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Engineering geological investigation of a cave spa cut into rhyolite tuff

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1. ABSTRACT

The goal of the paper is to determine the properties of the host rock and perform stability analysis of an artificially formed underground thermal bath in Demjén, Hungary.

The host formation is rhyolite tuff which is abundant in the area. Cellars and similar underground facilities were cut in this rock for hundreds of years. What makes this case special, is that the rhyolite tuff is quite water sensitive and have a considerable reduction in strength in saturated state. Furthermore, the layout of the underground openings is very complex compared to a cellar which usually cut into this formation. The aim was to determine, if the planned support was sufficient either in construction phase and in case of pool leaking which means reduced rock mass strength. The physical parameters of the rhyolite tuff were determined under laboratory conditions. The complex layout of the facility made it necessary to carry out calculations both in 2D&3D. For modelling the underground openings finite element software products (Rocscience, Cesar) were used. The paper shows the underground thermal bath in construction phase and the experience of the tunnel driving also concluded since the spa is now open.

Keywords: *rhyolite tuff, underground opening, stability analysis, finite-element method*

2. INTRODUCTION

In 1961 exploratory drillings for oil and gas were conducted in the area of Demjén, Hungary. In one particular well, hot karst water came to the surface. It was found, that the water has unique chemical composition, similar to Pamukkale in Turkey, which is a hot spring spa since the roman times, so it was obvious how to make use of it.

By the end of 2010 they built a spa complex in the valley which became too

expensive for many people to afford. The owner of the (now built) cave spa saw the potential in drilling another well thus creating a simpler, but cheaper spa just 3km-s south of the existing one. There was one problem: the well was too far from the road, so they built a gravity-fed pipeline which brought it closer. In order to do this they had to cut a small tunnel through a small hill with rhyolite tuff inside. Then came the idea to create a cave spa into the hill next to the planned outdoor spa.

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For centuries, thousands of cellars and other underground caverns have been cut into the rhyolite tuff in the surrounding regions without any particular support and many are still in use, so it was not an impossible idea. However the planned facility was far more complex.

3. GEOLOGICAL ENVIRONMENT

The spa is located south of the Bükk-mountains in its foreland, in a transition zone between the lowlands and mountainous area. The oldest known formation is Triassic limestone which is considered to be the basement rock in the area, with a depth of 700-800 m. This is covered by Eocene conglomerates with a thickness of around 100m. On top of this Oligocene sandstone and marl was deposited with a considerable 500-600m thickness. The last important layer was formed during the Miocene due to volcanic activity in the area. Several cycles of eruption produced 300-400m thick blankets of rhyolite tuff. This appears on the surface in a 30 km wide region. The uppermost layers are: Pleistocene clay which was created through the erosion of tuff. In the valleys Pleistocene and Holocene sediments can be found: silt, clay sometimes coarse rock debris.

3.1. Hydrogeology

Groundwater does not affect the planned facility since it's level is several meters below the floor level.

The water which supplies the entire spa comes from a well located a few hundred meters away from pools. It has a depth of 696m-s (Eocene layer) with a flow rate of 500l/min. The water is 69°C. As it comes to the surface and pressure is lost, the dissolved mineral content is precipitated. This can sometimes occlude the duct pipes. Near the well mentioned in the introduction the water is let to run down on the hillside, this way beautiful white formations are created.



Figure 1: „Salt hill” precipitated minerals at Egerszalók

3.2. Description of the rhyolite tuff

The rhyolite tuff is a basic pyroclastic rock. It has a cream color when dry, and greenish-yellow when wet. Three main components can be distinguished: rock matrix, phenocrysts, rock blocks and volcanic bombs. The typical composition of the first is 20% silica 55% feldspar 25% biotite and amphibole. The structure is spongy and porous. This property affects the water resistance negatively. It can be stated for rhyolite tuffs in the region of Eger based on experience and many studies, that the water saturation leads to a considerable drop in rock strength.

The tuff can be easily carved, therefore it was widely used in this region as a building material and host rock for any underground cavern throughout history. It has also an important role in vine culture.

