ANALYSIS OF THE GROUNDWATER INFLUENCE ON THE CATEGORIZATION OF THE ROCK MASS AND SUPPORT TYPE OF THE ZENICA TUNNEL ON THE ROUTE OF THE VC CORRIDOR

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ABSTRACT

The Zenica tunnel is located as part of the highway on the Vc corridor, Ponirak section - southern exit from the Zenica tunnel. The tunnel is a two-tube with a length of about 3.300 meters. During the excavation of the Zenica tunnel, large amounts of groundwater were recorded in several sections in both tunnel pipes, from wet to flowing. During the tunnel excavation, the engineering-geological data on the rocks through which the excavation was carried out was regularly recorded, and on the basis of these data, the RMR classification of the rock mass was determined. The paper presents one of the possible solutions to control the inflow of groundwater during tunnel excavation by making subhorizontal wells and installing self-drilling anchors for the purpose of directing groundwater into drainage pipes or tunnel sides. The main goal of controlling the groundwater inflow is to reduce the impact of groundwater on further tunnel excavation and to modify the category of rock mass (additional benefit), and thus to reduce the unit price of tunnel excavation.

KEYWORDS:

tunnel, impact, subgrade, rock mass classification, groundwater control

1 INTRODUCTION

The "Zenica" tunnel is located as part of the highway on corridor Vc, section Northern administrative border of the municipality of Zenica (Nemila) - Zenica North, subdivision Ponirak - southern exit from the Zenica tunnel. It is a two-tube, two-lane road tunnel where the left and right tunnel tubes are connected with ten cross passages for pedestrians, three passages for vehicles as well as three parking niches. According to the design solution, the length of the left tunnel tube is 3.281,994 m, and the length of the right tunnel tube is 3.329,850 m.

Figure 1. Geographical position of the Zenica tunnel on the route of the Vc Corridor

2 BACKGROUND AND METHODS

2.1 G EOLOGICAL AND HYDROGEOLOGICAL CHARACTERISTICS OF THE ROCK MASS IN THE "ZENICA" TUNNEL EXCAVATION ZONE

The lithological structure of the "Zenica" tunnel is represented by Mesozoic formations (felsic upper Vrandučka series 2JK). In the excavation profile, marls, marly limestones, subordinately layered sandstones with cracks perpendicular to the layering and rhythmic appearance of silicified clay with interlayer filling of calcite and clay with fragments of the base rock were determined.

The rapid and frequent change of lithological members along the vertical and horizontal axis and pronounced cracking as a consequence of tectonic activities resulted in the oscillation of the groundwater level.

Figure 2. The presence of water in the form of wetting

Figure 3. The presence of water in the form of wetting

The flysch as a whole represents a watertight medium, but due to the cracking that is the result of exogenous and tectonic processes, numerous cracks have become predisposed paths for the circulation of underground, i.e. precipitation water that seeps into the massif on contact with clays or through fault zones. These are rocks of fissure-fissure porosity with the function of a relative hydrogeological barrier above which infiltration and underground water flows mainly take place. During the excavation of the Zenica tunnel, large amounts of groundwater were recorded in several sections in both tunnel pipes.

Groundwater in certain sections of the tunnel was present in the form of wetting (<10 l/min), wet (10-25 l/min), dripping (25-125 l/min) and flowing (>125 l/min). Figures 2, 3, 4, and 5 show the various forms of groundwater in the Zenica tunnel during excavation.

Figure 4. The presence of water in the form of dripping

On all sections of the tunnel where the presence of underground water was recorded during the excavation of the Zenica tunnel (left and right tunnel tubes), the groundwater yield was measured 10m' from the face of the excavation. All data obtained by measurement were recorded in a longitudinal engineering-geological (IG) profile. The determined yield of underground water in the Zenica tunnel ranged from (<10 l/min) to (900 l/min)

2.2 ASSESSMENT OF GROUNDWATER INFLOW DURING TUNNEL EXCAVATION

The analysis of the literature shows that during the past ten years, many efforts have been made to predict the calculation of groundwater inflow during the construction of tunnels. In fact, various methods have been developed from analytical, semi-analytical, empirical, semi-empirical and numerical methods. Despite everything, due to various potential factors, accurate assessment of groundwater inflow into the tunnel remains challenging [1].

