The influence of underground water on rock mass behaviour during tunnelling

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Abstract: The main research hypothesis is that the initial swelling rock desiccation increases the swelling effects. This hypothesis has been confirmed by numerous in situ and laboratory testing. The introduction of various swelling laws, depending on the desaturation level, results in a new characteristic rock curve, which is non-linear in the semi-logarithmic scale. Also, an original method for protecting saturated swelling rock samples during transport, storage and preparation is proposed.

Key words: tunnelling, water, rock, swelling

Introduction

It is noted that in swelling soils and rocks one distinguishes between the swelling potential and the amount of swelling. It is possible for a soil with a high swell potential to exist in a state in which the swelling will not take place. The factors affecting the amount of swell can be classified into two groups. In the first group are the factors related to the characteristics of solid particles (clay mineral types and quantity) that define primarily the swelling potential. These factors define the inclination of the material to swell irrespectively under which conditions In the second group are the factors that control the amount of swelling and are not related to the soil particles characteristics (dry density, moisture content, soil structure, electrolyte level in water, the amount of water causing swelling, stress level). These are environmental factors and they define the extend to which the swelling potential will be exhibited (Seed et al., 1962). One distinguishes: mechanical, osmotic, intercrystaline swelling, hydration effects and some other mechanisms. The clays from the smectite group are prone to the intercystaline swelling (true meaning of swelling). It is generally accepted that all the swelling mechanisms contribute to the swelling phenomenon, however, their relative importance and interaction is still being debated. The swelling rocks are mostly hydrogeologic barriers, seldom with seeping groundwater in the discontinuities that could trigger swelling during excavation. The excavation is usually done without water, described as excavation in dry condition. If the excavation is done in an unsaturated zone, the swelling is triggered as soon as the rock is flooded. However, if the rock is saturated, the swelling in the true sense will not take place as long as the rock is saturated. Only after the initial desiccation the swelling potential will be realized upon flooding. Flooding of an unsaturated claystone initiates, in addition to the swelling, the rock disintegration that is the consequence of desiccation and slaking (air breakage). The swell amount expressed by swell deformation or by

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swell stress of a swelling rock will depend on the degree of saturation at the moment of flooding. This means that in order to predict its behavior the form, the extend and the character of the unsaturated zone must be known. The desiccated zone can be numerically modeled if the boundary conditions at the excavated surface and the rock characteristics controlling evaporation are known. The boundary conditions are: the cavity form, relative humidity in the tunnel, the air speed at the surface and the air temperature. The rock characteristics are contained in the diffusion coefficient. The evaporation rate is proportional to the partial pressure gradient of water vapor between the rock surface and air and is described by Dalton's equation of mass transfer. The maximum evaporation rate is obtained when the rock surface is saturated. This rate is called the evaporation potential. The actual evaporation rate is reduced when the rock surface is desaturated (FREDLUND AND RAHARDJO,1993).

RESULTS AND DISCUSSION

A saturated rock will activate its swelling potential if conditions prevailing in the surrounding space bring this swelling potential to an active state. In tunnelling, two phenomena bring the swelling potential into such an active state: (a) rock unloading; (b) partial rock desaturation due to tunnel ventilation. Each of them, or both at the same time, will provoke swelling if the quantity of water in open discontinuities (water in liquid state) is sufficient. During excavation, the swelling of the saturated rock is mainly provoked by an unloading action. A long time after the excavation (during construction of long tunnels or during tunnel use) the swelling is due to partial desaturation because loading forces are at that point mostly in a balanced state. In this case, the swelling zone is identical to desaturation zone. The laboratory and field testing of the swelling-prone rock mass was conducted in order to prove the above assertions. The laboratory testing focused on determining influence of saturation on the behaviour of samples when immersed in water. This testing has shown that the saturated rock with high swelling potential and slaking does not react to immersion in the water which has the chemical composition similar to that of pore water, because these potentials are not in an active state. If rock is allowed to dry out (occurrence of negative pore pressures and reduction in basal spacing of active minerals) the swelling potential still remains invisible but it now comes to an active state. The potential activated by the first desaturation can be brought to the balanced state by water only, the consequence of which is swelling and slaking. The phenomenological model of such a behavior has been described in detail (VRKLJAN, 1997). Partial rock desaturation due to tunnel ventilation is a phenomenon that inevitably occurs during construction of underground structures. It has been demonstrated by laboratory testing of compacted untreated (natural) bentonite that the same rock may follow different swelling laws, depending on the saturation level. The introduction of various swelling laws, depending on the desaturation level, results in a new characteristic rock curve, which is non-linear in the semi-logarithmic scale (VRKLJAN, 2002).

