDITIONS FOR THE CONSTRUCTION OF THE VRŠNIK TUNNEL ON THE NIŠ–PRIŠTINA HIGHWAY

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Summary: *Within the Construction Design of the Niš–Priština Highway, from the loop road "Merošina" to the settlement Pločnik, among other structures, the construction of the Vršnik Tunnel is also envisaged. The designed tunnel has a total length of 265 m (from km 19+510 to km 19+775) and will be constructed through a rock mass composed mainly of fine-grained gneisses, which belong to the lower complex of crystalline shales. The paper presents and analyses the results of testing the dynamic properties of the rock complexes using geophysical methods, as well as geotechnical classification and categorisation of the rock mass.*

Keywords: *Tunnel, rock mass, construction conditions, classification*

1. INTRODUCTION

The construction of the E-80 Highway from Niš to Priština is important from the economic and social aspects for the southern part of the Republic of Serbia. The total length of the highway route is 77 km, along which the construction of numerous important objects (58) is planned, including six tunnels [1]. This paper presents the geotechnical conditions for the construction of the Vršnik Tunnel (Figure 1).

Before the construction of the tunnel, it is necessary to do quality site investigations, which will give us relevant data on the rock mass for which we are planning the works. Detailed engineering–geological plotting of the terrain was performed by surveying all natural

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outcrops, observing the condition of notches and slopes of existing local roads, etc. In addition, a special attention is paid to the phenomena of instability, as well as other similar occurrences in the terrain, which may be important for assessing the conditions for the tunnel construction, with a special reference to the area of the tunnel portal. After a wide inspection of the terrain, in the area of the future tunnel starts the research of the rock mass and the collection of data with field and laboratory investigations. *In situ* investigations are the most authoritative investigations, because they are performed in the natural environment. However, they require large financial resources, and thus they are often combined with laboratory investigations and such obtained parameters are valid. Geophysical investigations through several stages and with several methods provide information on the properties of rock mass, and can help in choosing the construction technology, dynamics of excavation, etc. It is not enough just to identify the layers by their stratigraphic terminology, but soils and rocks should be described by their own mechanical properties and their expected short-term and long-term construction-related behaviour. Namely, one of the numerous classifications should be performed, which will greatly help in the subsequent design of the tunnel in all stages.

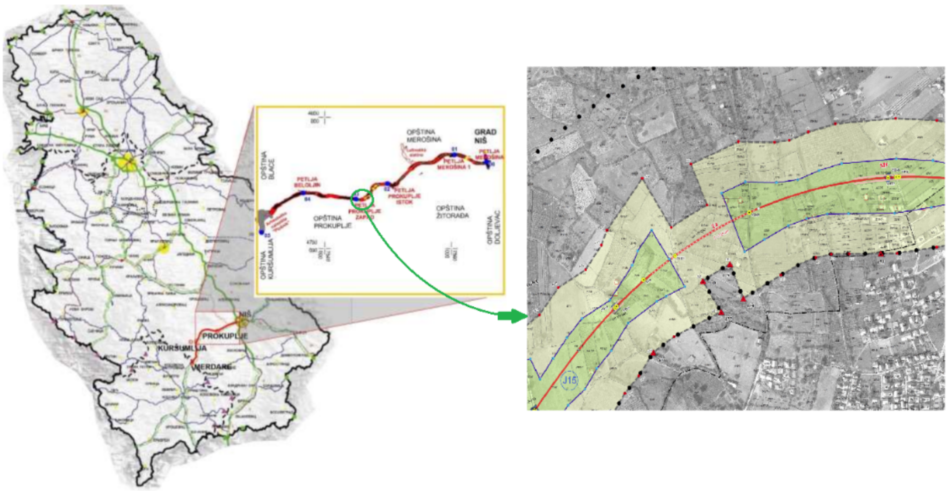

Figure 1. Highway route with characteristic details on the section Niš–Pločnik (modified according to [1,2])

The Vršnik Tunnel is 200m long. According to the Preliminary Design, the initial chainage at the entrance portal of the tunnel was at 19+510 km, and later the tunnel was shortened by 40 m, so the final chainage at the entrance part is at 19+550 km, and at the exit part 19+750 km. The ground level in the area of the entrance portal is 336 m and in the area of the exit portal is 345 m, whereas the highest ground level above the tunnel pipe is about 351 m. Acording to the Design, the construction of two tunnel pipes is envisaged at the central distance between the axes of the tunnel pipes of about 37.5 m. The pavement structures in the tunnel are designed with a grade of 4%. The height of the tunnel in relation to the pavement structure is about 7.8 m [2].
It should be pointed out that at first the construction of a tunnel was not planned at this location, but only the dapping of the rock mass between the two bridges. Later, however,

the decision was made to build a tunnel. It is important to note that in the area of portal sections, the overburden height varies from 5 to 8 m, from the left or right pipe, whereas the highest overburden ranges from 12 to 13 m, which can be considered as a relatively small overburden.

