Tunnels in karst and flysch in Slovenia

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Abstract: Several tunnels were planned and some of them were constructed or are in construction in southwestern part of Slovenia. The adequate prediction of main geological-engineering, hydrogeological and water resources protection factors lies upon thorough investigation of karstification phenomena, lithological sequences and tectonic lineaments.

Keywords: Tunnel, Karst, Flysch, Groundwater Resources, Kastelec, Dekani

Introduction

Slovenia is situated on crossing of many main trans-European transportation ways. Especially on southwestern part of Slovenia several main transport ways are in planning stage or in construction phase. Several highway and railway corridors passing this territory were studied; some of them were accepted others remained as studies.
The morphology of southwestern part of the state is characterized by specific geological structure: the highland of karstified limestone, mostly of thrust nature, steeply lowers toward lowlands consisted mainly of flysch sediments. Some of proposed/constructed tunnels in this region cross this barrier, while others run in the limestone/flysch formation itself.

Table 1. The main proposed/constructed tunnels of transport ways in SW Slovenia

Name	Type of tunnel and stage of realisation	Main features
Markovec	Water supply tunnel near coast; constructed in 1995	Flysch, swelling
Tabor	Highway tunnel in karstified limestone, built in 1996	Some major caves
Kastelec	Highway tunnel in karstified limestone, 8 % in marl interlayers; construction begun in 2002	Well developed cave system was found
Dekani	Highway tunnel in flysch; construction begun in 2002	Folded structure in alternating flysch sequence
Solkan	Motorway tunnel in flysch and limestone; designing stage	Alternating limestone, flysch and slidy cover layers
Barnica & Tabor	Highway tunnels in flysch; designing stage	Slidy cover layers on flysch formation
Markovec	Motorway tunnel in flysch; designing stage	Thick layer of calcarenite
II. rail Divača – Koper	Railway tunnels mostly passing karstified limestone and flysch terrain; designing stage	Highly karstified limestone partly in saturated zone

Scientific paper

In Table 1 some of the main tunnels are presented. The table indicates that most of tunnels still have to be constructed. The experiences and actual geological and hydrogeological conditions that were obtained from two motorway tunnels under construction, Kastelec (in carbonate rocks) and Dekani (in flysch formation), are of valuable advantage for a better predicting practice and a further investigation design.

KASTELEC TUNNEL

The double tube Kastelec Tunnel (app. 2200 m long) passes the upper part of the limestone/flysch contact, named Karst edge, on the future highway from Ljubljana to Koper. After investigation work in 1999 and 2000 the construction works began in 2002 and the tunnel was excavated in 2003.

The rock mass consists mainly of Eocene alveoline-nummulite limestone with two marl interlayers. Already by the investigation phase it became clearly evident that the karstification phenomena could considerably influence the construction process. The big investigation effort was done to predict the places in tunnel line with higher probability of occurrence of caverns and caves. On the surface, the flat land named Petrinjski kras, numbers of sinkholes are developed and in near vicinity four caves were thoroughly explored. Two main features were a rather crucial part of further interpretation of karstification: 1) aerophoto analysis clearly showed that sinkholes are oriented in two straight lines passing the tunnel line; 2) in Škrklovica cave it was observed that the karstified structure is developed along bedding planes and subvertical fissures. On the basis of these two main characteristics and other investigation results (mapping, boreholes, geophysics…) the probability of occurrence of major karstification and water inflow zones was assessed and the final prognostic profile was made. The prognostic profile served very well during excavation; e.g. a) on January 2003 the tunnel passed the predicted cave (Fig. 1); b) as it was predicted there were no problems with groundwater

Figure 1. Cave in the left tube on chainage 645

inflows - considering that the tunnel is located above the groundwater table some minor water inflows along karstified discontinuities were expected in limestone formation. On the other hand, the actual amount of water in the stratigrafic and tectonic contact zones between flysch and limestone was not so important as it was predicted. Obviously these zones are not as important as tectonic and karst elements in limestone itself.

Dekani Tunnel

The Dekani tunnel was investigated in the period 1999-2000 and excavated in 2003. It is a double tube tunnel entirely built in Eocene flysch that consists of an alternation of marl, sandstone and calcarenite (Figure 2). The main character of the tunnel was determined in the investigation phase: folded layers due to orogenic pressures oriented NE–SW. The position of discontinuities in tunnel axis is very important for the excavation stability. The folding with amplitude of 1 to 30 m was clearly seen in surface outcrops during the investigation phase and also in the tunnel during the excavation. The folding orientation was predicted very well. The tunnel is 2200 m long and bordered with gullies of local streams. Three bigger gullies are crossing or approaching very close to the tunnel line so particular amounts of water were expected in positions 240-490 m, 940-1130 m and 1340-1580 m. The appearance of water inflows was also expected due to the occurrence of sandstone layers. Three types of inflows were predicted: 1- inflows depending strictly on the rain events, 2- permanent inflows with sufficient recharge area depending on structure of sandstone layers and folds, and 3- short-term inflows during the excavation originating from the depletion of relatively closed fissures.
The exact prediction of the folded, imbricated and tectonically disturbed sandstone layers in the intersection with the tunnel line could be very uncertain, thus also the prediction of the exact position of inflows in the tunnel during the excavation could be uncertain.

Discussion and conclusions

The position and extension of karstification is the most important factor that should be considered in tunnel designing and excavating in carbonate rocks in SW Slovenia. It was demonstrated that with careful investigation of karst features, morphology and lithology the karstified zones and caves could be predicted with high reliability not only in the vicinity of the tunnel but also in the position of the tunnel line. The water inflows in the tunnel depend on the discussed phenomena as well as on lithological changes. However, the lithological changes are the secondary ones. At this moment there is no tunnel under construction passing the saturated zone of the karst aquifer.
In tunnels located in flysch formations the position of marl and sandstone is the most important factor, which could be predicted only with careful geological investigation of all outcrops in the area (Figure 3). The exact position of the intersection of sandstone layers and the tunnel line could be sometimes hardly defined because of heterogeneity of folding and tectonic movements in this type of geological formation.
The positions of inflows and the excavation conditions could be quite well predicted for tunnel lines located in carbonate rocks, while this prediction could not be so reliable for

Figure 3. Folds of sandstone on surface (left) and in the tunnel (right).

tunnel lines located in flysch terrains. The swelling pressure should be considered in all investigation and designing practice in flysch terrains. Moreover, since at certain terrains flysch rocks represent an important aquifer for local water supply, the investigations should be very carefully performed also in this field of work.

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