EXPERIENCES OBTAINED BY EXECUTION OF HIGH PRE-CUTTINGS AND TUNNELS IN ROCKS OF THE HSSR TYPE IN CROATIA

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SUMMARY

The paper presents research works, design solutions, building and monitoring on relatively high pre-cuttings and tunnels in fragile rock on the part of the three-lane two-way road Kupjak-Vrbovsko which is built for the purpose of a better connection of the town of Rijeka and the coastal parts with the inland of the country within the E-65 corridor. On the section under construction Kupjak-Vrbovsko, near the locality of Ravna Gora, two tunnels were executed «Javorova Kosa» and «Pod Vugleš», with the total length of about 2 km. The tunnels are built in the categories of most fragile rocks of the HSSR (Hard Soils – Soft Rocks) type. That category comprises rocks which are mostly unstable against the influence of weather. Exploratory works for this type of rocks are specific in relation to other geotechnical explorations and must be aimed on testing of the stability (weathering) or the wear of soft rocks and the corresponding classifications (Geodurability).

1. INTRODUCTION

For the need of the project documentation, there were extensive geological, engineering-geological, hydrogeological and geophysical explorations carried out along the «Javorova Kosa» and «Pod Vugleš» section, with exploratory drilling and geotechnical laboratory testing of representative samples. For excavation of tunnels, ceiling protected with steel injected pipes (pipe roof technique) excavation technology was applied.

With the purpose of reducing the hazard and the risk during excavations and primary securing, «RMR», «Q» and «Geodurability» classification procedures were carried out, which was not the case in the practice of tunnel construction in the Republic of Croatia until then. The «JAK» (Jasarevic & Kovacevic, 1996) classification procedure was also carried out, which was verified in carbonate rock masses through existing explorations, but not in clastic Paleozoical deposits too.

According to the guidelines of the International Tunnelling Association (ITA), tunnel construction procedure which is constantly adjusted to tunnel-progress can be realised by combining the calculation methods, the empirical way of designing and the direct interpretation of in-situ measurements. During that, in-situ measurements of the massif deformations, and deformations and strains in the substructure are constantly used for the confirmation of the project or it’s replacement. The starting sections with intensive instrumentation give input data for that procedure. The interpretation of the measured values provides an insight into the conduct of the massif as the reaction on the progressing of the tunnel. The in-situ measurements do not verify only the stability and the applied project
calculation model, but they also verify the basic concept of the reaction of the massif on the excavation of the tunnel opening and the effectiveness of safety construction elements. For the most critical and representative sections in the tunnel set aside in advance by classification and categorisation procedures in an exceptionally heterogeneous and anisotropic rock mass, a complete program of measurements was carried out consisting of measuring of the convergence in the tunnel, measuring of vertical and horizontal displacement of the terrain, measuring of displacement of the ground around the underground opening, and measuring of the strain in substructure elements. Thereby the hazard and risk during the excavation and primary securing works is reduced. Monitoring enabled corrections of design solutions for securing the works (drainage, long pre-stressed anchors, and reinforced jet concrete) during the construction in accordance with the results of measurements.

Fig.1 The tunnels "lower" level of highway of Rijela-Karlovac, section Kupjak-Vrbovsko

2. THE COMPARISON OF RESULTS OF THE CLASSIFICATIONS: RMR, Q, JAK AND GEODURABILITY

With the purpose of reducing the hazard and the risk during planning (propriate geostatic calculation) and building (excavations and primary securing) classifications procedures RMR, Q and Geodurability were carried out which was not the case in the practice of tunnel construction in the Republic of Croatia until then. The JAK (Jasarevic and Kovacevic, 1996) classification procedures was also carried out which was verified in carbonate rock masses but not in clastic Paleozoical deposits, too. Rational conception of research works, which provide geotechnical solutions in particular phases of planning and building, is the most important because the need of aditional researches is being reduced without raising risk and conception is being undercontroled by the investor and the designer. Schematic review of planing, building and monitoring of the tunnel was annouced by The International Tunneling Association (ITA, 1998) after they had conducted opinion poll about tunnel construction in several countries in the world. The plan review includes the following elements:
- the works research, engineering geological and geotechnical researches
- the constructive design of the tunnel project
- calculation model
- building – taking into account the contractual problems, with the emphasis on the risk aspect
- monitoring - the in situ measurements during the construction which confirm or deny presumption of plan.

EGM (Engineering geological model), GM (geotechnical model) and CM (calculation model) were directly included in this plan. To make those models, a building half-space should be divided into the sections with similar mechanical properties which can be only achieved by specific investigations and classification procedures.

The classification of rock masses is providing:
- informations to determine criterion for rock mass strength (Hoek’s, Brown’s and etc.)
- informations to determine parameters of rock masses deformability
- making a plan for underground entrance stabilization
- making standard’s norm to describe rock masses that can be useful for all who are included in research, planning and building.

On the base of field and laboratory researches that were performed and classification procedures RMR, Q, JAK and Geodurability that were also applied, the categorisation along the route axis of both tunnels was carried out.