2. GEOLOGICAL PROPERTIES OF THE TERRAIN

For the needs of the construction of the E-80 Highway, 121 exploratory holes were drilled [2]. In the tunnel area, the nearest holes are BM-46, BM-47, and BM-48, from which a total of 10 rock and soil samples were taken. The values of mechanical properties were tested on five rock samples, provided that one sample, although taken from a greater depth, was tested in the laboratory of soil mechanics. In the exploration holes in the surficial part, two tests of the standard penetration test were also carried out. According to the Survey on geological investigations, a part of the highway route, which also represents the Prokuplje bypass, is built of solid rock mass of different quality (Figure 2).

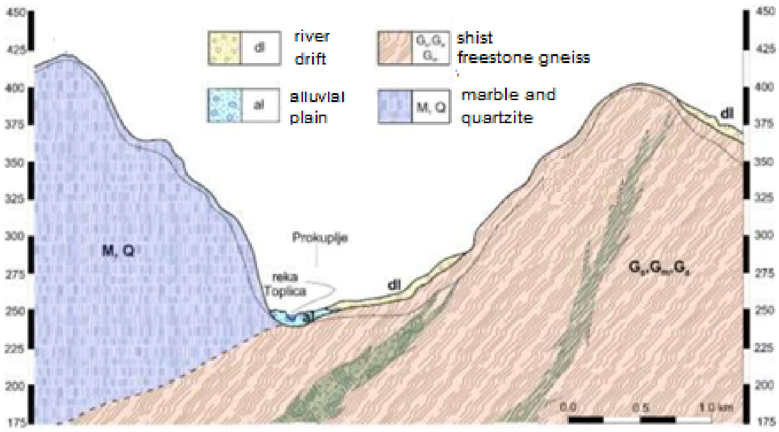

Figure 2. A characteristic engineering–geological cross-section of a shist complex [1]

3. METHODOLOGY FOR THE PREDICTION OF GEOTECHNICAL CONSTRUCTION CONDITIONS

For the purpose of the prediction of geotechnical construction conditions of the tunnel, a combined empirical–static–dynamic methodology of connecting the necessary parameters for analysis was applied. Namely, the results of exploratory drilling, data from static laboratory tests of strength and deformability and dynamic investigations by geophysical methods were used. Based on lithological and tectonic characteristics, and conditions and properties of rock masses, the initial zoning of the rock mass along the longitudinal axis of the tunnel was done, whereby several quasi-homogeneous zones are marked off in terms of physical and mechanical properties and expected behaviour of rock masses during the construction and in interaction with the structure.

The parameters of the monolithic parts of the rocks were defined using standard or recommended procedures by ISRM methods (Suggested Methods of the International Society for Rock Mechanics).

For the needs of preparing the Survey of geotechnical conditions for the tunnel construction at the level of the Final Design, additional exploration holes were drilled and related geophysical investigations were performed (Figure 3). A number of tests was performed regarding point load strength index (PLT index) on a total of 18 test samples, bulk weight on 6 samples, as well as compressive strength and deformability on two samples in laboratory conditions. It should be noted that the drill cores were quite cracked and that it influenced the total number of investigated PLT test samples (Point Load Test). Relatively low values of bulk weight, but also large variations of data in the PLT test, indicate the decomposed rock mass. As for the bulk weigth, based on these results, in Figure 4, for the characteristic sections along the tunnel length, the appropriate values for the parameters were adopted. Compressive strength tests indicate the values of UCS = 10 to 14 MPa, and the modulus of deformation on the monolith Ei = 10 to 21 GPa (Figure 4). It is worth mentioning that a certain range of geophysical refractive and reflexive profiles was performed. The layout of the 2 (two) performed geophysical profiles is shown in Figure 3. The dynamic properties of rock masses are interpreted based on the measured velocities of longitudinal (*Vp*) and transverse seismic waves (*Vs*), which were used to determine characteristic dynamic parameters using the following equations [3]:

