Rock mass characterization during the construction of a twin-tube motorway tunnel in Hungary

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ABSTRACT: A twin-tube motorway tunnel has been under construction near Sopron in Hungary. Geological inhomogeneity during the excavation required the redesigning of the schedule and reorganisation of the project. The geological overbreaks and weak, unstable tunnel faces caused minor stability problems that could be handled locally, but did not substantially affect the planned support. The thick and hard conglomerate layers, harder than expected, caused a significant reduction in the speed of progress and justified the purchase of more powerful excavation tools. A wide tectonic zone appears in the form of several minor dislocations (0.1-1.5 m), characterising a complex strike-slip fault with persistent dislocations caused by minor normal and reverse faulting. This condition represented the most complicated part of both tunnels in terms of stability. Based on the face mapping information, indicator numbers were assigned to the geological layers and then GSI values were calculated using different equations.

Keywords: weak rock, rock mass classification, calcareous sediment, local instabilities.

1 INTRODUCTION

A better knowledge of ground conditions can help to optimise construction time and costs. Risk analysis should start at the planning phase, when all relevant existing maps, boreholes and data are collected. In this phase, data may already be available about the geotechnical properties of the rocks, some known or hypothetical fault lines, fractures, fracture zones, major tectonic zones. If there is any obvious gap or uncertainty within the geological/geotechnical information, it needs to be filled by additional exploration such as site visits, geological/geotechnical mapping, drilling, geophysical surveying, etc. When all required data is available, their potential risks needs to be evaluated. From the beginning of the construction, this needs to control the excavation during tunnelling, through supportive engineering geology.

Twin tunnels are built as part of the M85 motorway in Sopron. It was already known from previous geological research that the hill and its surroundings are built by siliciclastic and calcareous sediments of the Miocene period, coeval with the development of the Vienna Basin, and could be considered as a transition to the Little Hungarian Plain. A more precise picture emerged from surface exploration of the site, in which shallow marine formations of varying sedimentological and geotechnical characteristics were described, with the identification of two important tectonic zones. The geological/geotechnical research carried out during the construction of the tunnel has further clarified this picture and in some places has also made major changes to it.

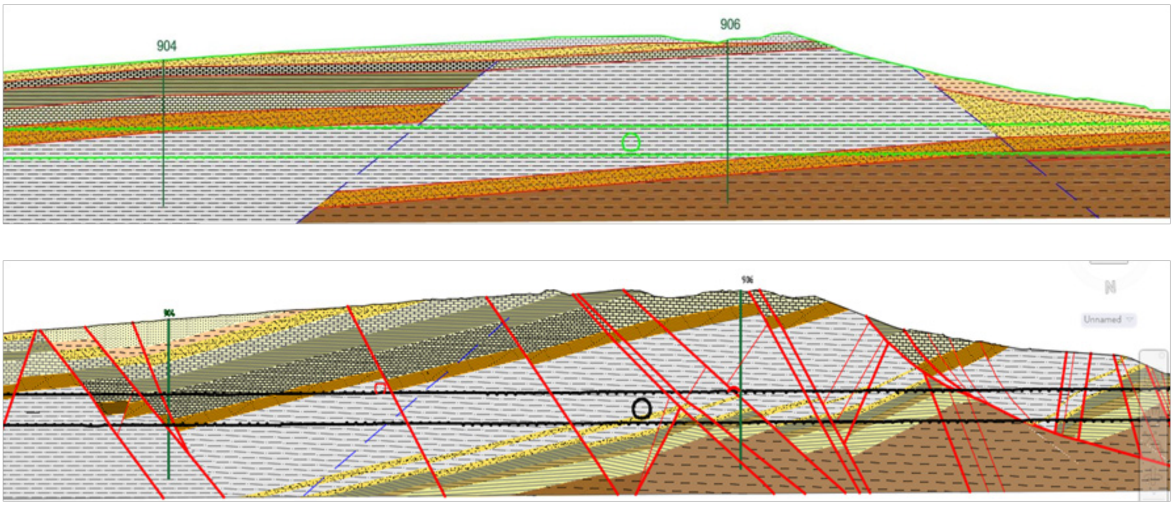

Figure 1. The same detail of the North tunnel geological longitudinal section before (top) and after (bottom) construction. The section on the left side points to East (91), on the right side points West (271), the length of section is approximately 400 m.