![Fig.2 The possible engineering geological profile review - part of the tunnel “Javorova Kosa” route](image-url)
The rock massif with following classification RMR, Q and JAK is part of IV and V category. The Geodurability classification was established at only two of the parameters (Duncan’s swelling coefficient and uniaxial compression strength), but it can’t be compared to neither of the above classifications. The results of Geodurability classification show that it is about the hard soils-soft rocks (V and VI category or “E” and “F”) rock type.

<table>
<thead>
<tr>
<th>Category description</th>
<th>Category</th>
<th>“RMR”</th>
<th>“Q”</th>
<th>“JAK” (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very good</td>
<td>I</td>
<td>81-100</td>
<td>54.6-503.8</td>
<td>&lt;1.5</td>
</tr>
<tr>
<td>Good</td>
<td>II</td>
<td>61-80</td>
<td>6.6-54.6</td>
<td>1.5-2.5</td>
</tr>
<tr>
<td>Favourable</td>
<td>III</td>
<td>41-60</td>
<td>0.7-6.6</td>
<td>2.5-3.5</td>
</tr>
<tr>
<td>Poor</td>
<td>IV</td>
<td>21-40</td>
<td>0.1-0.7</td>
<td>3.5-4.5</td>
</tr>
<tr>
<td>Very poor</td>
<td>V</td>
<td>&lt;20</td>
<td>&lt;0.1</td>
<td>&gt;4.5</td>
</tr>
</tbody>
</table>

3. THE SHORT REVIEW OF GEOTECHNICAL DESIGNS FOR THE HIGH PRE-CUTTINGS OF THE INTERTUNNELS AND TUNNELS

3.1. High pre-cuttings

At the basis of the short review of engineering geological, geophysical and geotechnical properties very complex condition in heterogenous rock massif can be stated. The rocks which belong to HSSR increase the problem of excavation and substructuring in pre-cuttings as well as in the tunnels.

*Fig.3 The core from drill hole on the pre-cut section of the tunnel “Javorova Kosa”*
Intertunnel, 35 m in length (Fig. 1, marked with B) is defined by the elevation of the tunnels “Javorova Kosa” and “Pod Vugleš” as well as by the existing creek which directs the flow of the surface waters and rainfalls.

The building of the tunnels started with construction of the pre-cut for the tunnel “Pod Vugleš” from Zagreb direction and pre-cut of the tunnel “Javorova Kosa” from Rijeka direction.

The works on excavation were carried out in sections from the top towards bottom using simultaneous protection of the slope with shotcrete (sprayed concrete) and geotechnical anchors of the different lengths ($l = 8$ m and $l = 30$ m).
3.2. The analysis and the synthesis of the high rock slopes securing database

The optimal solution was found as: Slope height between two berms 10 m with inclination 3:1, berme width 5 m. The slope is to be secured by microreinforced shotcrete d=15-20 cm geotechnical anchors are to be applied.

For slope with total height of H=30m, the B of Q included the following information:

- excavation using pre-split mining and transportation of this material (quantities dependant of the cut geometry)
- drilling of holes φ102m/m² for installation of geotechnical anchors having length L=6 to 15 m
  
  \[ 0.50 \text{ m}^2/\text{m}^2 \text{ of the slope} \]

- purchase and installation of geotechnical anchors φ36mm (steel 1080/1230), weight approx. 10 kg/m², with anticorrosive protection (plastic pipe) and injection with cement mass over whole length of anchors. The anchors are to be installed at the distance of 5 x 4 = 20 m²

  \[ 4.5 \text{ kg/m}^2 \text{ of the slope} \]

- the injection mixture for RQD rock masses = 30% is 250 kg/anchor

  \[ 12.5 \text{ kg/m}^2 \text{ of the slope} \]

- purchase, drilling and installation of drainage tubes φ100 mm/m, L=25 m, at the distance of 7x10=70 m²

  \[ 0.35 \text{ m}^2/\text{m}^2 \text{ of the slope} \]

- making the ditch with berm (MB 30) simultaneously with the jet concreting works

  \[ 0.1 \text{ m}^2/\text{m}^2 \text{ slope} \]

- total geotechnical monitoring (purchase and installation of inclinometers and micrometers) – with the purpose to determine the slope stability.

In this case of intertunnel and “Javorova Kosa” and “Pod Vugleš” tunnels slope security, H=15 m to 25m and whole area of 4000 m², the quotas are:
Overall costs are about **250 eur/m² of slope** – the distribution of which can be seen on fig. 8.

![Pie chart showing costs distribution](image)

**Fig.8 Overall costs of securing the high rock’s slope**

### 3.3. The tunnels

The excavation and the primary securing of the tunnel in the most difficult category (V) has been planned to be carried out in two phases. In the portal zone and V category soil the foreseen system to be used was the “pipe roof” system.