Extensive field testing conducted in Chiffa and Harbil tunnels has confirmed the nonlinearity of the characteristic curve. The tunnels were excavated in Medea basin marl, which dates back to the Miocene epoch and is prone to swelling. The nonlinearity of the characteristic curve is of great significance in the design and construction of tunnels. This form of curve emphasizes - more than any other form - the danger of installing resistant tunnel supports, while pointing to advantages of yielding supports.

The fact that the saturated swelling rock does not swell, lead to an original method for protecting saturated swelling rock samples during transport, storage and preparation. During sample treatment in laboratory, it enables the use of water as liquid for cooling tools, instead of liquids with low dielectric constant. In the period between sampling and testing, the deloaded saturated rock will best be protected against desaturation if it is immersed in water.

Table 1. Influence of the boring with water on the water content change

Rock type	**Uniaxial compr. str. (kPa)**	**Water content [2] (%)**	**Water content [1] (%)**	**Sampling by boring with water as cooling liquid**
Sandstone Specimen: 030344	**718**	**9,8**	**9,8**	
	566	**10,1**		
	580	**10,0**		
Siltstone Specimen: 030345	**487**	**7,7**	**8,5**	
	1173	**7,8**		
Siltstone Specimen: 030346	**905**	**10,1**	**10,07**	
	919	**10,2**		
	619	**10,0**		

[1]- Water content immediately after rock excavation (%)
[2]- Water content after testing. Boring and cutting has been executed by water as cooling liquid
Location: North portal of the Hrastovec tunnel

Table 2. Storing the marl specimens in water

Water content immediately after rock excavation (%)	**Water content after specimen had spent 22 days in water (%)**	**Rock specimen after testing**
11,68	**11,67**	**Uniax. compr. str.: 2,2 MPa**
		

Tunnel: Vrtlinovec Rock type: Marl Specimen designation: 003 -2002

The procedure is implemented in everyday use in Geotechnical department in Civil engineering institute of Croatia. It was demonstrated that in handling the saturated rock specimens (transport, storage, trimming) it is not necessary to use low dielectric constant fluids (petroleum, gasoline, oil etc.), but water with the same chemical composition as the groundwater at the sampling site. Thus, many problems associated with the use of such fluids have been solved.

CONCLUSIONS

The investigation work has unambiguously demonstrated that the initial desiccation of a swelling soil is an essential condition for the swelling potential to be realized. The observation that the saturated rocks do not react to the submergence in water, motivated the development of two inovative method:

- In the saturated swelling rock, the swelling zone is similar to the desaturation zone. The consequence of this is the non-linearity of the characteristic rock mass curve on the semi-logarithmic scale,
- Method for conserving the specimens from field drilling to laboratory testing. The desaturation of saturated swelling rock samples during their transport, storage and processing can be avoided by immersing them in water.

While the phenomenological model of such a behavior has been described in detail (VRKLJAN, 1997 and 2002), a quantitative assessment of the process is still not possible. Further understanding of the swelling process and the influence of desiccation on such a process is only possible within a framework of a rational theory. Once such a theory is developed it will lead to a better understanding of the physical processes and provided the basis for the quantification of the observed behavior. The developed model will be an invaluable tool in the design process of engineered structures within, or on, swelling rocks (tunnels or foundations). It will provide the designers with a quantitative assessment of how deep the desiccated layer will be, how much swelling will be exhibited in the layer and what will be the consequences for the designed structure. Thus, a rational predictive tool will replace an empirical understanding of the behavior of a swelling rock for the design purposes.

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