2 GEOLOGICAL AND GEOTECHNICAL SETTINGS

Stratigraphically, from east to west the tunnel reveals a sequence of sediments from the Sarmatian to the Badenian stage of the Miocene period. These sediments according to Harzhauser & Piller (2004) and Spahic & Rudic (2015) are connected to the Sopron-Eisenstadt sedimentary basin. In terms of the geological characteristics of the sequence, shallow marine siliciclastic sediments and deltaic calcareous sedimentary environments could be described, having transgressively deposited on the top of open water sediments. The dip direction of sediment beds is mainly East and in some sections is North-Northeast. There are several tectonic features and a wide tectonic zone with 270-330° and 110-140° dip directions. Due to the associated lateral and vertical heterogeneity of these layers, they are present with different thickness, and sometimes different appearance in the two tunnels. Geotechnical variability results not only from sedimentological features but also from changes in the degree of calcareous cementation process during diagenesis. These features vary meter by meter, from one face to the next.

In the construction design, investigated soil and rock layers were classified in four geotechnical categories: 1. Rock, 2. Bonded or well-cemented soil, 3. Slightly bonded or slightly cemented soil, 4. Cohesionless soil. Geotechnical design uses these categories and used its properties for predicting deformation and calculating suitable tunnel driving, tunnel shape and support system:

- Sequential excavation method was applied in varying length
- Excavators were used for tunnelling
- Conventional shotcrete, steel wire mesh and lattice girder were the main elements of the support system.
- Because of the shallow overburden, a pipe roof umbrella had to be installed in the first 30-50 m from the western side of the hill and 80-90 m from the eastern side.
- SDA/SN bolts (steel bars) installed through lattice girders by drilling or hammering in every excavation step as additional support elements as forepoling, where it was required.

- Some sections, where the tunnel faces were weak, or its need to stopped for significant time, additional temporary face support was applied with shotcrete and additionally with wire mesh, SDA/SN anchors, load distribution beams

Figure 2. A few characteristic geological situations.

3 GEOTECHNICAL INVESTIGATION DURING CONSTRUCTION - METHODS AND DATA

In order to get more specific information about the soil and rock mass environment, geotechnical designers made claims for geotechnical investigation during construction. Contractual requirements also demanded specific information from the construction environment. The methods of investigation were geological mapping of the exposed part of the tunnel face, in situ and laboratory testing of soil and rock samples and probing in the tunnel. Engineering geological description consists of soil and rock type classification, defining sedimentary structures, measuring the orientation of stratification and tectonic features. In order to verify the correctness of the applied design parameters, we collected samples and performed laboratory analyses. On average, 20 m geological probe holes were drilled, with usually 10 percent overlap, with measurement while drilling (MWD) data collection system, with no core recovery. Deformations were measured by optical convergence sections in every 10 m, extensometers (MPBX) and NATM pressure cells were installed in two locations.

This paper evaluates the geological mapping data of tunnel construction. Although not all but most tunnel faces were assessed during the construction, detailed data collection was therefore accomplished in the project. Based on the need of additional support installation and the tunnel driving speed, it can be recognized as a pattern in which geological settings define the maximum tunnel driving speed. Different geological situations e.g. the coexistence of cohesionless gravel and hard conglomerate in the same tunnel face determine the usage of additional support and reduced tunnelling speed. Based on the different geological aspects, tunnel sections have been defined. In each tunnel section, all face mapping results were evaluated which served as a basis of aggregate rock mass classification results in RMR (Bieniawski, 1989), Q (Barton, 1974) and GSI (Hoek et al., 1995).

4 GEOLOGICAL PROBLEMS REVEALED DURING CONSTRUCTION

Geological inhomogeneity during the excavation such as irregular shaped gravel and conglomerate bodies, or layers with very different cohesion, sometimes combined with tectonic elements usually caused minor stability problems (e.g. geological overbreaks, weak, unstable tunnel faces) which could be handled locally, but did not essentially affect the planned support. It can assign tunnel sections to geological situations and evaluate tunnel progress speed in the function of geology. It was revealed that beside other problems (logistic and price issues of construction materials because of the war in Ukraine), the main reason for decreased tunnel progress speed is the geological difficulties (Figure 3).