$$\mu_{din} = \frac{Vp^2 - 2 \cdot Vs^2}{2} \cdot (Vp^2 - Vs^2) \quad (1)$$

$$G_{din} = \rho \cdot Vs^2; \; \rho = \gamma / g \quad (2)$$

$$E_{din} = 2 \cdot (1 + \mu_{din}) \cdot G_{din} \quad (3)$$

$$K_{din} = E_{din} / [3 \cdot (1 - 2 \cdot \mu_{din})] \quad (4)$$

where μ_{din} is the dynamic Poisson's ratio, and G_{din}, E_{din}, and K_{din} are the dynamic shear modulus, dynamic elasticity modulus, and dynamic volume modulus, respectively.

Figure 3. Locations of the performed geophysical profiles [3]

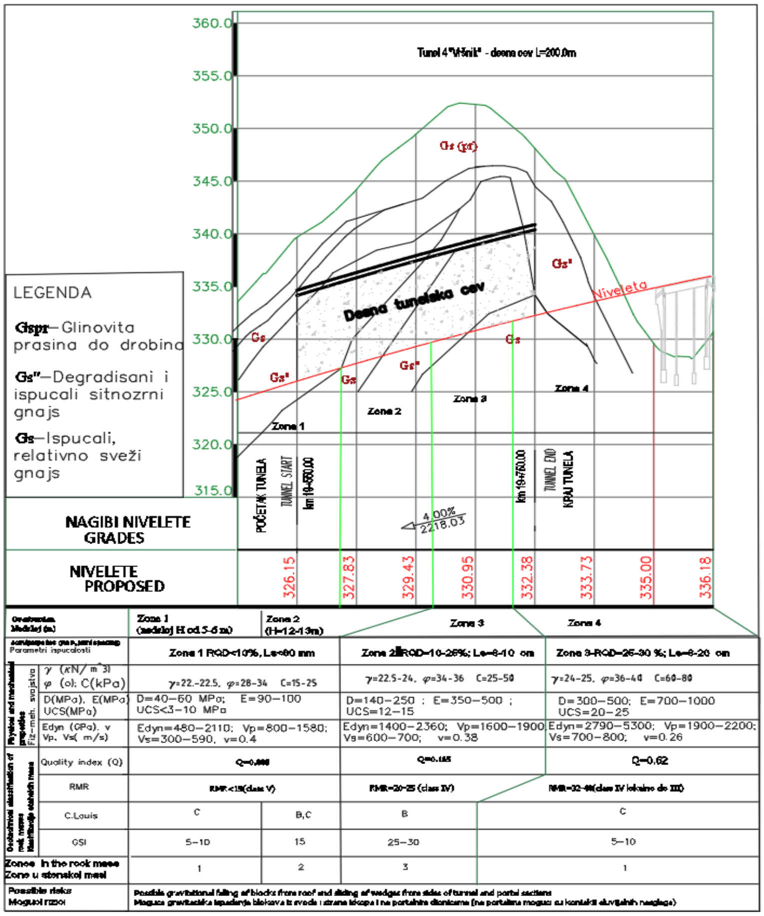

Figure 4. Geotechnical section for the right tunnel pipe of the Vršnik Tunnel [4]

Based on the obtained results, several zones can be distinguished from the geophysical aspect, which are shown in Table 1.
The obtained results define the following zones according to the seismic wave velocity parameter:

1. Surficial zone with values: Vp < 200–750 m/s, Vs < 80–280 m/s, with the thickness from 1 to 4 m;
2. Subsurface zone, which would match to the weathering crust with values: Vp < 800–1580 m/s and Vs = 300–590 m/s, with the thickness of 8 to 11 m;
3. Quite degraded gneisses with values: Vp = 1600–1900 m/s; Vs = 600–700 m/s;
4. Degraded cracked gneisses with values: Vp = 1900–2200 m/s; Vs = 700–800 m/s.

