SOME CHALLENGES OF TUNNELING IN HIGH SQUEEZING GROUNDS

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INTRODUCTION

The correct prediction of the behaviour of the squeezing ground conditions plays an important role in tunnel design and construction as these conditions cause many problems in completing underground works. Squeezing ground conditions are a consequence of changed stresses conditions. Nevertheless, only the high advance rate leads to economical tunnel construction.

The same rock could show non-squeezing characteristics at a low height overburden and high squeezing characteristics at a high height overburden. Squeezing grounds are overstressed at low stress level as a result of their low strength and high deformability and the strength of squeezing ground formations are not constant and for this reason they become weaker when exposed into a tunnel.

COMPUTIONAL ASSESMENT OF THE SQUEEZING GROUND CONDITION RATE BY DIFFERENT AUTHORS

A number of theories have been proposed by different authors. Several of them based on practical experiences and documented case histories. Identification and indication of squeezing grounds and potential tunnel squeezing problems are discussed bellow.

Jethwa et al. (1984): Degree of squeezing is defined as the ratio of uniaxial compressive strength and rock mass unit weight to overburden height.

Singh et al. (1992): Theory is based on rock mass quality Q of Barton et al. and considers overburden height H.

Goel et al. (1995): Theory is based on the rock mass number N and considers overburden height H and tunnel diameter B.

Computational assessment is based on data obtained by different geotechnical investigations based on the project of the Trojane Tunnel. The 2.900 m double tube tunnel of Trojane forms a part of the highway section between Celje and Ljubljana and a part of the highway road system connecting

Lendava and Koper with adjacent roads. The squeezing ground condition rate is carried out following Singh, Jethwa, and Goel theory.

Table 1: Input parameters for analysis (Likar, 2004).

Rock Mass Quality (Q)	Q (/)	0.38
Uniaxial comprehensive strength	σ_{cm} (kPa)	250
Overburden height	H (m)	244
Tunnel diameter	B (m)	10
Volume mass	γ (kN/m^3)	24
Cohesion	c (kPa)	30
Inner friction angle	φ (°)	28

Table 2: Overview of the computational assessment.

Jethwa	Singh	Goel
$N_c = \frac{\sigma_{cm}}{p_0} = \frac{\sigma_{cm}}{\gamma H}$	$H \gg 350\, Q^{1/3}$	$H \gg (270\, N^{1/3}) B^{0.1}$
$N_c = 0.04$	$244 \gg 44.33$	$244 \gg 43.06$
High squeezing	High squeezing	High squeezing

It was established that all three theories present a similar solution. The Trojane Tunnel was constructed through high squeezing ground conditions. These findings are very important for designing.

Defined rate of squeezing grounds provides a reasonable and rational design of support measures under evaluation advance rate of excavation face. This can be carried out by two different conventional excavation methods.

CONVENTIONAL EXCAVATION METHODS IN HIGH SQUEEZING GROUNDS CONDITIONS

The multiple heading method

The multiple heading method is one of the safest methods for underground construction in high squeezing ground conditions but requires careful planning of the details supporting elements and qualitative preparation of the essential plans for the implementation. In the planning phase sequence of the excavation the size of the tunnel cross-section, ground conditions and time limited development of deformations should be considered. In non squeezing ground conditions there is no need to construct an invert but in mild squeezing ground conditions it is necessary to construct it due to providing a support ring of the primary lining. Deformations and settlements of the top head are common and larger in relation to prescribed in high squeezing ground conditions that is why it is required to install a temporary invert. In exceptional circumstances is recommended that the face excavation of bench tunnels is divided into six segments. In extreme situations the installation of rock bolts could be ineffective and it is absolutely necessary to install yielding elements.

Full face excavation method

The full face excavation method is relatively highly risky because any part of the support system can fail. There is a potential threat that a large volume of material could collapse into the excavation space. On one hand, the multiple heading method ensures that the outer shotcrete shell is not overstressed at any stage of the excavation process and also provides better stability of the smaller faces. On the other hand, full face excavation allows the immediate closure of the primary support lining in the immediate vicinity of the excavation face. In non squeezing ground conditions excavation constructed with face buttress, which supports top head, is optional. In mild squeezing ground conditions attention should be paid to excavation face stability. It is recommended to ensure stability by installing fiberglass dowels grouted especially in the top head and the bench for face reinforcement. By weakening of the ground conditions, related to the increasing of the squeezing, it is required to install forepoles, steel seets and in high squeezing ground conditions yielding elements must be used. Yielding elements enable controlled deformation of the primary lining and prevent the escalation of the load bearing capacity which if overloaded can lead to failure.