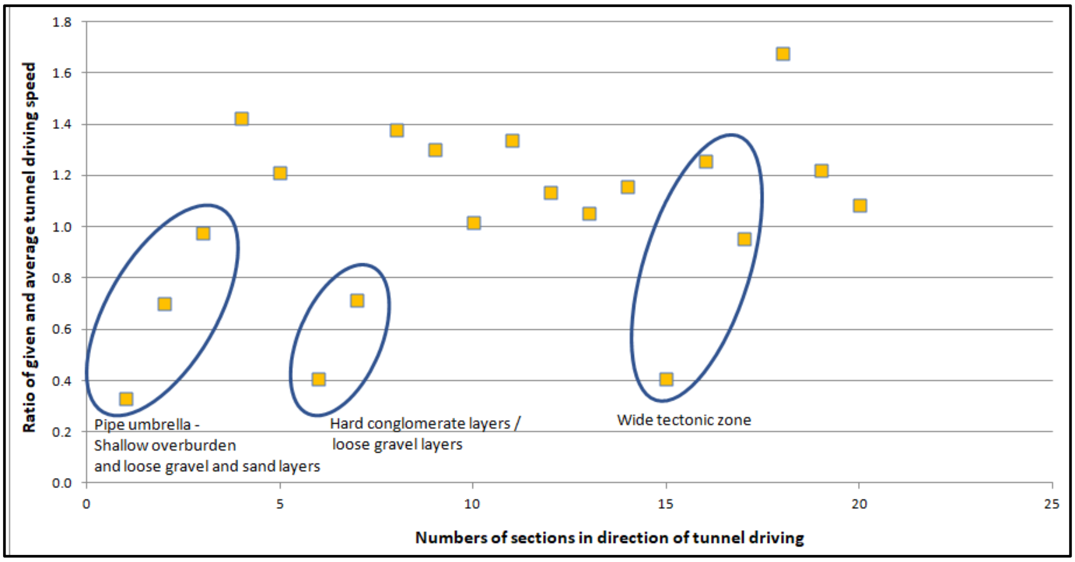

Figure 3. Geological problems in the aspect of average tunnel construction speed.

These problems were solved by drilled SDA or hammered SN bolts through the lattice girders or in more serious cases, with the application of shotcrete, wire mesh, face anchors, reduced length of excavation, sequential excavation, or various combinations these elements.

In both tunnels, at both entrances, pipe umbrellas were applied in different length in the case of shallow overburden combined with thick, loose gravel and sand layers. In these sections, there were no significant coherent rock beds between the tunnel roof and the surface.

The thick and hard calcareous conglomerate layers in the North Tunnel, which were harder and more compact than expected, caused a significant reduction in the speed of progress and justified the purchase of more powerful excavation tools.

A wide tectonic zone appears in the form of several minor dislocations (0.1-1.5 m), characterizing a complex strike-slip fault with persistent dislocations caused by minor normal and reverse faulting. This condition represented the most complicated part of the tunnel in terms of stability.

5 ROCK MASS CHARACTERIZATION

Petrik (2022) determined and compared the GSI value for the geological units during the construction of the Sopron tunnels using the equations recommended in Hoek & Diedrichs (2013). Based on the information obtained about the geological layers, he assigned indicator numbers to the layers and performed the calculations using the described equations. The results of the GSI equation (Hoek) are shown in the GSI diagram (Figure 4). It can be stated that geological units received GSI values between 15-35, and the sandy siltstone and pebbly coarse sandstone layers were evaluated below 20. All sediment beds can be classified as weak rocks, except calcareous sandstone and conglomerate layers. However, in general all layers differ more or less from the properties experienced during the construction of the tunnels (see in Figure 4). Calcareous conglomerate showed much more favourable values and is thus completely separated from the other design layers. It can also be stated that it achieved a better rating than the assumed GSI=50 value during the final design.