Table 1. Separated zones based on geophysical seismic investigations

Parameter	Zone 1	Zone 2	Zone 3	Zone 4
Vp (m/s)	200–750	800–1580	1600–1900	1900–2200
Vs (m/s)	80–280	300–590	600–700	700–800
γ(kN/m^3)	15–18.5	18.5–21	21–21.5	21.5–22.5
μ_{din}	0.4–0.42	0.42	0.42	0.42
E_{din} (MPa)	30–420	480–2110	2180–3050	3050–4180
G_{din} (MPa)	10–150	170–750	770–1070	1070–1470
K_{din} (MPa)	50–860	980–4350	4450–6480	6480–9140

Furthermore, the results indicated certain anomalies and discontinuities, which may lead to a conclusion on the possible existence of faults. Looking at the results, it is obvious that up to the depth of the performed investigations, the basic rock mass does not have a high velocity of longitudinal waves. This helps, based on the known relations between the quality of the rock mass and *Vp* [4,5], to indirectly define more specific geotechnical categories of rock masses, as well as the expected conditions for the construction of the tunnel. Thus, for the main quasi-homogeneous zones, along with the values of *Vp* and *Vs* of waves (which are affected not only by the quality of the rock mass, but also by the overburden), the obtained values of geotechnical parameters and rock mass classes are also presented in Figure 4.
When determining the number of zones and their prediction length, it was taking care of how often it makes sense to change the construction technology and the type of tunnel structure. Thus, the following zones were separated by zoning [3,7]. Zoning along the longitudinal axis of the tunnel has to a certain extent subjective character. This primarily refers to the boundaries between the zones of more severely degraded rock masses and the zone of fresher mass. The prediction of the location of the fault zone in the central part of the tunnel is presented. The selected zones are marked from 1 to 4, and their prediction length is shown in Table 2.

Table 2. Selected zones with prognosis length

No.	Chainage (approximately) [km]	Description
1.	19+550 – 19+590	Entrance portal of the tunnel section to the zone of layer height up to about 10 m, V category according to RMR
2.	19+590 – 19+665	IV category according to RMR
3.	19+665 – 19+730	Section with often changes between IV and III category according to RMR
4.	19+730 – 19+750	Exit portal of the tunnel section to the zone of layer height up to about 15 m, V to IV category by RMR

In terms of zoning, as for other tunnels in this highway section, the aggravating circumstance is that in the immediate, and even in the wider zone of the designed tunnel, there are no notches and cuts, so that the rock mass was not visible due to the larger surface cover. For these reasons, detailed engineering–geological plotting and determination of structural–textural properties (orientation and composition) and degree damage of rock mass are not possible, which makes rock-mass categorisation difficult.

4. APPLIED METHODOLOGY FOR EXTRAPOLATION OF PARAMETERS AT THE LEVEL OF ROCK MASS

Having in mind the fact that, for the mechanical behaviour of the rock mass, the relevant parameters are at the level of rock mass in the area of interaction with the structure (tunnel), in this case, a methodology based on a combination of rock mass classification parameters was applied using the methods RMR (Rock Mass Rating), Q system, and GSI (Geological Strength Index) system (different versions according to Hoek, Marinos, Ulusay, etc.), as well as own experience and derived correlations of empirical character by combining classes of rock masses and seismic wave velocities [4,5,7].
The RMR classification proposed by Bieniawski (1989) was adopted as the basic rock mass classification and is based on the determination of the following parameters: uniaxial compressive strength (monolith), rock quality designation of exploration hole cores (RQD), distance between cracks, crack condition and condition of ground water. In addition, for the main zones, the classification according to the Q system was done, as well as the mentioned GSI classification. The results are shown in Table 3.

Table 3. Results of RMR and Q classification in the selected zones

	RMR	Q
Portal zone of tunnel sections 1 and 2	6–10	0,008
Zone 2 i 4	20–25	0,165
Zone 3	32–37	0,624

The range of values of the GSI parameter is defined within the following limits:

– *Degraded and cracked gneiss: lower gneiss decay zone - (Gs *)*: GSI: 17–26;
– *Fractured, cracked, and less decomposed gneiss - (GsI)* with clearly defined discontinuities and microcracks - petrologically defined as "calcite gneiss". The rock was intensively brecciated and calcited, locally easily broken and split: GSI: 26–40;
– *Weakly cracked gneiss - (Gs)* - petrologically defined as "calcite gneiss", the rock was brecciated and calcited: GSI: 40–55.

The basic data used to define the parameters were laboratory tests on all samples of rock masses. A general classification was performed on them using uniaxial strength.