Figure 5. The presence of water in the form of flow

Unfortunately, these developed methods are applicable mostly for tunnels with regular cross-sections such as square, circular or elliptical. In reality, the cross-section of most of the tunnels being built is asymmetrical, that is, horseshoe-shaped [2]. Xu Zhiye and others established an empirical model for determining groundwater inflow into a horseshoe-shaped underground chamber as follows [3]:

$$Q = k(S + C)H \quad (1)$$

- Q - groundwater inflow [m3/s],
- k - hydraulic permeability of the rock [m/s],
- S - coefficient that is related to the shape and depth of the tunnel,
- C - the second coefficient that depends on the shape and depth of the tunnel and
- H - height distance of the tunnel from the surface waters.

Most of the used methods and approaches make assumptions that do not fully reflect the real situation of rocky areas where tunnels are built [4]. Accurate predictions or estimates of groundwater inflow into tunnels are still unsolved problems of hydrogeology and all related sciences [5].

2.3 THE INFLUENCE OF UNDERGROUND WATER ON TUNNEL EXCAVATION

Groundwater inflow during tunnel construction could be a potential geological hazard that could affect the progress and costs of tunnel excavation [6].

The most significant difficulties arising from groundwater intrusion during tunnel construction include the reduction of stability of the rock mass around the tunnel, as well as the imposition of additional pressure on the primary subgrade [7], which not so often leads to the collapse of the primary subgrade.

The inflow of underground water during the construction of the tunnel is not only an important factor that controls the progress in the dynamics of the works, but it can also represent a potential danger from the aspect of safety to all participants in the construction [8].

The presence of underground water during excavation makes it difficult and slows down, and in some cases it can even make it impossible to carry out certain phases of work. In the rock mass, water appears both in pores and in discontinuities. The flow of water in the rock mass is mostly associated with flow through discontinuities. The amount of seepage depends on whether the discontinuities are open or closed, and if they are filled then it depends on the type of filling material [9].

Water at the head of the excavation can occur in the form of scattered or concentrated sources that can be permanent or occasional in nature. Permanent or intermittent sources appear in the zone of larger cracks and faults. Faults can have the function of hydrogeological drainage of groundwater from local aquifers.

The presence of water at the head of the excavation makes it difficult to carry out the work that follows after the excavation. Based on that, it is necessary to capture water from the face of the excavation, and arrange the runoff to be controlled. With the help of fast-setting additives, suitable mortars can be prepared and with them gradually, by fast and persistent application, scattered sources of consciousness can be transformed into concentrated ones. As part of these actions, it is sometimes useful to drill directional wells and perform appropriate drainage sealings.

The water collected in this way is directed into the drainage system, i.e., normal conditions are created for the continuation of work in accordance with the requirements. Without a responsible presence in the collected and controlled drainage of groundwater, favorable conditions cannot be created for the successful and correct execution of works during tunnel excavation [10].

2.4 RMR CLASSIFICATION FOR THE NEEDS OF CONSIDERING THE OVERALL QUALITY OF THE ROCK MASS

The use of classification systems is a significant factor in the estimation of parameters of rock masses [11]. With the help of classification, we determine the important parameters of the rock mass. They allow us to create an assessment of the stability of the rock mass, and indicate its strength and deformability [11].

In order to assess the overall quality of the rock mass in the "Zenica" tunnel, the geomechanical RMR (˝Rock mass rating˝) classification was applied.

The RMR classification is primarily intended for defining the substructure of tunnels and various other underground structures [12].

This classification system takes into account six parameters [13]:

- Uniaxial compressive strength,
- Kernel Quality Index (RQD),
- Distance of discontinuity,
- State of discontinuity,
- Groundwater conditions, and
- Orientation of discontinuities.