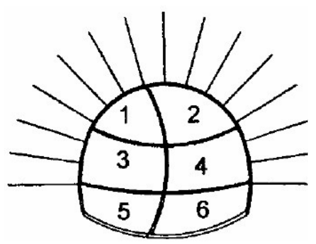
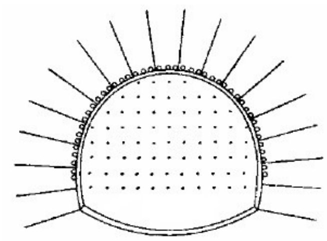
MULTIPLE HEADING METHOD		- Self drilling anchors are installed at the top and upper part of bench - Excavation face at six times divided profile - Thickness of the shotcrete lining is 200 mm
FULL FACE EXCAVATION METHOD		- Self drilling anchors are installed at the top and bench - Friction anchors are installed in excavation face - Forepole is installed at the top and upper part of bench - Thickness of the shotcrete lining is 200 mm

Figure 1: Example of tunnel construction with multiple heading and full face excavation methods in addition support measures for each of methods in high squeezing grounds (adapted from Hoek, 2001).

The choice between the full face excavation method and the multiple heading method depends on ground conditions, and environmental aspects, on the magnitude of settlements at the surface and economic consideration. Both methods can be used in certain cases although frequent changes in the excavation method are uneconomical. The design engineer should prescribe or limit the choice in the method only if there are compelling reasons based on project restrictions. The responsibility of the method selection should be left to the contractor, based on the owner's ground conditions description and the limits set by the design engineer.

YIELDING ELEMENTS

An ordinary shotcrete lining exhibits a high lining resistance but an extremely low deformation capacity. In the case of overload, shotcrete lining generally loses its load-bearing capacity due to brittle failure even if it is reinforced by the customary steel mesh. Therefore, a shotcrete lining without special support measures is not suitable in the squeezing grounds conditions.

Nowadays reliability of primary support system can be improved by using recently discovered yielding elements that enable controlled release of the primary support system. In fact the yielding elements are able to incorporate defined changes and furthermore plastically deform due to increasing stress field along the circumference of the lining.

The yielding elements currently available on the market are:

- System LSC (Lining Stress Controller) is produced by Alwag
- System hiDCon (High Deformable Concrete) is produced by Solexperts
- The honeycomb stress controller known as "Wabe" is produced by the Bochumer Eisenhütte Heintzmann GmbH & Co.

Total displacements are larger with installed yielding elements but the final axial force in the shotcrete lining is much lower. Integration of yielding elements in the shotcrete lining allows substantially greater failure of rock mass and the liner must be compatible with deformability of the rest of the support elements.