5. PREDICTION OF GEOTECHNICAL CONDITIONS OF TUNNEL CONSTRUCTION

Prediction of geotechnical conditions of construction includes the selection of the appropriate excavation method and the supporting technique, the analysis of the stability of the blocks as a case that cannot be included in the general classification, and the risk assessment during the construction of the tunnel. For prediction of the excavation method, as well as for defining the method of tunnelling and protection of the excavation, it was performed a classification of the terrain as a working environment – the Louis' method [6] (Figure 5, left), as well as a somewhat newer method based on the GSI value [6], were used (Figure 5, right). Typical classification parameters and the corresponding rock mass categories are shown in Figure 4. From this figure, the following can be determined:

1. Basically, the entrance- and exit-portal areas are in the V category according to the RMR system;
2. The largest part of the rock mass is in category IV;
3. In the central part, faults are possible, but also frequent changes of categories (most often category IV to category III);
4. In the areas of the tunnel crown, category changes may occur, and in the areas of the portals and the approach cuttings, in the upper zones, an appearance of modified rock mass up to the degree of the soil is possible.

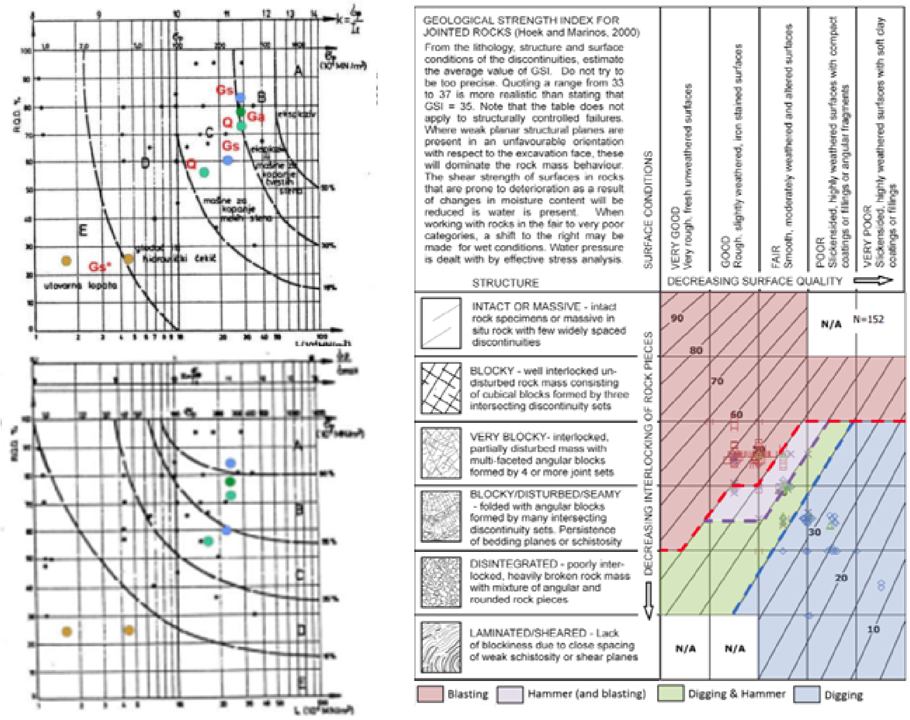

Figure 5. Geotechnical classification of terrain in terms of mechanical behaviour by the Louis' method [3] and using GSI values [6]

The analysis of possible special cases of instability was carried out using the UNWEDGE software. An instability of possible blocks at the head of the excavation, in the crown, and on the sides are shown in Figure 6. From the analysis, it can be concluded that if the excavation remains without a primary support for a long time, gravity-type falls from the crown and at the head of the excavation are possible. Analyses of possible wedge or planar fractures were performed on the portal sections of the tunnel. As for these cases, in certain situations, especially for the saturated state along the cracks, there are kinematic conditions for fracture, which means that the excavation should be performed by the technique of excavation from top to bottom with applying appropriate protection, which should be defined in the design.