The scoring values for the specified parameters are shown in table 1 [12], and the guide for determining the condition of the cracks is shown in table 2. By adding up the points for the specified parameters, and adding the repair with regard to the orientation of the crack system and the engineering problem that is being solved, and according to table 3 and 4, the value of RMR is obtained. There is no definition of favorable or unfavorable orientation of cracks, but each problem should be solved separately.

Table 1. Classification parameters and associated points

<table>
<tr><th colspan="10">A. CLASSIFICATION PARAMETERS AND THEIR RATINGS</th></tr>
<tr><th colspan="3">Parameter</th><th colspan="7">Range of values</th></tr>
<tr><td rowspan="3">1</td><td rowspan="2">Strength of intact rock material</td><td>Point-load strength index</td><td>>10 MPa</td><td>4 – 10 MPa</td><td>2 – 4 MPa</td><td>1 – 2 MPa</td><td colspan="3">For this low range – uniaxial compressive</td></tr>
<tr><td>Uniaxial compression strength</td><td>>250 MPa</td><td>100 – 250 MPa</td><td>50 – 100 MPa</td><td>25 – 50 MPa</td><td>5-25 MPa</td><td>1-5 MPa</td><td><1 MPa</td></tr>
<tr><td colspan="2">Rating</td><td>15</td><td>12</td><td>7</td><td>4</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td rowspan="2">2</td><td colspan="2">Drill core quality RQD</td><td>90% - 100%</td><td>75% - 90%</td><td>50% - 75%</td><td>25% - 50%</td><td colspan="3">< 25%</td></tr>
<tr><td colspan="2">Rating</td><td>20</td><td>17</td><td>13</td><td>8</td><td colspan="3">3</td></tr>
<tr><td rowspan="2">3</td><td colspan="2">Spacing of discontinuities</td><td>>2 m</td><td>0.6 – 2 m</td><td>200 – 600 mm</td><td>60 – 200 mm</td><td colspan="3"><60 mm</td></tr>
<tr><td colspan="2">Rating</td><td>20</td><td>15</td><td>10</td><td>8</td><td colspan="3">5</td></tr>
<tr><td rowspan="2">4</td><td colspan="2">Condition of discontinuities (See E)</td><td>Very rough surfaces Not continuous No separation Unweathered</td><td>Slightly rough surfaces Separation <1 mm Slightly weathered walls</td><td>Slightly rough surfaces Separation <1 mm Highly weathered walls</td><td>Slickensided surfaces or gouge <5 mm thick or Separation 1-5 mm</td><td colspan="3">Soft gouge >5 mm thick or Separation >5 mm continuous</td></tr>
<tr><td colspan="2">Rating</td><td>30</td><td>25</td><td>20</td><td>10</td><td colspan="3">0</td></tr>
<tr><td rowspan="4">5</td><td rowspan="3">Ground water</td><td>Inflow per 10 m tunnel length (l/m)</td><td>None</td><td><10</td><td>10 – 25</td><td>25 – 125</td><td colspan="3">>125</td></tr>
<tr><td>(Joint water press)/ (major principal σ)</td><td>0</td><td><0,1</td><td>0,1 – 0,2</td><td>0,2 – 0,5</td><td colspan="3">>0,5</td></tr>
<tr><td>General conditions</td><td>Completely dry</td><td>Damp</td><td>Wet</td><td>Dripping</td><td colspan="3">Flowing</td></tr>
<tr><td colspan="2">Rating</td><td>15</td><td>10</td><td>7</td><td>4</td><td colspan="3">0</td></tr>
</table>

According to the RMR system, the rock mass is classified into 5 categories shown in table 5. The same table also shows the shear strength parameters of individual rock mass categories [14].

Bieniawski also published recommendations for tunnel excavation and support. A connection was established between the RMR system and the criteria of strength and deformability of the rock mass, which is why this classification gained importance in the excavation of tunnels and various other underground structures.