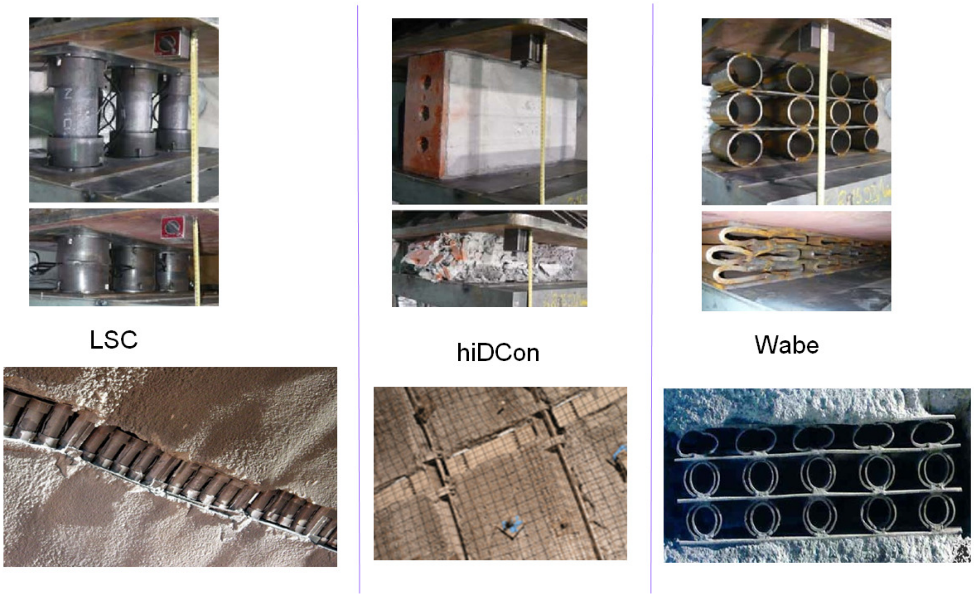


Figure 2: In the top line, yielding elements are being compressed by centric normal force and in the bottom line yielding elements are incorporated into temporary shotcrete lining (adapted from Barla G., 2011 and Opolony et al., 2011).

As mentioned before, shotcrete is one of the most commonly used support elements and because of this reason a comparison between shotcrete linig with incorporating yielding elements and without them is carried out. It is considered that the shotcrete thickness is uniform and the tunnel is of a circular shape. Young's modulus is assumed as a constant; the fact is that the shotcrete strength is time dependent.

In Chart 1 it can be seen that the state of equilibrium is reached at the point of the intersection between support characteristic curve of the shotcrete lining with yielding elements and ground characteristic curve. Furthermore there is no intersection between the support characteristic curve of shotcrete lining without yielding elements and ground characteristic curve. We can conclude that a support failure occurres in the liner without yielding elements, because it is not able to accommodate the pressure and displacements which are generated from excavation work and rock mass. However, the main aim is to achieve a state of equilibrium and it is often necessary to install support as close as possible to the excavation face to ensure the safety of workers. With the longitudinal displacement curve a distance from excavation face where support should be installed is determined. This curve also describes the radial displacements in the longitudinal direction and shows the local and temporal condition of the displacements along the tunnel.