4. GEOTECHNICAL INVESTIGATION

The aim of this part was to determine the input parameters for further calculations and modeling. This process was divided into four main parts: gathering existing literature from the vicinity of the spa, field tests and sample collection, laboratory tests, evaluation of the information.

4.1. Field and literature exploration

Since the construction was in progress when these investigations were to be carried out sample collection and field tests were easy. Some of the tunnels were already cut, so the blocks could be retrieved directly from the tunnel walls and crown. It was also easier to get an idea on

the rock mass properties, how fractured it was, compared to individual drill samples.

Preliminary tests and calculations were carried out by a company. This included mapping of discontinuities, compressive tests, preliminary stability analysis. Some of their results were used as well.

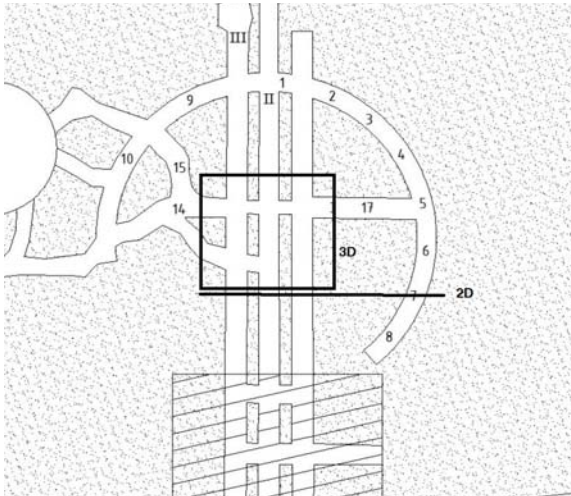


Figure 2: Layout of the planned facility

4.2. Laboratory tests

The collected samples were prepared and tested at the university's¹ department lab. The carried out experiments were: water content and saturation tests, indirect tensile strength test, uniaxial compression test, triaxial compression test. All of these were conducted according to the ISRM blue book.

To verify the results, values from the contractor's samples were used. These were tested in ÉMI's accredited lab. The numbers I-III are marking our samples 1-17 are ÉMI's on figure 2.

4.3. Results

The rock mass is mainly homogenous the entrance area is jointed (marked with lines on fig 2.) due to erosion and movement towards the valley. The homogenous part has a water content around 17-20m/m% with an average of 1,5MPa uniaxial compressive strength. Compared to literature data these values correspond to results of rhyolite tuff in the area.

When fully saturated the rock has 24-25% water content and the compressive strength is reduced to an average of

0,4MPa. This can be a problem in an occasional pool leak in the future.

The input parameters for modeling are:

Table 1. Elastic rock mass properties

Name	Unit weight kN/m ³	Elasticity module MPa	Possion's ratio -
original state tuff	16	270	0.22
saturated tuff	17	40	0.23

Table 2. Plastic rock mass properties

Name	Friction angle deg	Cohesion MPa	Tensile strenght MPa
original state tuff	43	0,054	0,124
saturated tuff	37	0,034	0,028

Elastic properties were obtained from the σ - ϵ diagrams of uniaxial compressive tests. Plastic properties are form triaxial tests which were evaluated in Roc-lab.

5. STABILITY ANALYSIS

It can be seen, from the layout, that the task is hard to be simplified to a two dimensional problem. One cross section was chosen for two dimensional-, and one region in the middle for three dimensional analysis. (fig. 2) The tunnel profiles are reverse U shaped 3.8m wide and 3.8m high. The goal was to determine stability during construction phase and to give an estimate to an emergency case: leaking pool.

5.1. 2D analysis

For the modeling Rocscience's Phase 2 finite element method software was used. Input parameters according to Table 1 and 2. As these are characteristic values, during a shear strength reduction analysis strength reduction factor 1.5 or greater was acceptable.

During the construction phase injected anchors were installed. By an analytic calculation we determined that the lowest of the possible failure modes was pull out resistance, because of the tuffs properties. These were also taken into account in the calculations. In construction case analysis there was no further support. In