Table 2. Guide for classification of discontinuity states

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY CONDITIONS					
Discontinuity length (persistence) Rating	<1 m 6	1 - 3 m 4	3 – 10 m 2	10 – 20 m 1	> 20 m 0
Separation (aperture)	None 6	<0,1 mm 5	0,1 – 1,0 mm 4	1 – 5 mm 1	>5 mm 0
Roughness Rating	Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0
Infilling (gouge) Rating	None 6	Hard filling <5 mm 4	Hard filling >5 mm 2	Soft filling <5 mm 2	Soft filling >5 mm 0
Weathering Rating	Unweathered 6	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0

Table 3. Correction of points with regard to the orientation of the discontinuity

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)						
Strike and dip orientations		Very Favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Ratings	Tunnels and	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	-60

Table 4. Effect of discontinuity orientation in tunnel construction

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING			
Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip Dip 45°-90°	Drive against dip Dip 20°-45°	Dip 45°-90°	Dip 20°-45°
Very favorable	Favorable	Very unfavorable	Fair
Drive against dip Dip 45°-90°	Drive against dip Dip 20°-45°	Dip 0°-20° Irrespective of strike	
Fair	Unfavorable	Fair	

Table 5. Rock mass category according to the RMR classification

Number of ratings (RMR)	Category of rock mass		The average stability time of an unsupported opening	Approximate values of the shear strength of the rock mass	
				C (Kpa)	$\phi(^0)$
100-81	I.	Very good	20 year for a spacing of 15 m	>400	>45
80-61	II.	Good	1 year for a spacing of 10 m	300-400	35-45
60-41	III.	Favorable	1 week for a spacing of 5 m	200-300	25-35
40-21	IV.	Weak	10 hours for a spacing of 2,5 m	100-200	15-25
<20	V.	Very weak	30 minutes for a spacing od 1 m	<100	<15

2.5 CATEGORIZATION OF THE ROCK MASS SECTION OF THE RIGHT TUNNEL PIPE WITH HIGHER GROUNDWATER FLOW

For this work, the section of the right tunnel pipe made of chainage was selected 1+060,00 to 1+130,00 where the inflow of groundwater from wet to flowing was recorded. View of the section of the right tunnel pipe from chainage 1+060,00 to 1+130,00 on the IG longitudinal profile is shown in Figure 6.

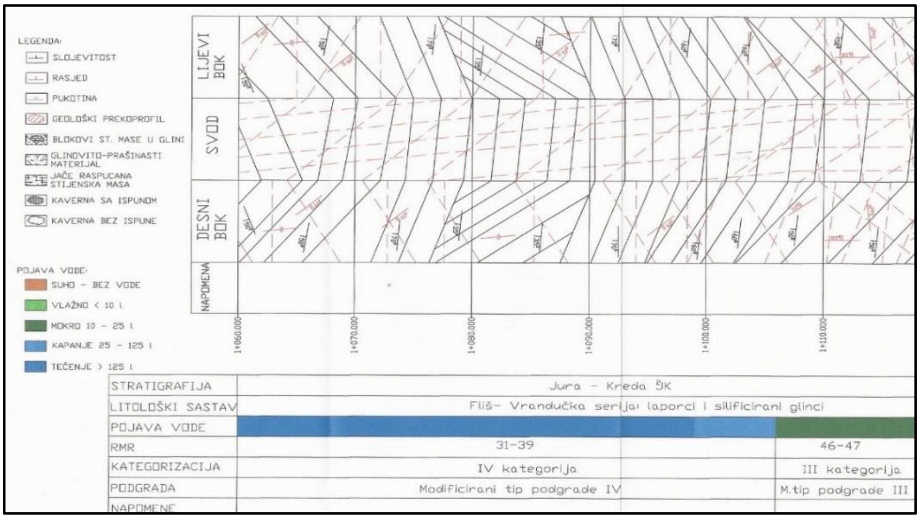

Figure 6. Longitudinal IG profile of the right tunnel pipe from chainage: 1+060,00 to 1+130,00