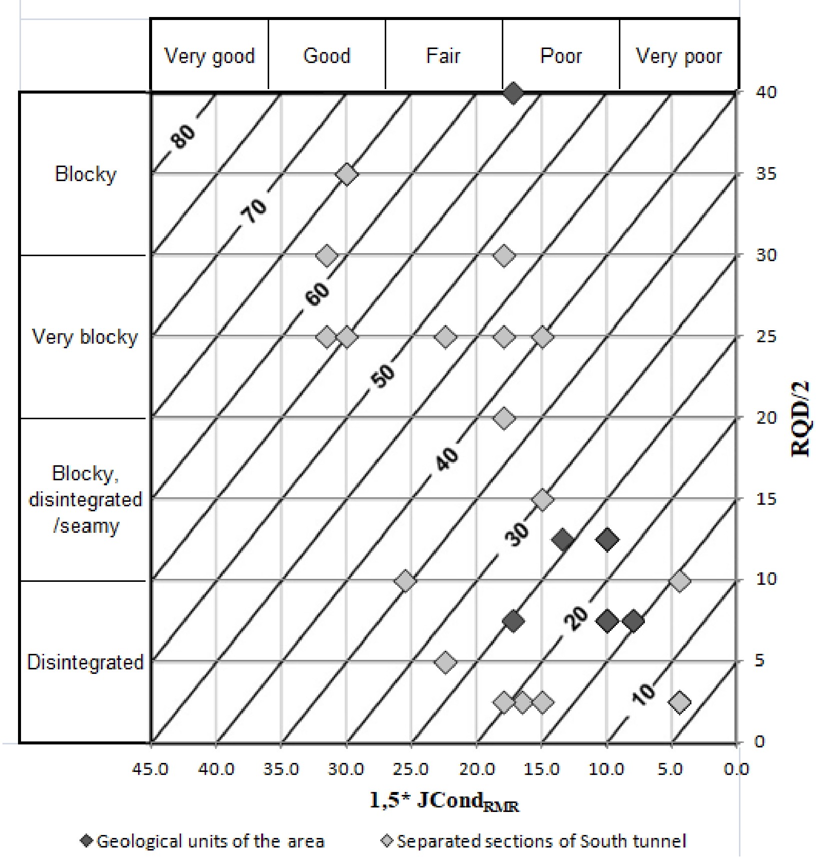

Figure 4. GSI (Hoek, 2013) values according to geological units and in separated geological conditions.

Different tunnel sections with characteristic stratigraphic conditions (e.g.: conglomerate overlying sandstone, silty clay overlying conglomerate) have been studied in this paper. The mixed layers in the tunnel face have varying classification values because of geological characterization as different sedimentary bed thickness, surface condition, joint density and varying uniaxial compressive strength properties. For example, a preliminary result of the evaluation revealed that more than half of the tunnel length can be characterised by very low uniaxial compressive strength factor, 1-5 MPa according to the RMR classification, and almost 15% of the length is between 25-50 MPa, and this fact had a very significant impact on excavatability conditions as well, similar to Chaniotis et al. (2017).

In Figure 4. a broad range of characterization results have appeared, which is close to the real construction conditions. According to the figure, the values of geological units and tunnel sections have significant differences that affected the construction plan and the project schedule.

6 CONCLUSION

It is a matter of course, as tunnel excavation progresses more information becomes available, and this requires the re-evaluation of project knowledge about geotechnical conditions and geological risks. Our experience and this paper wish to draw attention to the important role of the systematic geological data collection during constructions.

The use of geological data collection or rock mass classification method can be useful for the initiation of tunnel specification. However, if a project only has a minor amount of geological investigation or geotechnical data, it is less useful as a prognostic method during construction although it can be suitable for revealing the project concerns amidst severe economic conditions.

A good understanding of a complex geological situation requires more effort for proper data collection and evaluation. This may imply that original rock mass classification may not be the best approach for geotechnical characterization, especially for the problems of weak rocks and significant anisotropy. In the future, our research will tend to use different approaches such as ARMR (Saroglu et al. 2018).

The initial determination of the tunnel support system in the design phase needs proper geological information but this doesn't mean an overemphasis on data collection. Every project has more or less uncertainty about ground conditions and in the design phase this degree of uncertainty must be defined by geotechnical experts. In general, the degree of geological uncertainty decreases during the progress of tunnel construction which enables us to focus on other problems of construction.

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