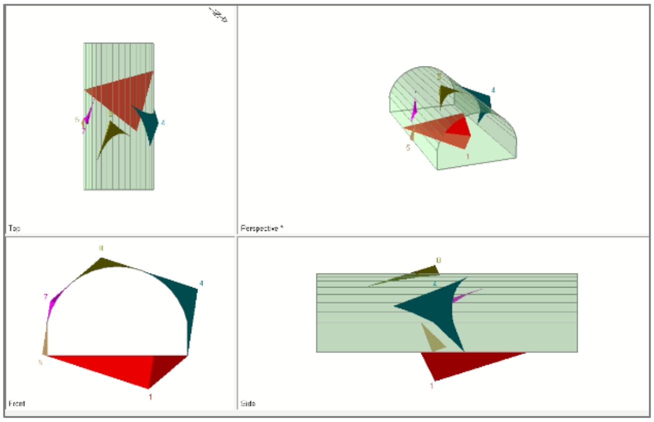

Figure 6. Overview of possible cases of structural-controlled instability

To select a support system, in the first iteration, the design engineer can use the recommendations of Barton or Bienawski, or diagrams presented in Figure 7, taking into consideration the categories shown in Figure 4.

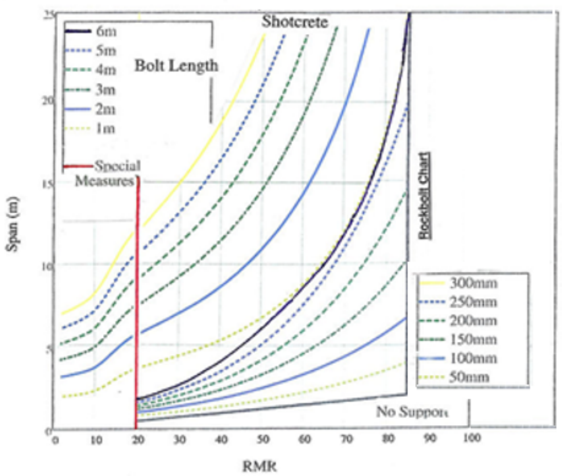

Figure 7. Diagram for predicting the support system using RMR values [4]

In general, it can be said that the tunnel will be built mostly in the IV category, which requires careful tunnel construction. This primarily refers to the part in the approach cutting areas, the portal parts of the tunnel with a small overburden height, and around the fault zones where a certain inflow of ground water can be expected. In accordance with that, the excavation technology and support systems should be adjusted, and if necessary, appropriate drainage measures should be envisaged. If the NATM (New Austrian Tunnelling Method) excavation method is applied, due to the small overburden height, there might be a need to apply the pipe roof method at the portal sections or in front of the fault zones.

6. CONCLUSION

The Vršnik Tunnel consists of two tunnel pipes, whose central distance is large enough, so that their mutual influence can be neglected. The construction is performed mostly in gneisses and degraded gneisses. The finished road level is inclined by 4.0% towards the entrance portal. Since the Vršnik Tunnel is shorter than 300 m, in accordance with the norms for the design and construction of tunnels on highways, no special safety measures have been designed, but sidewalks are used as evacuation routes. During the construction of the tunnel, the application of contemporary tunnel construction technology is predicted - the concept of the New Austrian Tunnel Method (NATM). For geotechnical conditions of the construction of the tunnel it can be concluded that they are favourable within Zone 2, which covers approximately 65% of the length of the tunnel. The Zone 4 is assessed conditionally (relatively) favorable (about 15%), whereas for the remaining part of the tunnel more difficult construction conditions are expected. Such difficult conditions are expected primarily at the part in the approach cutting areas and at the portal sections of the tunnel with a small overburden height, as well as in case of possible occurrences of a larger amount of ground water. It is necessary, in accordance with all the above stated, to adapt excavation technology, support systems, and appropriate drainage measures.

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ГЕОТЕХНИЧКИ УСЛОВИ ИЗГРАДЊЕ ТУНЕЛА ВРШНИК НА АУТОПУТУ НИШ - ПРИШТИНА

Резиме: *У оквиру пројекта изградње аутопута Ниш - Приштина, од петље „Мерошина“ до насеља Плочник, поред осталих објеката, предвиђа се и изградња тунела Вршник. Пројектовани тунел је укупне дужине 265м (од км 19+510 – км 19+775) и биће изведен кроз стенску масу изграђену углавном од ситнозрних гнајсева, који припадају доњем комплексу кристаластих шкриљаца. У раду су дати приказ и анализа резултата испитивања динамичких карактеристика стенских комплекса применом геофизичких метода, као и геотехничка класификација и категоризација стенске масе.*

Кључне речи: *Тунел, стенска маса, услови изградње, класификација*