Based on the geomechanical RMR classification for the rock mass, geological mapping defined the following parameters on the chainage 1+063,60:

- The rock mass is moderately (W3) eroded. The lithological structure of the rock mass consists of gray marls and reddish brown aluminas. The percentage of marl is about 95%, and alumina about 5%.
- The uniaxial compressive strength of clay, based on laboratory tests and field tests using a geological hammer, is in the range of 25-50 MPa, while that of marl is in the range of 50-100 MPa. Based on the percentage of alumina and marl, the compressive strength value was determined.
- The quality of the rock mass (RQD) measured at the face of the excavation is in the interval of 50-75%, which corresponds to moderately cracked rocks of satisfactory quality.
- The distance between primary and secondary discontinuities is mostly in the interval of 6-20 cm. The length of primary discontinuities is in the interval of 10-20 m, so in terms of continuity, they are of high stability, while the length of secondary discontinuities is in the interval of 1-3 and 3-10 m, so in terms of continuity, they are of low and medium stability.
- Cracks are mostly closed within the limits of 0,1-5 cm thick, fresh solid calcite filling and soft clay completely friable filling >5 mm thick.

- The walls of cracks that are filled with clayey fill are slightly rough, while the walls of cracks that are filled with clayey fill are smooth.
- The occurrence of underground water at the head of the excavation was recorded. The yield of groundwater was measured, and on that occasion a yield of 11 l/s was measured. which corresponds to the flow. The layers extend perpendicularly to the axis of the tunnel with an inclination of 50° against the direction of progress of the tunnel excavation, which represents a good orientation of the layering in relation to the axis of the tunnel. Figure 7 shows the geological report of the right tunnel tube on chainage 1+063,60.

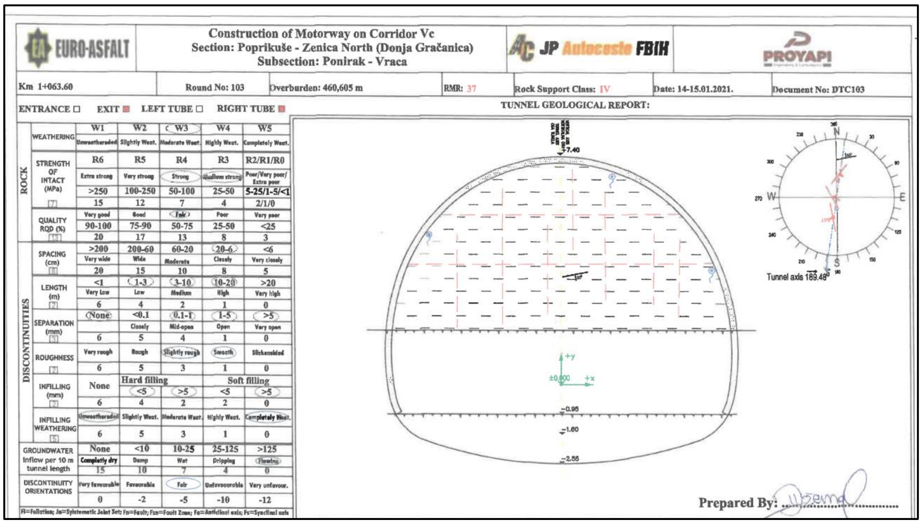

Figure 7. Geological report, chainage: 1+063,60 – right tunnel tube

From the attached geological report, it is evident that the RMR classification of the open face of the excavation at chainage: 1+063,60 received 37 points, which corresponds to the IV category of rock mass.

It is evident from the attached geological report that the number of points due to the presence of underground water in the form of flow is zero. To what extent would they bring the inflow of underground water under control, so that the inflow of water would be in the form of dripping, in that case, according to the RMR classification of the rock mass, they would have more 4 (four) points. In that case, the total number of points would be 41, which corresponds to the III category of rock mass.