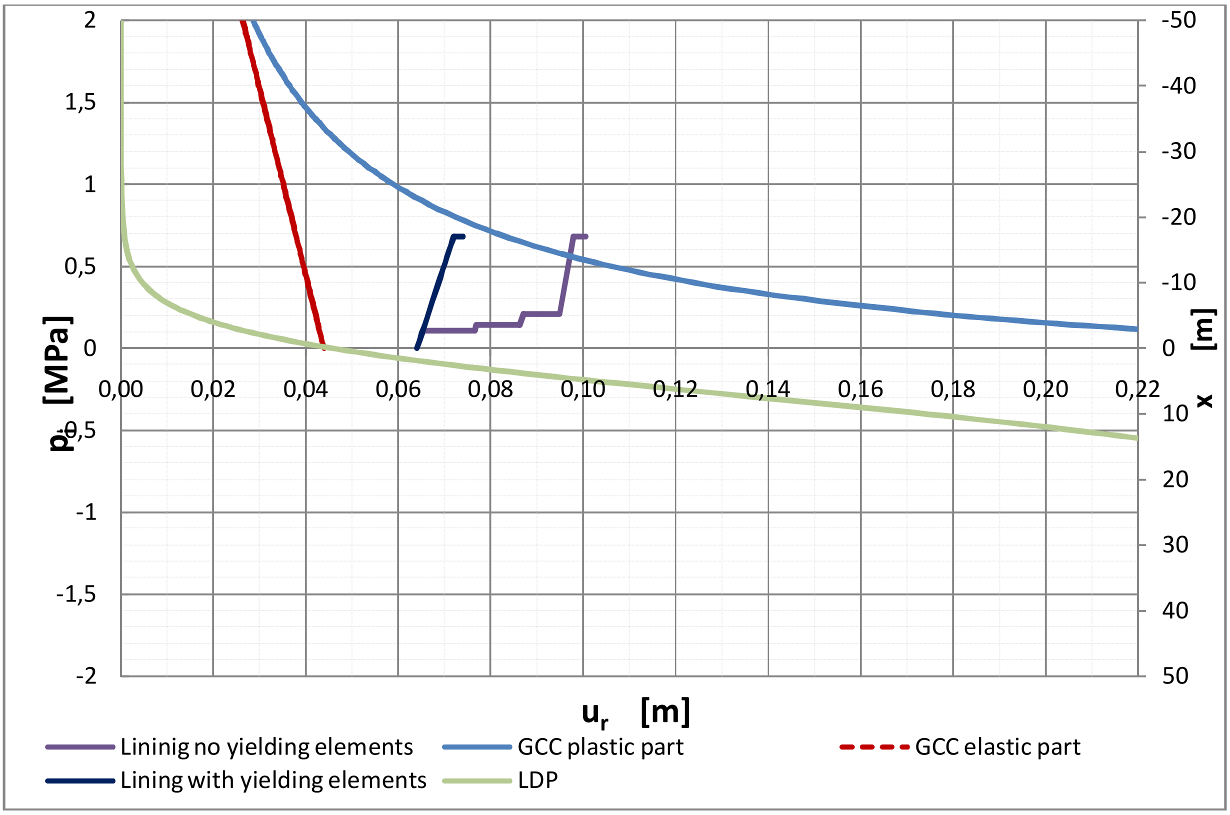


Chart 1: Longitudinal displacement profile, support characteristic curve, ground characteristic curve with elastic and plastic part.

Where u_r is radial displacement, p_i is support pressure and x is distance from the tunnel face.

3D NUMERICAL MODEL

Two 3D numerical analyses are performed by using Midas/GTS. The calculation of both numerical models is based on iterative method and includes the spacious (3D) and planar (2D) elements. All of them are interconnected into the discretization points. Dimensions of both 3D numerical model are 120 × 50 × 250 m and 75 000 finite triangular shaped elements are totally generated.

The simulation procedure

The simulation is preformed in a total of 51 stages. During the first stage primary stress state is analyzed where the displacements are eliminated. During the second stage excavation with one meter long excavation step is simulated and the third stage is followed by the next excavation step with the same length and installation of the primary lining in second stage. At the same time yielding elements are also installed. Characteristics of primary lining are used for young shotcrete. During the fourth stage the third excavation step is simulated and installation of primary lining with young shotcrete characteristics is described as well. Simultaneously yielding elements are installed . At that point in the second phase characteristics of the hardening shotcrete are considered. The process of excavating and supporting is repeated until the 51st stage. Numerical analysis without yielding elements is carried out in the same sequence.

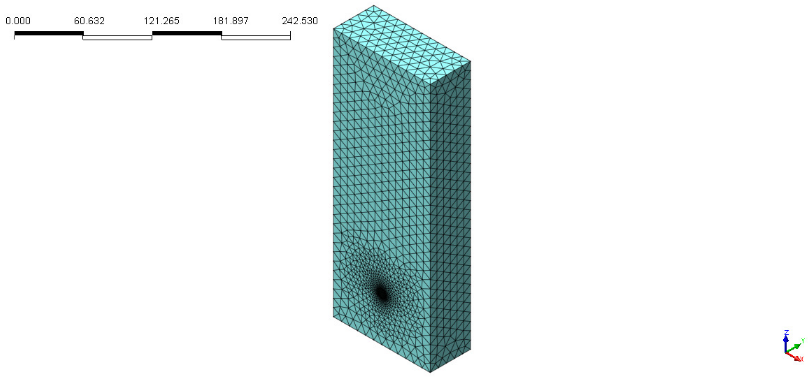


Figure 3: 3D numerical model.

The results of 3D numerical analysis with and without considering the yielding element

In the numerical analysis, the sizes of maximum compressive axial force in shotcrete lining and maximum radial displacement are compared regarding the installation of yielding elements. The yielding elements are clearly seen in right side of the Figure 4. They are longitudinally included into shotcrete lining at four places around the shotcrete shell. In the top line, the maximum compressive axial force in shotcrete lining is carried out from the analysis, and it is three times higher in shotcrete lining without yielding elements. In the bottom line of the same Figure the maximum radial displacement is carried out, and amounts to 120 mm in the model without yielding elements and 200 mm in the model with them.