![Cross section of tunnel](image)

**Fig.9 The cross section of tunnel in the first phase (a), the second phase (b) and on the part with “pipe roof” (c)**
4. MONITORING IN TUNNELS AND PRE-CUTTINGS

4.1. About measurements

According to the guidelines of the International Tunneling Association (ITA), the procedure of the construction of tunnels that is constantly adjusted to progressing can be realized by combination of the calculation methods, the empirical way of planning and the direct interpretation of in situ measurements. During that, in situ measurements of massif deformations and also substructure deformations and stresses are constantly used for the confirmation of the project or its replacement. The starting section with intensive instrumentation gives input data for that procedure. The interpretation of the measured values provides an insight into the behaviour of the massif as the reaction on the progressing of the tunnel. The in situ measurements do not verify only the stability and the applied project calculation model, but they also verify the basic concept of the reaction of the massif on the excavation of the tunnel opening and the effectiveness of safety elements constructed.

The results of measurements should be interpreted accordingly to the phases of excavation and works on the support, thus comparing them with the calculation results and connecting them with security solutions. The comparison and possible improvement of numerical model should be carried out by geotechnical designer. The particular problem during the construction presents the influence of excavation in some phases on the stability of the tunnel. If order to have that influence followed and the reactions predicted in time, the complete measurement program was carried out (monitoring) which is composed of the convergence measurement in the tunnel, measurement of vertical and horizontal displacement of the soil, measurement of displacement of ground around the underground opening and measurement of the stresses in substructure elements. The special consideration was aimed to the influence of excavation of the tunnel “Javorova Kosa” on possible deformation of ground which can cause the injury of residential area of Bajt.

The measurement of the convergence in tunnel, measurement of vertical and horizontal displacement of the soil, measurement of displacement of the ground around the underground opening and measurement of the stresses in substructure elements showed insignificant influence of the excavation phases along cross section of the tunnel on the stability of the intertunnel, and well as on deformations that might cause damages to the buildings in the residential area of Bajt.

4.2. The measurements of the convergence

The control measurements of the convergance were carried out with the purpose to make workers and building site safe during excavation and substructuring. The basis for that measurement was made by the optical tridimensional measurements of deformation of the underground excavation. The control measurement profile was composed of 5 measurement points which were fixed in the tunnel substructure. The measurements were done by geodetic electronic teodolit within the integral monitoring of the tunnel. The measurements are being performed until the displacements completely seize.
Fig. 10  The results of convergence measurement in characteristic measurement profile (only I phase of excavation)

4.3 The measuring of vertical and horizontal displacement of the soil around the tunnel on the surface of the ground

The measurements were used for registration of the displacement of the soil before, during and after passing by of the tunnel-head through-out the zone of measurement profile. Measurement profiles performed were with 3 vertical drills. The measurements of vertical displacement were carried out by sliding deformeter and the measurements of horizontal displacements were carried out by inclinometer. Those measurements were being conducted until the displacements completely siezed.
**Fig. 11** The scheme of measurement of vertical and horizontal displacements of the soil around the tunnel on the surface of the ground

**Fig. 12** The results of measuring of the relative vertical deformations and displacements of the soil using sliding deformeter
4.4. The measurement of displacements of the soil around the underground excavation

The measurement of displacements of the soil around the underground excavation was carried out by means of 5 drilled holes per measurement profile and measuring probe $\phi$ 24mm. The measurements are carried out until the displacements completely seize.

**Fig.13** The results of horizontal displacements measurement using inclinometer, direction A

**Fig.14** The scheme of displacements measurement on the soil around the underground excavation
4.5. The measurement of stresses in the elements of substructure complex

The measurement of stresses in the connection point between the soil and primary substructure element and measuring of stresses in the jet concrete have been done by pressure cells. In the measurement profile, seven measurement points were used with two pressure cells. For measurement of radical stresses between soil and substructure seven pressure cells up to 50 bars were used, and for measurement of tangential stresses inside of jet concrete substructure seven pressure cells up to 200 bars were used. The measurements were carried out continually until the change in stresses seized.

![Graph showing stress measurements](image)

Fig.15 The scheme and the results of measurements of the stresses in the elements of substructure complex.

5. CONCLUSIONS

- In this paper the experiences, which were acquired by excavation of pre-cuttings and tunnels in soft rocks of HSSR (hard solis-soft rocks) type in the area of future Karlovac-Rijeka highway on the section Kupjaky-Vrbovsko where the heterogenous rock massif was shown, was represented.

- Sediments in which the excavation was made belong to the soft rocks type, HSSR – therefore, beside use of the usual classification procedures RMR and Q there also was need to use Geodurability classification procedure. The fundamental property of the analysed massif is “weathering”. Those rocks were characterized by decrease of mechanical properties during the excavation for which we have to use Geodurability classification.

- During excavation und primary securing, RMR, Q, JAK and Geodurability classification procedures were carried out together for the first time in Croatia.

- The most critical sections in the tunnel, previously determined, have complete geotechnical monitoring with the purpose of reducing the hazard and risk during excavations and primary securing.
6. REFERENCES


TECHNICAL PROJECT DATA

(1) Elaborata o provedenim istražnim radovima za dio trase autoceste Kupjak – Vrbovsko, IGH, Zagreb, 1996. god.