Bearing in mind all the mentioned negative impacts of underground water on tunnel excavation mentioned in this paper, as well as the fact that the price of excavation with primary subgrade in rock mass of category IV is significantly higher (over 100%) than the price of excavation and installation of primary subgrade in category III rock mass. At the Zenica tunnel, a studious analysis was undertaken to find a solution to bring the inflow of underground water under control.

3 RESULTS AND DISCUSSION

A detailed analysis of all the engineering geological and hydrogeological characteristics of the rock mass in the excavation zone of the "Zenica" tunnel defined a solution for controlling and draining the underground water on the section of the right tunnel pipe on chainage: 1+063,60. The solution involved making subhorizontal drainage wells around the perimeter of the open face of the top heading at a distance of approx. 2 m. Wells are drilled with a longitudinal slope of 10° to 15°. It is necessary to drill 7 subhorizontal boreholes of 50 m length on the open frontal profile. A schematic representation is given in the Figure 8. Also, short self-drilling anchors were installed in the ceiling part of the top heading for the purpose of directing groundwater into the drainage pipes or the sides of the tunnel.

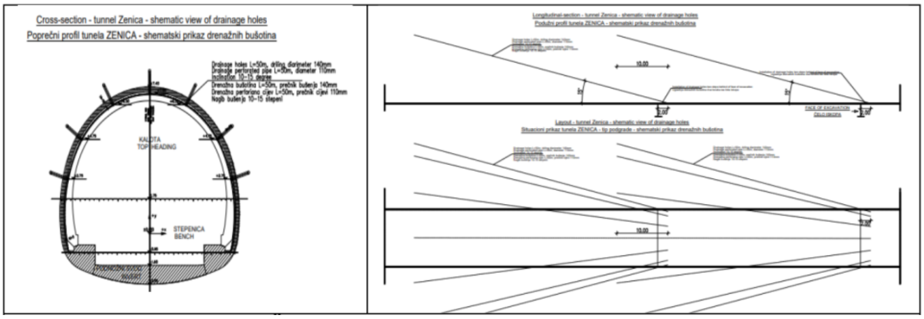

Figure 8. Schematic representation of the execution of drainage wells

Figure 9. shows the very act of drilling sub-horizontal drainage wells on an open frontal profile with a Beretta T46/S2 drill at station: 1+063,60 while Figure 10 shows the layout of the drainage wells. While Figure 11. shows the inflow of water through the built-in drainage wells.

Figure 9. Drainage holes drilling

Also, with the progress of the work on the excavation and installation of the primary support, in order to reduce the presence of groundwater to the smallest possible extent, short IBO anchors were installed at a distance of approx. 1,5 x 1,5 m in the top part of excavation face. After completion of the installation, the anchors were injected with a quick-setting injection compound. A schematic representation of the installation of short injection anchors for the purpose of diverting the groundwater inflow is shown in the Figure

12, as well as a representation of the installation of anchors in accordance with the scheme (Figure 12) in the ceiling part of the right tunnel pipe is shown in Figure 13.