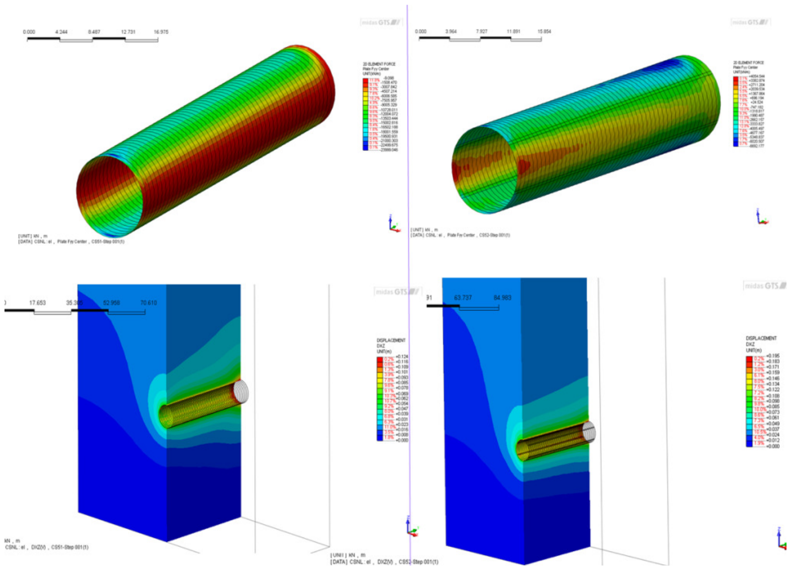


Figure 4: The model without yielding elements is on the left side and the model with yielding elements is on the right side.

The analysis shows that in high squeezing grounds a shotcrete linig without yielding elements is not appropriate because the bearing capacity is exceeded. It must be taken into account that the radial displacement is computed and impossible in reality due to extreme expansion of the cracks. This displacement is realistic only in the case that the shotcrete lining is able to resist enormous compressive stresses.

Computational assessment

Maximal comprehensive axial force F_c (no yielding elements) :

(1)

In thus follows that the maximum comprehensive stress :

—

(2)

where

– surface area.

Maximal comprehensive axial force F_c (with yielding elements):

(3)

In thus follows that the maximum comprehensive stress :

—

(4)

where

– surface area.

Characteristic compressive strength of shotcrete f_{ck} is 20 MPa and results show that it is not exceeded in shotcrete lining with yielding elements.

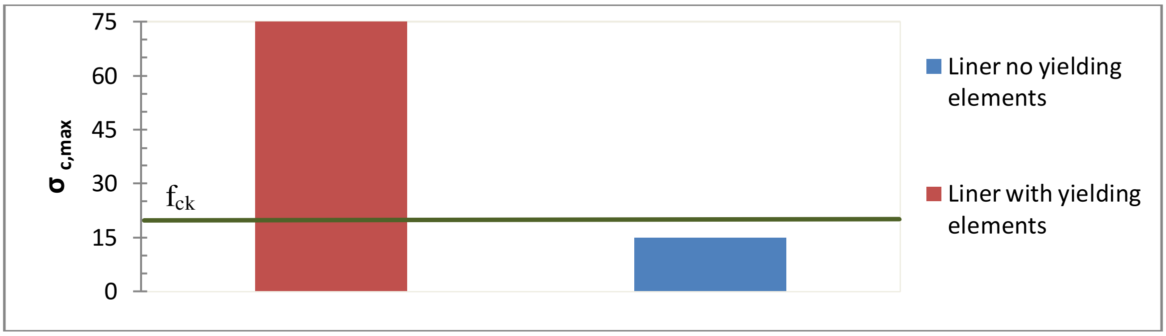


Chart 2: Comparsion of characteristic compressive strength

CONCLUSIONS

This paper discusses some challenges of tunnel construction in high squeezing grounds and offers a solution when shotcrete as support measures is used in high squeezing ground conditions. Shotcrete is one of the most commonly used support elements and the shotcrete shell could be improved by using recently discovered yielding elements. There are different numerical analysis carried out and it is found out that the total displacements are larger with installed yielding elements but the final axial force is lower and also characteristic compressive strength of shotcrete is not exceeded. The paper also offers some theories for defining the rate of high squeezing ground conditions.

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