Figure 10. Drainage holes' placement

Figure 11. Water inflow through built-in drainage holes

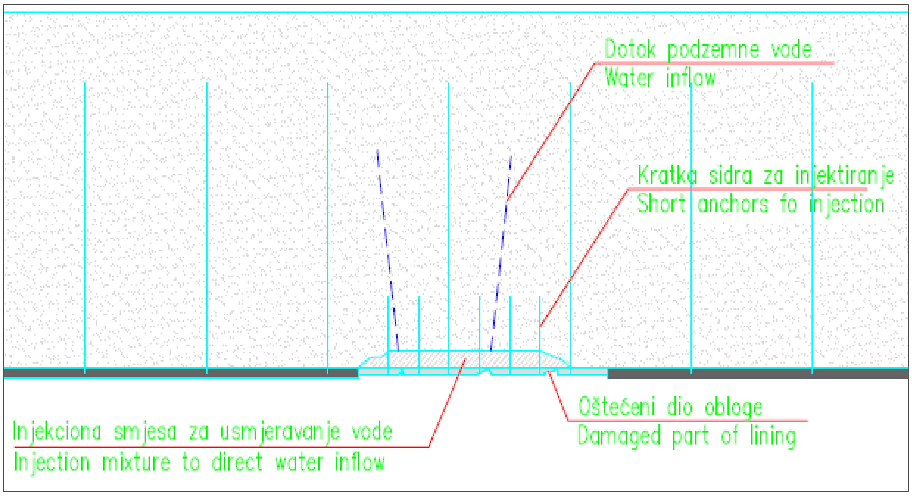

Figure 12. Schematic representation of the phase of installation of short injection anchors for the purpose of diverting groundwater inflow

Figure 13. Display of installed short anchors for the purpose of diverting groundwater inflow

The installation of sub-horizontal drains and short anchors to redirect the flow of groundwater into the drainage wells and sides of the tunnel gradually reduced the flow of groundwater into the tunnel excavation from flowing to wet. Thus, at chainage: 1+106,00 in the right tunnel tube, 46. points were obtained by mapping the open face of the RMR rock mass classification (the presence of underground water was recorded in the form of wet). The geological report from chainage 1+106,00 is shown in Figure 14.

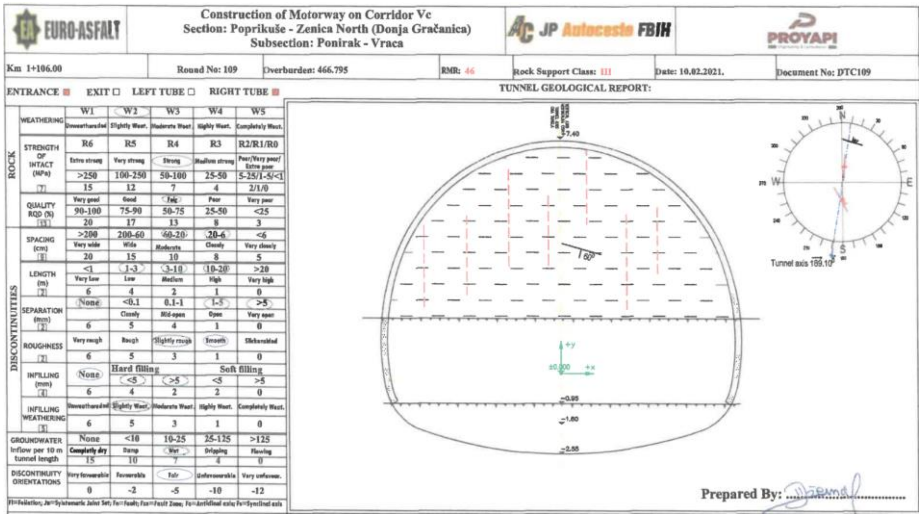

Figure 14. Geological report, chainage: 1+106,00

4 CONCLUSION

Construction of the tunnel is a demanding interdisciplinary work. The works are carried out in a geological environment that is never fully known.

During the tunnel excavation, engineering-geological data about the rocks through which the Zenica tunnel was excavated was regularly recorded. The behaviour of the rock mass is determined by the behaviour of the intact rock mass, but also by the behaviour of discontinuities, i.e. their properties such as roughness, crumbling, filling, gap, distance, stability, orientation, and seepage of water as natural weaknesses in it. Based on these data, the RMR classification of the rock mass was determined, and based on the obtained results, one of the project substructure systems was selected. During the excavation of the Zenica tunnel, large amounts of underground water were recorded in several sections in both tunnel tubes, from wet to flowing.

Bearing in mind all the negative impacts of underground water mentioned in this paper, both on the tunnel excavation and on the safety of all construction participants, the paper presents one of the possible solutions to bring the underground water under control during tunnel excavation.

The main goal of controlling the inflow of groundwater is to reduce the impact of groundwater on further tunnel excavation and to modify the category of rock mass (additional benefit) and thus to reduce the unit price of tunnel excavation.

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